OPTICAL SURFACES FLATNESS MEASUREMENTS USING THE THREE FLAT METHOD

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Abstract

Traceability, repeatability and reproducibility of measurement results are the main concerns at a metrological lab. Traceability can be obtained by calibration of standards on national or international labs, while repeatability and reproducibility strongly depend on very well established procedures, the correct use of these procedures and skilled personnel, in order to obtain the reliable results.

This work presents results of a calibration process of very flat (optical) surfaces by interferometry, the so-called "The Three Flat Method". It briefly describes the measurement process using a Mark IV GPI XPS interferometer to calibrate simultaneously three optical surfaces that had from 50 mm to 100 mm diameter. The flatness PV is defined as the distance in quota between the highest peak (P) and the lowest valley (V) of the surface. Five different observers made measurements along 2 years, and PV values ranging from 15 nm to 30 nm were found for the best surfaces. As the surfaces had very good parallelism, special care had to be taken in order to avoid the influence of the interference between the 2 surfaces of the same pattern. The main problems for the correctness in the procedure, among others, were: 1) the definition of what a zero fringe pattern is; 2) different zooming of the surface; 3) measurement of different areas of the surface; 4) surface(s) relative positioning. Nowadays this calibration process is the base for the flatness measurements of our lab, which has been accredited by the Brazilian Calibration Net (RBC), INMETRO, since 2001.

Introduction

The errors of flatness of an optical surface are generally measured against a reference flat. What is in fact measured is the difference between the two surfaces. Considering that in general the reference flat is one order of magnitude flatter than the measured sample, all the differences are assigned to the latter. However, when measuring samples that are as flat as the reference, this cannot be done. There are important papers in this field as the ones presented by Dew [1], Fritz [2] and Swantner[3], discussing the Three Flat Method, as a tool for absolute calibration of optical flats. The use of digital cameras to obtain the interferogram and the use of digital image processing equipment allowed better accuracy for this measurement process. But there are small details about the procedure applied to perform the measurements that must be observed, in order to get reproducible results.

This paper discusses important aspects of the use of the Three Flat Method on measuring very flat surfaces of 50 mm and 100 mm diameters. Values around 15 to 30 nm were found on measuring the Peak-to-Valley flatness.

Experimental Setup

The measurements were done using a Zygo Mark IV XPS interferometer, a Matrox board data acquisition card and a HP 100 workstation. The interferometer is placed over a 2-ton granite/iron table with anti-vibration accessories. The system is based on phase-shifting measurement interferometry.

The experimental procedure consists of the measurement of one surface of 3 different samples. The surfaces to be measured in each sample are labeled as **A**, **B** and **C**. Each surface is measured against the other 2, and one of them is rotated 180 degrees and the last measurement is recorded, as in Fig. 1. It must be noticed that the second surface of each sample should not be very parallel to the first, avoiding a fixed pattern due to the interference between the surfaces, that can be observed in Figure 2. To attenuate this pattern, the second surface must have its reflectivity changed, which can be done by applying a uniform layer of resin. The effectiveness of the layer can be checked by a simple analysis of the interferogram.

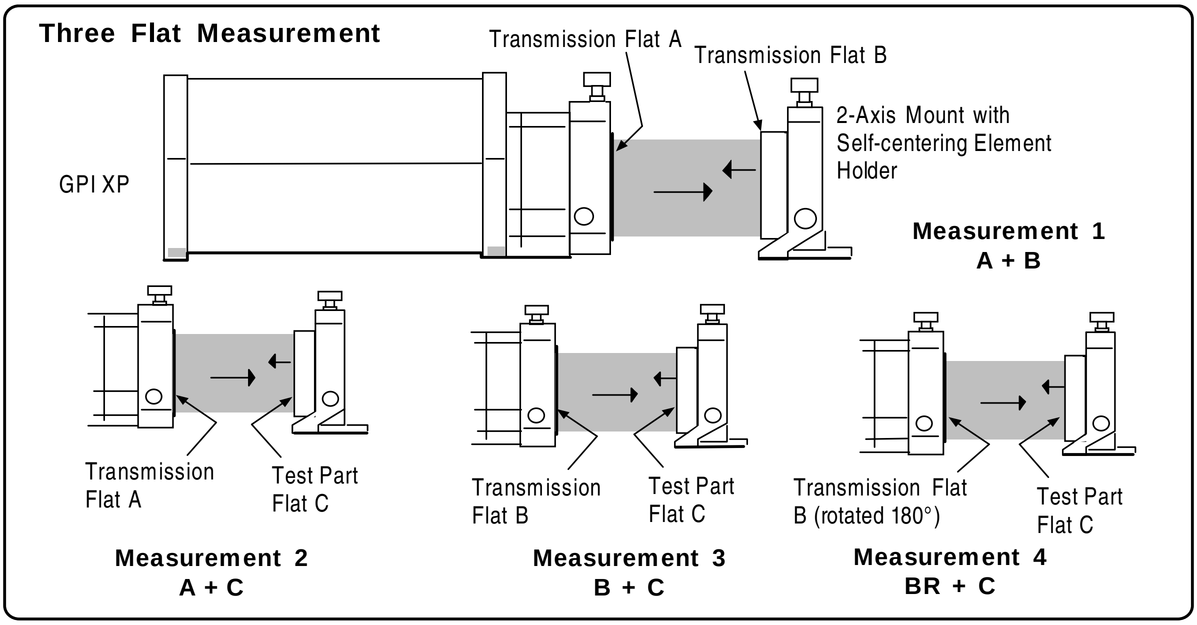

Figure 1: Schematic view of the measurement sequence, according to Zygo4.

All the electronic filters are removed for this measurement. These filters are normally used for tilt and piston removing. The "zero fringes" condition, i.e., the minimum number of fringes must be obtained at each step of the measurement. This is obtained by a careful alignment of the flat surfaces that are being measured. To assure that the same area of the surfaces are measured at each measurement step, a conjugation of electronic and mechanical masks are applied. An electronic (image) fiducial is defined over the measured surface B mounted on the interferometer. It is aligned in a way that it contains the entire surface. A very small piece of tape is than glued to the top of surface B, aligned to the vertical line of the fiducial. Surface B is then mounted on a 2-axis Mount with self-centering element holder. Surface B is then positioned and aligned to surface A mounted on the interferometer. This is one of the critical points of the measurement process, as this is the warranty that the same area is being measured on each surface. All the equipment zooming must be adjusted before this step. The magnification should be the greatest possible to improve resolution, but the image must contain the entire measured surface.

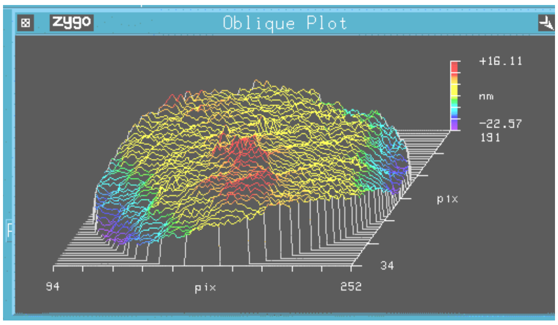

Figure 2: Influence of the sample second surface on the tri-dimensional flatness error result obtained. A waved pattern can be seen on the surface.

Five specimens were measured, in groups of 3. There were: 1 Zygo reference flat 100 mm diameter, 1 Zygo transmission flat 100 mm diameter, 1 optical flat named IEAv-2 125 mm diameter, 1 optical flat named IEAv-1 125 mm diameter, 1 Edmund Scientific optical flat 50 mm diameter. In order to check the reproducibility, different observers performed the measurements described in this work. There were previous measurements to check the exact use of the procedure. The main problems found were: problems on aligning the optical flats, improper adjust done between the measurements (zoom and alignment after first measurement) and measurements out of zero fringe condition.

Results and Discussions

The first round of measurements was done using 50 mm as the measured area. In fact, due to contour conditions limitations, a circle of 90% of the sample is measured. The results presented in Fig. 3 refer to the vertical profile of Reference Flat B, measured by 4 different observers in June 2000. The interferometer wavelength is 633 nm. Apparent good agreement on the results can be observed, because the unit used for this measurement is the wave fraction. A new round of measurements was carried out and the results are in Table 1. After the measurement it was noticed that the positioning of surface C was not kept constant, as this sample is the only one that can be freely positioned. Then, all the following measurements took into account the positioning of surface C. Surface A was a Reference Flat from Zygo, Surface B a Transmission flat from Zygo and Surface C an Edmund Scientific optical flat 50 mm diameter. Only the central portions of the Zygo flats were measured and this area was limited by the use of a mask.

Surface	A, PV (nm)		B, PV (nm)		C, PV (nm)	
Axis	vertical	horizontal	vertical	horizontal	vertical	horizontal
Observer 1	13.90	15.06	23.14	19.27	16.09	31.70
Observer 2	17.15	13.30	22.37	15.20	28.27	35.78
Observer 3	18.40	11.39	21.65	15.66	20.71	25.20
Observer 4	15.52	14.18	22.19	21.71	16.99	29.08

Table 1: Results of measurements done by 4 different observers, using the Three Flat Method.

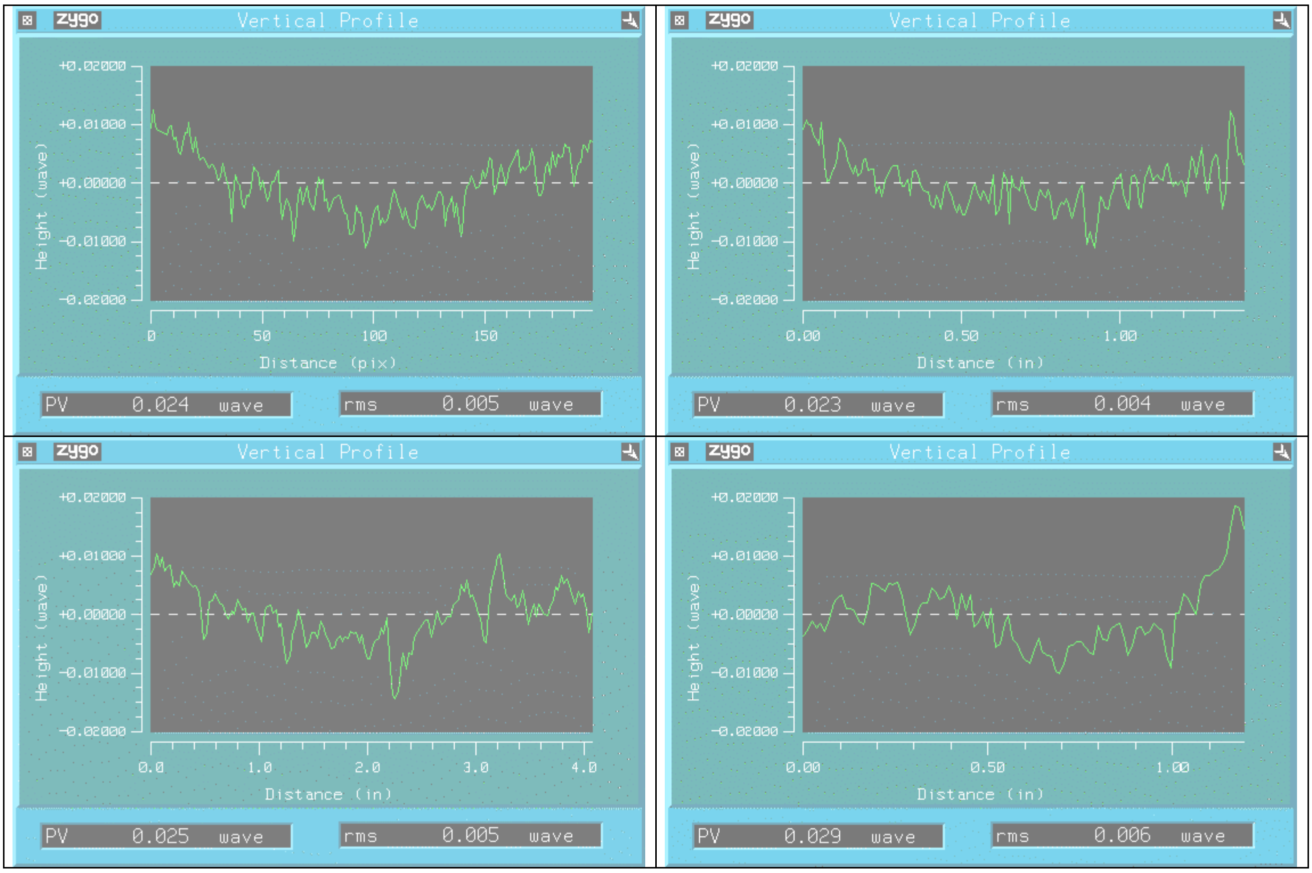

Figure 3: The vertical profile of the Reference Flat B, measured by 4 different observers.

Other rounds of measurements were performed and minor procedure adjustments were taken into account. As a good practice of the lab, this intercomparison was done every 6 months, besides other procedures. In order to check the procedure, measurements were taken using the optical flats named IEAv-1 and IEAv-2 as Surface C, one at a time. The results are presented on table 2. A good agreement was found.

Surface	RF, PV (nm)		TF, PV (nm)		IEAv-1, PV (nm)	
Axis	vertical	horizontal	vertical	horizontal	vertical	horizontal
Round 1	24.49	20.64	17.91	19.20	41.23	27.68
Surface	RF, PV (nm)		TF, PV (nm)		IEAv-2, PV (nm)	
Round	20.07	20.04	17.90	17.01	19.38	20.77

Table 2: Peak-to-Valley results of the Three Flat Method using 2 different flats as surface C.

Conclusions

The Three Flat Method is a good tool for calibrating optical flats, as long as careful understanding of what each procedure step really is intended for. The alignment and the fringe zeroing are essential for exact use of the technique. Reproducible results were obtained, even when performed by different observers.

[1] Dew, G. D., Journal of Scientific Instruments, vol. 43, pp 409-415, 1966.
[2] Fritz, B.S., Optical Engineering, vol. 23(4), 379-383, 1984.
[3] Applied Optics, vol. 19(1), 161-163, 1980.
[4] Three Flat Test Application Note, Zygo's Reference Manual.