INFLUENCE OF DIFFERENT NUMERICAL APERTURES ON HARDNESS VALUES USING AN AUTOMATIC SYSTEM OF MEASUREMENT

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Abstract – The objective of this work is to analyse and discuss the influence of the use of different numerical apertures (NA) and its magnification on the measurement of indentations on Vickers (HV) and Brinell (HB) hardness blocks previously certified. It was used a new reference Vickers and Brinell measurement system, recently installed and qualified at the Brazilian National Metrology Institute (Inmetro) by the National Institute of Metrological Research (iNRiM/Italy) [1].

The system used was a Galileo Galvision (LTF S.p.A., Italy) that carries out automatic measurements throughout two methods, the direct and the indirect ones. In the present work both direct and indirect methods were used.

In general, the 10x lens magnification and its 0,25 numerical aperture yielded the acceptable normalized error (E_n) for almost all HV and HB indentation measurements done, no matter the method used.

As reference values six certified blocks in three levels of hardness were studied, e.g. blocks of low, medium and high hardness values. Among them, the lowest range of Vickers hardness provided the better normalized error. The same results were obtained by analyzing the highest range of Brinell hardness, no matter the method used.

Keywords: Hardness, Indentation, Numerical Aperture.

1. INTRODUCTION

In the last decades image analysis systems have become widely used to measure Vickers and Brinell indentations. The dedicated methods can provide better results if one compare with the stage micrometers conventionally used, not considering the operator influence anymore, once the image analysis technique uses computer software and a camera to determine automatically the size of the indentations.

In the conventional method the operator must determine by a microscope's ocular where the edge of the indentation is. This human interaction can yield different results from one individual to another, considering e.g., the focus adjustment [2].

Nevertheless, automatic measurements do not provide always perfect results, some errors associated with the image system also can occur [3]. Normally, the automatic methods determine the edge of the indentations by capturing the image throughout the shade of light and dark. If the line

definition is not well determined, due to any scratch made by the poor surface finishing or due to phenomena like pile-ups or sink-ins, the computer may assume an incorrect edge.

For one side, the automatic mode/direct method used in this work, do not allows all kinds of indentation measurements, because it uses a "picture" of an indentation to make a measurement, so it's limited by the ratio of the window software size and the indentation size. However, good results were obtained by this method if one compares the uncertainty obtained in this study with those declared on the reference values certificates.

For another side, the automatic mode/indirect method, allows in theory, any kind of indentation measurement, because it uses a Linear Variable Displacement Transducer (LVDT) and the edge of the indentation to measure the diagonal of Vickers hardness and the diameter of Brinell hardness. Thus, it does not depend on the computer screen. However, in some situations, it was not possible to determine the hardness values for very small indentations, probably due to some limitation regarded to the size of the indentations and their respective measurements made by the computer software as a consequence of the lower magnification/NA lenses considered [4].

In general, for both direct and indirect methods, the 10x lens magnification and its 0,25 numerical aperture yield acceptable normalized errors, $E_n<|1|$, according to the reference hardness values. This seems to be derived from the fact that the numerical apertures 0,25 presented the most suitable parameters to furnish the best Vickers and Brinell hardness values for the hardness range studied.

Taking into consideration the non-uniformity of the blocks obtained by the two methods, the lens magnification of 10x and the numerical aperture of 0,25 also provided good results for almost all HV measurements [5]. Nevertheless, in spite of the set 10x/0,25 had provided good E_n results for HB measurements, if one considered only the non-uniformity values, it was not possible to attain a good lens magnification/NA set as was made for HV [6].

2. MATERIALS AND METHODS

It was used an automatic image analysis system, the Galileo Galvision, to make the measurements. This system operates by using an LVDT, a Charge Coupled Device (CCD) video camera and a set of 5 objective-lenses of the microscope. In general, the analysis shows some

dependency on both the light beam and the surface focus. These lenses have characteristic magnifications and numerical apertures (NA), respectively, of the following relations: 2,5x/0,07; 5x/0,12; 10x/0,25; 20x/0,40 and 50x/0,75.

As reference values this work used 06 hardness blocks certified by different laboratories in Europe in the following ranges: 100 to 800 HV30 and 100 to 600 HBW2,5/187,5, where in each scale studied, three levels of hardness values were taken, e.g., low, medium and high ones. The ranges specified in this study were those most demanded in Brazil for Vickers and Brinell hardness [7].

In unused blocks it were made five indentations on each of them which were analysed individually by each cited lens magnification and its associated NA.

Throughout this work two methods could be used, the direct and the indirect ones, both automatic.

The direct method follows the way of measurements where a CCD camera captures indentation images and they are analysed afterwards. This method is strictly dependent on the ratio of the image magnification, the size of the window software and the computer screen resolution, where the software looks four edges of the indentations for, necessarily included on the window in order to be possible making the readings.

The indirect method allows, in theory, any kind of indentation measurement. The measurements are made by using a CCD camera to visualize the indentations, an algorithm to determine its edges and an LVDT to make the length measurements of a relevant dimension (diagonal or diameter, depending on the hardness scale) by moving it from one edge to another. By using all above-mentioned devices, the software determines the apex of an indentation edge, move away the LVDT and the microscope table to the other indentation edge until meeting the other apex and a consequent reading is made and computed. Next, it's necessary to turn the microscope table in 90º in order to make the reading of the other length following the procedure just described, up to complete the full measurement procedure.

The normalized error (E_n) method was used to analyse the results (1). It's a very efficient statistic tool to compare a reference value against measured values providing easy understandable information about the acceptance of a measurand [8].

$$E_n = \frac{x - X}{\sqrt{\left(U_{lab}\right)^2 + \left(U_{ref}\right)^2}} \qquad (1)$$

where:

x – is the measured value.
X – is the reference value of the hardness block.
U_{lab} – is the measured uncertainty.
U_{ref} – is the uncertainty of the reference hardness block.

3. RESULTS AND DISCUSSIONS

3.1. Vickers indentations

The Tables I and II show Vickers hardness block data taken as reference (Ref.) values and the obtained hardness values with the respective measured uncertainty (U_{lab}) and E_n, both in absolute values, using three sets of lenses. The Table I show the measurements done by the automatic mode/indirect method, whereas the Table II shows the values obtained by the automatic mode/direct method.

TABLE I. Vickers hardness results (HV30) and a comparison with three reference blocks BP268, BP238 and BP239 measured by the automatic mode/<u>indirect method</u>

Mag./NA	10x/0,25	20x/0,40	50x/0,75
Ref. value	BP268 (134,80 ± 2,00) HV30		
Results	134,91	131,72	136,31
U_{lab} (abs.)	2,66	2,17	3,34
E_n	0,033	0,31	0,39
Ref. value	BP238 (453,90 ± 6,20) HV30		
Results	455,92	457,97	460,27
U_{lab} (abs.)	5,65	4,21	6,86
E_n	0,24	0,54	0,69
Ref. value	BP239 (851,10 ± 11,40) HV30		
Results	868,89	877,70	875,40
U_{lab} (abs.)	15,81	13,87	11,47
E_n	0,91	1,48	1,50

TABLE II. Vickers hardness results (HV30) and a comparison with three reference blocks BP268, BP238 and BP239 measured by the automatic mode/<u>direct method</u>

Mag./NA	5x/0,12	10x/0,25	20x/0,40
Ref. value	BP268 (134,80 ± 2,00) HV30		
Results	134,75	135,38	"extrapolated"
U_{lab} (abs.)	0,080	0,040	---
E_n	-0,023	0,29	"extrapolated"
Ref. value	BP238 (453,90 ± 6,20) HV30		
Results	428,09	457,97	461,30
U_{lab} (abs.)	1,28	0,20	0,13
E_n	-4,08	0,66	1,19
Ref. value	BP239 (851,10 ± 11,40) HV30		
Results	814,81	865,08	875,37
U_{lab} (abs.)	3,19	1,00	0,48
E_n	-3,07	1,22	2,13

From these values, it's possible to infer that the lens magnification of 10x with 0,25 of NA yields an acceptable measurement and the minor normalized error among the other lens results also acceptable, as emphasized in Fig. 1 and Fig. 2. These figures show the graphic of the normalized error (E_n) versus the magnification/numerical aperture (Mag./NA) using the indirect and direct methods of measurement of Vickers hardness, respectively.
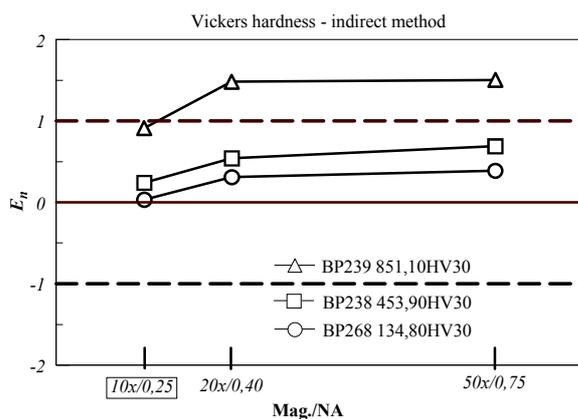
Fig. 1. E_n x Mag./NA graphic of Vickers hardness results by indirect method
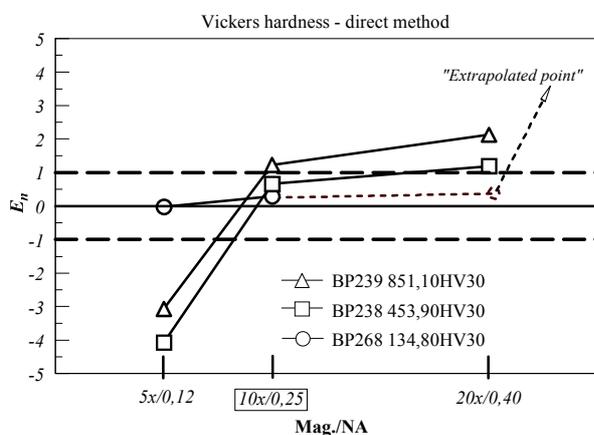

Fig. 2. E_n x Mag./NA graphic of Vickers hardness results by direct method

It's also interesting to point-out that, according to the Tables I and II and the Fig. 1 and Fig. 2, the normalized error increased (in modulus) as the set of lens magnification/numerical aperture was increased.

3.2. Brinell indentations

Similar analysis can also be done for the Brinell hardness blocks, see Tables III and IV, where it can be seen the provided Brinell hardness block data taken as reference values and the obtained hardness values with the respective U_{lab} and E_n, in absolute values, using three sets of lenses in the automatic mode by indirect method and by direct method, respectively.

TABLE III. Brinell hardness results (HBW2,5/187,5) and a comparison with three reference blocks BP227, BP196 and BP229 measured by the automatic mode/<u>indirect method</u>

Mag./NA	2,5x/0,07	5x/0,12	10x/0,25
Ref. value	BP227 (135,10 ± 2,10) HBW2,5/187,5		
Results	120,63	126,78	134,72
U_{lab} (abs.)	3,79	3,12	3,41
E_n	-3,34	-2,21	-0,095
Ref. value	BP196 (338,00 ± 2,00) HBW2,5/187,5		
Results	318,85	332,89	336,64
U_{lab} (abs.)	13,52	8,26	7,81
E_n	-1,40	-0,60	-0,17
Ref. value	BP229 (595,90 ± 7,90) HBW2,5/187,5		
Results	583,81	591,99	604,11
U_{lab} (abs.)	11,91	12,49	12,32
E_n	-0,85	-0,26	0,56

TABLE IV. Brinell hardness results (HBW2,5/187,5) and a comparison with three reference blocks BP227, BP196 and BP229 measured by the automatic mode/<u>direct method</u>

Mag./NA	2,5x/0,07	5x/0,12	10x/0,25
Ref. value	BP227 (135,10 ± 2,10) HBW2,5/187,5		
Results	123,28	128,93	"extrapolated"
U_{lab} (abs.)	4,05	2,97	---
E_n	-2,59	-1,70	"extrapolated"
Ref. value	BP196 (338,00 ± 2,00) HBW2,5/187,5		
Results	325,54	332,34	337,06
U_{lab} (abs.)	6,87	6,69	6,78
E_n	-1,74	-0,81	-0,13
Ref. value	BP229 (595,90 ± 7,90) HBW2,5/187,5		
Results	591,91	598,31	606,77
U_{lab} (abs.)	12,07	12,62	12,38
E_n	-0,28	0,16	0,74

It's also possible to see in this case that the set of lens/NA 10x/2,5 provided the best E_n in the studied situations of this work according to the results presented in the Table III and Table IV.

However, having in mind the global analysis, an opposite situation occurred for the Brinell measurements results, that means, the normalized error decreased (in modulus) as well as the set of lens magnification/numerical aperture was increased, Fig. 3 and Fig. 4, respectively, for the indirect method and direct methods.
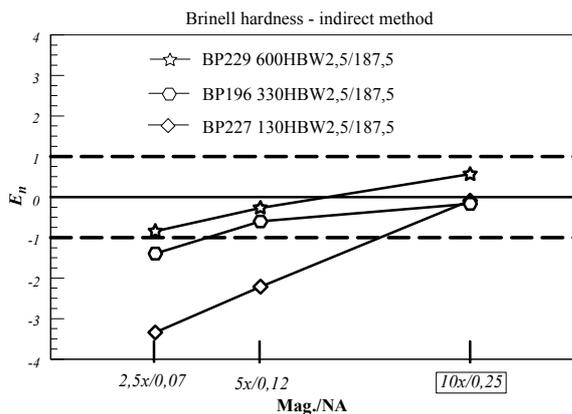
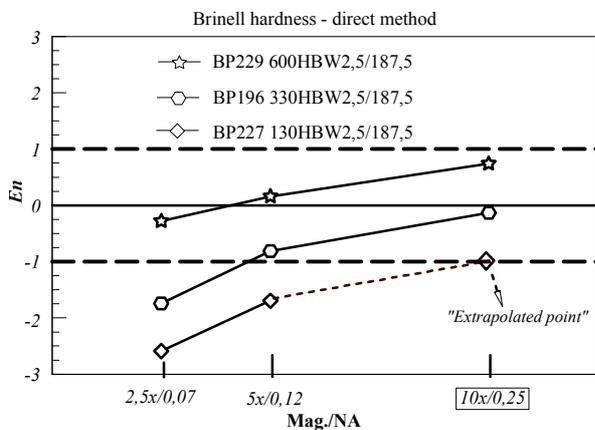Fig. 3. E_n x Mag./NA graphic of Brinell hardness results by indirect method

Fig. 4. E_n x Mag./NA graphic of Brinell hardness results by direct method

2.1. Vickers and Brinell indentations analysis

Only to illustrate, the Fig. 5 shows the general curves for both, Vickers and Brinell results considering the length of the indentations, d (diameter and diagonal), versus E_n measured by the indirect method.
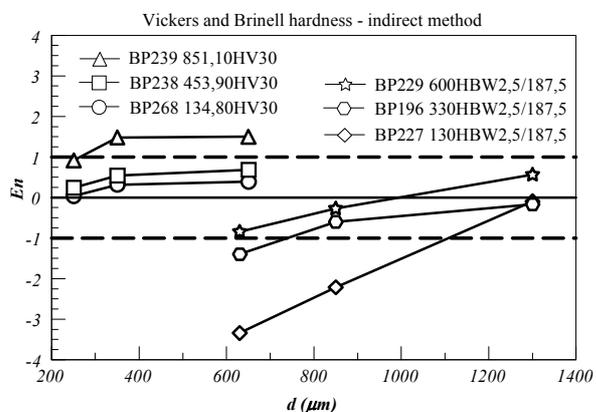

Fig. 5. E_n x Mag./NA graphic of Brinell hardness results by direct method

In the Fig. 5 is possible to see that the slope of the curves are similar but opposite between them. That means, in the sense of the good E_n values started with the lower d for Vickers, for the Brinell case, the good E_n values finished with the highest d.

4. CONCLUSION

This work dealt with the use of different objective-lenses magnifications and numerical apertures in terms of comparison of indirect and direct methods of measuring Vickers and Brinell indentations in the automatic mode of the a new reference Vickers and Brinell measurement system, installed at the Brazilian National Metrology Institute. The main conclusions were:

- By using the normalized error E_n approach, which, in turn, used the attributed reference and measured hardness values, respectively, the Vickers hardness results showed, among the three sets of magnification/numerical aperture lenses, the 10x/0,25 one had the lower (in modulus) E_n. Doing the same analysis for the Brinell tests again the 10x/0,25 lens provided the best results.

- For Vickers, the normalized error increased (in modulus) as the set of lens magnification/numerical aperture was increased, in opposition to the Brinell results.

- The indentations analysis showed that for Vickers ones the 10x/0,25 lens were nearly all the time the first set of applicable lenses whereas for Brinell ones in all situations the mentioned lens appeared as the last in the set of applicable lenses.

- In all situations studied in this work (indirect and direct methods, Vickers and Brinell hardness scales) the 10x/0,25 lens set was the only one where all used hardness blocks lied in the tolerance limits established for this work (± 1).

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