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COMPARISON OF BRINELL MEASUREMENT SYSTEMS ON THE EDGE INDENTS IDENTIFICATION

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Abstract − This paper describes a comparison carried out among three measuring systems used to determine the Brinell indentation diameters. One of them is a high precision profilometer, which is a contact method. The other one is a non-contact method that works by image analysis and it is the current system applied at INMETRO's hardness laboratory. The other, that is also a non-contact method, was the one developed at INMETRO's laboratories and it is a system that works with image processing by edge enhancement.

Keywords: Brinell indentation, profilometer, digital image analysis

1. INTRODUCTION

As principle, the Brinell hardness is determined when a ball indenter is forced into a surface of a test piece and, after removal of the force, the diameter of the indentation left in the surface is measured. The indentation left is assumed to take the shape of the unloaded ball indenter, and its surface area is calculated from the mean indentation of linear diameter and the ball diameter.

However, it is actually dependent on a combination of the area and indentation depth, where the Brinell hardness is determined as in (1).

$$HBW = 0{,}102 \times \frac{2 \times F}{\pi \times D^2 \times \left[1 - \sqrt{1 - \frac{d^2}{D^2}}\right]} \qquad (1)$$

where
- *HBW* is the Brinell hardness;
- *F* is the applied test force, in N;
- *D* is the diameter of the indenter ball, in mm and;
- *d* is the mean indentation diameter, in mm.

One of the probable reasons behind the use of linear dimensions (diameter) is probably the difficulty in measuring areas with traditional techniques. Commercial hardness equipment and some calibration systems normally require that the operator perform the measurements manually with the aid of a microscope and a linear measuring device, where direct area measurements are, in some cases, tough to obtain in these systems [1]. Even in the automatic measuring system, the operator has some influence on the measurements, e.g., when making the focus or while selecting the microscope objective and consequently the numerical aperture (N.A.).

Digital image processing techniques can be very helpful in this context. With the correct combination of image acquisition devices, processing and analysis, the edges of the indentation can be in such a way accurately identified and the corresponding hardness values determined.

Nevertheless, lately, is being a consensus, for the point of view of the National Metrology Institutes (NMIs) [2, 3, 4, 5], that the conventional procedures stated on the international standards methods [6, 7] are not enough to calibrate primary Brinell reference blocks.

This is, probably, because Brinell indentation shapes changes after the force releasing, mainly due of the elastic recovery of the test material surface around the contact area. This region can be deformed upwards or downwards along the z axis where the load is applied. This behavior is called piling-up, in the upward case and sinking-in, in the downward case. When the indented material is deformed elastically, sinking-in occurs. The presence of these phenomena has a negative effect on the determination of the Brinell hardness indentation [8].

Then, having these issues in mind, it was run a comparison among three Brinell measurement systems, focusing on the edge indents identification. The considered reference system was a high precision profilometer where the tip has constant contact with the surface. It was compared against the current system used at INMETRO's hardness laboratory, which is a non-contact system and against the system developed in house, which is based on the image processing by edge enhancement, which is also a non-contact system.

2. METHODOLOGY

For this particular comparison, each of the three systems performed their measurements using its own procedure for the edge identification and then the Brinell values were determined. Beyond the comparison, the results were also used, in such a way, to characterize the image processing measurement method developed at INMETRO.

2.1. Profilometer measuring method – Reference system

This method was the one established as reference for this particular study. It is a high precision cross-sectional profilometer measuring system.

The Brinell measurements were carried out with a surface profiler laser sensor, with 2 µm stylus tip radius. It was used a Form Talysurf 120 instrument, which has 8 mm vertical range in Z and 0,2 nm of resolution. This instrument has 120 mm transverse unit in X and a 100 mm displacement in Y.

From this method, the hardness blocks were positioned in a table with an automatic cross-sectional movement in Y, where 11 measurements were carried out next to the region of the indentation center from one edge to the other, in order to build a 3D image, as Fig. 1. Through the analysis of these images, the true indentation edge center was identified. At this position, 10 repeated measurements were carried out in order to get a good repeatability.

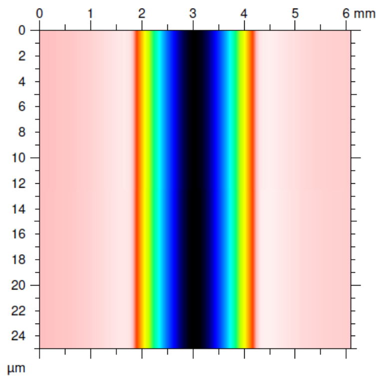
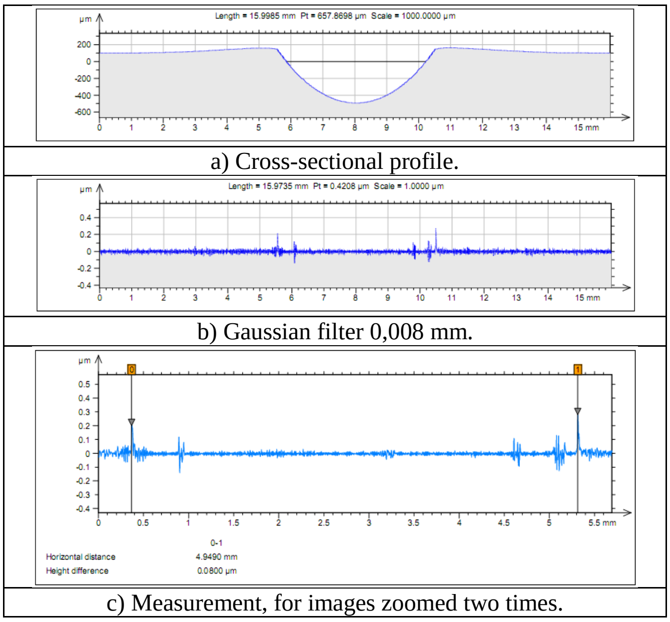


Fig. 1. Example of a 3D image of the central region of an indentation obtained with a profilometer system.

It was used the Talymap Gold software to analyse the diameter measurements, which used a waviness and roughness Gauss filter with 0,0025 mm for the smaller indents (2,5/187,5), and a filter with 0,0080 mm for the bigger ones (10/3000), where the images were zoomed two times in order to make possible the indentation readings [9].

In Fig. 2 is it possible to see an example of the Brinell profile indent obtained by the cross-sectional profilometer system, where the indentation edges were determined through the point of the maximum change in slope after the indent profile determination (Fig. 2.c)).



a) Cross-sectional profile.

b) Gaussian filter 0,008 mm.

c) Measurement, for images zoomed two times.

Fig. 2. Analysis of a 10/3000 Brinell indent by the Talymap software.

Despite the time consuming for the measurements by using this system, it was quite easy to select the profile that identified the indentation contact edge, e. g., from the 10/3000 Brinell indent. The sequence for this identification was done like in the Fig. 2, where the Fig. 2.a) is the raw Brinell indent profile, following by Fig. 2.b) that is the profile slope after the Gaussian filter, and then the Fig. 2.c), where, normally, the slope drop occurs, that means, at the maximum peak. The Fig. 3 is showing an example of this peak after it zoomed.

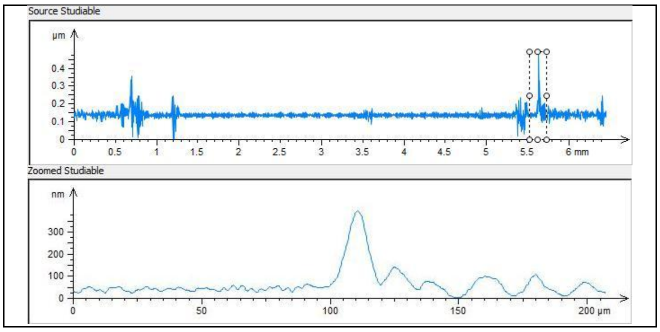


Fig. 3. Example of a profile peak, characteristic of the Brinell indentation edge, made by the Talymap Gold software.

2.2. Image analysis method – INMETRO's system

One of the non-contact methods used in this comparison was the current image analysis system installed at the INMETRO's hardness laboratory (Galileo Galvision - LTF S.p.A., Italy). This system carries out automatic measurements through direct and the indirect procedure. In the present work it was used the indirect procedure for the Brinell indentation measurements.

The operation mode of this system is done through the use of an LVDT (Linear Variable Differential Transformer), a Charge Coupled Device (CCD) video camera and a set of 5 objective-lenses of a microscope. In general, this image analysis system shows some dependency of the light beam and of the surface focus. The lenses have, respectively, the following magnifications and numerical apertures (N.A.): 2,5X/0,07; 5X/0,12; 10X/0,25; 20X/0,40 and 50X/0,75.

A 10X lens magnification with its 0,25 numerical aperture was the one selected for the smaller indents (spherical indenter of 2,5 mm and applied force of 187,5 kgf). The ratio 2,5X/0,07 was selected for the bigger indents (spherical indenters of 5 mm-10 mm and applied forces of 750 kgf-3000 kgf).

2.3. Image processing method – developed system

The use of the image processing method, developed at INMETRO, had two goals. One was the participation on the comparison for the Brinell edge identification itself, and the other was its characterization for future use at INMETRO's hardness laboratory.

This measurement system has a microscope with magnification up to 500X, a video camera for scanning the images, and a table of linear displacement with a displacement transducer coupled.

In order to determine the indentation diameters, images of the indent edges were captured by shifting the microscope table up to each end of the indent, observed through the video camera.

The indentation ends on the images are identified automatically by using an edge detection algorithm called "*CannyMethod*" [10]. After the determination of the points of the indentation ends, in pixel, it is used a mathematical model that associates the pixel coordinates to the lengths measured by the LVDT [11].

Through this method, the Brinell hardness values were obtained by averaging five runs of an image processed**.** An example of an image processed by this method can be seen in Fig. 4.

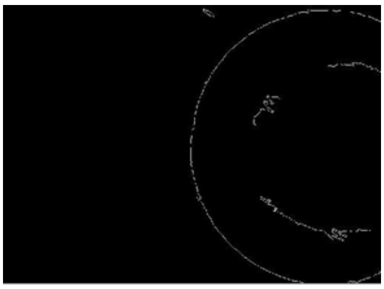


Fig. 4. Example of a 2,5/187,5 Brinell indentation image after its edge enhancement.

3. DISCUSSIONS AND CONCLUSIONS

This comparison took as consideration the own methodologies for each measurement system to determine four different Brinell diameters, built by the following ratio of sphere indenter/applied force: 2,5/187,5; 5/750; 10/1000 and 10/3000.

From Table 1 to Table 3 it is possible to see the obtained values for the three systems and their respective expanded uncertainties (*U*). The high precision profilometer was considered the reference system. It was compared against the Galvision measuring system and against the images processed, which is an in house developed system.

The values obtained during this comparison for the image processing system, were also considered for its characterization for future uses at the INMETRO's hardness Laboratory.

Table 1. Brinell diameter values obtained by the profilometer reference system.

Hardness block # / Ratio of indents	**Brinell diameters**	
	Profilometer (mm)	*U* (mm)
BD005 / 2,5/187,5	0,699	0,001
BD200 / 5/750	1,371	0,001
BD203 / 10/1000	2,543	0,001
BD199 / 10/3000	4,980	0,001

Table 2. Brinell diameter values obtained by the Inmetro's system.

Hardness block # / Ratio of indents	**Brinell diameters**	
	Galvison (mm)	*U* (mm)
BD005 / 2,5/187,5	0,686	0,040
BD200 / 5/750	1,378	0,080
BD203 / 10/1000	2,566	0,080
BD199 / 10/3000	4,960	0,260

Table 3. Brinell diameter values obtained by the in house developed system.

Hardness block # / Ratio of indents	**Brinell diameters**	
	Image processing (mm)	*U* (mm)
BD005 / 2,5/187,5	0,686	0,040
BD200 / 5/750	1,374	0,080
BD203 / 10/1000	2,571	0,080
BD199 / 10/3000	5,060	0,260

The Table 4 is showing the differences, in mm and in %, among the reference values and the other two measurement systems. It is possible to notice in this table, the good compromise among the diameters measuring systems used in this work. As example, is possible to see in this table the difference on the indents determination made by the ratio 5/750, which for the reference measuring system and the Galvision measuring system was 0,0070 mm, while for the image processing method the difference was only 0,0030 mm. Similar analysis can be done for the other ratios, e.g. 10/3000, providing in this way, a good compromise among the systems, including the developed method, no matter the size of the indents.

Table 4. Difference among the reference system, the current INMETRO's system (Galvision) and the in house developed system (image processing).

Hardness block # / Ratio of indents	Method		Method	
	Galvision	Image processing	Galvision	Image processing
	Difference from reference (mm)		Difference from reference (%)	
BD005 / 2,5/187,5	0,013	0,013	1,860	1,860
BD200 / 5/750	0,007	0,003	0,511	0,219
BD203 / 10/1000	0,023	0,028	0,904	1,101
BD199 / 10/3000	0,020	0,080	0,402	1,606

The consistency among the three systems measurement is confirmed when their results are compared, by using the *E*n method, having as reference the profilometer system. It is possible to see in Table 5 and in Fig. 5 that all values came inside the *E*n tolerance (± 1), with very small differences among them and close to zero.

Table 5. *E*n values by comparing the reference system against the current INMETRO's system and the in house developed system.

Hardness block # / Ratio of indents	*E*n values	
	Galvison (mm)	Image processing (mm)
BD005 / 2,5/187,5	0,325	0,325
BD200 / 5/750	0,087	0,038
BD203 / 10/1000	0,287	0,350
BD199 / 10/3000	0,077	0,308

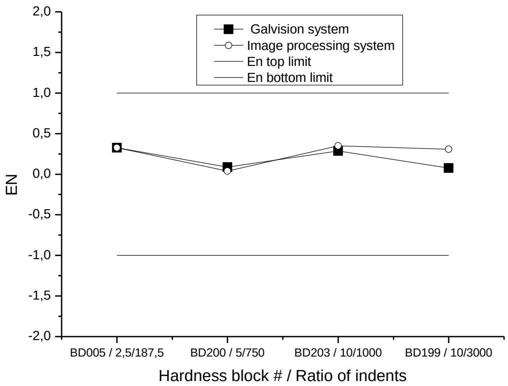


Fig. 5. Graphic representing the *E*n values due to the comparison of the reference system against the INMETRO's system and against the in house developed system.

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