United States Patent [19]
Baker et al.

[11] **3,814,943**
[45] **June 4, 1974**

[54] **METHOD OF AND APPARATUS FOR ANALYSING PATTERNS AND INSPECTING OBJECTS**

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[22] Filed: **June 12, 1973**

[21] Appl. No.: **369,334**

Related U.S. Application Data

[63] Continuation of Ser. No. 88,791, Nov. 12, 1970, abandoned, which is a continuation-in-part of Ser. No. 65,824, Aug. 21, 1970, abandoned.

[30] **Foreign Application Priority Data**

Aug. 26, 1969 Great Britain 42500/69
Nov. 13, 1969 Great Britain 55595/69

[52] **U.S. Cl.** .... **250/550**, 250/571, 250/572, 350/162 SF, 356/71, 356/163
[51] **Int. Cl.** **H01j 39/12**
[58] **Field of Search** .... 250/550, 556, 559, 223, 250/237, 233; 350/162 R, 162 SF, 3.5; 356/106, 107, 109, 111, 156, 163, 167, 71

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Assistant Examiner—D. C. Nelms
Attorney, Agent, or Firm—Sughrue, Rothwell, Mion, Zinn & Macpeak

[57] **ABSTRACT**

A method and apparatus for analysing two-dimensional patterns, particularly printed matter carried on sheet-like objects, and for inspecting such sheet-like objects to locate defects therein.

The invention performs such analysis of inspection by subjecting the moving pattern or sheet to light which may be incoherent and scanning the light beam to periodically vary its intensity at some stage in the process. The spatial frequency of scanning (cycles/mm) is preferably variable and the scanned light as affected by the pattern or sheet is used to produce an electrical test signal as a function of the fourier transform thereof. The test signal is subsequently compared with a reference signal or stored data to evaluate the characteristics of the pattern or to determine the presence of defect-indicative information.

33 Claims, 9 Drawing Figures

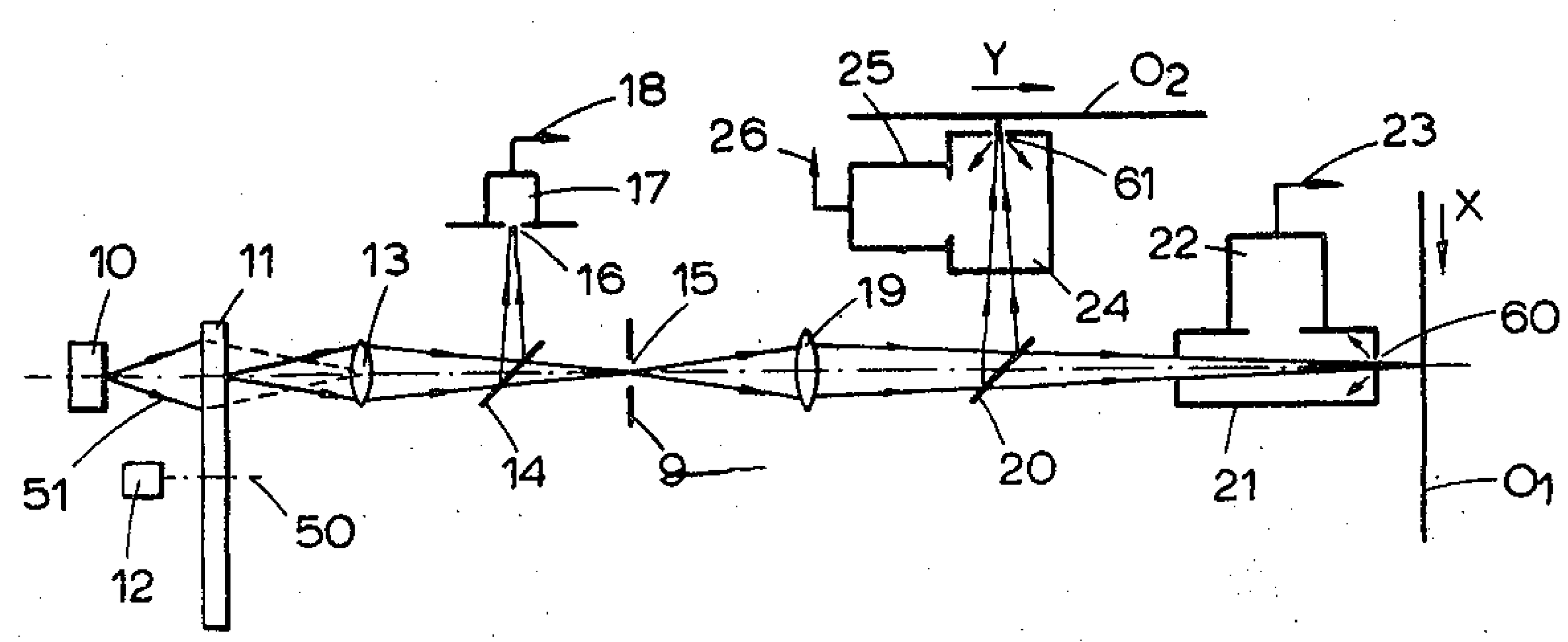
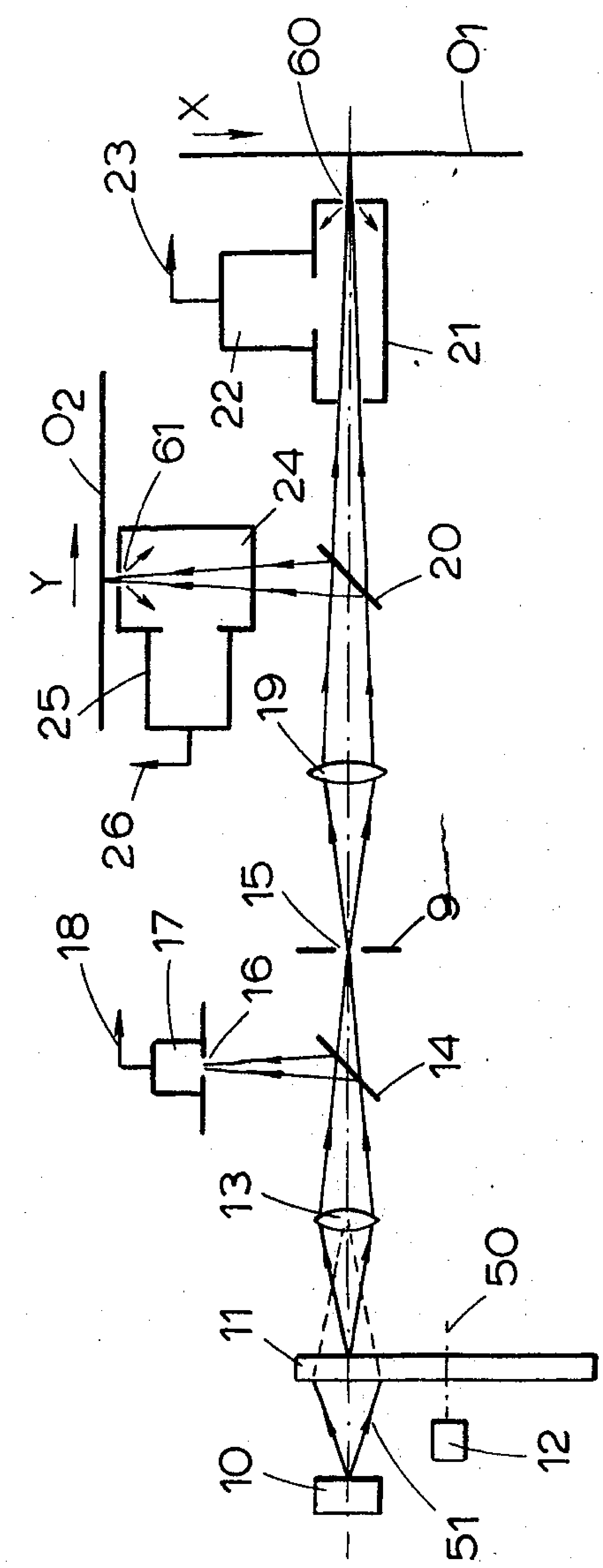


FIG. 1.


X
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O2
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FIG. 2.

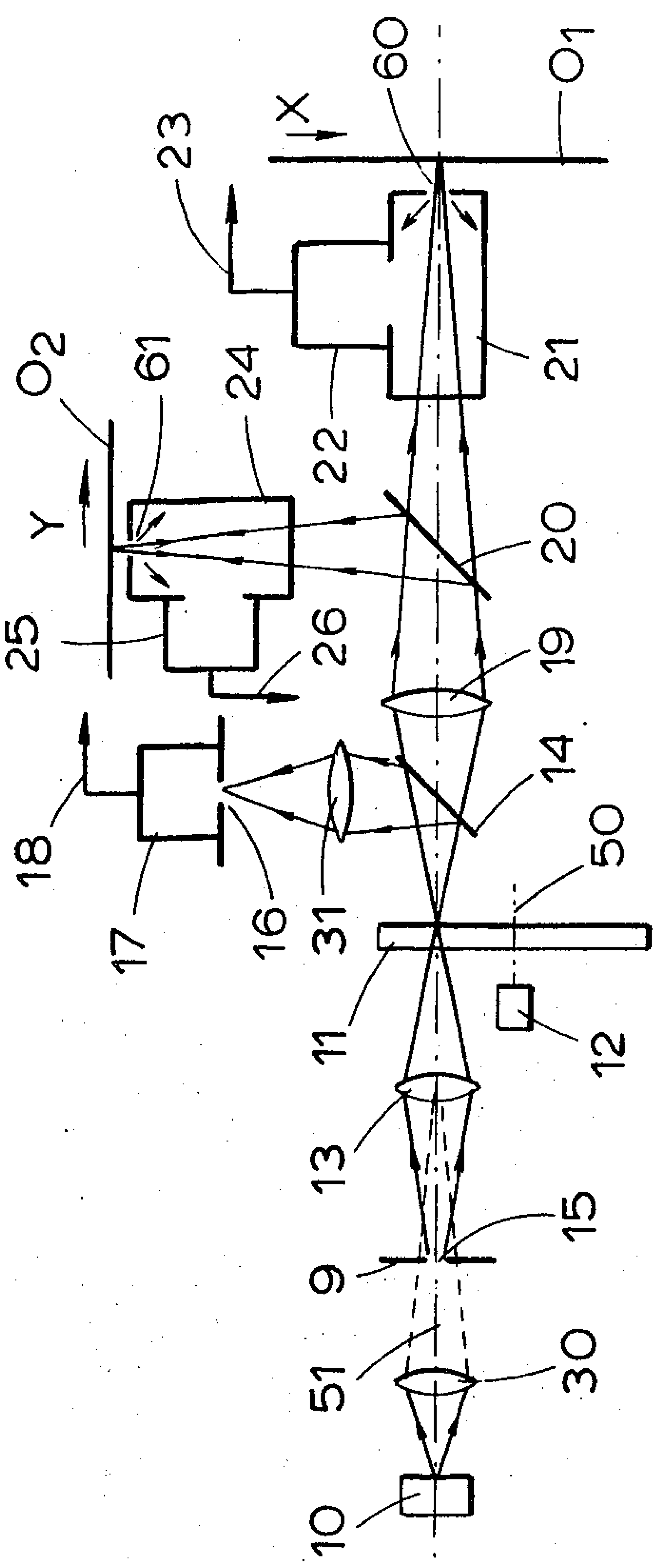
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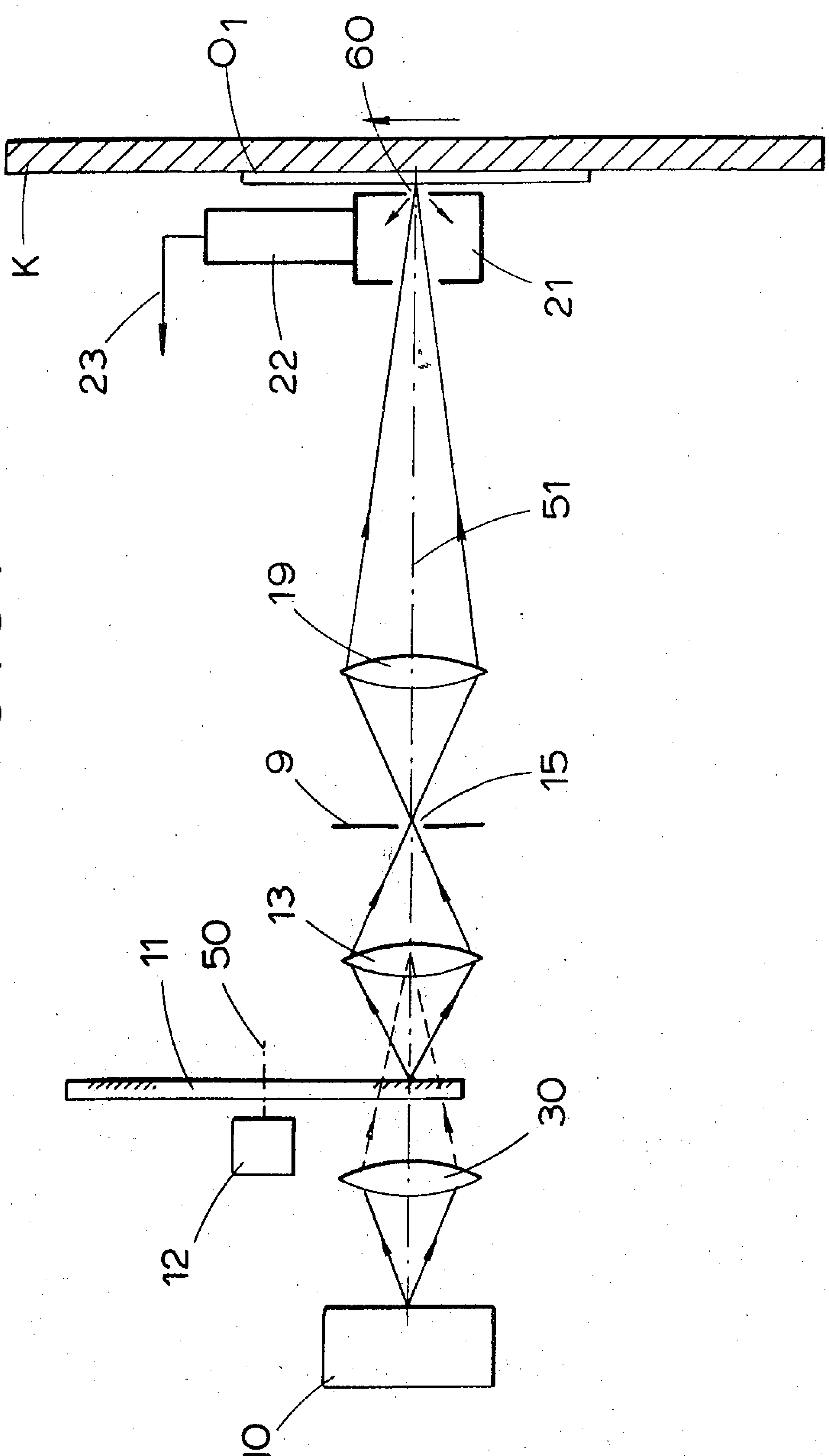
FIG. 3.



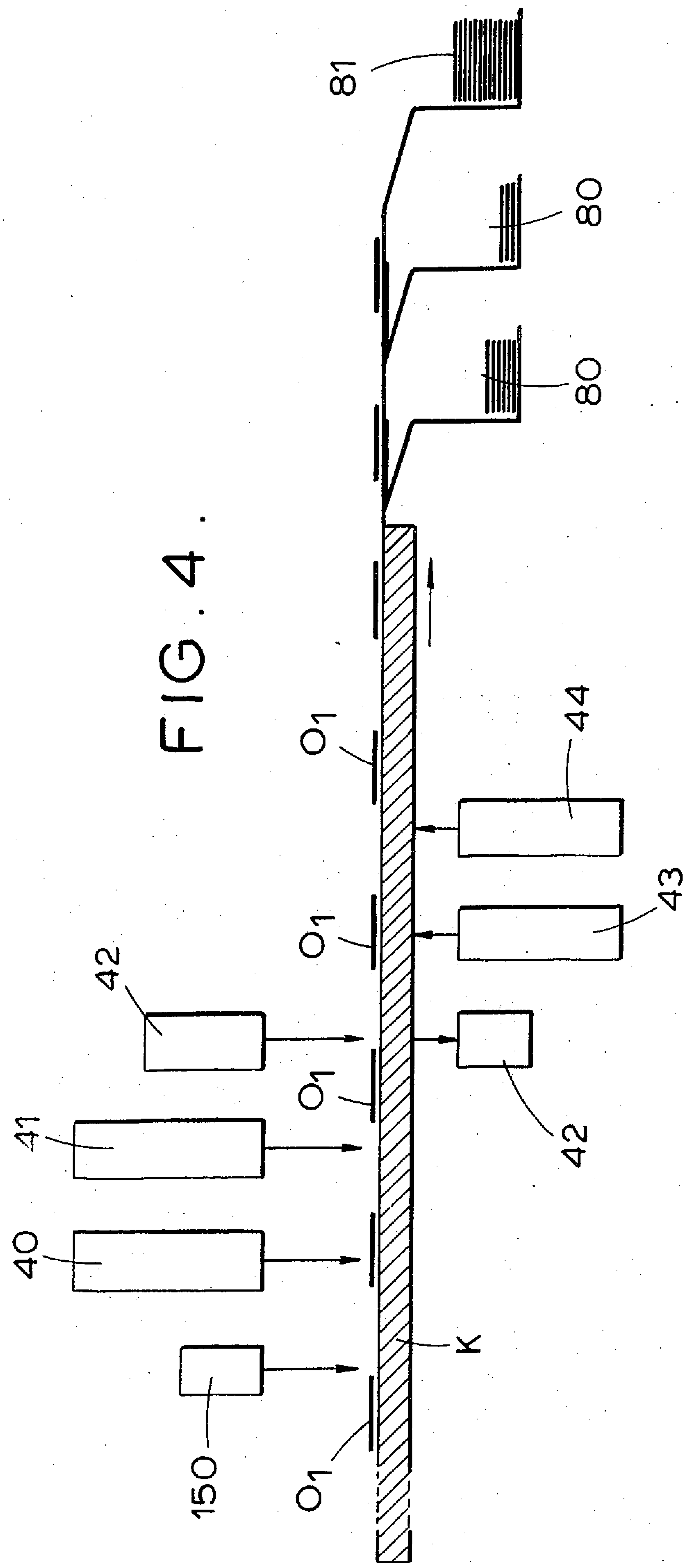


FIG. 4.

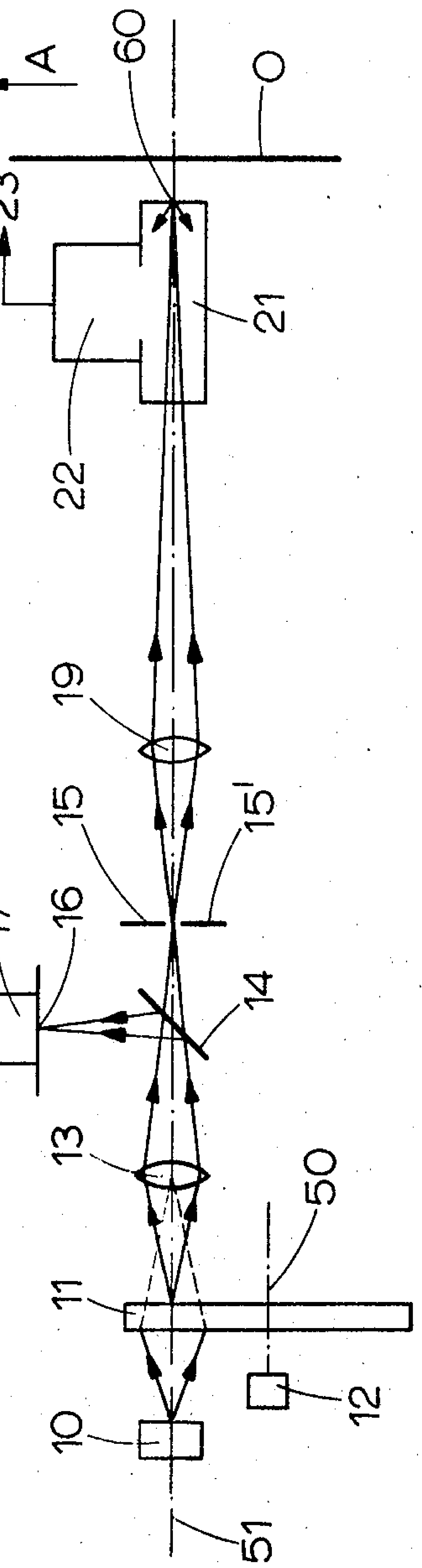


FIG. 5.

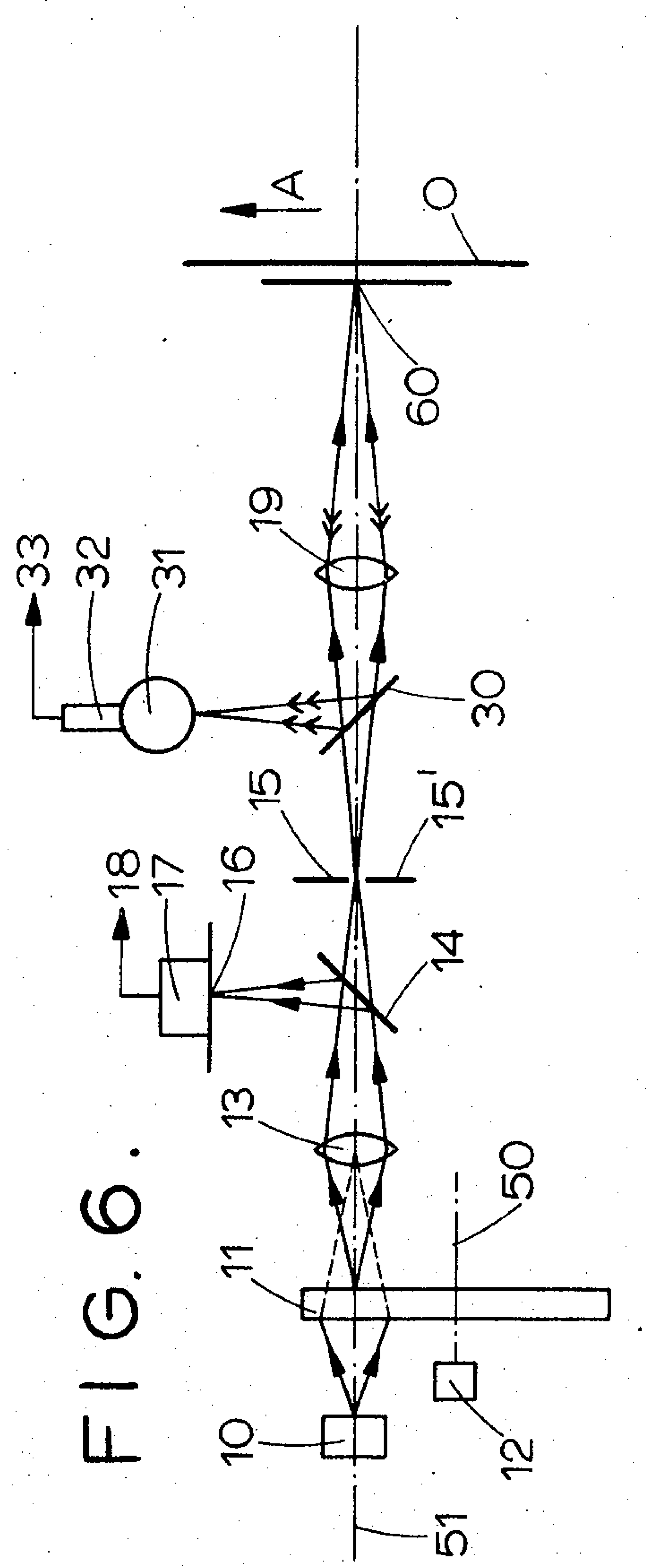


FIG. 6.

FIG. 7.

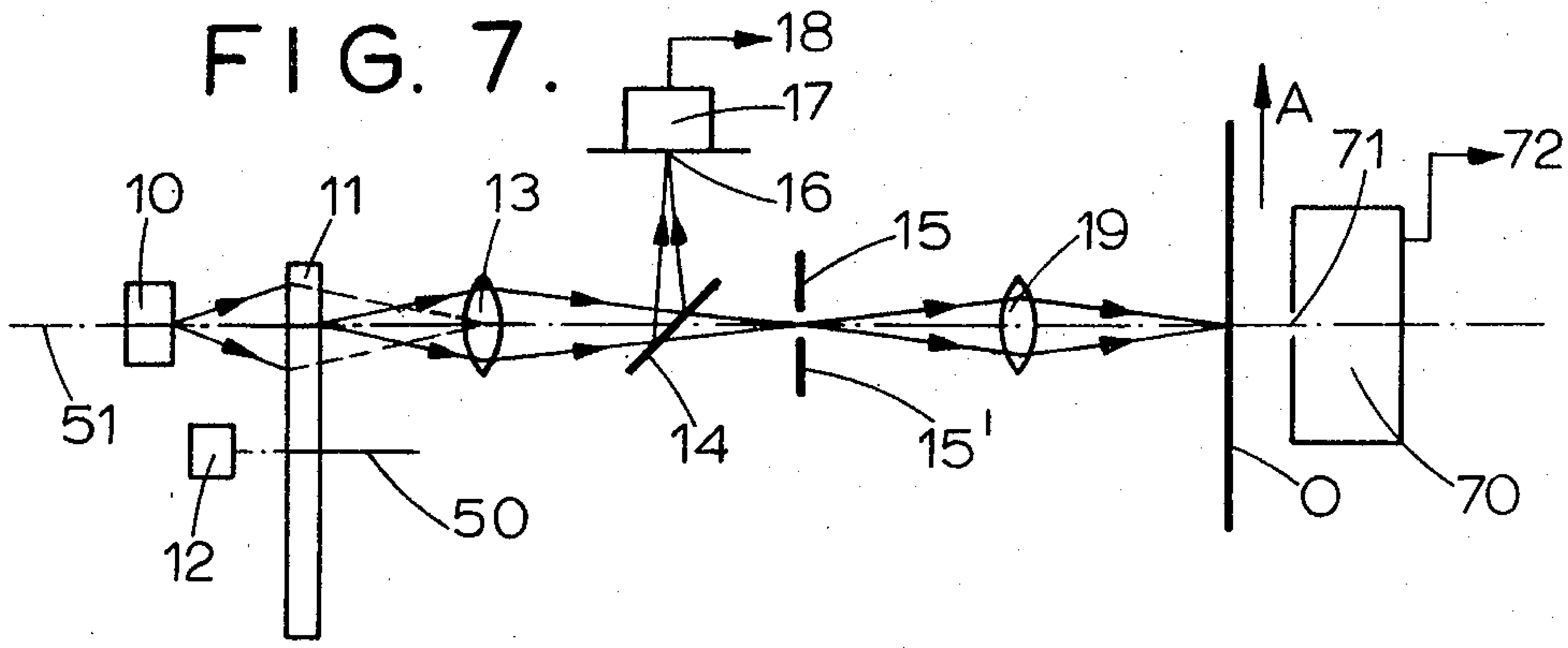


FIG. 8.

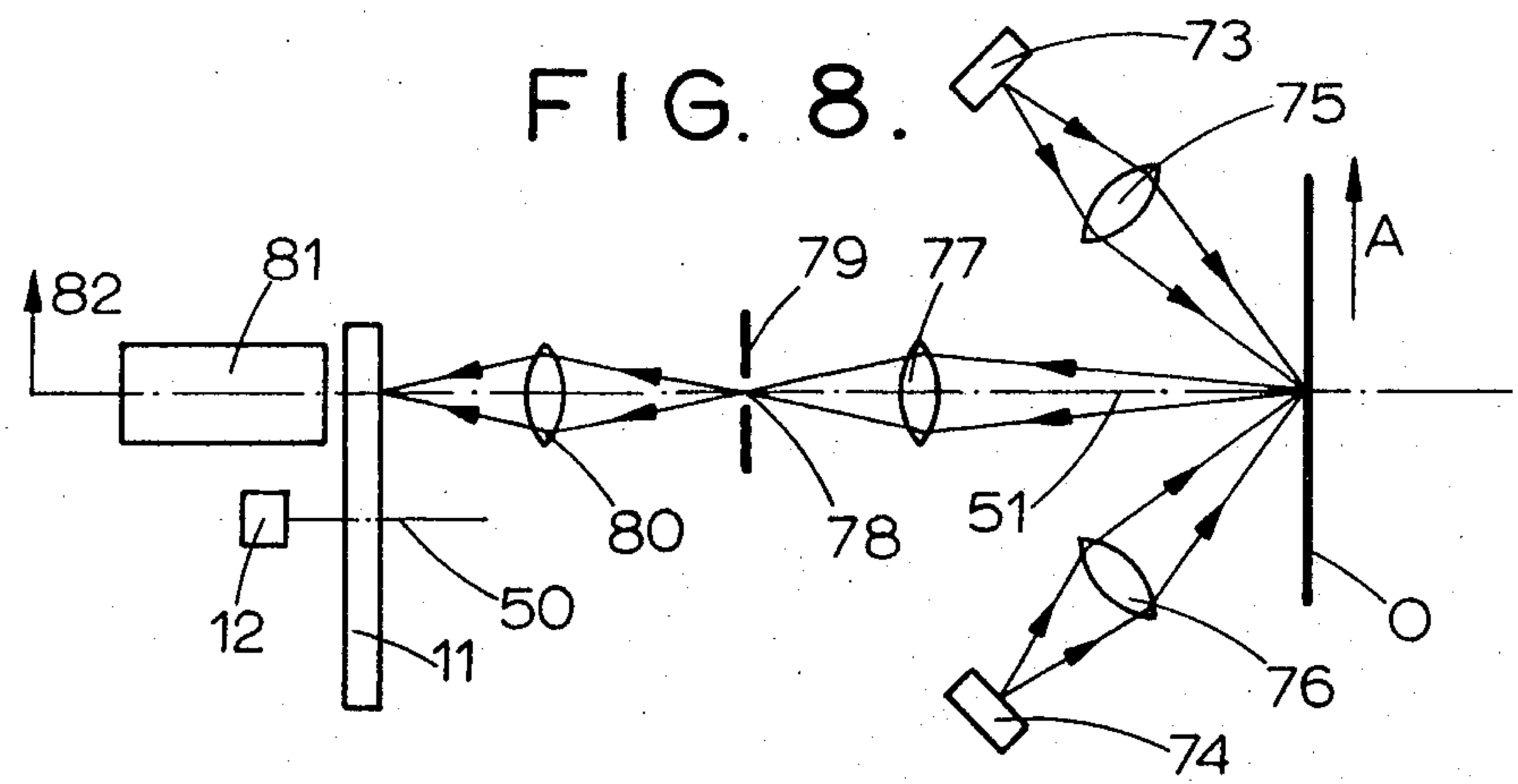
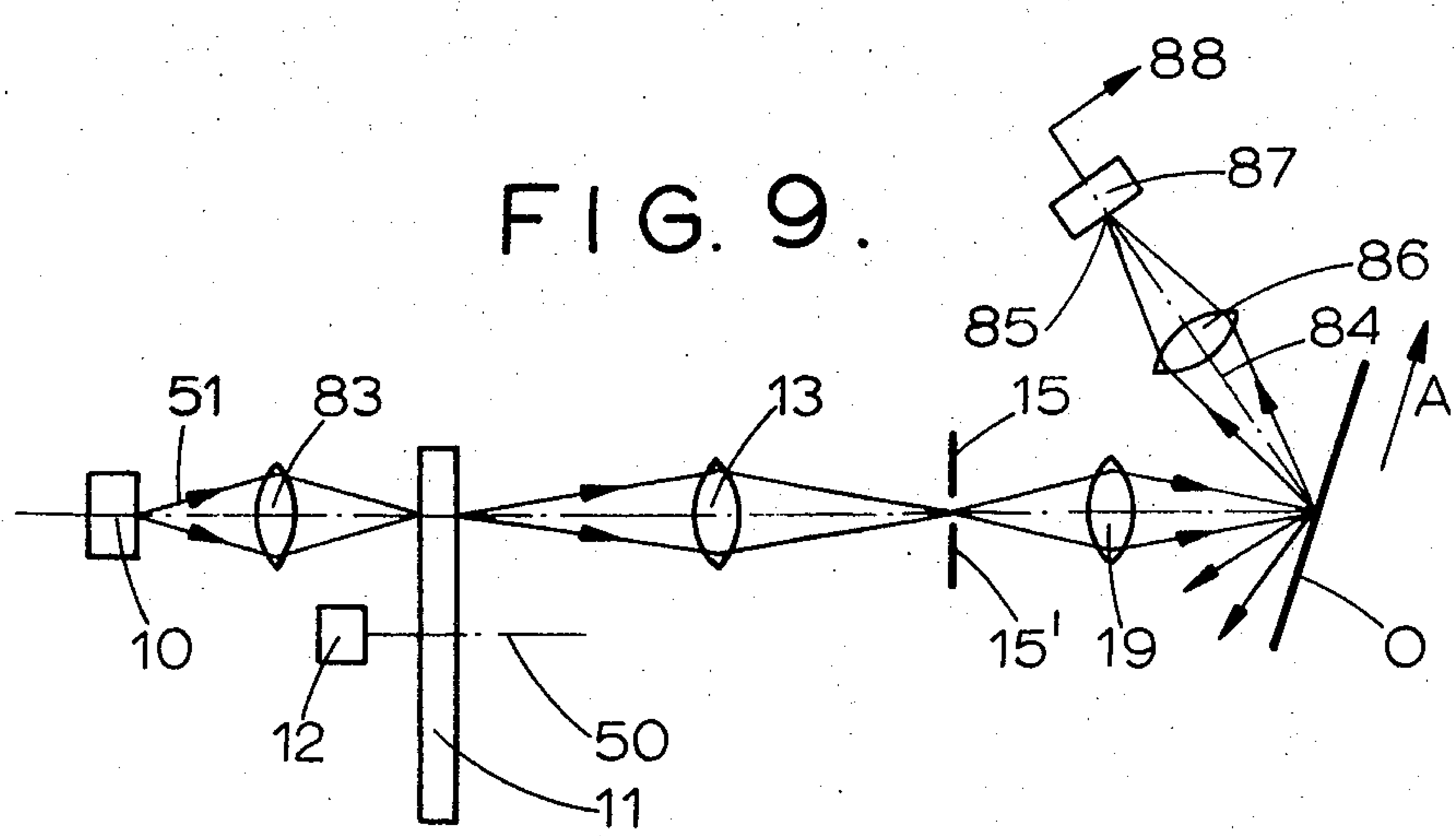


FIG. 9.



METHOD OF AND APPARATUS FOR ANALYSING PATTERNS AND INSPECTING OBJECTS

CROSS-REFERENCE TO RELATED APPLICATIONS

This is a continuation of application Ser. No. 88,791, filed Nov. 12, 1970, now abandoned which is a continuation-in-part of application Ser. No. 65,824, filed 8-21-70 now abandoned.

BACKGROUND OF THE INVENTION

In one aspect, the present invention relates to a method of, and an apparatus for, analysing two-dimensional patterns or inspecting objects. Although the term "two-dimensional pattern or patterns" is intended to apply particularly, but not solely, to patterns carried by objects, it is to be understood that the term two-dimensional pattern is also intended to apply to the outer profile and/or inner features of substantially two or three dimensional objects. Particular applications of the present invention are in analysing objects carrying patterns in the form of printed matter such as bank notes, stamps, labels, drawings or the like. Other examples of objects is this nature which can be analysed in accordance with this invention include printed circuits, micro circuits, patterns on cathode ray tubes, photographic transparencies, radiography photographs, items used in printing, biological and other microscope specimens, and fingerprints. The invention can also be utilized in analysing objects such as sheet metal, ceramic or synthetic plastics piece parts, typically gearwheels, cams and other precision components.

One object of the invention is thus to provide a method of, and an apparatus for, analysing two dimensional patterns particularly patterns carried by objects such as those mentioned above.

The invention is also concerned with a method of, and an apparatus for, inspecting objects. In this aspect, the invention is particularly, but not solely, concerned with inspecting planar surfaces of objects in the form of sheet materials in order to locate surface defects and with inspecting thin sheet materials for internal defects not present on the outer surfaces.

Examples of objects with which the present invention can be advantageously employed are as follows:

sheet metal, tiles, sheets of plastics or rubber, sheets of paper, glass objects, magnetic tape and emulsive materials. The term defects is intended to encompass cracks, blemishes, holes, internal discontinuities, surface roughness and also local colour variation where applicable. Another application of the invention is in determining the depth of a turning mark on a metal component.

Another object of the invention is thus to provide a method of and apparatus for, inspecting objects such as those mentioned above.

SUMMARY OF INVENTION

According to the present invention there is provided a method of testing or analysing a two dimensional pattern, as hereinbefore defined, said method comprising subjecting at least a portion of the pattern to be tested to a beam of electromagnetic radiation, deriving an electrical test signal as a function of the Fourier transform of the radiation generally reflected by and/or transmitted through the pattern, and comparing said

test signal with a reference signal or the equivalent thereof.

Further according to the invention the method may further comprise scanning the beam to periodically vary its intensity before it impinges on or passes through said pattern or scanning the radiation generally reflected by and/or transmitted through, the pattern to periodically vary the intensity of said radiation, the electrical test signal being derived from the radiation generally reflected by and/or transmitted through the pattern and after the scanning operation.

The term "generally reflected" is intended to include diffraction, reflection and scattering or other effects produced by the presence of the pattern.

The term "transmitted" is intended to apply where the object is of such nature that when subjected to radiation, radiation passes through a radiation-transmitting part or parts of the object.

In accordance with a preferred method the radiation is visible light which is scanned before it impinges on or passes through the pattern. The light beam may be aplit into two components directed at a reference pattern and a pattern to be investigated. The electrical signal from the patterns can then be compared. The pattern or patterns may also be moved so that the entire pattern can be analysed continuously.

According to another aspect of the present invention there is provided a method of inspecting an object to determine the presence of defects, said method comprising subjecting at least a portion of the object to be tested to a beam of electromagnetic radiation, deriving an electrical test signal as a function of the Fourier transform of the radiation generally reflected by and/or transmitted through the object, and comparing said test signal with a reference signal or the equivalent thereof to determine the presence of defect indicative information in said test signal. is provided an apparatus for testing or analysing a two dimensional pattern as hereinbefore defined or for inspecting an object to detect defects, said apparatus comprising means for producing a beam of electromagnetic radiation, means for directing said beam at the pattern or object under test, means for scanning the beam to periodically vary its intensity and means for producing an electrical test signal which is a function of the Fourier transform of the radiation generally reflected by and/or transmitted through the test pattern or object after the scanning operation.

The scanning spatial frequency can be constant or varied to produce a part of, or a complete Fourier transform response of the radiation reflected by or transmitted through the pattern or object.

The electromagnetic radiation is preferably visible light although the infra red, ultra violet and even X-ray or X-ray spectrum can be employed. The scanning means is preferably in the form of a light transmissive disc carrying radial grating lines which scans the radiation, for example, prior to its impingement on the pattern or object under test. In pattern analysis the light beam emitted by the source may be split after scanning into two components which are directed at a reference pattern and a pattern to be investigated. The patterns are preferably moved and the electrical signals indicative of the characteristics of the patterns can be compared preferably automatically so that any variations in the pattern being examined from the reference pattern may be identified by inequality of said signals.

The signals may be compared by a "cross-correlation process" generally involving the effective superimposition and relative movement of the signals.

A further electrical signal of non-varying phase can be derived and compared with the signal representing the pattern or object under investigation.

Instead of employing a scanning means to produce the test signal a test signal can be derived as the requisite Fourier transform function of the radiation by employing a static array of photo electric elements.

This array may be so constructed as to exhibit a sinusoidal variation in sensitivity along some predetermined axis. To this end photographic masks or Moire gratings can be placed over an array of identical photo-electrical elements.

Where defects are to be detected on the outer surface of the object the surface can normally produce specular or diffuse reflection and in the latter case the scanned radiation diffusely reflected by the surface can be collected and converted into said test signal. Where the surface produces specular reflection either the scanned radiation specularly reflected can be collected and converted into the test signal or else the scanned radiation diffusely reflected from defects on the surface can be collected and converted into the test signal which will be present only when defects are apparent.

The object under investigation can be moved and it follows that the invention is particularly useful in the automatic inspection of objects of the kind mentioned hereinbefore.

The invention may be understood more readily, and various other features of the invention may become more apparent, from consideration of the following description.

BRIEF DESCRIPTION OF DRAWINGS

Embodiments of the present invention will now be described, by way of examples only, with reference to the accompanying drawing wherein:

FIG. 1 is a block schematic diagram of a pattern-analysing apparatus made in accordance with the present invention

FIG. 2 is a block schematic diagram of a modified pattern-analysing apparatus made in accordance with the present invention;

FIG. 3 is a block schematic diagram of a further pattern-analysing apparatus as employed in the installation illustrated in FIG. 4;

FIG. 4 depicts an installation for the automatic inspection of banknotes;

FIG. 5 is a block schematic diagram of an inspection apparatus made in accordance with the present invention;

FIG. 6 is a block schematic diagram of a further inspection apparatus made in accordance with the present invention;

FIG. 7 is a block schematic diagram of a further inspection apparatus made in accordance with the invention;

FIG. 8 is a block schematic diagram of yet another inspection apparatus made in accordance with the invention; and

FIG. 9 is a block schematic diagram of a further inspection apparatus made in accordance with the invention.

DESCRIPTION OF PREFERRED EMBODIMENTS

For the purposes of this description in connection with FIGS. **1** to **4** it is assumed that an object to be tested designated **01** is in the form of a sheet carrying a two dimensional pattern and by way of example the object **01** can carry coloured printed matter and be a banknote or a stamp.

As shown in FIG. **1** the apparatus has a light source **10** which has a high intrinsic brightness and can be in the form of a laser or a tungsten lamp. The light beam emitted by the source **10** is scanned by being passed through a radial grating in the form of a light-transmitting disc **11** having a large number of radial grating lines thereon. A lens (not shown) may be disposed between the source **10** and the disc **11.** The disc **11** is rotated at constant speed by a drive means **12** which can be in the form of a synchronous motor. The disposition of the main optical axis **51** of the apparatus in relation to the axis of rotation **50** of the disc **11** can be appreciated from considering the drawing. As mentioned hereinafter, the axis of rotation **50** of the disc **11** can be fixed or rotatable relative to the main optical axis **51** of the apparatus. The construction of the disc **11** may be as described in U.K. patent specification No. 970,369 and the spacing of the grating lines of the disc **11** is made commensurate with the particular application to which the apparatus is put. The image of the scanning radial grating lines on the disc **11** is focused by means of a lens **13** onto a slit **15** in a plate. By rotating the disc **11** at a constant speed the light beam is made to vary in intensity to provide a regular carrier frequency signal. The spatial frequency or effective pitch of the lines of the grating on the disc **11** crossing the slit **15** can be varied by altering the relative dispositions of the axes **50, 51** from a minimum of zero cycles/mm to a maximum determined by the actual pitch of the grating and the magnification of the lens or lenses used. Instead of employing a disc carrying lines at a single spacing it is possible to use a disc carrying several groups of lines each with their own characteristic spacing. Such a disc would produce several carrier frequencies which can be analysed independently.

As an optional feature, a beam splitter **14** is positioned between the lens **13** and the plate **9** and the light reflected from the beam splitter **14** passes into a pin hole **16** and thence into a photo-electric device **17** such as a photo multiplier. The electrical output from the photo-electric device **17** is designated **18** in the drawing and provides a phase reference signal the function of which is described hereinafter.

The image of the slit **15** is also focused by a lens **19** onto the object **01.** As depicted in the drawing a further slit **60** may be positioned closely adjacent the object **01** to receive the image of the slit **15.** In many applications however, the slit **60** can be dispensed with. As a further optional feature, a beam splitter **20** is positioned between the lens **19** and the slit **60** and the light reflected from the beam splitter **20** as passed onto a further slit **61** positioned closely adjacent a reference object **02.** It should be understood that the presence of the reference object **02,** beam splitter **20** and associated parts is not essential and in some modes of operation they may be dispensed with as expalained hereinafter.

The light transmitted through the beam splitter **20** and onto the slit **60** passes through a light collector in the form of an integrating sphere **21** and likewise the light reflected by the beam splitter 20 and onto the slit 61 passes through a light collector in the form of an integrating sphere 24. The slits 15, 60 61 extend perpendicularly to the plane of the drawing and the length of the slits 60, 61 is preferably sufficient to cover the entire width of the objects 01, 02. An image of the scanning grating lines on the disc 11 is thus formed on the objects 01 02 and the light generally reflected back from the objects 01 02 into the spheres 21 24 is collected thereby. The collected light is then converted to electrical signals by means of photo electric devices 22 25 respectively. The devices 22 25 can again be in the form of photo multipliers and the electrial signals or outputs of the devices 22 25 are designated 23 and 26. The electrical output 23 is a function of the Fourier transform of the light reflected by the pattern on the portion of the object 01 which is illuminated through the slit 60 and is indicative of the characteristics of the pattern on the portion of the object 02 which is illuminated through the slit 61.

If the objects 01 02 are moved in synchronism in the direction of arrows X and Y the objects 01 02 can be scanned continuously. In this mode of operation the disc 11 is rotated at constant speed and the optical relationship between the axes 50 51 is maintained constant so that the spatial frequency of scanning (cycles/mm) is maintained at a constant value. The outputs 23 and 26 vary according to the nature of the pattern on the objects 01 02 and assuming that the object 02 is a reference or standard object any deviation between the outputs 23 26 whilst the objects 01 02 are moved will indicate differences in the pattern on the portions of the objects 01 02 being examined.

Instead of scanning with a constant spatial frequency, the spatial frequency can be varied by altering the optical relationship between the axes 50 51 to provide a complete Fourier transform response. By altering the spatial frequency the effective response of the apparatus is varied and the alteration in the output 23 or both outputs 23, 26 can be determined as a function of spatial frequency to provide a Fourier transform response. In this operational mode, it may be possible to illuminate the whole of the object 01 under investigation.

In the embodiment illustrated in FIG. 1 it is assumed that the object 01 is generally non-light transmitting or light transmitting to only a smal degree. Where the nature of the object permits, instead of reflecting light from a portion of the object 01 the light may be transmitted through the object and the photo electric device 22 positioned on the side of the object 01 remote from the slit 60 such as would be the case with a photographic transparency. The same modification would of course be made in the case of the reference object 02 in situations where the latter is employed.

The reference signal 18, the phase of which under given conditions does not vary, can be compared with the output signal 23, the phase of which may vary according to the nature of the pattern being analysed to ascertain the phase relationship between the signals 18, 28. This phase comparison is important with certain patterns where, for example, registration of one or more colours relative to one or more other colours may be poor. Thus under certain conditions analysis of both the amplitude and phase of the signal 23 may be desirable. Instead of a relative measurement of the phase and amplitude of the signal 23 the real and imaginary parts of the signal can be recorded by suitable known apparatus.

As mentioned, the reference object 02 is optional and the presence of the reference object 02 may be more desirable where an automatic comparison of the outputs 23, 26 is made. This comparison can be achieved by a suitable circuit which equates the outputs 23, 26 but the physical presence of the object 02 may not be necessary where a reference response is known. In this case, a recording device such as a pen recorder can be driven by the output 23 and thereafter the printed result compared with a pre-printed reference response. In an alternative arrangement the output 23 can be stored on magnetic tape or fed into a computer or otherwise stored and subsequently the stored information can be compared with the equivalent information previously derived from a reference object.

The known process of "cross-correlation" can be used to compare the two signals representing the two patterns i.e. the test and reference signals. This process involves the effective superimposition of the two signals to be compared and relatively moving one signal with respect to the other. Any difference between the signals is indicated by the resultant signal produced by the process. The cross-correlation process iteslf can be carried out in various ways, for example, electronically, by calculation e.g. by a computer, or optically.

In a modified arrangement depicted in FIG. 2 much of the apparatus is the same as in FIG. 1 and like reference numerals have accordingly been used to designate like parts. The difference between the apparatus of FIGS. 1 and 2 is that in FIG. 2 light emitted by the source 10 is transmitted by a lens 30 onto the slit 15 and the image of the slit 15 is then scanned by the disc 11. This alternative arrangement has the advantage that the slit 15 can be illuminated more efficiently and the optical dimensions can be made shorter thus rendering the apparatus more compact.

In a further optional modification the disc 11 is placed in a position such that the light reflected by or transmitted through the object 01 is scanned. Thus in contrast to the arrangements shown in FIGS. 1 and 2 the light beam is directed at the object without initially undergoing the scanning process and this scanning process is carried out on the light as influenced by the object. The invention is not limited to the use of radiation solely in the visible light spectrum but longer wavelengths in the infra-red region and shorter wavelengths in the γ and X-ray region can be utilised to perform the analysis. The object to be analysed can also take other forms than the essentially sheet-like nature of banknotes, postage stamps and the like and examples of other objects in the form of precision components have been mentioned hereinbefore. Such a component would be placed in the position 01 in FIG. 1 and in this application it is generally preferred not to use a reference object 02. Instead a reference signal is compared with the test signal in the manner mentioned above. Depending upon the nature of the object light or other radiation reflected by, transmitted through and/or past the object would be converted into a test signal for subsequent evaluation.

In applications where only fairly coarse defects are encountered the test signal can be analysed by simpler techniques. For example, the gradient of a particular portion of the test signal or the peak level of some portion of the test signal can be compared with some preset value.

FIGS. **3** and **4** depict an apparatus and an installation intended for the automatic inspection of banknotes and again for convenience like reference numerals are used in FIG. **3** to denote like parts to those previously described.

It has been found that it is not necessary in this application to produce a complete Fourier transform by varying the spatial frequency of the radiation passed through the disc **11**, i.e. by altering the relationship between the axes **50, 51.** Instead a particular spatial frequency is selected and the banknotes to be tested are each scanned at the selected spatial frequency appropriate to a certain type of defect. For example at low spatial frequencies say about 0.1 cycles/mm faults such as creases tears, stains and large scale pattern defects can be identified whereas at about 0.3 cycles/mm faults such as spew, feathering and broken print can be identified more readily.

As shown in FIG. **4** the banknotes to be inspected, again designated **01**, are conveyed a moving conveyor K past a number of units designated **40** to **44.** The conveyor K is depicted as being of the endless belt type but other types of conveyor such as rotatable drums are feasible.

The units **40** to **44** would each be constructed as generally depicted in FIG. **3** and would operate as described hereinbefore. In this example the units **40, 41** would analyse light reflected by the front faces of the banknotes the units **43, 44** would analyse light reflected by the reverse faces of the banknotes and the unit **42** would analyse light transmitted through the banknotes. The units **40** and **43** would be set to one spatial frequency to detect one type of defect and the units **41, 44** would be set to another spatial frequency to detect another type of defect. Likewise, the unit **42** would be set to one particular spatial frequency. The banknotes can be moved at speeds of up to 20 banknotes per second with known transporters but higher speeds may be achievable. Analysis of the light reflected by the banknotes can be readily indicate printing defects such as spew, feathering or broken print, as well as the presence of foreign matter such as oil, defects in registration, creases and in some circumstances physical tears. By analysing the light transmitted through the banknotes in addition to the light reflected by the banknotes assessment of watermarks and the registration between patterns on the front and reverse sides of the banknotes can be made. As mentioned before for transmission measurement the light collector (integrating sphere **21**) and photo electric device (**22, 25**) would be positioned on the side of the banknote remote from the light source **10** i.e. beneath the conveyor K. To enable colour checks to be carried out selectable filters can be incorporated in the apparatus.

Preferably an edge detecting device **150** is used to sense the presence of each banknote and to initiate the data correlation process. The edge detecting device **150** may be a simple light source and photo-sensitive element adapted to sense the presence or absence of each banknote in turn. Depending upon the analysis performed by the units **40–44** the banknotes would be separated automatically by electrical processing signals, into reject and accept stations **80, 81** respectively, disposed at the end of the conveyor K. To this end pivotable flaps **82** can be provided over the stations **80** which flaps are lowered upon reception of an energising signal to cause a banknote to fall into one or other of the stations **80.** Instead of two reject stations **80** a single station **80** could be used.

The inspection apparatus depicted in FIG. **5** is particularly intended for inspecting objects with one or more diffusely reflecting surfaces such as sheets of plain paper although with some modification, described hereinafter, the apparatus can be used to inspect objects with one or more specularly reflecting surfaces, such as certain types of sheet metal.

As shown in FIG. **5,** the apparatus has a light source **10** which has a high intrinsic brightness and can be in the form of a laser. The light beam emitted by the source **10** is passed onto a radial grating in the form of a rotatable light transmitting disc **11** having a large number of radial grating lines thereon. The disc **11** is rotated at constant speed by a drive means **12** which can be in the form of a synchronous motor. The disposition of the main optical axis **51** of the apparatus and the axis of the rotation **50** of the disc **11** can be fixed or relatively movable. The general construction and operation of the disc **11** can be as described in our U.K. patent specification No. 970,369.

The image of the radial grating lines on the disc **11** which scan the light beam emitted from the source **10** is focused by means of a lens **13** onto a slit **15** in a plate **15'**. The slit **15** extends perpendicularly to the plane of the drawing. A beam splitter **14,** such as a semi-silvered mirror or the like, is positioned between the lens **13** and the slit **15.** Light reflected from the beam splitter **14** is passed into a pin hole **16** and hence into a photoelectric device **17,** such as a photo-multiplier. The electrical output signal from the device **17** is designated **18.**

The image of the slit **15** is focused by means of a lens **19** onto a further slit **60** psoitioned closely adjacent an object **0** to be inspected. The slit **60** again extends perpendicularly to the plane of the drawing. The slit **60** can be omitted in certain applications. The light which is focused onto the slit **60** passes through an integrating sphere **21.** The light is generally reflected in a diffuse manner by the object **0** and the reflected light is scattered back into the integrating sphere **21** to be collected thereby. The collected light is converted to an electrical signal by means of a photo-electric device **22** which can again be a photomultiplier. The electrical output signal from the device **22** is designated **23.** The signal **23** can be fed to various electronic circuits and processed thereby. The signal **23** is a function of the Fourier transform of the lgiht diffusely reflected by the portion of the object **0** which is illuminated by the slit **60** and is thus indicative of the surface quality of that portion of the object **0.** The object **0** can be moved continuously in the direction of arrow A so that the entire surface of the object **0** can be inspected.

The apparatus can be operated so that the optical relationship between the axes **50, 51** is maintained constant value. Deviations of the signal **23** from a reference level and assessed by a comparator circuit will be indicative of a defect in the surface. In an alternative mode of operation, the spatial scanning frequency is varied by altering the optical relationship between the axes **51, 51.** In this manner a complete Fourier transform response of the light reflected from the surface of the object can be obtained by determining the variation in the output signal **23** for a corresponding change in spatial frequency. The output **18** provides a reference signal since its phase remains constant under given conditions. Thus, the signals **18, 23** can be phase compared when, and if, desired. Where the object **0** is of such nature that it reflects light in a specular manner rather than a diffuse manner then the apparatus depicted in FIG. **1** may be used but the light collected by the sphere **21** will represent diffuse reflection and be indicative of defects rather than the surface itself. Alternatively the specularly reflected light can be analysed directly and FIG. **2** depicts an apparatus suitable to perform this function.

In FIG. **6** the same reference numerals denote the same parts shown and described in connection with the apparatus of FIG. **5**. In FIG. **6** however, the image of the slit **15** is focused onto the slit **60** by a lens **19** and a second beam splitter **30** is disposed between the slit **15** and the lens **19**. Again, the slit **60** can be omitted in certain cases. The light impinging on the object **0** under investigation is specularly reflected and passes back through the lens **19** to be diverted by the beam splitter **30** into an integrating sphere **31**. The light collected by the sphere **31** is converted to an electrical signal by means of a photo-electric device **32** which can again be a photo-multiplier. The output signal from the device **32** is designated **33**. Any defect in the surface of the object **0** illuminated by the slit **60** tends to absorb or scatter the incident light and reduces the intensity of the reflected beam passing into the sphere **31**. As with the apparatus shown in FIG. **5** the spatial frequency can be constant or varied and preferably the object **0** is moved in the direction of arrow A so that its surface is scanned for defects on a continuous basiw.

In both embodiments when the spatial frequency is varied the object is effectively inspected for defects of all sizes. If defects of a certain size only are of interest then it is preferable to carry out the inspection at one fixed spatial frequency or over a limited range of spatial frequencies. By utilizing two or more spatial frequencies simultaneously defects of certain sizes can be detected separately. To this end two or more discs **11** each having grating lines of characteristic spacing can be used or else a single disc **11** having multiple sets of scanning lines can be used.

As can be appreciated the invention can be applied to automatic inspection of objects with the objects being successively inspected one by one and each scanned over a position of its surface or over its entire surface. Any defects giving rise to a variation in the signal **23, 33** can be recorded as a deviation from a standard value and an appropriate visual marking made upon the object for use in a subsequent operation.

Certain objects may be too large or otherwise inconvenient for direct inspection. In such cases the object can be photographed and the resultant negatives examined for defects using the transmission mode described hereinafter.

The foregoing description related to FIGS. **5** and **6** has dealt essentially with surface inspection but it is to be appreciated that the invention is applicable to the inspection of the internal structure of objects by examining the light transmitted through the object. FIG. **7** depicts an apparatus suitable for inspecting objects such as paper by transmission meansurement and like reference numerals denote like parts to those shown in FIGS. **5** and **6**. In this modified apparatus the lens **19** focusses the image of the slit **15** onto the object **0** and the light transmitted through the object **0** is passed through an aperture **71** into a photo-electric device **70**. The device **70** produces an electrical signal **72** which can then be processed by electronic circuitry to detect the presence of internal defects in the object **0** as discussed hereinbefore. In certain applications it may be desirable to collect radiation transmitted through the reflected by an object and in this case, for example, the photo-electric devices **22** and **70** of FIGS. **5** and **7** would be used together.

Instead of using the disc **11** to scan the light before it is directed onto or through the object the disc **11** can be used to scan the light after it has been directed onto or through the disc **11**. An example of an apparatus which operates in the latter manner is depicted in FIG. **8**. The apparatus depicted in FIG. **8** is especially suitable for detecting small dirt spots in paper materials.

As shown in FIG. **8**, the object **0**, in this case sheet paper, is illuminated by means of two separate light sources **73, 74** which may be tungsten filament lamps, and associated lenses **75, 76**. A single light source could be employed provided that it gave a sufficient high level of illumination. The light reflected from the surface of the object **0** is focussed by means of a lens **77** onto a slit **78** in a plate **79**. The image of the slit **78** is then focussed by means of a lens **80** onto the disc **11** and the light transmitted through the disc **11** is collected by a photo-electric device **81** which provides an electrical signal **82** processed as described hereinbefore. In a particular application high quality optical character recognition paper moving at 1,000 ft/min. can be examined for dirt spots by the apparatus of FIG. **8**. A relatively narrow strip of the paper is examined as a sample and the number of spots detected in the strip is generally representative of the total spot content. The size of dirt spot which is registered is between 0.05 and 0.13 mm. but spots of greater size than 0.13 mm. can be registered separately. To this end as mentioned before it is possible to employ two discs **11** having grating lines of different characteristic spacing thereby producing different spatial frequencies, or else a single disc **11** can be provided with two sets of grating lines of different spacing. The resultant electrical signal **82** would then contain components corresponding to the two spatial frequencies which could be processed separately.

Instead of detecting individual surface defects the invention can provide an apparatus suitable for examining the overall surface roughness of sheet material such as paper or metal or to measure the depth of a turning mark in the surface of a component. An example of such an apparatus is shown in FIG. **9** where like reference numerals denote like parts to those shown in FIGS. **5** and **6**. The object **10** in this case is inclined in relation to the optical axis **51** so that the light impinging on the surface is scattered by the surface structure of the outer surface of the object **0** which is being investigated. The light scattered in one particular direction is focussed by a lens **86** into an aperture **85** of a photo-electric device **87**. The device **87** produces an electrical signal **88** which can be processed as discussed hereinbefore.

By moving the common axis **84** of the device **87** and the lens **86** relative to the axis **51** and altering the spatial scanning frequency for each position of the axis **84** the characteristics of the surface structure can be obtained. Typically the angle between the axes **51**, **84** is in the order of 50°.

As in the previous embodiments, a phase reference signal **18** may be provided in the apparatus depicted in FIG. **9**.

We claim:

1. A method of analyzing a two-dimensional test pattern; said method comprising the steps of:

a. scanning a beam of electromagnetic radiation with a moving attenuation pattern which is cyclic along a path of movement of the attenuation pattern to provide a modified beam of radiation;
b. subjecting the test pattern to be analyzed to said modified beam of radiation;
c. collecting radiation derived from said modified beam and subjected to the influence of a part of the test pattern and to the influence of a part of the attenuation pattern extending over a plurality of cycles thereof exerted simultaneously by the whole of said part of the attenuation pattern;
d. producing an electrical test signal from the collected radiation and representing part of a defined Fourier transform of said part of the test pattern; and
e. comparing said test signal with a reference.

2. A method according to claim **1**, and further comprising splitting the beam into two components after the scanning operation, directing one component at the pattern under test and directing the other component at a reference pattern, collecting further radiation subjected to the influence of said part of the attenuation pattern and to the influence of a part of the reference pattern corresponding to said part of the test pattern, producing from said further collected radiation an electrical reference signal which represents part of a defined Fourier transform of the said part of the reference pattern, said reference signal constituting said reference and the comparison being effected between the test and reference signals.

3. A method according to claim **1**, wherein the test pattern is moved so that said part of the test pattern changes.

4. A method according to claim **1**, wherein the characteristic spatial frequency produced by the scanning operation is varied.

5. A method according to claim **1**, wherein the test signal is used to provide a data record and this data record is automatically compared with another record constituting said reference.

6. A method of analyzing a two-dimensional test pattern, said method comprising the steps of:

a. subjecting the test pattern to be analyzed to a beam of electromagnetic radiation;
b. scanning the radiation influenced by the presence of the test pattern with a moving attenuation pattern which is cyclic along a path of movement of the attenuation pattern;
c. collecting radiation subjected to the influence of a part of the test pattern and to the influence of a part of the attenuation pattern, extending over a plurality of cycles thereof, exerted simultaneously by the whole of said part of the attenuation pattern;
d. producing an electrical test signal from the collected radiation and representing part of a defined Fourier transform of said part of the test pattern; and
e. comparing said test signal with a reference.

7. A method according to claim **6**, wherein the test pattern is moved so that said part of the test pattern changes.

8. A method according to claim **2**, wherein the test and reference patterns are moved in synchronism so that said parts of the test and reference patterns change.

9. A method according to claim **6**, wherein the characteristic spatial frequency produced by the scanning operation is varied.

10. A method according to claim **6**, wherein the test signal is used to provide a data record and this data record is automatically compared with another record constituting said reference.

11. An apparatus for use in analyzing or inspecting an object; said apparatus comprising:

a. conveying means for moving the object in a direction;
b. means for producing a beam of electromagnetic radiation;
c. means for scanning said beam of radiation with a moving attenuation pattern which is cyclic along a path of movement of the attenuation pattern to provide a modified beam of radiation for direction at the object under test;
d. means for collecting radiation derived from said beam which has been subjected firstly to the influence of a movable part of the object under test and secondly to the influence of a part of the attenuation pattern, extending over a plurality of cycles thereof, exerted simultaneously by the whole of said part of the attenuation pattern;
e. means for defining said part of the object under test so that said part extends generally laterally of said direction; and
f. means for producing from the collected radiation an electrical test signal which represents part of a defined Fourier transform of said part of the object under test.

12. An apparatus according to claim **11**, wherein the scanning means is in the form of a rotatable radiation-transmissive disc having radial grating lines thereon, the axis of rotation of said disc being displaceable to thereby vary the characteristic spatial frequency produced by the scanning operation.

13. An apparatus according to claim **11**, wherein there is provided a beam splitter which splits said beam into two components after the scanning operation, one component being directed at the object to be tested to produce said test signal, and the other component being directed at a reference object, there being further provided means for collecting further radiation which has been subjected firstly to the influence of a part of the reference object and secondly to the influence of a part of the attenuation pattern extending over a plurality of cycles thereof, exerted simultaneously by the whole of said part of the attenuation pattern; means for producing from the collected further radiation an electrical reference signal which represents part of a defined Fourier transform of said reference object, said reference signal being comparable with said test signal as a basis for the analysis of the test object.

14. An apparatus according to claim **11** and further comprising means for comparing said test signal with a reference.

15. An apparatus according to claim 11 and further comprising means for determining the presence of defect-indicative information in said test signal.

16. An apparatus according to claim 11, wherein said defining means also defines said part of the attenuation pattern.

17. An apparatus according to claim 16, wherein said defining means is in the form of a slit with a dimension extending substantially in the direction of movement of the attenuation pattern.

18. An apparatus according to claim 17, wherein there is provided means for focussing an image of the attenuation pattern onto said slit.

19. An apparatus for use in analyzing or inspecting an object; said apparatus comprising:

a. conveying means for moving the object in a direction;
b. means for producing and directing a beam of electromagnetic radiation at the object under test;
c. means for scanning the radiation influenced by the presence of the test object with a moving attenuation pattern which is cyclic along a path of movement of the attenuation pattern;
d. means for collecting radiation subjected firstly to the influence of a part of the test pattern and secondly to the influence of a part of the attenuation pattern extending over a plurality of cycles thereof, exerted simultaneously by the whole of said part of the attenuation pattern;
e. means for defining said part of the object under test so that said part extends generally laterally of said direction; an
f. means for producing from the collected radiation an electrical test signal which represents part of a defined Fourier transform of said part of the object under test.

20. An apparatus according to claim 19, wherein said defining means also defines said part of the attenuation pattern.

21. An apparatus according to claim 20, wherein said defining means is in the form of a slit with a dimension extending substantially in the direction of movement of the attenuation pattern.

22. An apparatus according to claim 21, wherein there is provided means for forming an image of the slit which image is scanned by the scanning means.

23. An apparatus according to claim 19, and further comprising means for comparing said test signal with a reference.

24. An apparatus according to claim 19 and further comprising means for determining the presence of defect-indicative information in said test signal.

25. An apparatus according to claim 19, wherein the defining means is a slit which defines an image of the radiation influenced by said part of the object which image is scanned by the scanning means, and a photoelectric device is provided for receiving the scanned radiation.

26. A method of inspecting an object to determine the presence of defects, said method comprising the steps of:

a. subjecting the object to be tested to a beam of electromagnetic radiation to establish a distribution of radiation influenced by the object;
b. scanning radiation influenced by the object with a moving attenuation pattern which is cyclic along a path of movement of the attenuation pattern;
c. collecting radiation subjected to the influence firstly of a part of the object and secondly to the influence of a part of the attenuation pattern, extending over a plurality of cycles thereof, exerted simultaneously by the whole of said part of the attenuation pattern;
d. producing an electrical test signal from the collected radiation and representing part of a defined Fourier transform of said part of the object; and
e. comparing said test signal with a reference, in the form of a preset electrical value, to determine the presence of defect-indicative information in said test signal.

27. A method according to claim 26, wherein the scanning operation involves simultaneous scanning at two or more different spatial frequencies and the components of the test signal related to said different spatial frequencies are separately processed.

28. A method of inspecting an object to determine the presence of defects, said method comprising the steps of:

a. scanning a beam of electromagnetic radiation with a moving attenuation pattern which is cyclic along a path of movement of the attenuation pattern to provide a modified beam;
b. subjecting the object to be tested to said modified beam of radiation;
c. collecting radiation subjected to the influence firstly of a part of the object and secondly to the influence of a part of the attenuation pattern, extending over a plurality of cycles thereof, exerted simultaneously by the whole of said part of the attentuation pattern;
d. producing an electrical test signal from the collected radiation and representing part of a defined Fourier transform of said part of the object; and
e. comparing said test signal with a reference to determine the presence of a defect-indicative information in said test signal.

29. A method according to claim 28, wherein scanned radiation reflected by an outer surface of the object in a diffuse manner is collected and converted into said test signal.

30. A method according to claim 28, where scanned radiation reflected by an outer surface of the object in a specular manner is collected and converted into said test signal.

31. A method according to claim 28, wherein scanned radiation transmitted through the object is collected and converted in said test signal.

32. A method according to claim 28, wherein scanned radiation is scattered by an outer surface of the object and the radiation scattered in a pre-selected direction is collected and converted into said test signal.

33. A method according to claim 28, wherein the scanning operation involves simultaneous scanning at two or more different spatial frequencies and the components of the test signal related to said different spatial frequencies are separately processed.

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