Simple method for thickness measurement in opaque samples with a Michelson-Sagnac interferometer.

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Abstract. We present in this work a method to measure thicknesses of opaque samples. The technique combines the use of low coherence interferometry with a Michelson-Sagnac configuration. This ring set-up let us to measure both faces of the sample simultaneously. So it is possible to obtain the thickness by measuring the optical path difference between a reference and both surfaces of the sample. Experimental results up to 1mm are shown in metal gauge block. A resolution better than 10 microns was obtained.

INTRODUCTION

Interferometry, as a measurement method, has allowed the developing of techniques to obtain profiles [1,3], thickness [2] and tomography [4, 5, 6] of different samples, with excellent results and high accuracy, generally employing a Michelson's configuration. Most of this works are limited to scan one sample's face at a time, employing a reference surface. Commonly both sample's faces have to be measured in a separated form. An example of this is the interferometric gauge block (IGB) [7]. There are some systems that measure, simultaneously, both sample's faces. Some of them use coherent light [8] or low coherence sources [9], and achieve good results at the cost of configuration or detection systems complexity.

In this work we present a simple and robust configuration in a compact system with a unique detection module. It use a wide spectrum light source and the interference signal is detected employing the technique commonly know as Fourier Domain Low Coherence Interferomery [3, 5, 6, 10]. This configuration allow to measure in real time, since the detection system simultaneously capture all interference signals generated by the interaction between the sample's faces and the reference arms. An additional benefit is that it avoids the phase ambiguity that appears in coherent systems.

This work describes the interferometric system, its characteristics and shows some results obtained in gauge samples.

EXPERIMENTAL CONFIGURATION

With the idea to get direct measurement we develop a low coherence interferometry that let us to obtain profile and thickness values in only one measurement.

In the Fig. 1 it is possible to see the set-up configuration of the Sagnac-Michelson interferometer. E_1 is the reference mirror; E_2 and E_3 are the mirrors employed to direct the light to each face of the sample. BS_1 and BS_2 are two beam splitters. The light source is a superluminescent diode and the detector is a monochromator. The sample (S in the figure) has a thickness d.

The different beams considered to get the interference signals are described as follows. The arm that ends in the mirror E_1, after the first beamsplitter (BS_1), is called the reference arm. After BS_2 the two beams are directed to each of the faces of the sample after reflections in the mirrors E_2 (arm I) and E_3 (arm II). We measured in the detector the superposition of these three beams.

In order to identify the origin of each of the interference signals we define the following optical path difference:

I_r is the path difference between the reference arm and the beam in the Sagnac interferometer when the sample was removed.

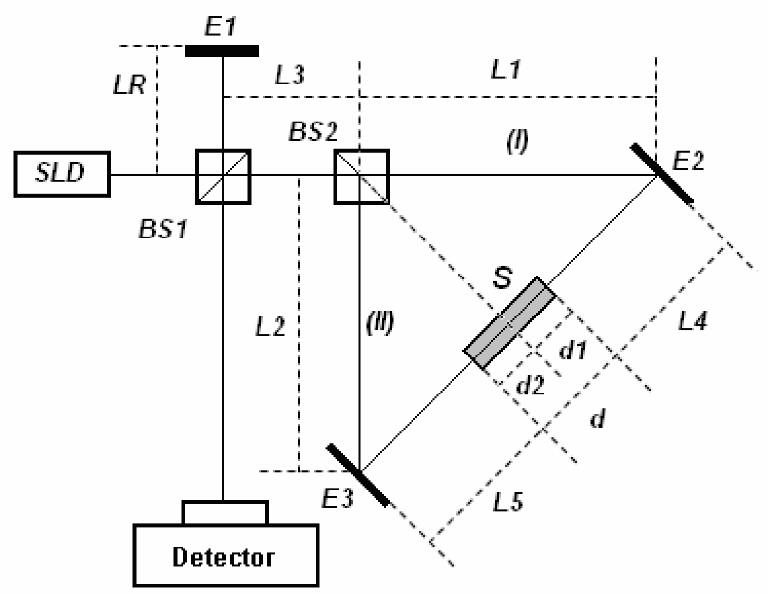

FIGURE 1. Sagnac-Michelson interferometer.

I_2 and I_3 represent the optical path difference between the reference arm and the reflections in each of the sample faces.

In order to be clear in this point we define the following relations:

$$Sg = (2L_3 + L_1 + L_2 + L_4 + L_5 + d) \tag{1}$$

Sg is the path length in the Sagnac arm when there is no sample When the sample is placed in the interferometer the path lengths I and II are defined as :

$$I = 2(L_3 + L_1 + L_4) \tag{2}$$

$$II = 2(L_3 + L_2 + L_5) \tag{3}$$

According to this definition:

$$I_r = 2LR - Sg \tag{4}$$

$$I_1 = II - I \tag{5}$$

$$I_2 = 2LR - I \tag{6}$$

$$I_3 = 2LR - II \tag{7}$$

So we obtain the following relation for the thickness value (d):

$$d = \frac{(I_2 + I_3) - 2I_r}{2} \tag{8}$$

It is important to notice that expression (8) is independent of the length of the interferometers arms and of the position of the sample. This is an advantage of this technique because no extra alignment is needed. However in this system the position of the reference mirror and the sample determine different configuration that have to be considered in the detection. In this paper we employed a particular configuration that we call symmetric, in which d_1 and d_2 (Fig. 1) are approximately equals. In this condition the relation between distances values are Sg > I > 0 and Sg > II > 0, and the relation between the interference peaks is:

$$I_r \leq I_2 \tag{9}$$

$$I_2 \leq I_3 \tag{10}$$

EXPERIMENTAL RESULTS AND DISCUSION

In Fig. 2 and 3 it is shown a typical example of the interference fringes obtained with the set-up of Fig. 1. These figures correspond to the superposition of the spectrum of the light source when two beam (Fig. 2) or three beams (Fig. 3) are directed towards the detector.

In Fig. 2 it is shown the interference fringes between both faces of the sample. In Fig. 3 it is showed the additional modulation produced when the reference beam is added.

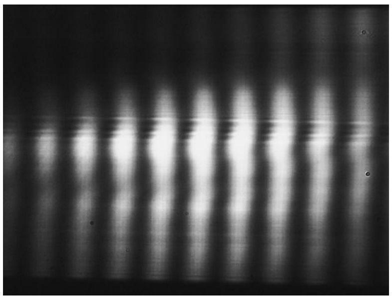

FIGURE 2. Interference figure from both faces.

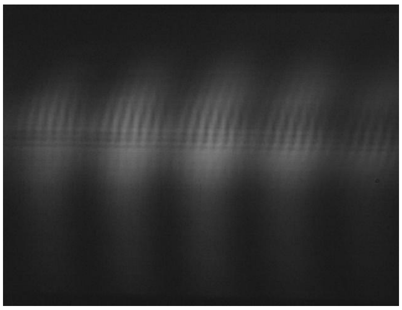

FIGURE 3. Interference figure from both faces and the references arm.

If a horizontal pixel line of the Fig. 3 is taken, we get an intensity curve as a function of the wavelength. After an FFT of this curve we get three peaks. Each of them gives us the OPD measurement as was presented in equation (4 to 7).

In Fig. 4 it is show an example of this curve for a typical measurement obtained when the sample is aligned as in Fig. 1.

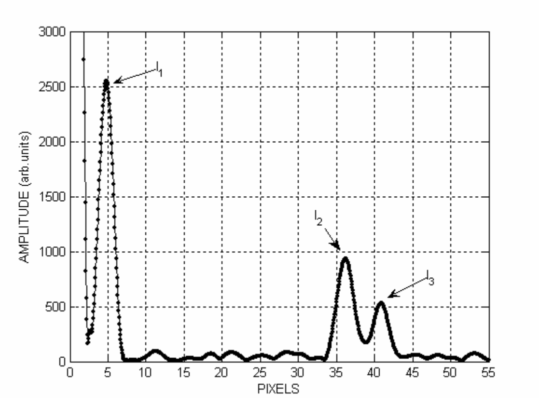

FIGURE 4. FFT curve of the intensity of a line of the interference image

This curve shows three peaks that correspond to the OPD value I_2, I_3 and I_1 according to previous definition.

MEASUREMENT IN OPAQUE SAMPLES

As a first example it was measured a rectangular gauge class II according to ISO 3650 (model M7T from C.E. Johansson). Its nominal thickness value is 1300 ± 0.45 µm.

To get the thickness value we placed the sample as it is shown in Fig. 5.

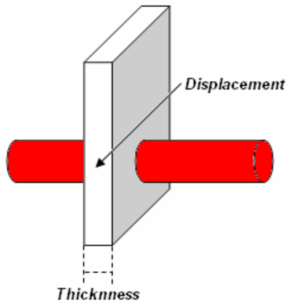

FIGURE 5

In Fig. 6.a it is shown a repetition of 500 values of the interference signals (I_1, I_2, I_3, I_r) in the same condition. The value for the thickness is d = 1.2978 mm with a dispersion $\sigma_d = 0.85789$ µm.

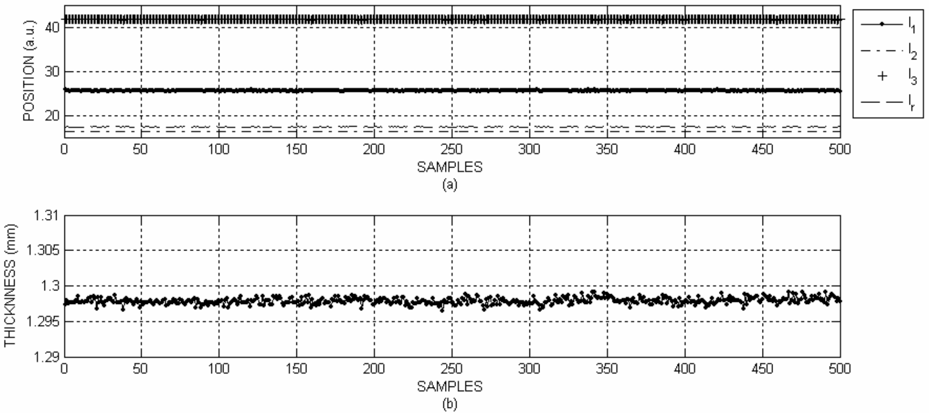

FIGURE 6. Measurements signals and thickness.

An important characteristic of this technique is that changes in its position or external vibration in the sample don't introduce a significant error in the thickness measurement. This is clear if we analyze the dispersion of the curves of Fig. 6. The experimental value for σ_d is 1/3 of the value obtained from expression (8) if we consider the dispersion of the I_r, I_2 and I_3 measurements.

PROFILOMETRY AND THICKNESS VARIATION

In this measurement we make a lateral displacement of the sample and we measure the same signals that in the previous example. The sample is a rectangular gauge with the same specifications as before with a nominal thickness of 1100 ± 0.45 µm.

We get the interference signals as the sample is laterally displaced a distance of 4 mm with steps of 50 µm. In each point we took an average of 50 samples.

In Fig. 7.a it is shown the interference signal between reflections in both faces of the sample. In the Fig. 7.b and 7.c it is shown the interference signals between each face and the reference. From this curves we can get the faces profilometry and the angular orientation with respect the reference plane

In Fig. 7.d the thickness is shown as a function of the steps in the lateral displacement. The average thickness value is d = 1091µm with a dispersion of 0.9µm.

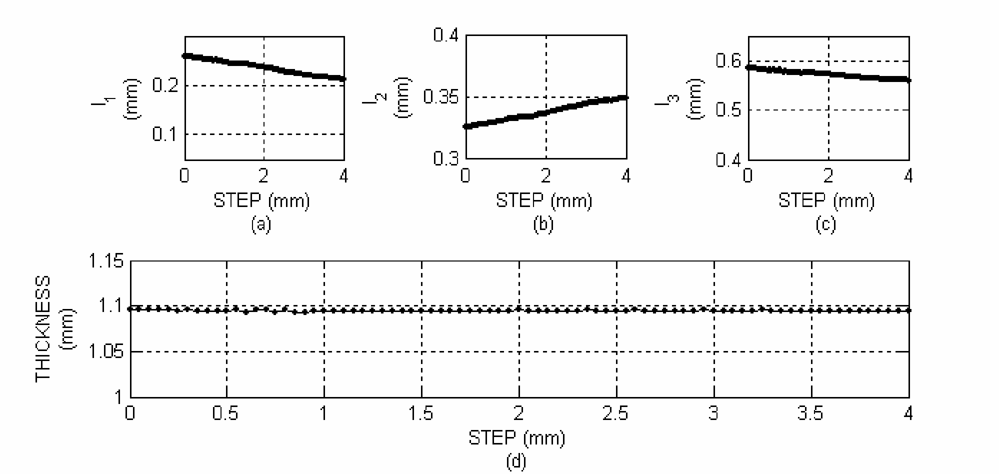

FIGURE 7. Interference signals and thickness.

CONCLUSION

In this paper we presented a simple method to measure, simultaneously, both faces of an opaque sample. The technique shows to be robust and insensible to vibration and to the position of the sample. We showed that the method can be employed to measure the angular alignment of each of the sample faces with a reference plane and the thickness variation in different sections of the sample.

Thickness up to 1 mm can be measured with this set-up, with a resolution in the order of 1 micron. We are actually working in applications in machined surfaces and semitransparent samples

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