ROTATIONAL SHEARING INTERFEROMATER

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Introduction

A rotational shearing interferometer is a modification of the Michelson's interferometer to obtain the spatial coherence of the light waves. It is mainly used for obtaining diffraction limited images of astronomical objects; through the turbulent atmosphere of the Earth. The fabrication of a solid rotational shearing interferometer with a fixed rotational shear of 180º is described. Also the use of the interferometer, for testing the aberrations of a telescope is described.

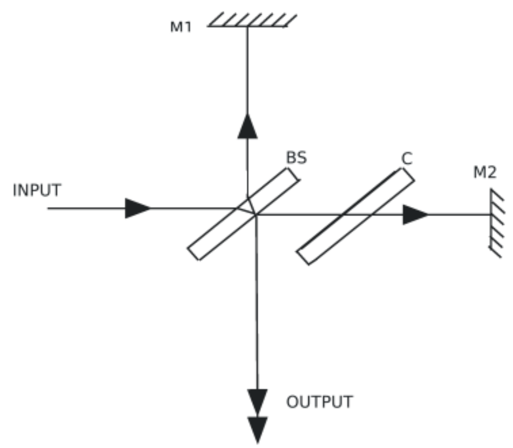

Fig. 1. Michelson Interferometer

(Temporal coherence)

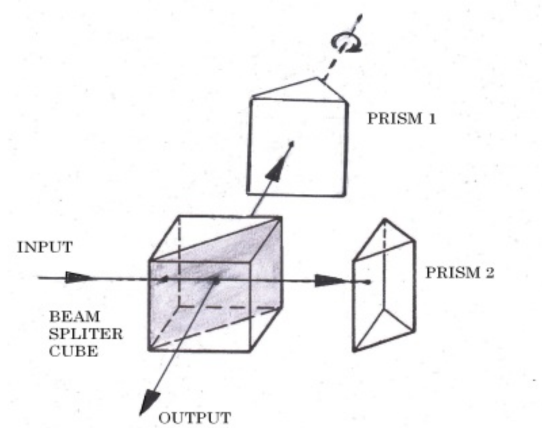

Fig. 2. Rotational shearing Interferometer

(Spatial coherence)

The Interferometer

A Michelson interferometer shown in Fig.1 is modified to a rotational shearing interferometer as shown in Fig.2. The reflecting mirrors M1 and M2 in the Michelson interferometer are replaced by right angle prisms, and the half silvered plate BS and the compensating plate C are replaced by the cube beam splitter. In a rotational shearing interferometer the wave front from one arm of the interferometer can be rotated through 0º to 90º by rotating the right angle prism. Apart from the rotation produced, the prism also flips the wavefront from left to right

A solid rotational shearing interferometer, with 180º rotational shear, as proposed by Breckinridge [1] is shown in Fig. 3.

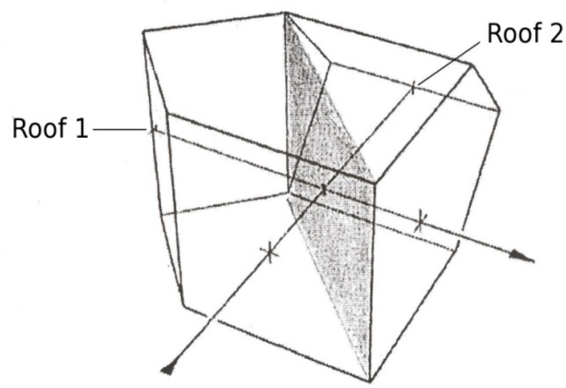

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Fig. 3. A solid rotational shearing interferometer

A solid rotational shearing interferometer was fabricated at IIA. The constructional details of which are given below:

A dove prism is a right angle prism with its apex being cutoff parallel to its base as shown in the fig.4.

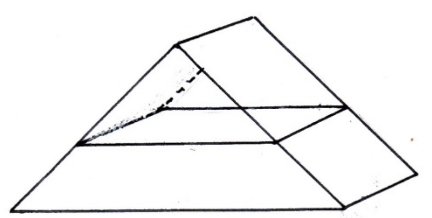


Fig. 4. A dove prism as a truncated right angle prism

When the dove prism is tested in a Fizeau type of interferometer (Zygo interferometer), it displays a fringe pattern as shown in fig.5. The fringes corresponding to the central portion represents the parallelism of the two faces BC and EF. These fringes are marked as P in the interferogram The fringes at the outer edges correspond to the right angle error of the prism. The outer set of fringes marked as R are due to reflections from the faces AE and DF which are part of the right angle prism, from which the dove prism was cut. The parallelism and angles of the prism could also be tested as given in Ref.1. ("Sub arc second testing of a right angle prism").

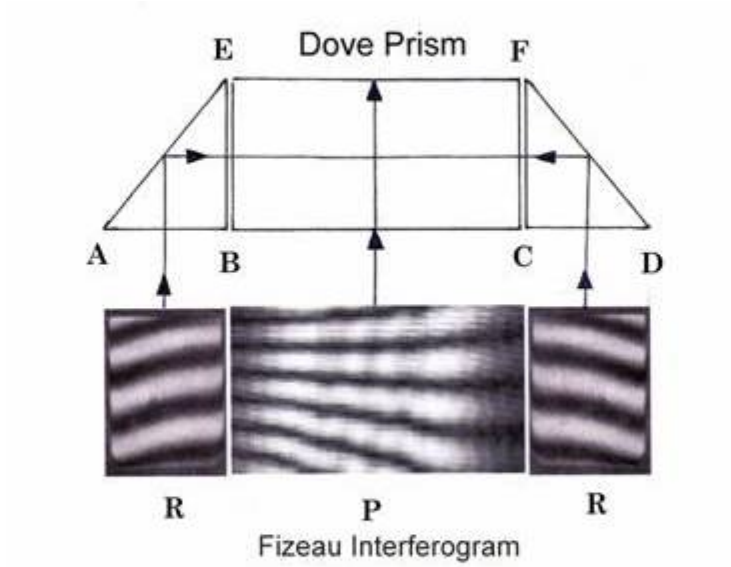


Fig.5. A dove prism and its Fizeau interferogram

Next, the prism was cut into two parts as shown in fig.6

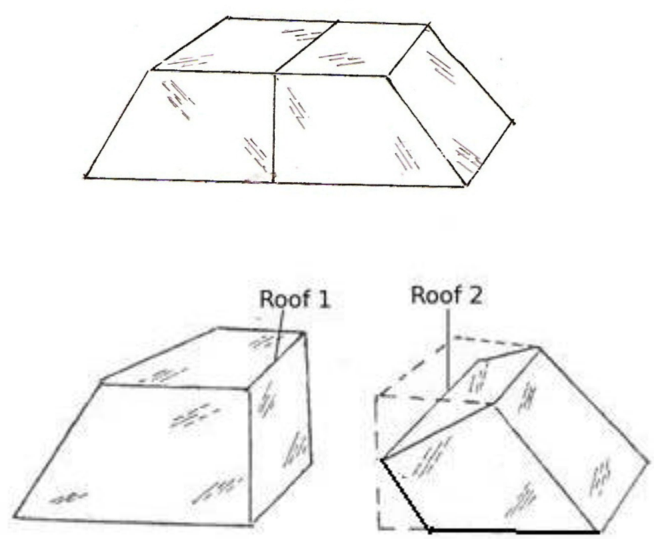


Fig. 6. The dove prism is being cut into two parts

One half of the prism acts as the first component having roof 1. In the other half of the prism the roof is made parallel to the hypotenuse face (Roof 2) as shown in fig.6. The two components were, then matched in size and assembled to form the solid interferometer shown in fig.3.

Path length equalization in the interferometer

The hypotenuse face of the prism containing Roof1 is coated with aluminium having 50% reflection and 50% transmission. The other prism is allowed to slide along the hypotenuse face of the first prism, by applying a thin film of Silicon oil whose index matches with that of the prism material. The prisms were made of BK7 glass whose index is Path length equalization is done by sliding the movable prism back and forth as shown in fig.7.

An f/3 convergent, He-Ne laser beam from the Zygo interferometer was used in testing of the optical components and for the equalization of path length in the interferometer. Path length equalization in a rotational shearing interferometer, using white light is a delicate operation.

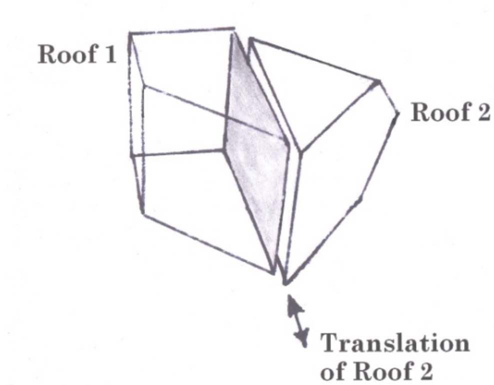


Fig.7. Path length equalization

Conventionally, path length equalization in a rotational shearing interferometer is done using the channeled spectra, observed using a direct vision spectroscope. In the case of a rotational shearing interferometer, where one beam is rotated 180 degrees with respect to the other beam, the Mutual Coherence Function (MCF) determines the visibility of the fringes. Hence it is difficult to obtain the interference fringes in white light. The interferometer, when placed in the path of the convergent beam, produced concentric circular fringes, when the path lengths are unequal. The fringes become progressively broader, as the path length approaches equalization. The fringes are made straight by tilting the interferometer, about its optical axis and the fringe spacing is made wider till the fringes are fluffed out (infinite fringe spacing). The sequence of fringe orientation, and their spacings as the path length changes is shown in fig.6. At this fluffed out fringe condition, the laser beam is replaced by a white light source and the interferometer is finetuned to give colored fringes, with a central bright fringe, since the fringes are cosine. Fringes as given by the equation:

$$I(u,v) = A2 + B2 + \Gamma(2x,2y) + \Gamma^*(2x,2y)$$
$$I(u,v) = A2 + B2 + \Gamma|(2x,2y)| \cos\delta$$

Where $\Gamma(2x,2y)$ is called the Mutual Coherence Function [1].

The following figures (Fig.8) depict the fringe pattern variations with respect to tilt and parallelism of the two arms of the interferometer in a Michelson interferometer. It follows the same pattern in the case of a rotational shearing interferometer. But when white light is used, instead of a coherent beam, locating the fringes is very difficult, as it involves the spatial coherence between diametrically opposite \points of the pupil, for a given source size. The distance between the light source and the interferometer was varied, till we were able to locate the interference fringes.

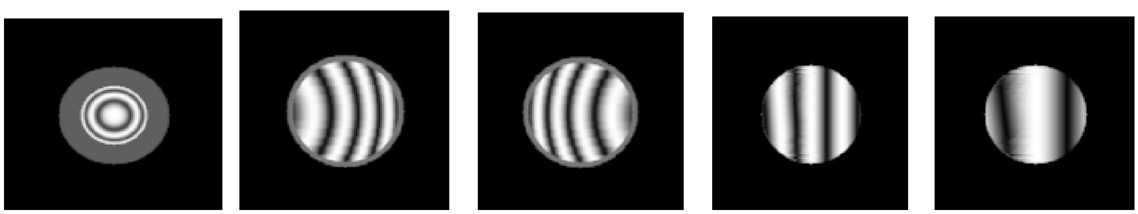


Fig. 8. The sequence of changes in fringe orientation as the path length changes.

In a Rotational Shearing Interferometer, the cosine fringes are modulated by the Mutual Coherence between diametrically opposite points in the wavefront. This makes it critical to locate the white light fringes, by equalizing the path lengths in the two arms of the Interferometer. With the source dimensions very small and the distance of the source from the interferometer very large; i.e. assuming the Fraunhofer condition, the white light fringes were detected. The fringes appear as a very small patch anywhere in the field of view. By careful adjustment of the path length and the tilt, it is brought to the centre of the field and the fringes were widened. The fringes extend all over the field if the source is unresolved. The visibility of the fringes extends over only a small region if the source is resolvable. This fact enables one to visually estimate the diameter of the source.

A solid rotational shearing interferometer was developed at IIA. All surfaces of the optical components were worked to better than λ/10 and the angle accuracies were worked to better than 0.5 arc second. The interferometer mounted in its cell is shown in fig.9 and the white light fringes obtained from the interferometer is shown in fig.10.

Fig. 9. The interferometer mounted in its cell

Fig. 10. White light fringes from the interferometer

An indigenous method of testing the prism angles, to sub arc second accuracy, was developed, using convergent beams [2] and was used in the fabrication of the interferometer's components.

A Rotational Shearing Interferometer with variable shear

It is proposed to build a Rotational Shearing Interferometer, with variable shear angle which was developed by Roddier et al as is shown in Fig. 11[3].

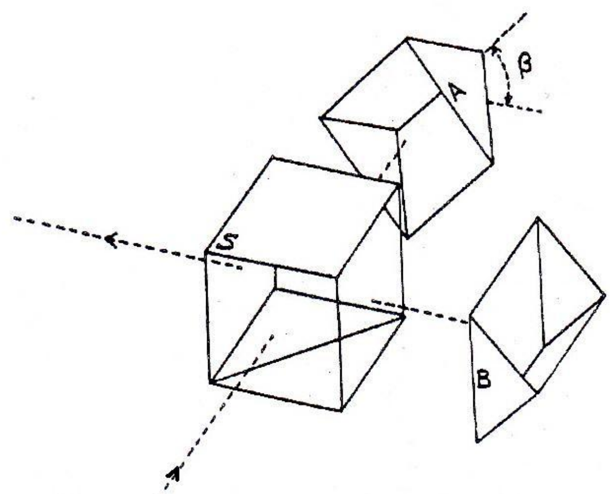


Fig. 11. A rotational shearing interferometer with variable shear angle β

It consists of a beam splitter cube and two right angled prisms as the reflecting arms of the Interferometer. The configuration shown in fig.11, with shear angle equal to 0º, corresponds to the Michelson's Interferometer. When prism A, is rotated through an angle θ equal to 90º, it becomes a Rotational Shearing Interferometer, with rotational shear of 180º. The beam splitter cube is made of two right angle prisms, with one of the prism's hypotenuse face being aluminium coated having 50% transmittance and 50% reflectance. The hypotenuse faces of the two prisms are kept in contact with a layer of oil whose index matches with that of the prisms.

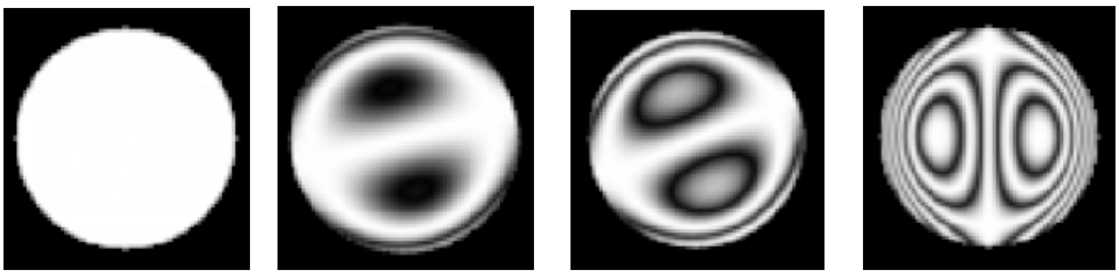
The beam splitter cube is tested for equal path length and also for parallelism in both directions, using a Fizeau interferometer.

Uses of the Rotational Shearing Interferometer

The interferometer was fabricated at IIA for imaging of astronomical objects, Resolving binaries, estimating the diameter of astronomical objects within the limits of resolution of the 2.34 meter Vainu Bappu Telescope at Kavalur. It is also proposed to be used for seeing measurements at the VBT observatory (estimating the Fried's parameter r_0).

The interferometer is also useful in determining the asymmetrical aberrations of telescope mirrors and telescope systems, especially the

Ritchey Chrétien Telescope, which is the world's professional and research telescope. (NASA's Hubble Telescope) The Ritchey Chrétien telescope, with its wide field of view, is designed to be free from coma and spherical aberration. It can be tested with the Rotational Shearing Interferometer. Simulations of the comatic error for various rotational shear angles are shown in fig.12.



a **b** **c** **d**

β = 0° **β = 30°** **β = 90°** **β= 180°**

Fig. 12. Third order comatic aberrations of a mirror, tested with a Rotational Shearing Interferometer

The output shown in Fig. 8a will be obtained in a Michelson interferometer, while the output shown in Fig. 8d will be obtained in a solid rotational shearing interferometer described above.

Conclusions

The solid rotational shearing interferometer, described above was fabricated with all indigenous materials available in the Institute. The translation stage for path length equalization was done at the mechanical workshop of IIA. The optical components were ground, polished and figured using classical polishing machines. They were all hand figured. No advanced electrical gadgets like actuators were used for equalizing the path length in the interferometer. No direct vision spectroscope was used in equalizing the path length. The instrument will be of great use in determining the size of astronomical objects and also for daily monitoring of seeing at observatories

Acknowledgement

The **a**uthor wishes to acknowledge the work of Sri. V. Robert, of the Photonics division of IIA, in fabricating the Interferometer prisms to sub-arc second angle accuracy and the surface accuracy to better than one tenth of a wave.

References:

[1] James B.Breckinridge, "Coherence Interferometer and Astronomical Applications", Applied Optics, Vol 11, No.12, 1972, pp 2996-2998.

[2]Saxena A.K. , L. Yeswanth. "Low Cost method of Sub arc second Testing of Right Angle Prisms", Optics Engineering 29, No. 12, pp 1515.

[3]. C. Roddier, F. Roddier, J. Demarcq, "Compact rotational shearing interferometer for astronomical application" Opt. Eng., Vol.28, No. 1, pp 66-70.