

# OPTICAL MEASURING SYSTEM FOR HARDNESS INDENTERS

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*Abstract: The described measuring system is a new system design in IMGCC and developed in cooperation with AFFRI. It can be used to measure the geometrical characteristics of the Rockwell and Vickers diamond indenters. It is based on the interferometric image analysis of different sections of the indenters. Special algorithms are implemented to obtain, from a section of the interferometric images, the indenter profile reconstruction.*

*The main characteristics of the measuring system are an adequate uncertainty to calibrate the indenters for the calibration of hardness testing machines and calibration of hardness blocks, fast measurement execution and low cost.*

*These characteristics allow to this instrument to be easily used by laboratories of Primary Metrological Institutes and by secondary laboratories as well industrial laboratories.*

*Keywords: hardness, indenter, measurement*

## 1 INTRODUCTION

It is well known the influence that diamond hardness indenters have in the hardness test and, consequently, in the hardness measurement and its related uncertainty [1, 2, 3]. In the relative standards [4, 5] are specified the characteristics that the indenters must have to be used for the calibration of hardness machines and the calibration of hardness blocks. The main characteristics to be controlled in the indenters are those geometric ones, even if it does not have to forget that the properly mechanical characteristics have a great influence (specially in the Rockwell scales) that still has not been completely investigated.

Many hardness laboratories of the Primary Metrological Institutes that maintain the hardness scales and some of the secondary laboratories that contribute to the hardness scales dissemination have developed different instruments to carry out this type of measurements.

Recently in IMGCC it was decided to develop a new one with the following characteristics:

- uncertainty adequate to calibrate the indenters for both uses: calibration of hardness testing machines and calibration of hardness blocks,
- fast measurement execution,
- low cost.

## 2 CURRENTLY USED METHODS

As mentioned, several instruments have been developed to calibrate the hardness diamond indenters. All these instruments can be subdivided in two categories for different type of measurement: with contact or optical.

In the first category there are the stylus measuring system, based on the measurement by contact with a displacement transducer of different cross sections of the indenters [6].

The optical category can be subdivided in other two: profile projection or interferometric observation. Due to the big uncertainty of measurement, the first type of instrument is normally used only to calibrate the indenters to be used for the hardness testing machine calibration. The second one, with normally very small uncertainty, is usually used only as zero detection for the angle measurement, carried out with a sin-bar system or a calibrated angular encoder.

Only one instrument based on the full field interferometric image analysis exists [7]; this type of instrument is based on the measurement of the optical-interferometric image of the indenter realized by means the interferences created between the indenter and a master reference artefact.

Up to now, in IMGCC, is used an instrument based on a rotating table on air bearing for the measurement of the spherical tip and a sin-bar coupled with an interferometric microscope for the

measurement of the angles [8].

The interferometric microscope combined with a sin-bar (or calibrated encoder) is wide used to measure the indenter angles in several metrological laboratories.

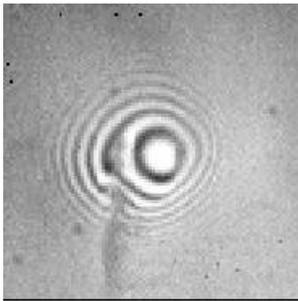
### 3 NEW IMPLEMENTED METHOD

The new instrument developed in IMGC is based on the interferometric image analysis of different sections of the indenters. The system is composed by the following devices:

- optical microscope with interferometric lens,
- rotating table for the indenters support, located under the microscope lens. It is motorised by a DC motor and equipped with an calibrated angular encoder,
- TV camera and frame grabber PC board for the image acquisition,
- software specially developed for the measurements.

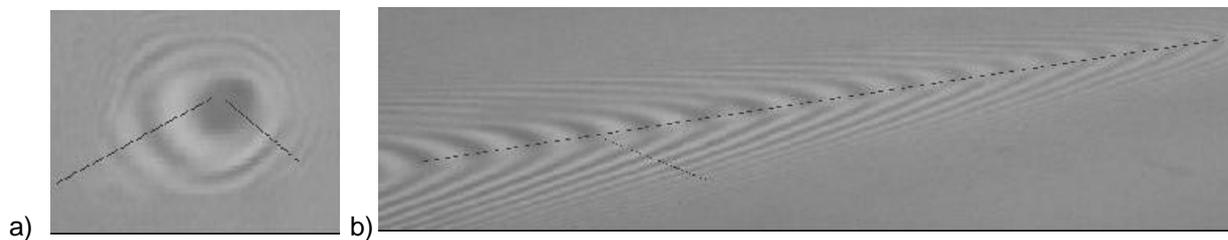
The Michelson interferometer can easily modified to perform surface examination [9, 10]. In the new system the images created by the interferometric lens are based on the wave-like theory of the light [11]. Essentially the objective is built by a series of lenses for the magnification of the image and by a reference plane. On the principle of the Michelson interferometer, the fringes are generated by means of optical interference. With this type of objective, observing the spherical tip of the Rockwell indenter, pseudo-circular fringes of interferences, like Newton rings, are generated (fig.1. With the TV camera and frame grabber PC board, the interferometric image generated by the interferometric lens of the microscope are acquired and elaborated to reconstruct the profile of the observed surface of the indenter.

As it is possible to see in figure 1, the interferometric image of the spherical tip of Rockwell indenters is like the Newton rings.

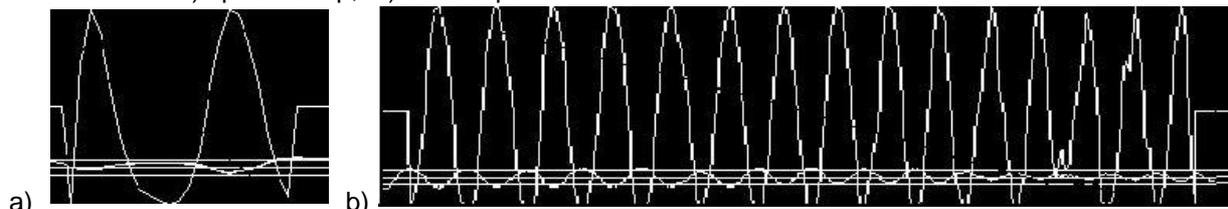


**Figure 1.** Interferometric fringes, like the Newton rings, of the spherical tip of Rockwell indenter.

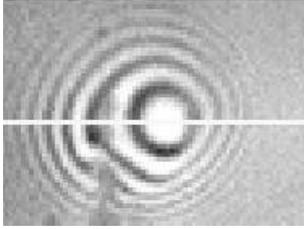
The measurement algorithm is based on the determination of the distance of any singular observed point, having the information on the grey level variation. From the wave like theory of the light, between one and the subsequent fringe, the variation of the depth of the observed surface is half of the wavelength of the light used to illuminate the surface ( $\lambda/2$ ). Starting from the optical image (fig. 2), through the luminance profile (fig. 3), it is possible to reconstruct the profile of the observed surface with the following algorithm:



**Figure 2.** Acquisition of the interferometric image of the Rockwell indenter:  
 a) spherical tip, b) conical part



**Figure 3.** Luminance profile of the extracted line of optical image and its normalization:  
 a) spherical tip, b) conical part



**Figure 4.** Central section of the image on which to execute the profile reconstruction.

- a. Acquisition of interferometric image
- b. Extraction of luminance profile of the selected line, normalization and reconstruction of the profile with the following procedure:
  - i. The elaboration of the indenter image is not a full field analysis but only on a section of the indenter. At the present realization of the prototype, the choice of the line on which must be analysed the profile is made manually. It is previewed later on the use of standard library algorithm to choice automatically the line on which to execute the elaboration (fig. 4)
  - ii. The line profile shown with a bright line on fig. 3a and 3b, must be normalized for the profile reconstruction. They have been determined the points of maximum of the function and then normalized.
  - iii. Starting from the normalized function, the profile reconstruction in the following:
  - iv. since the interferometric fringes are generated through the reflection between the indenter surface and the reference plan, every time that the distance is multiple of  $\lambda/4$ , a transition from a dark to bright fringe is observed (and vice versa). The normalized function represent, step by step with its maximum and minimum, the distance between the reference plan and indenter surface. Inside the fringe, the reconstruction of the profile of the indenter can be calculate with the following formula: 
$$y = \arcsen(f) \cdot \frac{I}{4p} \tag{1}$$

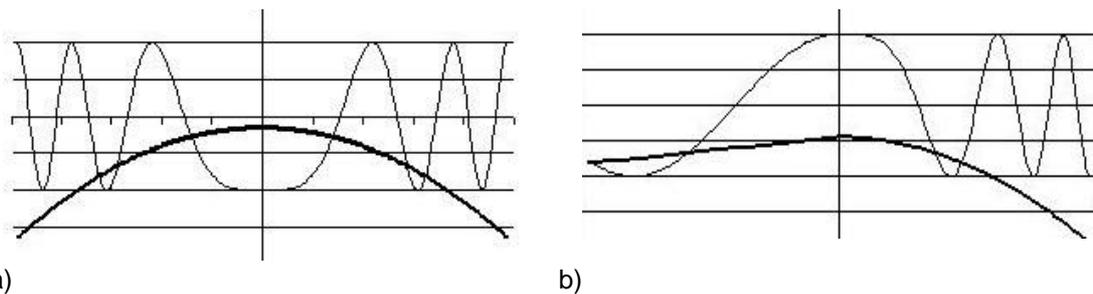
where  $f$  represent the normalized function.

Taking in consideration the shift of the fringes, the previous formula can be generalized adding, for any new fringe in examination, the  $y$  value calculated from the previous fringe. The more general formula can be expressed in the following terms:

$$y = \arcsen(f) \cdot \frac{I}{4p} + n_f \cdot \frac{I}{2} \tag{2}$$

where  $n_f$  represent the number of the examined fringe.

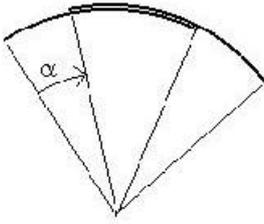
In this way, knowing the wavelength of the light used to illuminate the indenter, it is possible to reconstruct the indenter surface both in the spherical and conical part (fig. 5).



**Figure 5.** Profile reconstruction: a) spherical part, b) conical part

Due to the restricted field of observation, it is not possible with a unique image observe the entire part of the spherical tip. Rotating the indenter around the centre of the spherical tip with the motorised rotating table, it is possible to obtain several images of different parts of the examined section. Successively the system reconstructs the entire profile using the information of the angle of rotation measured with the encoder settled up on the rotating axis (fig. 7).

Since with an interferometric lens the focussing is constant, it is not possible to have information on the height of the positioning of the indenter. On the images analysis phase, it is necessary a partial overlapping of the images to reconstruct the global profile, through a best-fit algorithm that link in univocal way the subsequent images.

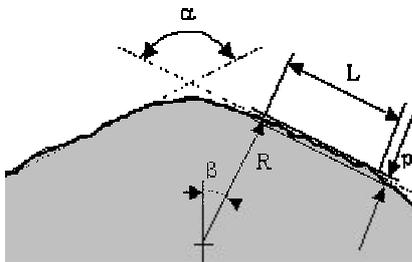


**Figure 7.** Reconstruction of the indenter profile from several different partial images.

On the indenter profile therefore determined could be possible the measurement the angle of the indenter, the straightness of the generatrix and the mean radius.

In the fig. 8 is shown the measurement that must be calculated on the indenter profile:

- The radius  $R$  is calculate with the least squared method, interpolating the point of the spherical part around  $\pm \beta = 30^\circ$ .
- The angle  $\alpha$  is calculated as angle between the two line interpolated along the side points for a length  $L = 0,4 \text{ mm}$
- The straightness is calculated as maximum distance of the points from the interpolating line.



**Figure 8.** Measured geometrical parameters on Rockwell indenter.

$\alpha$  = cone angle  
 $R$  = spherical tip radius  
 $p$  = surface straightness

Since the result of the interpolation are strongly dependent from the points on which interpolate the spherical and conical part, It is clear that it is fundamental a correct definition. The angle  $\beta$  has been obtained from the nominal values of the parameters the indenters must have [4, 5], while the length  $L$  has been estimated according to the part of the indenter involved during the indentation part of the hardness test in the case of softer material.

The measurement of the geometrical characteristics of Vickers indenters is remarkably easier. On the acquired interferometric image of the flat surface of the indenter, it is possible to calculate the following parameters:

- Inclination of the maximum slope plan  $\alpha_n$  (fig. 9a) by means of the elaboration of the central part made with the same algorithm described previously for the Rockwell indenter
- The angle of the maximum slope  $\beta_n$  between the indenter face and the reference plan, by means the measurement of the inclination angle of the interference fringes in respect of the TV axis. To calculate this slope, different sections of the image are elaborated. Successively an interpolation is made on the points of maximum using the least-squared method to determine the interpolating straight lines and their respectively angular coefficients (fig. 9b). The angle of maximum slope is calculated as the mean value of the angular coefficients of the straight line interpolated.



**Figure 9.** Schematic drawing of the creation of the interferometric fringes of a Vickers indenter:  
a) determination of the inclination of the maximum slope plan  $\alpha$ , b) elaboration for the determination of the inclination of the maximum slope plan

After a rotation of  $(180^\circ - 136^\circ) = 44^\circ$  made with the rotating table to present the opposite face of the indenter under the lens, a new image is acquired and the same parameters are calculate as previously described. The angle of the indenter is formed by the intersection of the two observed faces and it is calculated as follow:

$$g_{n-(n+2)} = 136^\circ + (b_n - b_{n+2}) \quad (3)$$

Rotating the indenter of  $90^\circ$  on its main axis, the same measurements are performed. The mean angle is calculated with the following formula:

$$\bar{g} = \frac{g_{n-(n+2)} + g_{(n+1)-(n+2)}}{2} \quad (4)$$

The four angles at the base of the pyramid (fig. 10) are calculated with the following formulas:

$$J_{1-2} = 90^\circ + (a_2 - a_1), J_{2-3} = 90^\circ + (a_3 - a_2), J_{3-4} = 90^\circ + (a_4 - a_3), J_{4-1} = 90^\circ + (a_1 - a_4) \quad (5)$$

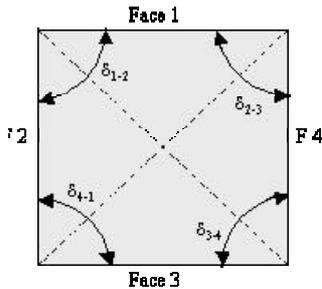


Figure 10. Measurement of the four angles at the base of the pyramid

#### 4 CALIBRATION

It is possible to calibrate the indenters measuring system through reference sphere and a reference plan. Substituting to the indenter the reference ruby sphere or the reference plan, it is possible to carry out the measurements of roundness and straightness; the results of these measurements can be used to calculate the differences from the nominal value. If the differences are significant compared the evaluated uncertainty, can be used to calculate correction coefficients to be applied at the measurement results.

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