A Fizeau Interferometer?
Do it Yourself!

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How to measure a flat with sodium light, according to Russell W. Porter.

The author declines all relative responsibility to the effects of a source different of the one that is recommended here.

Here, we describe the construction of a control interferometer to measure the shape of optical surfaces, for example in the case of Newton secondary telescope, Cassegrain or a Dall-Kirkham secondary, when they are compared to a reference surface. This means of control have been invented by Fizeau, one of the prominent French physicists of the XIX century.

Of course, this kind of device didn’t fail to be described in the professional and amateur literature, in particular by Jean Texereau in his famous book, “How to Make a Telescope” and copied by his epigones (Figure 1). I decided to come back over, first because as proposed in the CTA, it has for us some deficiencies. On one hand, it used a low intensity light neon bulb

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1 See page 113, second edition.
emitting numerous lines that harm the contrast of the fringes, on the other hand, the photographic exposition time is long and finally, and at the end, these fringes are observed in a painful position for the observer.

The interferometer that I propose, gives extremely clean and luminous fringes, because it use instead of Neon, a very common low pressure Sodium lamp. Here, the fringes are easy to photograph, while permitting a comfortable observation. Its total cost will turn around $100-130, the price of a good ocular of the trade.

The Newton Interferometers.

Robert Hooke (1635-1703) was the first interested in interferences of thin films that he describes in his book *Micrographia* published in 1665. He was followed by Newton (1662-1727) who in 1704 wanted to redo the same experiment but, being a supporter of the corpuscular theory, was not capable to propose an explanation of the observed phenomena. It will be explained one century later by Fresnel with is wave theory (1815).

The Newton interferometer is constituted by a monochromatic source of light, illuminating the tested surface and the reference plane, situated at least at a distance equal to five times the diameter of the piece under test.

In particular, the Edmund society sells, for a few hundred dollars, such device merely constituted of one or two germicidal low pressure mercury tubes which are without phosphorus. The green line of mercury is selected by a filter, which is situated between the tubes and a window, whose function is to stop the short lengths UV rays, which are very dangerous for the eyes and skin. **I must advise here against its use by amateurs.** A device using a sodium low pressure lamp also exists (Fig.2). Useless to say that such a device can be achieved easily by every amateur for a much lower cost. An improved version with a semi reflecting mirror, have been presented since a long time by Selby\(^2\) and by R.E. English\(^3\) (Fig.3). If this solution already permits to observe interferences, these lack good definition because the light

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\(^2\) Amateur Telescope Making Book II, page 124

\(^3\) Amateur Telescope Making Book III, page 161.
that is distributed by such a device attacks the surfaces at various angles. This means that fringes are moving with the head of the observer. The border between white and black fringes is not optimal and the black fringes receive an illumination too. The measurement of a surface becomes a bit arbitrary. What’s more, if one wants to limit the effect of the oblique rays for which the path of the rays is longer than the one of the perpendicular rays, the distance between the reference flat and the surface to test should be reduced to the minimum, some microns at most. Such a condition is susceptible to drag some scratches during the manipulations.

The Fizeau interferometer.

Fizeau (1819–1896) understood the importance of monochromatic collimated light generated by a small dimension source. Thus, if one wishes to test some flats, these will be attacked right-angled on the whole surface. All happens then as if the source was at infinity or in other words, the output wave front is flat. In these conditions, the fringes will be extremely clean. If one increases this through a metallic deposit for instance, the dark fringes will become thinner and therefore located more precisely. This can be sometimes interesting, like in the Fabry-Pérot interferometer.

Fizeau presented is interferometer at the Sciences Academy in June 1862 about glass parameters measurements. The source was a Brewster burner with a flame generated by alcohol, water and salt. The issued light was for sure the one of Sodium with two lines at 589nm and 589.6nm. A prism redirected the light at right angle toward the collimating lens and the observer had to witch in return the fringes through the same lens. The advantage was in the fact that the eye received a picture of the opening, which illuminates completely the tested surface without any parallax. In such a way, fringes are stable; there was not any ambiguousness on the measurement of the fringes.

In 1883 L. Laurent presented to the same Academy, a practically identical version to the one of Fizeau, but more convenient to use. The innovation, besides the mechanics, consists in replacing the prism by a diffusing surface made of paper and marked E on figure 4, in order to improve the uniformity of the illumination of the lens L. Besides, one avoids all contacts between the two surfaces, what will prevent the scratches and the too frequent cleanings.

Fizeau will note that he gets good interferences with 15mm spacing between the two surfaces in air with a thermal sodium source. Incidentally, that can give us a rough idea about the width of a sodium lines at the temperature used by Fizeau. The length of coherency C, which is equals to 15mm in the quoted case, is given by the following expression:

\[ C = \frac{\lambda^2}{\Delta \lambda} \]
in which the numerator is the central wavelength and the denominator, the width of the line (at 50%). One presumes a 50% decrease of contrast when this distance is reached. One finds a delta lambda equal to 0.024nm.

As there are two lines that are none correlated, one can suppose that in this case every line has, a width in the order of 0.017nm because they are added as root square of the squares, what is more than sufficient for the measurements. In fact, such a distance is not useful. One will be careful to minimize it in order to decrease the aberrations of the lens. The thickness is in the order of 0.025mm to 0.1mm, a cigarette paper will be this time very ecological to fulfill this function.

One notices incidentally that the return bundle of rays is not on a same axis as the bundle coming from the light source. That will introduce astigmatism, but if the F/D of the lens is higher than say F/6, that will be ok, at the cost of lengthening the device. If one wishes to keep a reasonable length, let's say 60 to 80 cm from top to bottom, the lens in our case will have a 140mm diameter, and should have an F/2 ratio.

A Plano-convex lens is recommended, but a lens in which the radii of curvature are in a ratio 1 to 6 will give a slightly better result since it will have the shape that gives the minimum spherical aberration for an index around 1.5.

It seems that it was Michelson who modified the Fizeau interferometer by arranging a semi reflecting mirror between the source and the collimator lens, to eliminate the astigmatism. This solution is not possible with the neon light because already weak, it would be one more time attenuated by a ratio of 4 by two reflections on the mirror. On the other hand it is quite manageable with a source of strong luminance like Mercury or Sodium. The system has to be perfectly on line and will then work in the best conditions. Three conditions must be nevertheless achieved for that: on one hand the two brilliant reflections that are reflections of the source, must be aligned and on the other, they must be put in the center of the picture, and last but not least, the picture must be done accurately orthogonally, what is not indeed the case on the picture of the figure 6, where one can see an interferogram produced by this sort of instrument.

That said, an analysis with the OpenFringe software gives a flatness of lambda/104 rms on the surface and around lambda/18 pv on the surface at 555nm. Certainly, the two flats are each around lambda/36 or lambda/18 on the wave.
The optics simulation showed that for an 70mm off axis ray, the distortion of the collimator was in the order of 0.5% or lambda/200, but here, the surface examined is only at 50mm. In fact, it is the distortion of the photo objective, the divergence of the bundle of rays given by spherical aberration and the orthogonal defect that will limit the precision of measurements.

**The low pressure sodium lamp.**

Various suppliers exist for low pressure Sodium lamps (SOX-E). In the past, a 10W GEC version existed, but the minimal power for such lamp is currently 18W and this is well enough. The lamp ignites with the help of specific ballast, which then control is current. To light the lamp there is inside a mixture composed of Neon and Argon that will illuminate the tube with a red color. Then, the cathode (see figure 8) emits the electrons that will heat the sodium.

Slowly the orange yellow column of Sodium light spreads in the tube up to fill it. The total ignition time is around 10-12min to get the nominal flux, when the whole column is illuminated. In case of extinction, it is recommended to wait for the same time before relighting, so that sodium condenses and a cycle can be restarted.

In this lamp, a very thin coating of indium oxide is deposited on the interior of the bulb. It reflects the middle infrared that will serve to heat the lamp. The socket of the lamp is a classical bayonet (Figure 8).

One can note that for ± 10% variations of the supply voltage, the flux of the lamp remains constant (Figure 9). Considering the few hundred volts pulse necessary to ignite the neon/argon mixture, one will choose a plastic connector for the bayoneted socket. That will work as well as the one recommended by the manufacturer and the cost will be much lower. Finally there are not any fundamental differences between the former SOX and the SOX-E even it is the one we will prefer, because of its longer life, given for 18000 hours.
That said, in the case that occupies us, it is rather the cycles of ignitions and extinctions that will limit the life time: lighted in the morning, the lamp will be extinguished in the evening. The total cost, lamp, connector, ballast etc is around $50 according to the suppliers.

The lamp and its ballast should be well fixed in a light insulated compartment, covered by a food aluminum foil in order to maximize the flux that will illuminate the opening. It doesn't seem that the internal temperature of the compartment would be an issue.

The illuminating hole, the mirror & the collimator.

I chose to have five circular holes one of them forming the entrance pupil, variable between 1.5mm and 5.5mm in more or less a geometric progression and chosen to have the best compromise between uniformity of illumination, brightness and resolution. These five openings are achieved in a sheet of circular brass of 0.3mm thickness and swiveling on its center,
blocked in position by a 3mm steel ball. Between the lamp and the opening, a frosted surface plastic foil is arranged in order to provide a uniform emitted light flux.

The front of the apparatus can be dismounted and then we can choose the diameter of the hole. It is a 4 mm opening that gives the most satisfactory results, considering the 280 mm focal distance and 140 mm diameter of the collimator lens. That’s approximately the diameter of the eye pupil. With F/4, we will go up to 6mm.

Any plano convex lens, so long as it is not too fast (between F/2 and F/5 would be ideal) and of good quality, will make the job. It faces downwards with the curved surface. It is possible too to put two lenses of double focal length, one behind the other, with excellent results. On the other hand it is necessary to avoid the use of a biconvex lens or to bring up these two lenses, plan against plan. The 22x22cm half-reflecting mirror is a plate of mirror without tin on the rear. The front face should be the aluminized face. The 4% reflection on the backplane will be divided by four and will be made inoperative.

The internal part of the box is painted in mat black in order to avoid the parasitic light reflections that would jeopardize the contrast, in particular behind the mirror and at the level of the accessible zone of the interferometer that reflect themselves in the mirror. The performance test between two flats Figure 7 get excellent results.

The realization.

The Fizeau interferometer was made from 8mm thickness plywood and has three sections. From top to bottom one finds the room sheltering the lamp, ballast, and hole, then the part where is the mirror and the collimation lens and finally the measuring compartment where one will arrange the reference and piece to be tested.

The lamp and its ballast on one hand, the lens on the other hand, are arranged on a removable small board that one can pull with the help of a handle out of the box in case of maintenance. In the same way, the mirror is arranged on a groove that keeps it at 45° angle relative to the lens of the collimator. It can slide out in order to be cleaned.

The inside of the top compartment is covered with a food aluminum foil playing the role of a reflector in order to maximize the luminous flux. The rest of the interior part of the box interior has been painted in black, and then rubbed with the help of a fine abrasive, so that the surface is absolutely dead black.

The outside part has been protected with aqueous varnish. A disk pierced with five circular openings and preceded by a sheet of frosted plastic will be the light source of the collimator, adjustable in size. A switch, here illuminated by a small neon lamp, allows the ignition of the lamp. Finally a handle situated on the top of the box (not visible on the figure 11), permits a comfortable transportation.
In order to take into account bending, one will always measure the tested flat on the reference flat and then, if it is possible, reference on the tested flat, if they don't have the same thickness. If the reference flat is sufficiently thick, it will be placed systematically underneath. In order to balance bending, it will have glued some millimeters cork in three points of its surface situated at 120°, on a radius representing 61% of the diameter, more or less.

If the flat to measure is of a thickness lower than 5% of the diameter, one will avoid bringing it closer to the reference; the electrostatic attraction could distort the fringes. The good length of coherency of the lamp will be put to profit by allowing for moving apart the two pieces by 0,1 mm or more.

The figure 12 represents the type of support used by Fizeau to make his measurements, the reference being situated on top. One will be able to set up such a piece on a lower platform, also having three screws in order to align the two reflections of the source hole in order to achieve a perfect collimation.

It is possible to remove the collimation lens. It is interesting for the test of a spherical surface like a secondary of Gregorian, which can be delicate to test by the Foucault. On Figure 13, one can see the diagram of such a test where it is the concave surface that is tested relatively to the reference that is convex. It is essential that the three radii of curvature are concentric. It is possible to change the position of the collimating lens in order to return the convergent bundle.

The reference will be a meniscus of reversed shape in relation to the figure 13 and the piece under test, plano convex. This position will be ideal too, for the test of a Cassegrain secondary. That said, in such a case, the use of the Newton interferometer could be a good idea too. Other methods exist, as the one of the test that achieves the measurement through the glass. That is explained on my internet site.
To conclude.

The manufacture of a Fizeau interferometer is quite easy for the amateur, because its realization is non critical. The choice of the source, here a sodium lamp, will also be a pledge of quality, of easiness of use, permitting a short exposure time. Its price doesn’t pass the level of a middle range ocular and much lower that a 100mm Newton secondary.

A good precision in the alignment of the source to the collimating lens, a exact lens distance to source, use of quality components for the lens, where one will avoid the lens of photo-enlarger condenser, some tools, handiness and imagination, that’s everything that is necessary to achieve an effective device, as I showed it in this article.

A reference flat is evidently necessary and if it could receive a treatment to increase its reflection coefficient by about 20%, it would be able then to characterize the uncoated glass as well as already aluminized glass. Another method uses three flats, tested in pairs; it is well documented in the literature and either OpenFringe, or AtmosFringe will permit an objective and precise characterization of the surface under test.

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Further reading.

- Murty M. V. R. K., Newton, Fizeau & Haidinger Interferometers, in Optical Shop Testing (Malacara), pp. 1-29.
The complete interferometer
Top: Other fringes, created by the Sodium lamp.
Neon Fringe in a Texereau-Fizeau interferometer
MICROGRAPHIA:
OR SOME
Physiological Descriptions
OF
MINUTE BODIES
MADE BY
MAGNIFYING GLASSES
WITH
Observations and Inquiries thereupon.

By R. Hooke, Fellow of the Royal Society.

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