

## ABSOLUTE CALIBRATION OF A FIZEAU INTERFEROMETER WITH A LIQUID PLANE

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**Abstract:** The calibration process of a Fizeau interferometer using a liquid reference plane in an accredited secondary laboratory is presented. Influence factors involved, mainly vibration effects, are considered. The interferograms obtained, are then processed by two means: with self-developed software, based on mathematical morphology theory; and with free available web software. For validation, the results of measurement are compared with two previous calibrations made with commercial interferometers. An uncertainty of 26 nm is associated to the calibration process.

**Keywords:** absolute calibration, liquid plane, Fizeau interferometer, traceability.

### 1. INTRODUCTION

Since 1893, Lord Rayleigh proposed the use of a liquid surface as a reference plane [1], and some National Laboratories, -NPL and PTB, for instance-, have worked with liquid reference planes for decades [2,3]. However, in absence of National Plane Standards, the use of a liquid plane as a reference, -considering the property of the free surface of a liquid contained in a vessel to achieve the Earth's curvature-, allows to accredited secondary laboratories comply the international standard ISO/IEC 17025:2005 traceability requirements, which is not frequent or found at all, and represents a good chance for a calibration laboratory to develop its own interferometer absolute calibration method.

### 2. METHODOLOGY

The instrument which was calibrated is a Fizeau interferometer *Davidson Optronics® 305L*, with an optical flat of 150 mm diameter supported horizontally, and a He-Ne laser tube (632.8 nm) as light source.

The use of a liquid plane requires to take into account some important features of its behavior, namely:

- a) A liquid plane is easily disturbed when is subjected to forces and vibrations externally produced. It is necessary to provide a special vibration isolation system to minimize undesirable effects on the liquid plane.
- b) The free surface of a liquid is permanently under the action of the gravity force, so, the vibration

natural frequency of the liquid plane must be considered when the vibration isolation system is analyzed.

- c) A liquid flat is easily disturbed by the action of shearing stresses (as small as they are), producing unwanted oscillations. It is convenient to avoid all the possible influence factors which could disturb the liquid surface and provoke waves on it.
- d) The liquid utilized as optical plane, once it has been externally excited, must have the property to return to its rest state rapidly.

Following the technique reported in [2,4], two different oils, namely *Dow Corning® 705* (175 cSt @ 25°C) diffusion pump fluid, and *Mexlub® 0353* (14.5 cSt @ 40°C) motor oil, were employed in the experiments to produce two different liquid planes. A 3mm depth film of each oil was poured in an aluminum containing vessel of 240 mm diameter, producing a sag due to the Earth's curvature of about 2 nm [2]. The vessel with the liquid plane was introduced within an outer vessel of 300 mm diameter, containing a film of 4 mm depth of *Mexlub® 0151* (620 cSt @ 40°C) transmission oil, which performs viscous damping. The set of the two vessels was put on the work table of the interferometer, -which was previously located on a base plate with 3 opposite leveling screws in order to tilt the instrument and the light beam for producing the interferograms-, resting on the granite surface plate of a CMM, supported by air dampers on a basement isolated from the rest of the main building of the laboratory (Fig. 1).



**Fig. 1** Experimental setup of interferometer calibration

For the calibration process, it was necessary to consider some influence factors which must be controlled, namely: vibration, current of air, dust particles, thermal disturbances, evaporation and water absorption, as well as capillarity.

### 2.1 Vibration effects

In order to reduce vibration effects, an analysis of sloshing in cylindrical tanks and flotation was carry out [5,6] showing that the natural frequency of the liquid plane, in Hertz, can be calculated from the following equation:

$$f_{ij} = \frac{\lambda_{ij}}{2\pi R} (gh)^{\frac{1}{2}} \quad (1)$$

where

$i$  is the number of nodal diameters;  $j$  is the number of nodal circles;  $\lambda_{ij}$  is the mode shape of vibration (1,8412);  $R$  corresponds to the vessel radius (120 mm);  $h$  is the depth of liquid in the vessel (3 mm) and  $g$  is the local acceleration of gravity (9 780mm/s<sup>2</sup>). With these data, a natural frequency of 0,42 Hz was calculated with eq. (1).

The needed depth of the viscous damping and the diameter of its basin are a function of the weight of the liquid plane and its vessel; as well as of its natural frequency, representing some limitations to get an effective damping, -taking into account the compromise of having a smaller natural frequency of the viscous damping than that of the liquid plane-, mainly because of the dimensions of the vessels are limited by the form of the interferometer. Nevertheless, the vibration damping system in the described conditions, provides enough stability to obtain defined and quiet interferograms in order to be processed (Fig. 2).

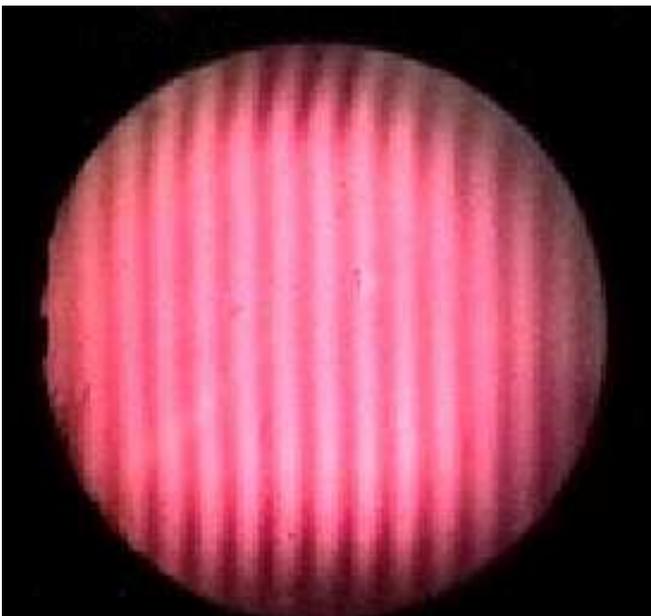


Fig. 2. Interferogram to be post-processed produced by the liquid plane as seen from the interferometer eyepiece

### 2.2 Current air, dust particles, thermal disturbances and capillarity

The experiments took place in a laboratory with filtered air and controlled temperature at  $20 \pm 0,5^{\circ}\text{C}$ . In order to avoid the effects of current air, dust particles and thermal disturbances, part of the interferometer and the liquid plane were covered completely with a polyethylene screen, leaving uncovered the eye piece where the interferograms are seen. Due to the good properties of the oils (mainly the silicon one) and the ambient conditions of the laboratory, the hygroscopicity and evaporation are not considered relevant. However, the relaxation time of the oils requires special attention and care, and a period of 24 hours or more is recommended to guaranty the vanishing of spurious fringes [2,4], avoiding disturbances of all kind. The liquid plane diameter is larger than the diameter of the interferometer's optical flat (240 mm vs 150 mm), so, it is possible to avoid boundary effects due to capillarity [2]. The separating distance between the liquid plane and the interferometer's optical flat was about 10 mm.

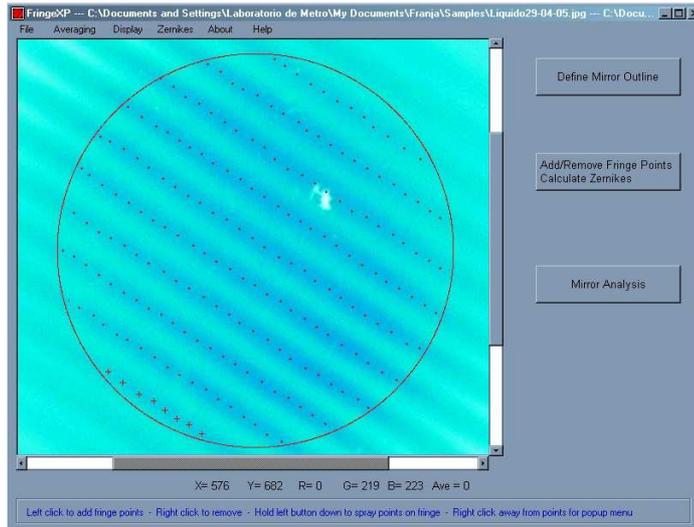
## 3. EXPERIMENTAL RESULTS

The experiments were carried out in two different ways:

a) Producing the interferograms with motor oil, filming it by a period of one minute with a fixed home video camera (640x480 pixels) without touching the interferometer, selecting images randomly, post-processing them with self- developed software based on mathematical morphology theory [7] and *MatLab*®, and measuring the peak-valley (PV) flatness deviation in interferograms in accordance with JIS [8] and the help of *Paint* from *Microsoft*®; and

b) Producing the interferograms with diffusion pump fluid, taking pictures with a fixed digital camera (2272x1704 pixels) avoiding any contact with the interferometer, selecting randomly a set of interferograms and measuring the PV flatness deviation with a free available web software, *FringeXP*. This program can measure a static interferogram and gives a two dimensional and cross-sectional plot of plane, and can average the Zernikes from several different maps [9], (Figs. 3 and 4).

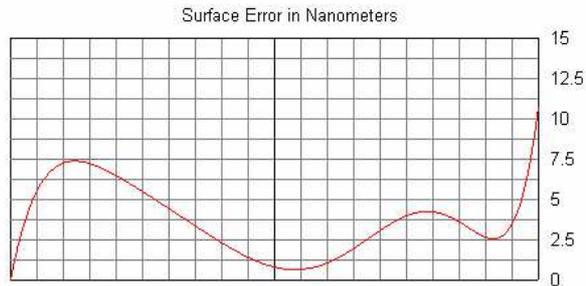
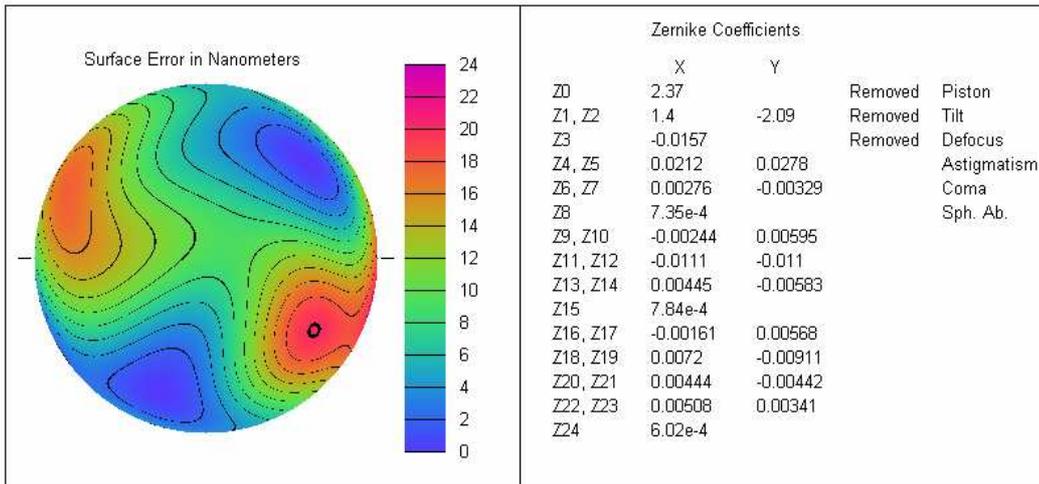
The method described in b) gave better results than that one mentioned in a). The area to be measured in b) was selected from the original image, defining a 100 mm diameter section, corresponding approximately to the clearly illuminated portion in Fig. 2, living the edge region of the plane without effect on the measurement. This is because the selected area is used at most in the very applications done, as optical flat calibration and gage block flatness measurement.



**Fig. 3 Interferogram been processed whit FringeXP**

FringeXP Test Report

At 633 nm:                      RMS Wavefront Error = 1/62 waves                      RMS Surface Error = 5.108 nm  
    Strehl Ratio = 0.99    P-V Wavefront Error = 1/15.41 waves



Other Data

Interferogram Wavelength = 633 nm	Mirror Diameter = 100 mm	Mirror RoC = 100000 mm
Target Conic Constant = 1	Best Fit Conic Constant = 1787	
Total Fringe Points = 205	Number of Fringes = 10	Fringe Spacing = 0.5 waves
RMS Zernike Fit Error = 0.01319 waves		

**Fig. 4. FringeXP Program report**

#### 4. UNCERTAINTY OF MEASUREMENT

Some authors [12] have calibrated a Fizeau interferometer as a black box, comparing the optical flat of the instrument against other optical flat calibrated by a primary laboratory, and conclude that influence factors as time of stabilization of the table where the measurement is realized; zoom over the test piece; focus, visibility, number and tilt of the fringes; temperature variation not greater than 1 °C, laser wavelength; as well as other variables considered in related literature, are all of them negligible in the uncertainty calculation. The only one which is representative is the flatness deviation of the optical flats used as standard and test piece, respectively.

The uncertainty of measurement was calculated following the GUM procedure [10], and the measurement process can be described mathematically as

$$F_{in} = F_{rep} + F_{pl} + F_{ca}. \quad (2)$$

where  $F_{in}$  represents the measurement result which is the best estimate of the value of the measurand and uncertainty associated with it;  $F_{rep}$  represents a random variable associated with repeated observations of measurement of flatness;  $F_{pl}$  is a random variable associated with the flatness of the liquid plane; and  $F_{ca}$  represents a random variable associated with the image distortion produced by the digital camera [11].

A set of eleven interferograms was taken for calculation, giving the following results (considering that the sensitivity coefficients ( $c_i$ ) are equal 1):

**Table 1. Uncertainty budget**

Source of uncertainty	Type and distribution	Standard uncertainty $u_i$ (nm)	$u_i c_i$ (nm)
$F_{rep}$	A normal	10	10
$F_{pl}$	B rectangular	1,3	1,3
$F_{ca}$	A normal	8	8

The expanded uncertainty, with  $k = 2$  for an approximately 95% confidence level is 26 nm or  $\lambda/25$ .

For validation purposes, the results coming from point 3 a) and b) were compared with the results of two calibrations of the interferometer's optical flat made with two different commercial interferometers at different times, as shown in Table 2. The concordance of the results is worthy of note.

**Table 2. Comparison between different measurements**

MEASUREMENT	PV RESULT
As described in a) (mean value)	1/11 $\lambda$ , 150 mm diameter
As described in b) (mean value)	1/12 $\lambda$ , 150 mm diameter
	1/15 $\lambda$ , 100 mm diameter
With WYCO interferometer	1/13 $\lambda$ , 150 mm diameter
With ZYGO interferometer	1/16 $\lambda$ , 100 mm diameter

#### 5. CONCLUSION

The use of a liquid plane as a flatness standard permits to an accredited secondary laboratory, with its inherent limitations and facilities, the absolute calibration of a Fizeau interferometer in absence of National Standards, satisfying ISO/IEC 17025:2005 traceability requirements. The material for the liquid reference should be selected properly and the influence factors, mainly vibration effects, should be sharply controlled. The proposed post-processing and measuring methods of interferograms by two different means, as well as the comparison with other two measurements made with commercial instrumentation, allows the validation to be performed with good uncertainty.

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