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A METHOD OF STUDYING VERY WEAK PHASE OBJECTS

Henri Royer and Felix Albe[(1)]

ABSTRACT. A phase object is illuminated by means of a laser. It is analyzed by means of a half-wave lamina which is defocalized with respect to its Fourier plane. One or several fringes are observed in the image. Their deformations give an exact measure of phase gradients in the object.

The usual detection methods for very weak phase objects can be categorized into two categories: /525*

— Interferential methods which result in a map of optical paths in the object in the form of a fringe distribution which is alternately dark and light. The deformations of these fringes are directly connected with the variations in the optical path within the object. Their importance can be determined by a geometrical measurement.

— Strioscopic methods which show the gradients of the optical path. A photometric measurement is required in order to evaluate these gradients which are connected with the variations of illumination in the image[(2)]. The accuracy of this measurement remains uncertain.

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*Numbers in the margin indicate pagination in the original foreign text.

(1)Note: Presented by M. Alfred Kastler. Session of February 2, 1970

(2)Differential interferometry is presently being used at the I.S.L. It cannot be assimilated into a strioscopic method unless the shift between the two interfering waves is small with respect to the details being observed. Its sensitivity, therefore, becomes too small so that it cannot be applied to very weak objects of interest here.

The smallest defect which can be detected by an interferometer (differential or nondifferential) is limited, in any case, by the wave nature of the light (0.1μ for a two-wave interferometer). The sensitivity of a strioscopic current can be increased indefinitely, at least according to theory. The method proposed intends to combine the advantages of the two above methods. These are: increased sensitivity and adjustability as a function of the object, as well as accuracy and ease of carrying out geometric measurements.

Strioscopy by Amplitude Subtraction

A classical strioscopic configuration with coherent light is used in which a half-plane which dephases by 180° is substituted for the analysis knife edge. The negative frequencies of the object are subtracted from the positive frequencies in this way, and an image is observed in which the dark regions correspond to points of the object where the optical path gradients are zero [1-3].

Introduction of an Imperfection in the Calibration

A defocalization of the lamina filter is equivalent to a quadratic phase imperfection in the object. A black fringe intersects the field parallel to the half plane edge. The dimension l of this fringe decreases in proportion to the increase in the defocalization ε:

$$l \approx \frac{\lambda R^2}{\varepsilon} \quad [5].$$

The presence of a weak gradient in the optical path Δ introduces a deformation of the fringe at the points corresponding to the object. If R designates the distance from the filter to the object and δy is the deformation of the fringe along the y axis referred to the object space, then we have

$$\frac{\partial \Delta}{\partial y} = \frac{\varepsilon}{R^2} \delta y \quad (fig. 1) \quad [7]$$

In this way it is seen how by a voluntary introduction of a calibration imperfection makes it possible to dispense with the densitometer. The sensitivity σ of the configuration, the ratio of the phase difference to the gradient causing it, can be adapted quite flexibly to the size of the imperfection being measured:

$$\sigma = \frac{\delta y}{\frac{\partial \Delta}{\partial y}} = \frac{R^2}{\varepsilon}.$$

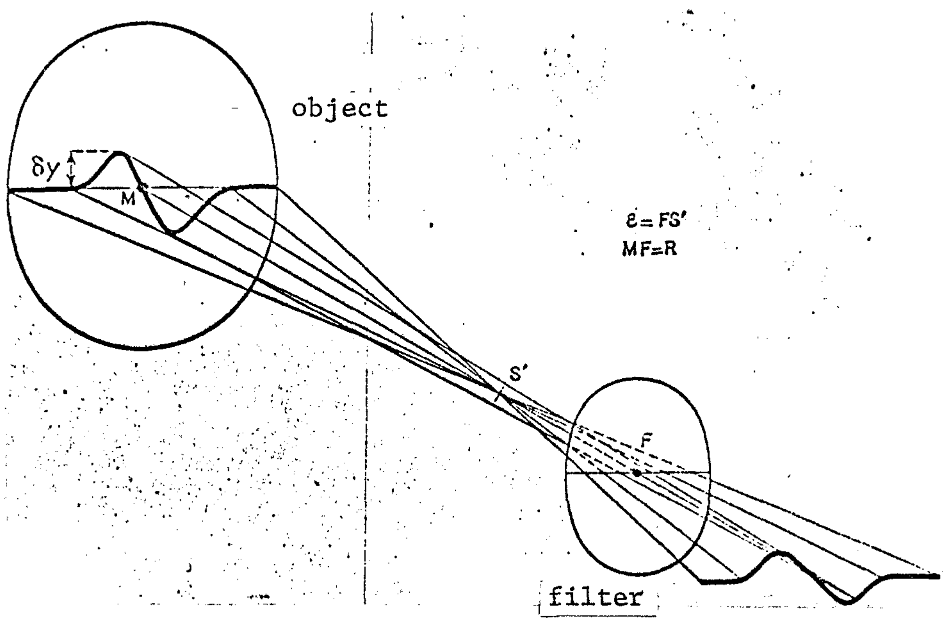

Figure 1.

Just as in interferential systems, the accuracy is always limited by the size of the black fringe [3, 4].

Positioning of a More Elaborate Filter

This method can be criticized because precise indications only result for points located along the one fringe. In order to increase the amount of information regarding the object, it appears desirable to multiply the number of fringes in the image field. This leads to the idea of replacing the half-plane filter by a periodic grid of dephasing bands (Figure 2).

It has been shown that, if the step p of the grid is sufficiently large, a series of rectilinear and parallel fringes are formed in the image [5]. The interfringe i, referred to the plane object, is proportional to the period p of the grid:

$$i = \frac{p}{2} \cdot \frac{R}{\varepsilon} = \frac{p\sigma}{2R}.$$

p must therefore be selected so that i remains larger than the fringe size for a given sensitivity.

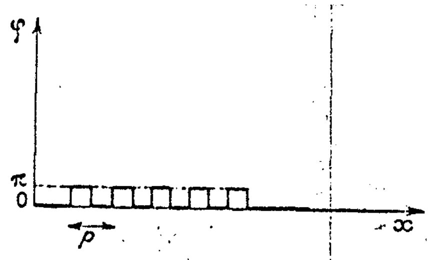

Figure 2.

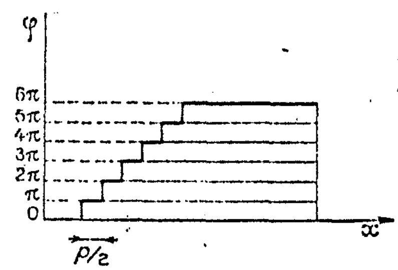

Figure 3.

It seems to be a delicate, if not an impossible, matter to build such a filter in a correct manner. In effect, the battlement function can be replaced by a staircase where each step has a "height" equal to π. Such a staircase corresponds to a superposition of half-planes which dephase by π

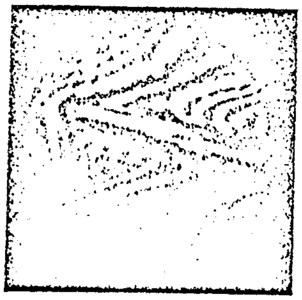

Figure 4.

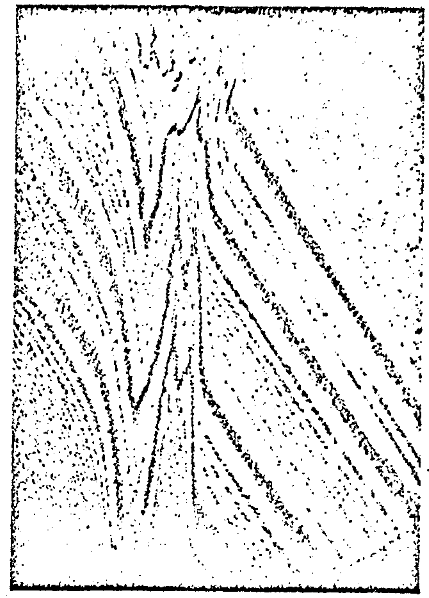

Figure 5.

and shift successively by p/2. It is relatively easy to make, and the result is the same (Figure 3) from the point of view of interferences [5].

Applications

In the present experiments, we used a sensitivity of $\sigma = 2.10^6$ mm.rd^{-1}. Thus, it was possible to measure gradients in the optical path on the order of a second of arc. With this sensitivity, this method of course becomes very well suited for the calibration of very small phase imperfections (for example, low pressure aerodynamic phenomena). For more pronounced imperfections, a very high degree of accuracy can be achieved. This can be used for correction of optical system aberrations and for studies in fluids at normal pressure.

As an example, Figures 4 and 5 show part of the influence of a wake of a hypersonic projectile (v = 3400 m/s, p = 60 mm of mercury) on the obtained fringes. These are also indicated by the effluence from a candle flame.

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