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(54) OPTICAL TRACKING APPARATUS

(71) We, AKTIEBOLAGET BOFORS, of S-690 20 Bofors, Sweden, a Swedish joint stock company, acting under the laws of Sweden, do hereby declare the invention, for which we pray that a patent may be granted to us, and the method by which it is to be performed, to be particularly described in and by the following statement:—

The present invention relates to a tracking apparatus.

More particularly the invention is concerned with a tracking apparatus which finds use in guiding a moving object towards a target. An example is the guiding of a missile towards a target. Such guidance may be effected by detecting deviations of the missile from the line of sight to the target in order to provide corrective action. The latter function is of no concern to the present invention. The tracking apparatus with which the invention is concerned includes an optical system for providing an image of the target to the operator who maintains a line of sight on a point on the target.

If a moving object, e.g. a missile, direct at the target is provided with means for emitting radiation, the deviation of the radiation means from the line of sight can be determined by means of a measuring device responsive to the emitted radiation. The radiation can be generated by a radiation source located within the housing of the moving object, or it can be generated by the propulsion motor of the moving object, in which case the radiation is infrared radiation. The radiation may also, however, be derived from reflector means arranged on the moving object. In this case, the radiation is generated by a radiation source located, for instance, at the site of the tracking apparatus and transmitted towards the moving object and then reflected by the reflector means towards the apparatus.

Previously known tracking telescopes are usually provided with an objective lens,

ocular and a visual sight reference symbol, generally some type of cross hairs, comprising thin lines on a glass surface located in the image plane of the objective. By means of the ocular it is possible for the operator to view the target and its background and by means of aiming knobs it is possible for the operator to point the visual sight reference symbol at the target and maintain the symbol at the target during the tracking operation. Because two different main functions, i.e. aiming and position measuring, have to be provided for, it has up till now been necessary to use two different optical systems, one for aiming at the target and another for measuring the position of the moving object. In order to attain an acceptable accuracy when measuring it is important that the relative position of the measuring and aiming devices is not influenced by mechanical deformations due to temperature changes. Disturbance of an optical or mechanical element may cause a change in the relative position of the optical systems. As a result the measuring systems are, in order to obtain an acceptable measuring accuracy, generally provided with means to control and adjust the sight line of the telescope and the axis of the measuring device.

According to the present invention there is provided a tracking apparatus having an optical system for providing an image of a target to an operator and including means providing a visual sight reference symbol for aligning the optical axis with the target, the optical system further comprising:

a beam splitter for separating from the image-forming optical path of the system light at a predetermined wavelength to direct it along a separate path, said beam splitter being located after said reference symbol means along the optical path;

means preceding the beam splitter along the optical path and active at said predetermined wavelength to provide a mask of

predetermined pattern to light at said predetermined wavelength travelling along the optical path;

means located along said separate path to detect light at said predetermined wavelength as patterned by said masking means, said detector means and masking means being relatively rotatable about the optical axis for such patterned light and the detector means being operable to provide a signal indicative of the deviation from the last-mentioned axis of a source of the light at said predetermined wavelength; and

said masking means and reference symbol means being supported in fixed spaced relationship along said optical path.

In the use of the tracking apparatus defined in the immediately preceding paragraph to track a missile fired at a target the operator aligns the image axis with the target and the source of the predetermined wavelength light is the missile whose deviations from the line of sight are to be detected.

It will be seen that up to the beam splitter a common optical system is used and the reference symbol means, e.g. cross hairs, and the masking means are restrained against relative displacement along the axis. Such an arrangement assists in avoiding differential changes in the apparatus as between the visual image aiming and the deviation measuring.

While the predetermined wavelength may lie within the spectrum providing the visual image for the operator, it is preferred to use a wavelength outside that portion of the spectrum, for example, to use infrared lying outside the visible spectrum. In this case the optical system can provide image planes for the visible light and light at the predetermined wavelength which are displaced along the optical image axis, e.g. different image planes for an objective of the optical system and at which the reference symbol means and masking means are respectively located.

From the foregoing, it will be understood that "light" as used herein includes radiation both within and outside the visible portion of the spectrum. The common portion of the optical system is thus to be effective at both the portion providing the visual image and the wavelength outside it.

In the apparatus described in more detail hereinafter the masking means is rotated to provide a cyclic modulation of the predetermined wavelength light, i.e. the infrared in the example quoted above. Both the reference symbol and masking means may be formed on opposite faces of a plate of optically transparent material or each may be formed on a surface of respective plate of such material, e.g. glass, the two plates being rigidly connected together against axial displacement. The modulated radiation is received by the detector which preferably has a

small photosensitive surface which results in low noise level and high sensitivity. The image plane, in which the mask is located, is projected onto the photosensitive surface with the highest possible reduction in size so that all of the light at the predetermined wavelength which passes the mask reaches the detector. A given size of detector surface will then correspond to the highest angle of deviation that can be measured. In several position measuring systems, however, the radiation emitted by the radiation source is usually strong when the angle of deviation is great. When measuring at short ranges, the measuring device must have a large field of view, while at the same time the signal level provided by the detector must be high. When measuring at long ranges however, where the field of view is small, the signal level provided by the detector is often not high enough.

We prefer, therefore, to use a photodetector which provides an acceptable signal level both at short and long ranges. Such a photodetector is located in or close to an image plane of the optical system along the separate path from the beam-splitter and is provided with a surface which is divided into two or more separate surfaces, each of them corresponding to a given viewing angle in which the position of the radiation source can be determined.

A preferred embodiment of the invention will now be described in more detail with reference to the accompanying drawings in which:—

FIGURE 1 illustrates the optical system of a tracking apparatus according to the invention;

FIGURE 2 illustrates an alternative embodiment of the system according to Figure 1;

FIGURE 3 illustrates means providing a visual sight reference symbol for facilitating aiming of the optical system;

FIGURE 4 shows a mask located in the common portion of the optical path;

FIGURE 5 illustrates a further embodiment of the invention including a photodetector having a sensitive surface which is divided in two separate regions;

FIGURE 6 illustrates the sensitive surface of the detector;

FIGURE 7 illustrates an alternative form of the detector surface;

FIGURE 8 shows an alternative form of mask;

FIGURE 9 is an enlarged sectional view of the region between the transparent and opaque portions of the mask; and

FIGURE 10 shows a preferred modification of the mask shown in Figure 9.

The optical system described herein is particularly suitable for including in a tracking apparatus for guiding a missile to a target

and for this reason it will be described in conjunction with an optical sight having two main functions, to view the target and maintain the line of sight on the target as well as compare the trajectory of a missile with the line of sight and determine the deviation between the missile and the line of sight. The manner of the measuring operation and how the deviation, determined by the measuring operation is converted into an electrical signal, and how this signal is processed and evaluated, do not form any part of the present invention and therefore will not be described herein in detail.

The optical system principally comprises an objective lens 1, a thick glass plate 2 and a beam splitting prism 3 to split up the visible light from the target and its background and the radiation at a particular wavelength emitted by the radiation source of the missile. The radiation source may be a laser diode, disposed on the missile in such a way that laser light is transmitted towards the optical system. The objective lens 1 collects both visible light and laser light and is designed in such a way that the focal distance for visible light and laser light is different. To this end the laser light lies outside the visible spectrum, for example at infrared. From this it follows that an image of the target and its background is projected in the image plane F_1 for visible light, while an image of the radiation source is projected in another image plane F_2 for laser light. In Figure 1 the ray path of the visual light is indicated by dotted lines while the laser light is indicated by continuous lines. The ray paths are separated in the beam-splitting prism 3 in a manner well-known in the art so that visible light passes through the prism and out through an ocular 4 to the eyes of an operator, but laser light, however, is reflected by the prism 3 and passes out along a separate path through a lens system 6 to a detector 7.

In order to facilitate the tracking operation, the optical system is provided with a visual sight reference symbol which consists of thin lines on one surface of the glass plate 2. This surface located in the image plane F_1 , so that the operator is able to view the target and its background together with the visual sight reference symbol in the ocular 4. The symbol may consist of one or more concentric circles 8 or arcs 9, see Figure 3, having the line of sight 10 as origin. This is preferred to conventional cross hairs when the mask (see below) rotates about the line of sight. The lines of the visual sight reference symbol must be so thin that they do not disturb the measuring device by blocking the light rays.

For determining the deviation of the missile from the line of sight, the optical system is provided with a measuring device, which includes a mask 11, see Figure 4, formed on

the opposite surface of the glass plate 2 and located in the image plane F_2 . The mask may consist of superposed dichroic layers in a prescribed geometrical pattern that provide a response transparent to visible light but opaque to laser light emitted by the radiation source. As the pattern is transparent to visible light, it does not interfere with the visual image and the visual sight reference symbol even when the mask is rotated.

The distance between the two image planes F_1 and F_2 is large so that the obscuring effect caused by the lines of the visual sight reference symbol is small. With the mask and the visual sight reference symbol disposed on the same optical element, as on each side of the glass plate 2 which sides coincide with the planes F_1 and F_2 , the axial spacing of the symbol and mask is fixed. As the glass plate is common to both the functions of aiming and position measuring, every change in the optical system gives rise to corresponding changes in both functions. No means for controlling and adjusting the line of sight and the axis of the measuring device is required.

Instead of one common glass plate two thin glass plates 13, 14 can be used, see Figure 2, in which case the image plane F_1 for the visual light preferably coincides with that surface of the glass plate 13 which faces the operator. The image plane F_2 for the laser light is required to coincide with the front surface of the glass plate 14. Also other arrangements using two glass plates are possible but the glass surfaces on which the visual sight reference symbol and the mask are applied must coincide with the associated image planes and both of the glass plates must be connected so that they cannot move relative to each other in the axial direction. To measure deviation the glass plate 14 (or the glass plate 2 in Fig. 1) is rotated. The glass plate 13 can be rigidly connected to the glass plate 14 and rotate therewith, for which the reference symbol of Fig. 3 is suitable, but it can be stationary in which case the visual sight reference symbol may consist of cross hairs. However, the cross hairs and mask plate 14 must be supported in fixed axial relationship.

Figure 3 shows a view of the glass surface located in the image plane F_1 with the visual sight reference symbol comprising concentric circles 8 and arcs 9 about an origin 15 which lies on the line of sight 10. The spot 16 represents the image of the radiation source, which image is unsharp in the image plane F_1 , but sharply defined in the image plane F_2 . In this case it is assumed that the wavelength of the radiation emitted by the radiation source is within the visible region of the spectrum. It may be preferable, however, to allow the wavelength of the transmitted radiation to be outside the visible region of

the spectrum in which case no blurred image appears in the image plane F_1 .

Figure 4 shows a mask 11 formed by a dichroic geometrical pattern superimposed on a glass plate and located in the image plane F_2 . The entire surface of the glass plate is transparent to visual light but the pattern superimposed thereon is opaque to radiation emitted by the radiation source. The shape of the boundary line 17 of the opaque pattern provides information regarding the position of the radiation source by the cyclic interruptions of the received radiation and the angular position of the mask as it is rotated about the origin 15. This is more clearly described in our co-pending application No. 50204/77 (serial no. 1596544).

In order to obtain a low noise level and a high sensitivity of the detector 7', the detector is located in an image plane F_1 , see Figure 5, in such a way that the radiation image of the laser radiation source at plane F_2 is projected with the highest possible reduction in size on to the photosensitive surface of the detector. All laser radiation which passes through the mask will then reach the detector 7'. The photosensitive surface of the detector is divided into two or more separate regions, whereby each of the separate regions corresponds to a given viewing angle with respect to the optical axis in which the position of the radiation source can be determined. Preferably the surface of the detector consists of an inner central surface 19 and an outer annular surface 20, see Figure 6.

The inner surface 19 corresponds to a viewing angle or measuring range in which the deviation of the radiation source is small, i.e. a narrow field of view of the optical system. The outer surface 20, however, corresponds to a viewing angle or measuring range, in which the deviation of the radiation source is large, i.e. a wide field of view of the optical system. The surfaces are isolated electrically in the detector so that the outer surface 20 can be disconnected electrically when the angle of deviation is small and a high sensitivity is required so that the measuring device is not affected by other radiation sources within the measuring range. Also the inner detector surface 19 can be disconnected electrically when the angle of deviation of the radiation source is considerable and the received laser light is strong.

In Figure 7 there is illustrated an alternative form of detector surface. As in Figure 6, the detector surface is divided into a central surface 21 and an outer surface 22. In this case the inner surface is square-shaped and the outer surface does not completely enclose the inner surface. Such detector surfaces are preferred when different measuring ranges are required in the vertical and horizontal planes. If the measuring range is not completely utilised in the vertical direction, the

corresponding region of the sensitive detector surface can be eliminated, which means that this surface can be reduced and a corresponding increase in sensitivity is obtained.

In order to obtain an accurate measurement of the position of the missile it is important that the boundary line 17, i.e. the transition between the transparent part 12 and the opaque part 18 of the mask, is clearly defined. In practice, however, this is difficult to achieve as the dichroic pattern consists of several thin dielectric layers disposed on the top of each other. As a result a transition zone is formed between the transparent and opaque regions of the mask in which zone the transmission changes gradually from a high to a low volume.

From Figure 9, which is an enlarged sectional view of the region between the transparent and opaque regions of the mask, it is evident that the dichroic pattern 12 consists of a number of layers 23, usually made of a dielectric material, which are disposed on the top of the glass plate and which together form an opaque layer for the radiation in question. Due to the large number of layers which are used, a transition zone d is formed. As mentioned, such transition zone is not satisfactory when an accurate measurement of the position of an object is required. As an example of the magnitude of accuracy which is required, a change in the amount of radiation passed by the mask of 90%, corresponds to a displacement in the measured position by 0.05.mrad.

In order to improve the edge sharpness of the dichroic pattern, and thereby reduce the transition zone, the edge of the pattern adjoining the transparent part of the mask is provided with a layer 24, which is opaque to the radiation in question, see Figure 8. This edge layer extends along the boundary line of the pattern and is very narrow. The edge layer preferably consists of aluminium. From Figure 10 it is evident that the metal layer is formed on the top of the dielectric layers. It is also possible however to form the edge layer below the dielectric layers along their boundary lines.

WHAT WE CLAIM IS:—

1. A tracking apparatus having an optical system for providing an image of a target to an operator and including means providing a visual sight reference symbol for aligning the optical axis with the target, the optical system further comprising:

a beam splitter for separating from the image-forming optical path of the system light at a predetermined wavelength to direct it along a separate path, said beam splitter being located after said reference symbol means along the optical path;

means preceding the beam splitter along the optical path and active at said predeter-

115

130

mined wavelength to provide a mask of predetermined pattern to light at said predetermined wavelength travelling along the optical path;

- 5 means located along said separate path to detect light at said predetermined wavelength as patterned by said masking means, said detector means and masking means being relatively rotatable about the optical axis for such patterned light and the detector means being operable to provide a signal indicative of the deviation from the last-mentioned axis of a source of the light at said predetermined wavelength; and
- 10 said masking means and reference symbol means being supported in fixed spaced relationship along said optical path.

2. A tracking apparatus as claimed in Claim 1 in which said predetermined wavelength lies outside the portion of the spectrum used to provide the visual image of the target for the operator, and said optical system provides different image planes which are spaced along the optical axis for the light in said spectrum portion and that at said predetermined wavelength and at which said reference symbol means and said masking means are respectively located.

3. A tracking apparatus as claimed in Claim 2 in which said reference symbol means and masking means are formed at respective surfaces of optically transparent material.

4. A tracking apparatus as claimed in Claim 3 in which said respective surfaces are opposite surfaces of a plate of the material.

5. A tracking apparatus as claimed in Claim 3 in which each of said respective surfaces is a surface of a respective plate of the material.

6. A tracking apparatus as claimed in Claim 5 in which said respective surfaces are facing surfaces of the plates.

7. A tracking apparatus as claimed in any one of Claims 2 to 6 in which the image planes are those of an objective of the optical system.

8. A tracking apparatus as claimed in any preceding claim in which said masking means is rotatably mounted.

9. A tracking apparatus as claimed in Claim 8 in which said reference symbol means is mounted to rotate with the masking means and comprises one or more circular indicia aligned with the optical axis.

10. A tracking apparatus as claimed in any preceding claim in which said mask comprises a plurality of superposed layers providing a dichroic response and formed in accord with said pattern.

11. A tracking apparatus as claimed in Claim 10 in which said mask includes a further layer of an optically opaque material overlapping the edge portion of the superposed layers to define the boundary of the

pattern.

12. A tracking apparatus as claimed in any preceding claim in which said mask pattern is imaged onto said detector at much reduced size.

13. Apparatus as claimed in any preceding claim in which said detector comprises separated radially inner and outer portions with respect to the optical axis at the detector.

14. Apparatus as claimed in Claim 13 in which said portions are isolated electrically.

15. Apparatus as claimed in Claim 13 or 14 in which said outer portion is an annulus.

16. A tracking apparatus substantially as hereinbefore described with reference to Figures 1, 3, 4 and 10; Figure 2, 3, 4 and 10, Figures 5, 6, 8 and 10, or Figures 5, 7, 8 and 10 of the accompanying drawings.

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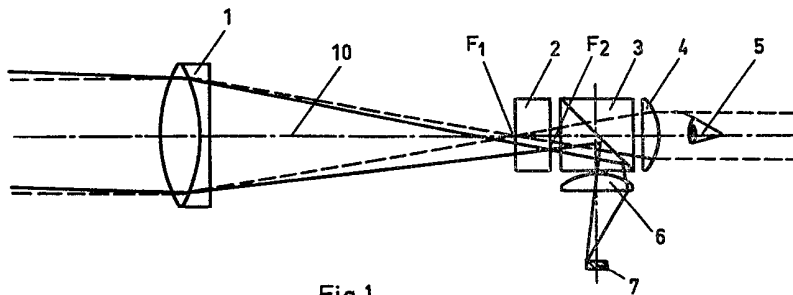


Fig. 1

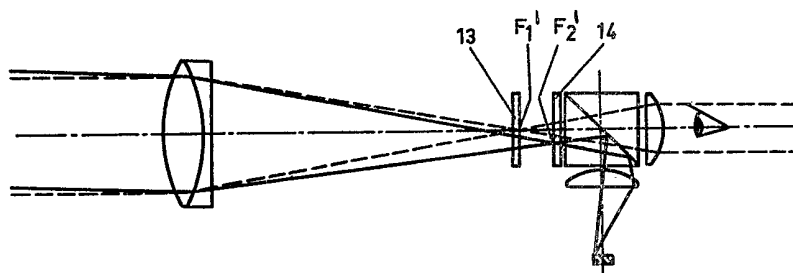


Fig. 2

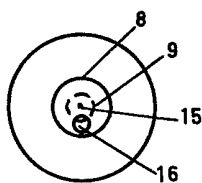


Fig. 3

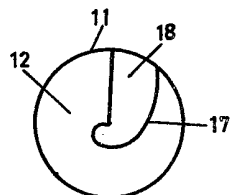


Fig. 4

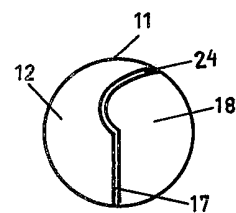


Fig. 8

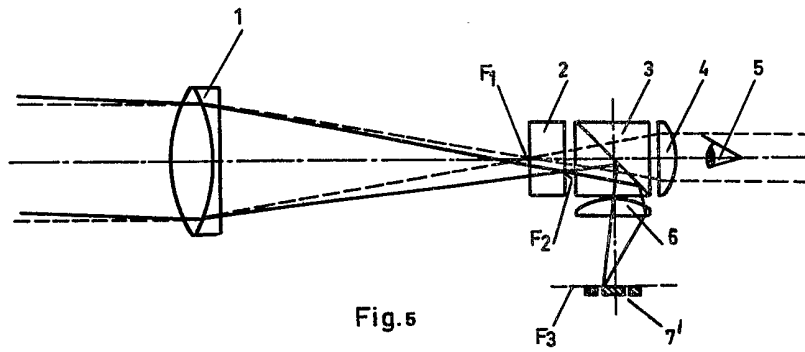


Fig. 5

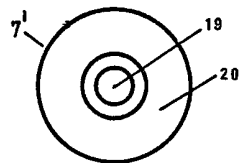


Fig. 6

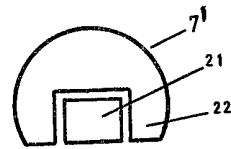


Fig. 7

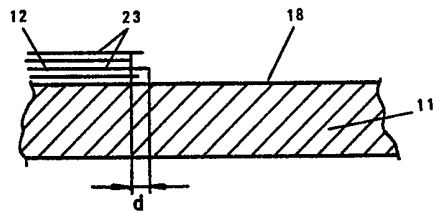


Fig. 9

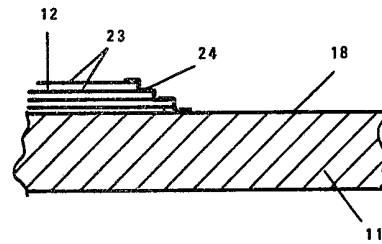


Fig. 10