

PATENT SPECIFICATION (11)

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(54) HOLOGRAPHIC APPARATUS

(71) We, KARL VOCKENHUBER, of 118, Pötzleinsdorferstrasse, Vienna 18, Austria, and RAIMUND HAUSER, of 2, Goldeggasse, Vienna 4, Austria, both Austrian citizens, 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 holographic apparatus.

In holographic apparatus, light from a coherent source is split into a reference beam and an object beam and after reflection of the object beam by an object the reference beam and the object beam are recombined to form an interference pattern.

There is known from British Patent Specification No. 1,382,523 holographic apparatus in which the holographic image of an object is stored and compared with a second holographic image. The two images are usually of the same object after having undergone a change in shape or position. The images are scanned, preferably electronically, and video signals are produced to generate an output signal which corresponds to the interference pattern. The two interference patterns are processed to form an image showing the points on the object which have undergone a change in position.

As is well known, holographic interferometry yields interference images which make changes in an object visible and measurable. The quantitative evaluation is generally not simple. A known method of evaluation is illustrated in Figure 1 of the accompanying drawings.

Figure 1 diagrammatically shows an object C upon which a beam of light is trained, this beam originating at a point A and being reflected as a beam 1¹ onto a point B where its phase is to be compared with that of a reference beam 2 also emanating from point A. The beams are generated by a common source of coherent light such as a laser. If the object C is displaced in such a manner that its re-

flecting point X moves along an elliptical curve 3 whose foci are the points A and B, the total length of the ray path 1, 1¹ between these points will not change so that the phase relationship between the reference beam 2 and the reflection 1¹ of the illuminating beam 1 at point B remains constant. Curve 3 is one of a family of ellipses, including similar curves 3a, 3b, etc. all with foci A and B, along which the relative phase of the two beams remains constant; if the object C moves towards the center of this family of ellipses, e.g. along the bisector of the angle 1—1¹, the luminous energy collected in point B will be modulated in intensity with a succession of peaks occurring whenever the reflecting point X passes an ellipse for which the ray path 1+1¹ differs from the distance A—B by a whole number of wavelengths λ . The successive ellipses 3, 3a, 3b, etc therefore differ from one another by λ in their path lengths A—X—B.

If the points A and B coincide, the ellipses turn into circles whose radii, therefore, differ by $\lambda/2$. In three-dimensional space we have ellipsoids of revolution and spheres, respectively.

Thus, if different reflecting points of object C are equidistant from a center coinciding with the origin A and the point of interferometric evaluation B of the illuminating and reflecting rays, and if the reflections from these object points are individually evaluated with the aid of a common reference beam (e.g. by conversion of the resulting luminous energy into an electric signal), the outputs from the object points will be substantially identical. These values will not change significantly if the reflected rays are allowed to pass through the center A, B for evaluation at points remote therefrom, provided that the rays of the associated reference beam accompany them without relative phase shift to the points of evaluation. The extensions of these reflected rays beyond the center A, B will then diverge on their way to a transverse receiving surface which they intersect along a curve representing all the reflecting

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points of object C equidistant from center A, B. Such a curve therefore, can be properly referred to as a contour line.

5 In accordance with the present invention, there is provided a holographic apparatus comprising a source of coherent light, means for splitting the light from the source into a reference beam serving to illuminate a receiver and an object beam for illuminating
10 an object, first focusing means for focusing the object beam onto a first point lying between the first focusing means and the object, and second focusing means, having an aperture stop determining the effective
15 aperture of the second focusing means, for imaging the reflected object beam onto the receiver to form an interference pattern with the reference beam, wherein the said first point, or a point conjugated therewith,
20 lies in or near the centre of the aperture stop of the second focusing means, or in a position conjugated therewith, whereby rays incident upon and reflected by the object are substantially parallel.

25 The apparatus of the invention enables electronic evaluation for example by means of video signals and also evaluation by any other light indicating method such as photography or xerography.

30 In a preferred embodiment of the invention, the object beam is deflected by a deflecting means onto the object, the deflecting means being disposed substantially on the optical axis of the second focusing
35 means.

The light deflecting means may be a semi-transparent mirror located in the aperture stop of the second focusing means or in a conjugated position, and serves both to
40 reflect the object beam onto the object and to reflect the reference beam onto the receiver.

Conveniently, a collimator may be arranged in the optical path between the
45 said second point and the object. In this way, the interference fringes indicate a change of position of the surface of the object in a direction parallel to the optical axis of the second focusing means. If three
50 such combined illumination and receiving units are simultaneously directed at the object at different angles, preferably such that the optical axis are mutually perpendicular a complete analysis of the changes in the
55 object in three dimensions becomes possible.

Alternatively, the light deflecting means may be in the form of a mirror which partly obturates the aperture stop of the
60 second focusing means.

In order to improve the intensity of the reflected image, the object may conveniently be coated with a retro-reflective layer.

65 The invention will now be described further, by way of example, with reference to

figures 2 to 7 of the accompanying drawings in which:

Figure 2 is a schematic representation of one embodiment of the invention.

Figure 3 is a similar representation of a second embodiment.

Figure 3a shows a detail of figure 3, and Figure 4, 5, 5a, 6 and 7 show further
70 embodiments of the invention.

In figure 2, the coherent light from a
75 laser L is incident upon a semi-reflecting mirror 4 which serves to separate the coherent light into a reference beam 2 and an object beam 1. The reference beam is again reflected by a mirror 8 and focused by
80 a lens 9 to a point B on a mirror M which reflects the reference beam onto the screen 6 of a television camera 7 connected to a television receiver 10. The object beam is
85 focused by means of lens 11 at a point A and illuminates the object C which is provided with a retro-reflective layer 5.

The reflected object beam 1¹ is focused by a third lens O at a point Q which lies in an aperture stop which defines the effective
90 aperture of the lens O. The lens O forms an image of the object C on the screen 6 which interferes with the reference beam 2 to form a hologram. The aperture stop is adjustable so that the marginal divergent
95 rays of the object beam 1¹ are cut off. Consequently the angle contained between the marginal rays of the light beam 1¹ reflected by the object C and the reference beam 2 can be made so small that the resulting light and dark spatial frequencies correspond to the resolving power of a television camera tube 7. The mirror M may be semi-transparent so that the reflected
100 object beam 1¹ can pass through it but alternatively it may be in the form of a small plate or strip around which the light may pass. Since the reference beam is focused at the point B, the reference beam appears to the camera tube 7 to emanate from near
105 the centre of the lens O.

In the embodiment of figure 2, it will be seen that the three points of focus A, B and Q all lie near one another. By "near" it is meant that the separation is considerably less than the path length of the rays to and from the object.

A preferred embodiment of the invention is shown in Figures 3 and 3a in which like reference numerals are used to designate like components. The light from the laser L is split by the semi-transparent mirror 4 into a reference beam 2 and an object beam 1. The reference beam 2 is reflected by three mirrors 8₁, 8₂ and 8₃ and
120 focused by a lens 9 onto a point B on a mirror M. The mirror and the aperture stop are shown in more detail in Figure 3A.

The method of operation of this embodiment is believed to be clear in view
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of its resemblance to the embodiment of figure 2 which has already been described and it will be noted that the point A at which the object beam is brought to a focus, the point B at which the reference beam is brought to a focus and the point at which rays from the object C are focused by the lens O all lie at the centre of the aperture stop.

As shown in Figure 3a, if the resolving power of the receiver is very high, it is possible to replace the mirror M by a mirror M¹ and the object beam 1 could be focussed at a point on this mirror. The reference beam may then be reflected by another semi-transparent mirror (not shown) onto the receiver. The small axial distance of the mirror M from the optical axis of the lens O is still negligibly small in relation to distance of the object so that sufficient intensity would be available in the reflected object beam 1¹.

The draw-back that the beam illuminating the object must pass through the lens O before reaching the object C is obviated in the embodiment of Figure 4. In this embodiment, the mirror M on which, as in Figure 3, the object beam is focussed, is arranged between the lens O and the object C. Additionally, a collimator lens K is provided so that the rays of the object beam incident on the object are parallel to one another so that the incident wavefront is a flat plane. The mirror M also serves to reflect the reference beam onto the receiver 6. The reflected image rays are focussed onto the semi-reflective mirror M and the lens O images the object and reference beam onto the receiver 6. The mirror M is arranged in the aperture stop plane P which is disposed between the lens O and the object. Virtual images of the points A and B are produced at A¹ and B¹ by the lens O at the centre of the image of the aperture stop 216¹. In this embodiment, the object beam 1 passes only once through the lens O and the loss of intensity is less than in the embodiment of Figure 3. However, since the reference beam 2 is also directed to the lens O, undesirable interference effects may arise in this common plane from reflections and imperfections in the optical system such as dust particles or glass inclusions.

In the embodiment of Figure 5, an improvement is obtained by placing the point of focus of the reflected object beam and the point of focus of the reference beam between the receiver and the lens O. In this, as in the other embodiments, it is not essential to use a television tube for evaluating the results of measurement. The television camera may, for example, be replaced by a photographic plate. Likewise,

it is alternatively possible to utilise a xero-graphic technique.

In Fig. 5, the point of focus A of the object beam 1 is reflected by a semi-transparent mirror M1 and its virtual image A¹ coincides with the image of the point of focus of the reference beam and of the reflected object beam. Since the mirror M1 is located between the lens O and the object C, the reference beam 2 is focussed upon the mirror at M2 provided between the receiver 6 and the lens O.

A similar arrangement is shown in Figure 5A. Here the mirror M1 is not located in the aperture stop P. Instead, the point of focus of the object beam 1 is reflected by the semi-transparent mirror M1 to form a virtual image A¹ lying within the aperture stop 216. The mirror M2 reflects the reference beam onto the screen 6 and forms an image of the point of focus B at a point B¹ lying within the aperture stop 216.

In the embodiment of Figure 6, the point of focus A of the object beam 1 lies on a semi-reflective mirror M1 disposed between the lens O and the object C, a collimator lens K being provided, as in the case of the embodiments of Figure 4, 5 and 5a. The mirror M1 is arranged within the plane P of the aperture stop and the mirror M2 is arranged to form a virtual image of the point of focus B of the reference beam at B¹ which also lies at the centre of the aperture stop. In this arrangement, it is particularly advantageous to reflect the object beam 1 by means of a small highly reflective mirror instead of a semi-reflective mirror so as to be able to use the full intensity of the object beam 1¹.

A preferred embodiment of the invention is shown in Figure 7, in which the point of focus B of the reference beam 2 is so reflected by the mirror M2 that its image B¹ lies within the aperture stop 216 of the lens O. The lens O comprises two optical parts, O¹ and O¹¹. The optical part O¹ forms an image C¹ of the object C between it and the optical part O¹¹, this image C¹ being in turn imaged by the optical part O¹¹ upon the receiver 6. The lens O as a whole forms an image of the aperture stop between the lens O and the object C in the plane of the mirror M1. The mirror M1 reflects the object beam 1 so that the point of focus of the object beam lies within the image of the aperture stop formed by the lens O.

The advantage of this embodiment is that it is again possible to reflect the beam 1 illuminating the object with a small highly reflective mirror M1 and the loss of intensity of the object beam is minimal. This also yields a purely mechanical advantage in that the aperture stop plane P and both the mirrors M1 and M2 are specially separated

from one another. Additionally, with the preadjusted positions of the points A and B and the aperture plane P as well as the positions of the object C and of the receiver 6, the focal length of the lens O can be varied by virtue of the lens being interchangeable or by zooming. This is particularly advantageous in the case of large objects.

In each of the described embodiments, the object beam 1 and the reference beam 2 can be reflected by means of semi-transparent mirrors. It is however more advantageous if the mirrors are fully reflective and have small dimensions so that the aperture stop is only partly covered. A non-axial arrangement is also possible. The mirror substrate need only necessarily be small. It suffices if the highly reflecting coating covers only a small part of the surface of the substrate while the remaining surface and the reverse side of the substrate may be devoid of a reflective coating and may, if desired, be provided with one that reduces reflection.

A parallel light beam illuminating the object offering the advantage of simple evaluation of the interference images described above, is obtained in embodiments of Figures 4 to 6 by the inter-position of a collimator lens K between the point of focus of the object beam and the object. The spacing of the collimator lens from the point of focus of the object beam is equal to the focal length of the collimator. In the embodiment shown in Figure 3, the lens O may itself be employed as a collimator. In such embodiments, the interference images produced correspond to the contour lines connecting points of equal displacement.

WHAT WE CLAIM IS:—

1. A holographic apparatus comprising a source of coherent light, means for splitting the light from the source into a reference beam serving to illuminate a receiver and an object beam for illuminating an object, first focusing means for focusing the object beam onto a first point lying between the first focusing means and the

object, and second focusing means, having an aperture stop determining the effective aperture of the second focusing means, for imaging the reflected object beam onto the receiver to form an interference pattern with the reference beam, wherein the said first point, or a point conjugated therewith, lies in or near the centre of the aperture stop of the second focusing means, or in a position conjugated therewith whereby rays incident upon and reflected by the object are substantially parallel.

2. A holographic apparatus as claimed in Claim 1, wherein the reference beam is focused at a point in the optical path between the means for splitting and the receiver, the latter point also lying in or adjacent the centre of the aperture stop of the second focusing means, or in a position conjugated therewith.

3. A holographic apparatus as claimed in Claim 1 or Claim 2, in which the object beam is deflected by a deflecting means onto the object, the deflecting means being disposed substantially on the optical axis of the second focusing means.

4. A holographic apparatus as claimed in Claim 3, wherein the light deflecting means is a semi-transparent mirror located in the aperture stop of the second focusing means or in a conjugated position and serves both to reflect the object beam onto the object and to reflect the reference beam onto the receiver.

5. A holographic apparatus as claimed in any of Claims 1 to 3, in which the light deflecting means is in the form of a mirror partly obturating the aperture stop of the second focusing means.

6. A holographic apparatus as claimed in any preceding claim, in which a collimator is arranged in the optical path between the said first point and the object.

7. A holographic apparatus substantially as hereinbefore described with reference to and as illustrated in any of Figures 2, 3, 4, 5, 5a 6 and 7 of the accompanying drawings.

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from one another. Additionally, with the preadjusted positions of the points A and B and the aperture plane P as well as the positions of the object C and of the receiver 6, the focal length of the lens O can be varied by virtue of the lens being interchangeable or by zooming. This is particularly advantageous in the case of large objects.

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