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(54) Title: VARIABLE FOCUS OPTICAL SYSTEM

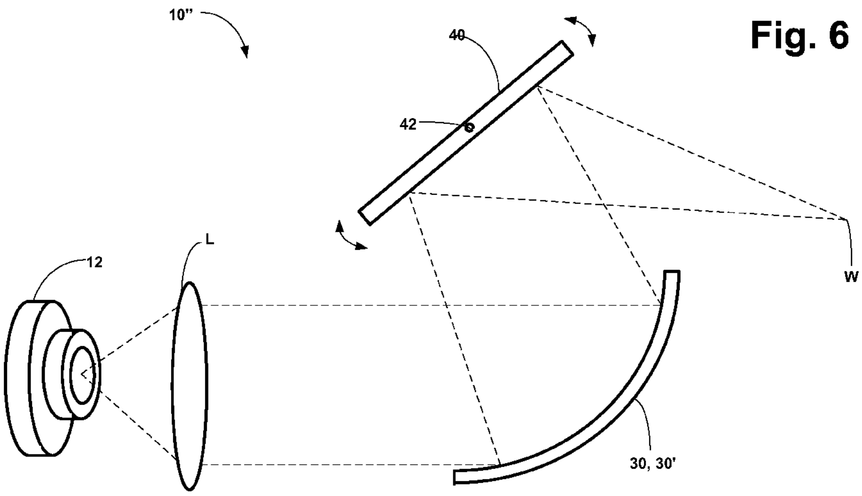

Fig. 6

(57) Abstract: A curved mirror is interposed into the path of light from the source of illumination of an optical illumination system. By varying the curvature of this mirror, the focus distance of light reflected from the mirror may be varied, varying the focus distance or beam waist position of light provided by the illumination system. Preferably, the curvature of the mirror is varied by providing a mount on which piezoelectric transducers are mounted so that the pressure applied to the curved mirror by the piezoelectric elements may be varied through adjustment of the voltage applied to the piezoelectric elements.

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VARIABLE FOCUS OPTICAL SYSTEM

BACKGROUND OF THE INVENTION

The present invention relates generally to optical systems and, more particularly, concerns an optical illumination system for code readers that provide increases depth of field (depth of read) through the use of an automatic beam focus and is free of moving parts.

Anyone who has shopped in a modern supermarket is familiar with optical code readers, in this case a bar code scanner, which facilitate rapid checkout by scanning barcodes imprinted on product packages. This is a relatively undemanding application of barcode reading, as a package is essentially brought to a standstill by the operator for purposes of reading the bar code. However, the barcode reader still must have a reasonable range of distances of operation, since the user cannot place a barcode at precisely the same location every time and accurate reading of the code requires that the laser beam remain in focus as it scans across the code.

More recently, optical code readers have been utilized in production lines where items are assembled, where they are inspected, where they are packaged, and the like. This application of optical code reading is far more demanding, as products move down a production line at a relatively high speed, for example, on a conveyor belt. In order to avoid the creation of a bottle neck on the production line, it is therefore important that accurate decoding of optical codes take place without reducing the speed at which the objects move down the production line. The speed at which an optical code can be decoded accurately therefore becomes a primary concern. Since accurate reading of the code requires that the laser beam remain in focus as it scans across the code and the distance of the code is constantly changing during the scan, the required depth of field, even at slow speeds, is beyond what is commonly available with image sensors of the type used for these applications. It will be appreciated that greater depth of field in the illumination system would allow objects to move at a faster rate of speed.

One form of optical scanner commonly used with linear barcodes projects a laser beam at a remote optical code and scans the beam linearly along the direction of the barcode. More of the laser beam is reflected from the light areas of the barcode than the dark areas (the bars), so the light reflected from the barcode, when sensed at the scanner, contains a sequence of bright and dark portions corresponding, respectively, to the spaces and bars of the barcode, respectively.

Accurate detection of the light and dark areas of the barcode requires that a well focused light source, typically one providing infrared laser light, be scanned over the barcode, to make an accurate determination regarding which areas are light or dark and, in particular, where the transition between the light and dark areas occurs. A common approach is to focus the light source to a specific position where the barcode is expected to be and to restrict the beam diameter by passing the beam through an aperture of predefined size. Restricting the beam diameter increases the depth of field and, therefore, the operating range over which the light source provides illumination sufficiently focused to allow accurate decoding of the optical code. Thus, the range can be increased by reducing the aperture, but only at the expense of reducing overall illumination. That is, a substantial increase in the brightness of the light source becomes necessary.

A typical laser beam illumination system 10 of this type is illustrated schematically in Fig.1. A laser light source, such as a laser diode 12 projects laser light forwardly. The light impinges upon and passes through a focusing lens 14, in this case, a fixed lens and, forward of the lens is passed through an aperture 16. A relatively narrow beam is projected from aperture 16 and exhibits a beam waist 18, or a minimum diameter, at a distance Z0 from aperture 16, the actual value of Z0 being determined, at a particular wavelength of light, by the focal length of lens 14 and the diameter of aperture 16.

In an effort to extend this operating range, such light sources have been provided with an autofocus mechanism containing a lens which includes a movable lens element. This usually yields an effective operating range for many applications.

Fig. 2 is a schematic representation of a known variable focus laser beam illumination system 10'. That is, the system 10' produces a laser beam in which the distance of the beam waist from the aperture maybe be adjusted. In this case, the light source 12 projects laser light forwardly onto and through a lens 20. Lens 20 is mounted for axial movement towards and away from light source 12. Light emitted forwardly from lens 20 impinges upon an aperture 22, which is variable in diameter. Through the movement of lens 20 and the simultaneous adjustment of aperture 22, the distance of the laser beam waist from aperture 22 can be adjusted through a range of values. By sensing the distance of a target from the aperture 22 and adjusting lens 20 and aperture 22 accordingly, the beam waist distance from the aperture 22 maybe adjusted through a range of values, so that it may be set at a distance corresponding to the distance of the target. As a result, the depth of field of the light source 10' is effectively increased.

System 10' has a number of disadvantages. First of all, modern code scanners, especially those that are handheld, have severe limitations on internal space. The distance moved by lens 20 must therefore be relatively short and its positioning must be highly accurate. Although there is significant improvement in the depth of read, the durability of this system is low because of the moving lens. Furthermore, a driving mechanism is required to move the lens physically. Typically, an electromechanical device, such as a linear actuator or voice-coil mechanism is utilized. Despite miniaturization, such electromechanical devices remain inordinately large, have limited reliability, owing to the moving parts, and have relatively high energy consumption.

Accuracy of positioning lens 10 requires small precise movements and has proven to be a particularly severe limitation. To overcome this limitation, lens 20 can be replaced by a system of lenses with one or more moving components. The distance traveled by the moving component is, however, substantially longer, allowing more accuracy but making it difficult to miniaturize. Durability of the system is low owing to the moving part, and an electrical mechanical actuator is still required to move the moving part.

Broadly, it is an object of the present invention to provide an automatic focus optical illumination system which overcomes the disadvantages inherent in prior systems of this type. It is specifically contemplated that automatic focus be achieved without substantial translational movement of physical components and without the use of linear actuators.

It is a further object of the present invention to provide an automatic focus optical illumination system which is amenable to miniaturization.

It is yet another object of the present invention to provide an automatic focus optical illumination system of increased durability and reliability, yet one which is relatively inexpensive and simple in construction.

SUMMARY OF THE INVENTION

In accordance with one aspect of the present invention, a curved mirror, preferably a cylindrical mirror is interposed into the path of light from the source of illumination of an optical illumination system. By varying the curvature of this mirror, the focus distance of light reflected from the mirror may be varied, varying the focus distance or beam waist position of light provided by the illumination system. Preferably, the curvature of the mirror is varied by providing a mount system with piezoelectric transducers, so that the pressure applied to the curved lens may be varied through adjustment of the voltage applied to the piezoelectric elements.

It is a feature of the present invention that, unlike prior optical illumination systems which utilize lenses with moving elements, it is not necessary to maintain a straight path for light emanating from the light source and reflected from the curved mirror, offering additional possibilities for miniaturization.

BRIEF DESCRIPTION OF THE DRAWINGS

The foregoing brief description and further objects, features and advantages of the present invention will be understood more completely from the following detailed description of the presently preferred, but nonetheless illustrative, embodiments in accordance with the present invention, with reference being had to the accompanying drawings, in which:

FIG. 1 is a schematic representation of a typical an optical illumination system utilizing an aperture to restrict the diameter of a beam from a light source, increasing its depth of field;

FIG. 2 is a schematic representation of a known variable focus laser beam illumination system making use of a moveable lens;

FIG. 3, comprising parts A and B is a schematic diagram illustrating the principle involved in the present invention;

FIG. 4 is a schematic representation of a first embodiment of an automatic focus mirror structure 30 in accordance with the present invention;

FIG. 5 is an alternate embodiment 30' of an automatic focus mirror structure embodying the present invention;

FIG. 6 is a schematic representation of a automatic focus optical illumination system embodying the present invention; and

FIG. 7 is a graph comparing the operating range of an automatic focus optical illumination system in accordance with the present invention ("New AF") with the operating range of an automatic focus optical illumination system employing single lens focusing system.

DETAILED DESCRIPTION OF THE PREFERRED EMBODIMENTS

FIG. 3, comprising parts A and B is a schematic representation illustrating the principle involved in the present invention. It will be assumed that a mirror M will be utilized which is made of a material that can withstand some flexing, without breaking or exhibiting fatigue failure. For example, a somewhat flexible plastic material may be used or a metal which not experience fatigue over the range of distortion which it will experience. Mirror M is provided with a finished reflecting surface F which can have the high reflectance ratio, preferably by virtue of using gold evaporation for finishing. Mirror M is maintained in a flexed or curved position such that collimated light impinging on the mirror is reflected there from and focused at a distance forward of a mirror. The focused distance will be determined by the curvature of the mirror. For example, in FIG. 3A, light impinging on the mirror from the right is focused at a distance f_1 from mirror M. In contrast, in FIG. 3B, mirror M is in a relatively flattened state where its curvature is much lower. In this case, light impinging upon the mirror is focused at a substantially greater distance f_2 from the lens. By controlling the curvature of mirror M, it is therefore possible to control the focused position or beam waist position of light reflected from the mirror, providing automatic focus to the light emitted by the optical illumination source containing the mirror M.

FIG. 4 is a schematic representation of a first embodiment of an automatic focus mirror structure 30 in accordance with the present invention. Structure 30 has a mirror M of the type described previously, preferably a cylindrical mirror. Mirror M is mounted in an arch to a curved position between the piezoelectric transducer elements 32, 32. As is known, piezoelectric elements will produce a force (in this case, in the direction indicated by the arrows) which is related to a voltage applied to them. By design, mirror M is mounted so that where no signal is applied to the elements 32, 32 it will have a curvature calculated to place the beam waist position at a design maximum distance from mirror M. A voltage is applied to the piezoelectric elements 32, 32 from a source 34. Application of voltage to the elements 32, 32 causes them to exert a force on the lens M in the direction of the arrows. With increasing force, the curvature of lens M is increased, bringing the beam waist position closer to the lens. By design, the maximum signal applied to the elements 32, 32 would be calculated to increase the curvature of mirror M to such a degree, that the beam waist position of reflected light occurs at a nominal minimum distance from the mirror. Piezoelectricity are well developed technology and will permit flexure of mirror M to be controlled very accurately.

FIG. 5 is an alternate embodiment 30' of an automatic focus mirror system embodying the present invention. In this case, the mirror M is mounted in a frame structure S which permits some lateral (vertical in the drawing) movement of the mirror. The piezoelectric element 36 is mounted to bear on the rear of the mirror and is controlled by the voltage source 34. By design, the mirror is mounted to exhibit the maximum curvature when piezoelectric element 36 has no signal applied to it. That maximum curvature is calculated to place the beam waist position at a nominal minimum distance from mirror M. When a voltage is applied from source 34 to piezoelectric element 36, it will exert a force to the right on the rear of mirror M, as indicated by the arrow. That force will have the effect of reducing the curvature of the mirror. By design, with a maximum signal applied by voltage source 34, mirror M will achieve a minimum curvature calculated to place the beam waist position at a nominal maximum distance from the mirror.

FIG. 6 is a schematic representation of an automatic focus optical illumination system 10'' embodying the present invention. Illumination ~~is~~ provided by a light emitting diode 12, passes through a collimating lens L and then impinges upon a automatic focus mirror assembly, such as 30 or 30'. Light reflected from the mirror assembly 30, 30' impinges upon a scanning mirror assembly 40 which is controlled to pivot about an axis 42 as indicated by the double-headed arrows. Light reflected from mirror 40 has a beam waist position W. In operation, mirror assembly 30 or 30' controls the distance W in the manner described above. A control system causes reciprocating pivotal movement of mirror 40 to achieve scanning of the reflected light across a distant barcode located at position W.

In practice, there would be a distance sensing subsystem to sense the distance of the barcode from the autofocus light source 10''. The focus distance of mirror assembly 30, 30' would then be adjusted to make the distance W equal to the distance of the barcode. In this manner, autofocus of optical illumination source 10'' is achieved so as to apply a well focused beam on the barcode at all times, even if it is on a moving object.

In the optical illumination systems utilizing an adjustable lens for automatic focus, the lens must be aligned axially with the light source, and the scanning mirror must then be spaced axially from the lens. The light source, lens and scanning mirror must therefore be spaced and aligned linearly, introducing a dimension extending from the rear of the LED to the scanning mirror which cannot be reduced. This imposes a serious limitation on the ability to miniaturize. That limitation is not present in accordance with the present invention, since the scanning mirror can be positioned laterally of the mirror assembly 30 or 30', offering additional opportunities for space reduction.

FIG. 7 is a graph comparing the operating range of an automatic focus optical illumination system in accordance with the present invention ("New AF") with the operating range of a variable focus optical illumination system employing single lens focusing system. Three operational situations are illustrated: the top pair of curves illustrate the respective operating ranges when the lowest tolerable resolution is 20 mils; the middle pair of curves illustrate the respective operating ranges when the lowest tolerable resolution is 10 mils; and the bottom pair of curves illustrate the respective operating ranges when the lowest tolerable resolution is 5 mils. In each group, the operating range of optical illumination system in accordance with the present invention is at least twice that of the system employing a lens. Thus, the present invention not only achieves improved durability and greater reliability by virtue of eliminating moving parts and substantial reduction in size, but also offers a substantially greater operating range.

Although preferred embodiments of the invention have been disclosed for illustrative purposes, those skilled in the art will appreciate that many additions, modifications and substitutions are possible without departing from the scope and spirit of the invention as defined by the accompanying claims.

WHAT IS CLAIMED:

1. A method for introducing variable focus to light produced by an optical illumination system including a source of illumination, comprising the steps of:

positioning a curved mirror so as to have incident upon it light emitted by the source; and

controlling the curvature of the mirror so as to position a point of focus thereof in the vicinity of an intended target for the illumination system.

2. The method of claim 1 further comprising detecting the distance of the target and adjusting the curvature of the mirror accordingly.

3. The method of claim 1 or 2 wherein the curvature of the mirror is increased with decreasing distance of the target.

4. The method of claim 3 wherein the curvature of the mirror is controlled by applying pressure thereto with an electrically controlled transducer.

5. The method of claim 4 wherein the transducer is a piezoelectric device.

6. The method of claim 4 wherein the pressure is applied at a periphery of the mirror to increase its curvature.

7. The method of claim 4 wherein the pressure is applied at a point inwardly of a periphery of the mirror to decrease its curvature.

8. The method of claim 1 or 2 wherein the curvature of the mirror is controlled by applying pressure thereto with an electrically controlled transducer.

9. The method of claim 6 wherein the transducer is a piezoelectric device.

10. The method of claim 8 wherein the pressure is applied at a periphery of the mirror to increase its curvature.

11. The method of claim 8 wherein the pressure is applied at a point inwardly of a periphery of the mirror to decrease its curvature.

12. A variable focus optical illumination system, comprising:

a source of illumination;

a curved mirror positioned to have incident upon it light emitted by the source; and

control means acting on the mirror to control the curvature of the mirror so as to position a point of focus thereof in the vicinity of an intended target for the illumination system.

13. The system of claim 12 further comprising means for detecting the distance of the target, said control means being responsive thereto to control the curvature of the mirror in accordance with the detected distance.

14. The system of claim 12 or 13 wherein the controller increases the curvature of the mirror with decreasing distance of the target.

15. The system of claim 14 wherein the controller includes an electrically controlled transducer applying pressure to the mirror to change its curvature.

16. The system of claim 15 wherein the transducer is a piezoelectric device.

17. The system of claim 14 wherein the transducer applies pressure at a periphery of the mirror to increase its curvature.

18. The system of claim 14 wherein the transducer applies pressure inwardly of a periphery of the mirror to decrease its curvature.

19. The system of claim 12 or 13 wherein the controller includes an electrically controlled transducer applying pressure to the mirror to change its curvature.

20. The method of claim 17 wherein the transducer is a piezoelectric device.

21. The system of claim 19 wherein the transducer applies pressure at a periphery of the mirror to increase its curvature.

22. The system of claim 19 wherein the transducer applies pressure inwardly of a periphery of the mirror to decrease its curvature.

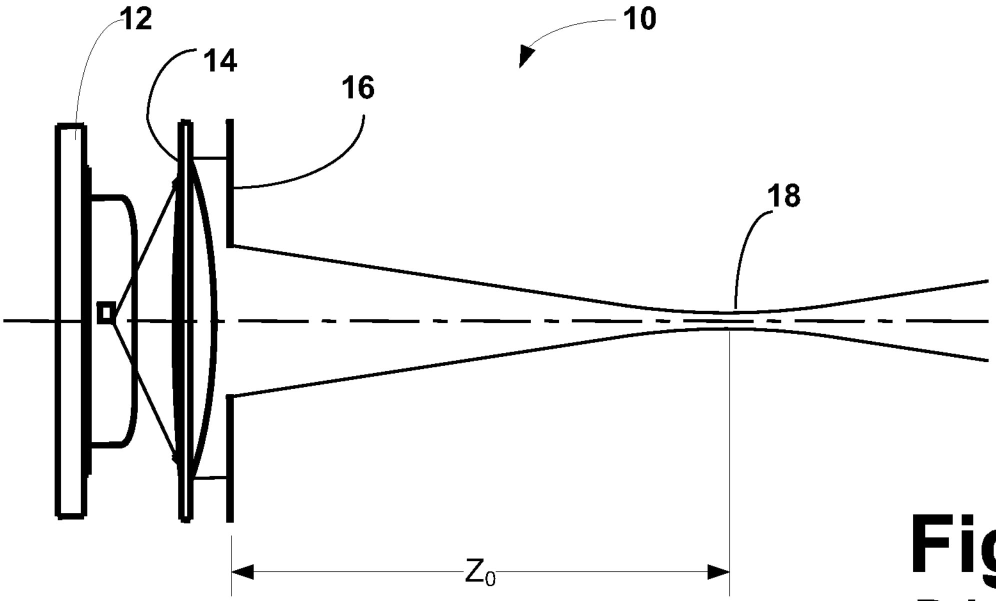

Fig. 1
Prior Art

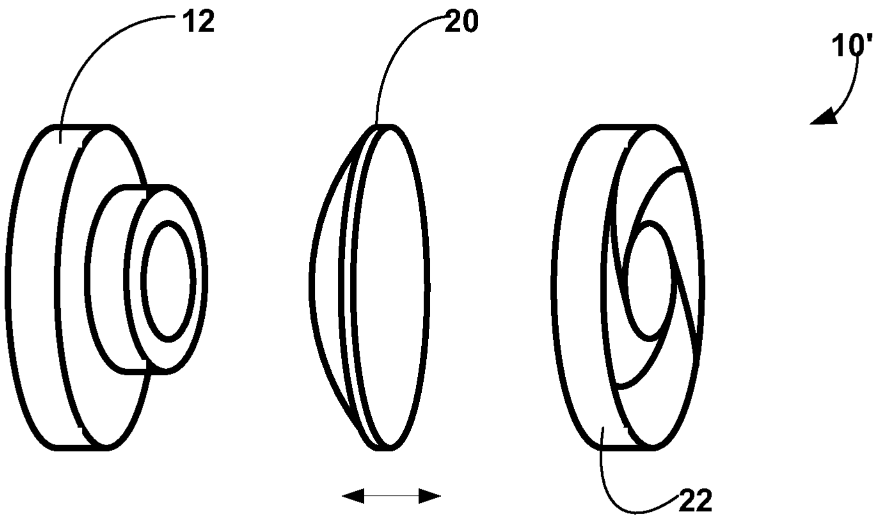

Fig. 2
Prior Art

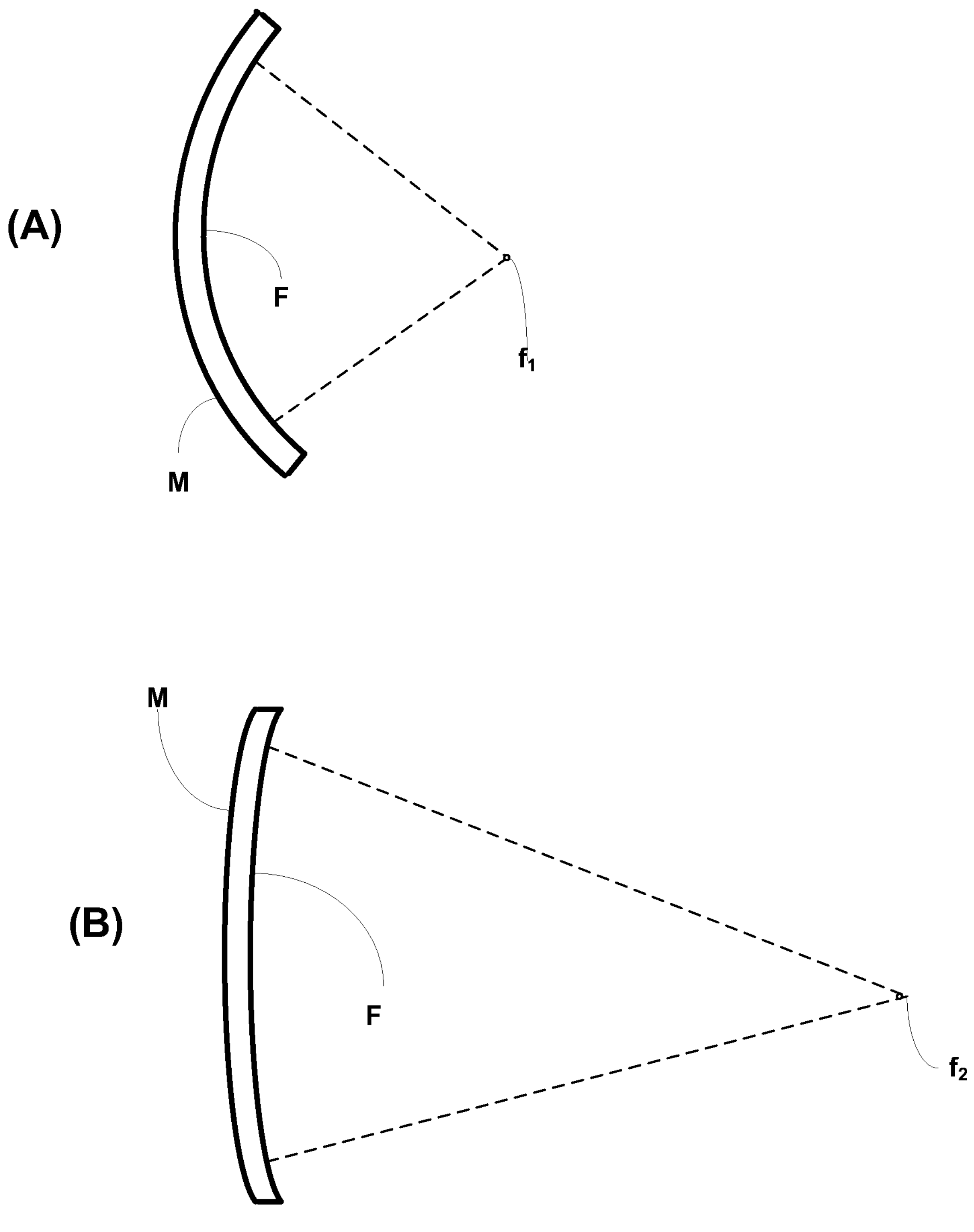

Fig. 3

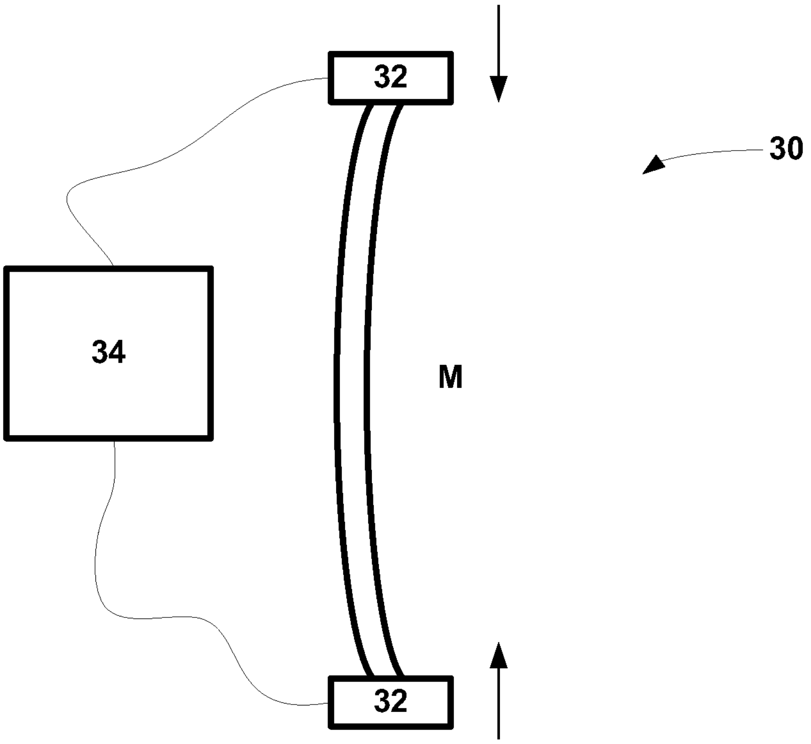

Fig. 4

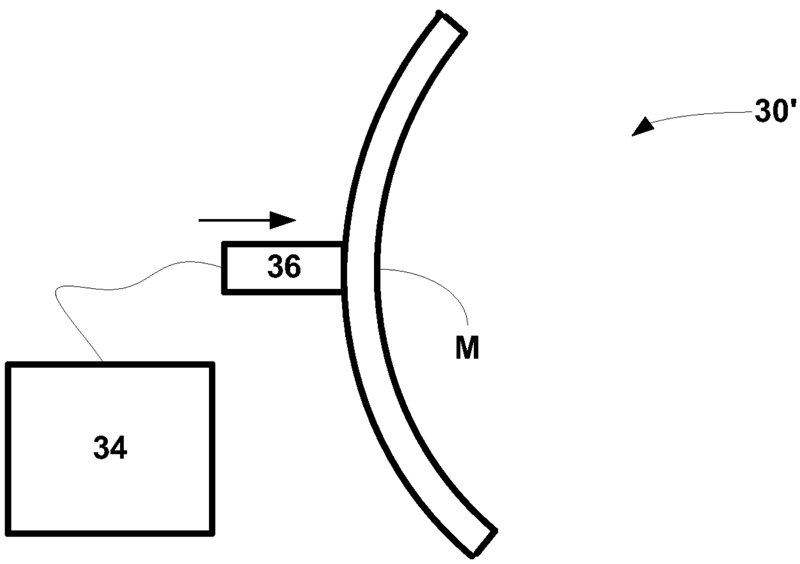

Fig. 5

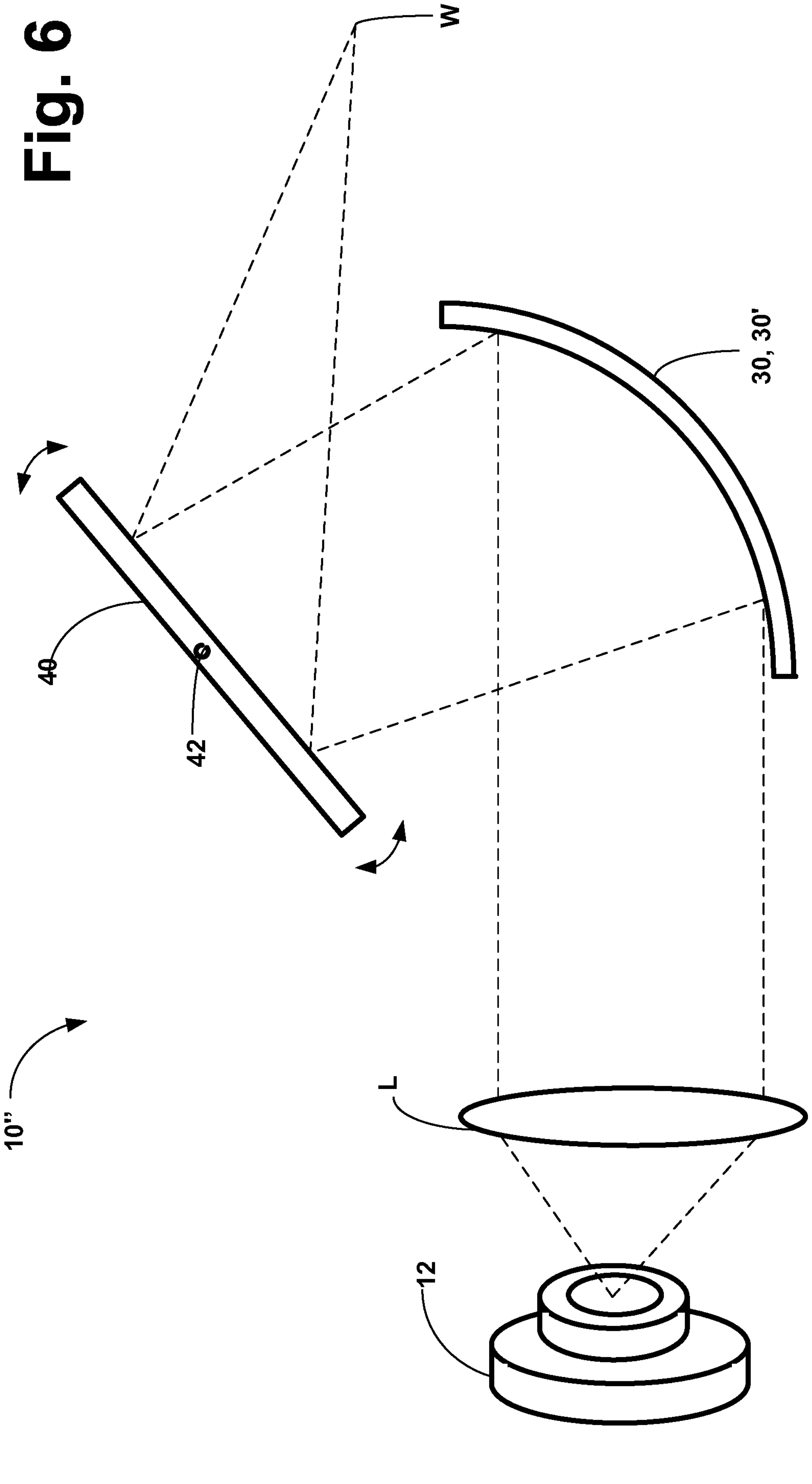

Fig. 6

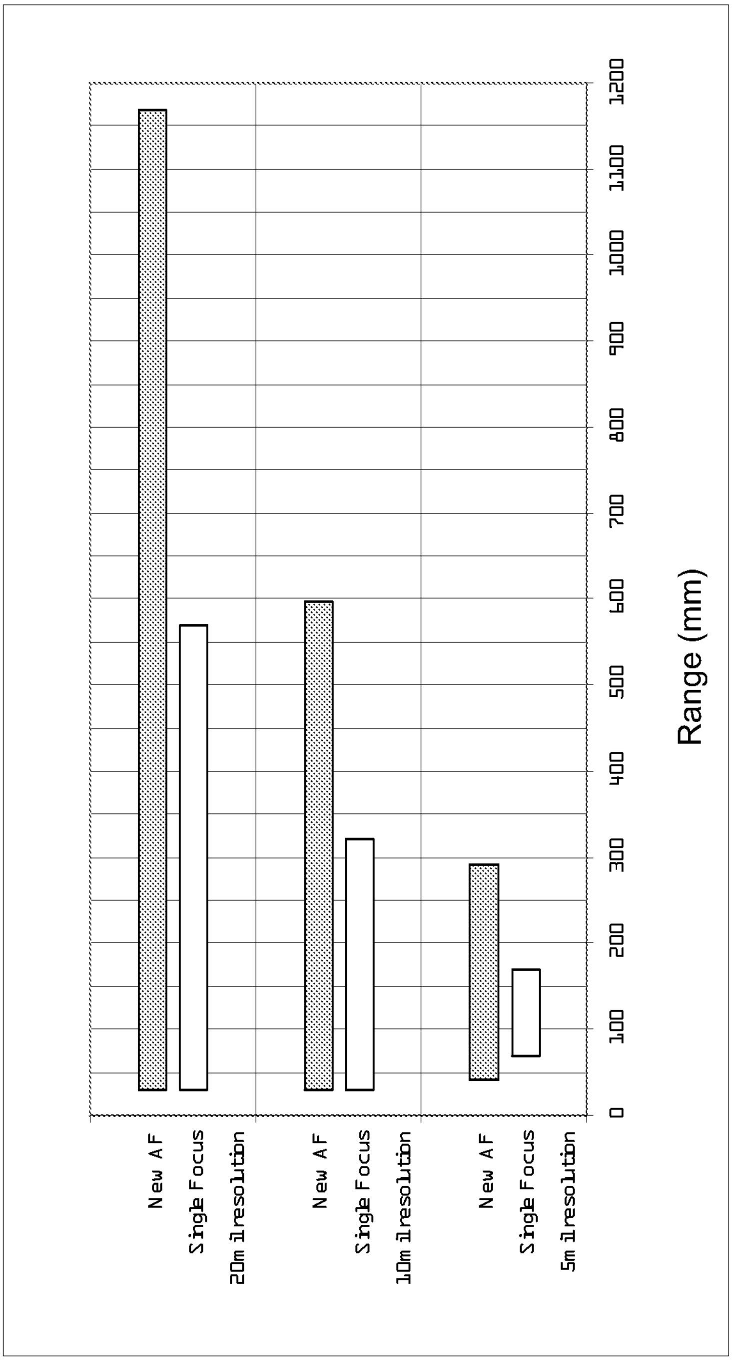
New AF
Single Focus
20mil resolution
New AF
Single Focus
10mil resolution
New AF
Single Focus
5mil resolution
0
100
200
300
400
500
600
700
800
900
1000
1100
1200
Range (mm)

Fig. 7

INTERNATIONAL SEARCH REPORT

International application No.
PCT/US2009/036895

A. CLASSIFICATION OF SUBJECT MATTER
IPC(8) - G02B 26/00 (2009.01)
USPC - 235/462.36
According to International Patent Classification (IPC) or to both national classification and IPC

B. FIELDS SEARCHED

Minimum documentation searched (classification system followed by classification symbols)
IPC(8) - G02B 26/00 (2009.01)
USPC - 235/462.36

Documentation searched other than minimum documentation to the extent that such documents are included in the fields searched

Electronic data base consulted during the international search (name of data base and, where practicable, search terms used)
USPTO EAST System (US, USPG-PUB, EPO, DERWENT)

C. DOCUMENTS CONSIDERED TO BE RELEVANT

Category*	Citation of document, with indication, where appropriate, of the relevant passages	Relevant to claim No.
X — Y	US 6,053,409 A (BROBST et al) 25 April 2000 (25.04.2000) entire document	1-2, 12-13 — 3-11, 14-22
Y	US 2007/0295817 A1 (MASSIEU et al) 27 December 2007 (27.12.2007) entire document	3-11, 14-22
Y	US 2006/0092393 A1 (HARMED et al) 04 May 2006 (04.05.2006) entire document	6, 9-10, 17, 20-21
A	US 4,939,356 A (RANDO et al) 03 July 1990 (03.07.1990) entire document	1-22
A	US 2006/0028703 A1 (GOVIL et al) 09 February 2006 (09.02.2006) entire document	1-22
A	US 6,304,316 B1 (JAIN et al) 16 October 2001 (16.10.2001) entire document	1-22

☐ Further documents are listed in the continuation of Box C. ☐

* Special categories of cited documents:
"A" document defining the general state of the art which is not considered to be of particular relevance
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"P" document published prior to the international filing date but later than the priority date claimed
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"X" document of particular relevance; the claimed invention cannot be considered novel or cannot be considered to involve an inventive step when the document is taken alone
"Y" document of particular relevance; the claimed invention cannot be considered to involve an inventive step when the document is combined with one or more other such documents, such combination being obvious to a person skilled in the art
"&" document member of the same patent family

Date of the actual completion of the international search	Date of mailing of the international search report
21 April 2009	12 MAY 2009
Name and mailing address of the ISA/US Mail Stop PCT, Attn: ISA/US, Commissioner for Patents P.O. Box 1450, Alexandria, Virginia 22313-1450 Facsimile No. 571-273-3201	Authorized officer: Blaine R. Copenheaver PCT Helpdesk: 571-272-4300 PCT OSP: 571-272-7774