Test of an Optical Flat by the Fabry Perot Etalon

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(Received Dec. 1, 1948)

Introduction

To test the flatness of an optical flat, it is usual to avail of the interference of the light reflected by the flat in test with that by the standard flat, placed in contact or slightly apart. This method is very convenient as the anomaly of the interference fringe or color indicates the elevation (or depression) in that portion. But as the fringe thus produced is very broad, the accuracy obtained is limited to about 1/20 λ. If more precise test is wanted, the interferometer that will give sharp and narrow fringes must be applied; for this the Fabry Perot interferometer or etalon is thought to be most suitable. Test of the parallelism of a plane-parallel plate to observe the Haidinger fringes will give, also, more accuracy if the plate is used as the Fabry Perot etalon by silvering.

It will be remarked here that when the fringe of the Fabry Perot interferometer is observed, the image of a flat cannot be seen simultaneously as the telescope is adjusted for infinity. Hence the anomaly in flatness merely makes the fringes diffuse as a whole and its amount in various portions of the flat cannot be afforded. This amount may be given if the opaque screen perforated with a small aperture is inserted in front of the etalon and moving the screen, the diameter of a fringe is measured, but this procedure is tedious and not very certain.

Recently, the writers have devised a simple optical system, combined with the Fabry Perot etalon, which affords sharp fringes in the image of the flat, and by this, the flatness of an optical flat and the parallelism of a plane-parallel plate were examined. In the following, the experimental procedure and the results obtained will be described.

Experimental Procedure.

The apparatus used is diagrammatically shown in Fig. 1. In this figure, S is the light source of a cadmium lamp and F is a filter to pick out the light of the red line (λ 6438 Å). L_1 is a collimating lens, 150 mm. in focal length, and E is the Fabry Perot etalon which consists of the optical flat to be tested and that to be referred. A lens L_2 is 650 mm. in focal length and makes the image of interference fringes at its focal plane where the iris I is placed, so as its centre coincides with that of the fringe. L_3 is a camera lens, 210 mm. in focal length and is adjusted to make the image of a flat on the photographic plate P.

In this arrangement, the light which forms the image on the plate consists of the rays which have left the flat in normal direction after the reflections of various numbers, and only when the distance between two flats d has the value given by the equation

$$2nd = m\lambda$$

in which n is the refractive index of the medium, λ the wave-length and m an integer, it affords a bright image by the inter-

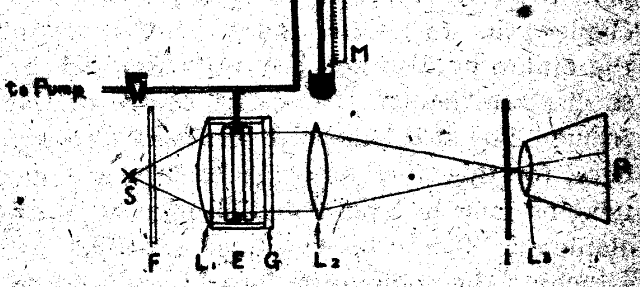

Fig. 1.

ference. Thus the locus of the points in the flat which fulfil the condition given by the above equation, makes a bright contour line in the image of the flat.

There are two methods to produce contour lines. One of them is to hold both flats in parallel, strictly saying, at a certain portion, for example, at their centres. In this case, if the elevation (or depression) of the flat is less than $1/2\lambda$, only one contour line appears and as the amount of elevation decreases it spreads to a wider area and finally the whole image shows uniform intensity. The other method is to hold the flat slightly oblique. In this case, the contour lines appear as straight lines, parallel and equidistant if the flat is perfect, but deviates where local elevation exists. For brevity, the former will be called the parallel method while the latter, the oblique method. When a plane-parallel plate is tested, the method is of course the parallel one.

The optical flats used are circular glass plates, both 75 mm. in diameter and 15 mm. in thickness and two surfaces of each flat are slightly oblique with the angle of 1 min. The ring of invar, which is inserted between the flats, is 75 mm. in outer and 65 mm. in inner diameter and has three studs, 3 mm. in thickness. The flat has been silvered by the evaporation in vacuum. To get a homogeneous silver film, the flats have been placed 13 cm. or further apart from the tungsten filament. The measured reflecting power is about 90% for the red cadmium light. As the test described here is to be applied to an excellent optical flat, only one contour line will appear in the parallel method. Therefore, it is desirable to find any device to displace a contour line in the image. This is done by various methods, 1) to vary the wave-length of the light by placing the light-source in a magnetic field, 2) to displace one of the flats without changing its inclination, 3) to change the refractive index of the air in the etalon by altering the pressure and 4) to displace the iris from the centre of the fringe. The third method has been adopted here; for this the etalon is held in a brass tube, 55 mm. in length and 95 mm. in inner diameter. The tube is made air-tight by attaching the collimating lens L_1 and a glass window G and is connected to a manometer M and a vacuum pump to evacuate as is shown in Fig. 1. With the distance between the flats d of 3 mm., the pressure difference of 30 cm. Hg. has been found to afford a change to the path-difference 2nd by λ. Hence the variation of the path-difference is given by measuring the pressure in the tube.

The plane-parallel tested is a glass Plate, 5 mm., 25 mm. and 40 mm. in thickness, breadth and length respectively and its both surfaces are silvered to make etalon. To displace the contour line, the fourth method described above has been adopted. If diameters of several interference fringes at the iris are measured, the relation between the path-difference and the displacement of the iris can be given.

The smaller the aperture of the iris, the narrower contour lines are obtained, but to avoid a prolonged exposure, it has been used in a diameter of 0.8 mm. through the whole course of this work. An exposure needed is about 15 min.

Results Obtained.

Fig. 2 is a photogram of an optical flat taken by the oblique method. In this, the contour lines have been taken in two oblique directions nearly orthogonal to each other.

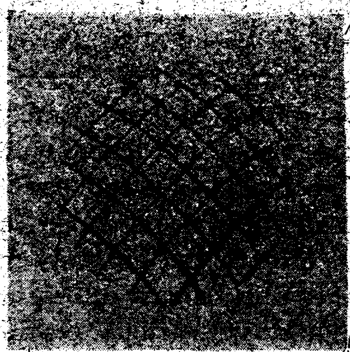

Fig. 2.

Fig. 3.

in the same plate. Contour lines are very sharp and narrow as are seen in their microphotometric record in Fig. 3. The half-intensity breadth measured is 1/12 of the distance between contour lines which is nearly twice as large as the value 1/25, theoretically computed using the observed reflecting power. Analyzing these contour lines, the depression of the flat along the contour line is indicated by the distance between the contour line and the straight line in Fig. 4. Accuracy of the measurement is estimated as $1/200\lambda$. For the convenience, the contour lines of relative depression to the centre, each $1/50\lambda$ apart, are also shown in the same figure. By this, it is seen that the flat is convex and the maximum depression is about $1/5\lambda$, provided that the flat referred to is perfect. In actual, the flat referred to is not perfect, this is the resultant of depression or elevation of both flats, namely the relative depression. However, if three flats are prepared and three relative elevations of the two are measured, the flatness of each flat can be given.

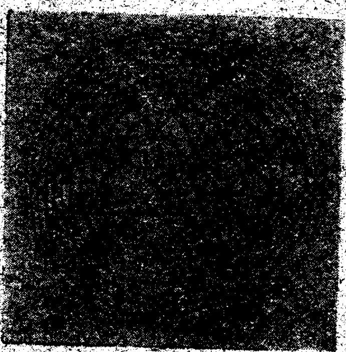

Fig. 4.

Fig. 5 is a photogram of the same optical flat taken by the parallel method. In this, the contour lines, each $1/25\lambda$ apart, are taken in the same plate. Comparing this

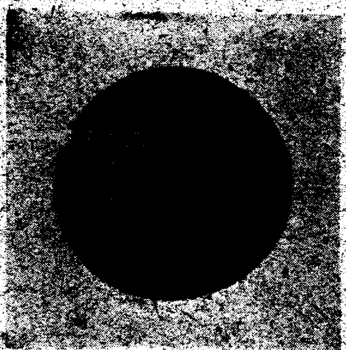

Fig. 5.

with Fig. 4, it will be found that they are in excellent agreement. The accuracy obtained is estimated as $1/150\lambda$. This method is complicated in experimental procedure, but it has a merit that the flatness can be surveyed without any analysis.

In Fig. 6, the photograms of the plane parallel plate are reproduced. In this figure, (a) and (b) have been taken at the different positions of an iris such as to give the change of the path-difference by $1/10\lambda$. It will be seen that the intensity distribution is reversed between (a) and (b). The accuracy obtained is about $1/50\lambda$, which is three times larger compared to that of the optical flat. This is because of that the accuracy of this method is limited not only by the resolving power of the etalon but also by the diameter of the iris relative to the magnitude of interference fringes there focused. If the iris is used in smaller diameter without regarding the prolonged exposure, more accurate results will be gained.

(a) (b)

Fig. 6.

In the oblique method of testing an optical flat, the displacement of one of the flats will cause the shift of all contour lines in the same direction, while the change of inclination between the flats will give the change of the distance between contour lines. Therefore, this method is thought to be available to measure a minute displacement or a small variation of an angle.

Summary.

To test the flatness of an optical flat, a simple optical system, combined with the Fabry Perot etalon, has been devised, which affords sharp contour lines of elevation (or depression) in the image of the flat.

When the flat to be tested is held oblique to that to be referred, the elevation is indicated by the deviation of contour lines which are to be straight, parallel and equidistant if the flat is perfect. Analyzing the

contour lines, the flatness has been measured with the accuracy of 1/200 λ.

When the flats are held in parallel, only one contour line appears and in order to displace the line, the pressure of air in the etalon has been varied. In this case, the flatness can be surveyed without any analysis.

This optical system is available to measure a minute displacement or a small change of an angle.

In conclusion, the writers wish to express their best thanks to Dr. J. Ôkubo, ex-superintendent professor of this institute, for his continued interest and encouragement in this work.