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ESTABLISHMENT OF BRINELL AND VICKERS HARDNESS SCALES AT UME

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Abstract – In this study the results of working on establishment of Brinell and Vickers hardness standards in UME Hardness Laboratory, made for several years, are presented. Brinell and Vickers hardness scales which had been aimed have been completed. Direct and indirect calibrations of the systems in accordance with ISO 6506-3[3] and ISO 6507-3[5] were made and good results were obtained. For the indirect calibration of the systems, hardness reference blocks calibrated by PTB (National Metrology Institute of Germany) were used. In addition, Brinell and Vickers Hardness Standard Systems of UME Hardness Laboratory are introduced and their performance results are interpreted.

Keywords: hardness standard machine, calibration, Brinell, Vickers.

1. INTRODUCTION

It has been worked on hardness measurements and establishment of hardness standards at UME Hardness Laboratory for several years. Under these circumstances, some scales of Brinell and Vickers Hardness on the same machine and some other scales on different machines were realized in accordance with EN ISO Hardness Standards [2,3,4,5]. For realization of the whole scales three machines are used: One machine for high load Brinell scales, one machine for low-force micro hardness scales and a third machine used in common for some Brinell and Vickers scales.

Now UME has one direct load application machine (dead weight type Brinell-Vickers Hardness Standard Machine, see Fig.1) to realize Brinell Scales from 5 kgf (49,03 N) to 250 kgf (2452 N) by making use of ball indenters with suitable diameters belonging to each of Brinell scale, and Vickers scales starting from 5 kgf (49,03 N) up to 100 (980,7 N) kgf by making use of a square based pyramid diamond indenter. In this machine only realization of indentations belonging to the Brinell and Vickers scales mentioned above is performed. Some of the force steps are used in common for Brinell and Vickers, so just the indenters are replaced to change the hardness scales.

A different system is used to realize Vickers low-force and micro hardness measurements. This small machine is also dead weight type machine and is capable of applying forces from 50 gf (4,903 N) up to 2 kgf (19,61 N). By this machine not only realization of indentation but also measurement of diagonal length of square shaped indentations is possible.

Recently a material testing machine (MTM) of Material Testing Laboratory (MTL) of UME was characterised to investigate its ability to extend our Brinell scale up to 3000 kgf (29420 N). At the end we have established Brinell scales from 500 kgf (4903 N) to 3000 (29420 N) kgf by making use of this machine.

So far I have dealt with realization of indentation systems. The last but not the least important system is the indentation measurement system. To measure the size of indentation (diameter of circular shaped indentation for Brinell and diagonal length of square shaped indentation for Vickers scales) we have two indentation measurement systems.

All machines are automatic and computer controlled. All machines have the ability to change load application time and dwell time in measurements and speed of load application and indenter approach, force (scale) selection and application.

2. BRINELL HARDNESS SCALES

At the beginning it was decided to establish Brinell scales with forces from 5 kgf (49,03 N) to 250 kgf (2452 N). It has been attained the aim by establishment of Brinell-Vickers HSM (Hardness Standard Machine). Later it was decided to investigate the possibility to extend the range to 3000 kgf by making use of a material testing machine of Material Testing Laboratory. It was made the calibration of force application system of the MTM and obtained the results within $1x10^{-3}$ which is a requirement of ISO 6506-3[3] for hardness reference block calibration. As a result Brinell indentations are realized by two machines: Up to 250 kgf (2452 N) by dead weight type Brinell-Vickers HSM and from 500 kgf (4903 N) up to 3000 kgf (29420 N) by a servo motor controlled MTM are used.

It was requested to realize as many scales as possible in Brinell and Vickers hardness. The scales realized by both machines by making use of suitable tungsten carbide ball indenters are given in Table 1.

Fig. 1. Dead Weight Brinell-Vickers HSM

Table 1. Brinell Hardness Scales Established On One Dead Weight And One Servomotor Controlled Machines

Hardness scale (HBW)	Force (N)
HBW1/5	49,03
HBW1/10	98,07
HBW2,5/15,625	153,2
HBW5/25	245,2
HBW1/30	294,2
HBW2,5/31,25	306,5
HBW2,5/62,5	612,9
HBW5/62,5	612,9
HBW10/100	980,7
HBW5/125	1226
HBW2,5/187,5	1839
HBW10/250	2452
HBW5/250	2452
HBW10/500	4903
HBW5/750	7355
HBW10/1000	9807
HBW10/1500	14710
HBW10/3000	29420

3. VICKERS HARDNESS SCALES

Vickers Hardness scales at UME are realized by two machines: The first one is the Brinell-Vickers HSM which is mentioned above. In this machine some mass stacks are used in common with Brinell, and there are some extra mass stacks belonging to Vickers scales. It just replaces the Brinell indenters by Vickers diamond indenter and made use of the same system and software to perform the testing cycle. From 5 kgf (49,03 N) up to 100 kgf (980,7 N) forces are realized by Brinell-Vickers HSM. The second machine, used to realize low-force and Microvickers scales, is the dead weight type Microvickers Hardness Calibration Machine (see Fig 2). In this machine forces from 50 gf (4,903 N) up to 2 kgf (19,61 N) are applied by mass stacks. The scales realized in Vickers Hardness by making use of the two dead weight machines are given in Table 2.

Table 2. Vickers Hardness Scales Established On Two Different Dead Weight Machines

Hardness scale (HV)	Force (N)
HV0,05	0,4903
HV0,1	0,9807
HV0,2	1,961
HV0,3	2,942
HV0,5	4,903
HV1	9,807
HV2	19,61
HV5	49,03
HV10	98,07
HV20	196,1
HV30	294,2
HV50	490,3
HV100	980,7

Fig. 2 Microvickers Hardness Calibration Machine

4. DIRECT CALIBRATION

4.1. Calibration Of Force - Verification Of Testing Cycle

In the Brinell-Vickers Hardness Standard Machine the force is applied by dead weights calibrated at UME Mass Laboratory at $1x10^{-5}$ level of uncertainty. Force application is automatically controlled by a servo motor. Since the mass stacks are applied by a frame hanged to a load cell, the load application and dwell times in Brinell and Vickers scales can be controlled. Indenter approach and load application speeds are also controlled by the servo motor and variable. Forces higher than 250 kgf (2452 N) are applied in the material testing machine and the testing cycle is also possible with control of the servo motor and a reference load cell. The low-force and Microvickers forces are calibrated with a mass comparator and all forces are obtained within $1x10^{-3}$.

4.2. Indenters

Tungsten carbide ball indenters in accordance with EN ISO 6506-3 standards[3] are used. The indenters are 1 mm, 2,5 mm, 5 mm and 10 mm ball indenters all calibrated at UME. For Vickers we use square based pyramid diamond indenters calibrated by INRIM (National Metrology Institute of Italy) according to EN ISO 6507-3.

4.3. Indentation Measurement Systems

Hardness measurement comprises two main steps: One is realization of indentation and the second one is measurement of the size of the indentation. Besides the realization of indentation the size of indentation is measured with two systems, each system consisting a microscope to magnify the little indentation, a CCD camera to transfer magnified indentations to a screen of a PC and a measuring software to measure the size of indentation. One of the systems is an independent indentation measuring one with a motorized platform having the possibility to measure indentations automatically and manually. All possible indentations (any size) can be realized by Hardness Standard Machine both in Brinell and Vickers hardness scales can be measured by making use of this system (see Fig. 3). The lenses present in this system are 2,5X, 5X, 10X, 20X, 50X.

The second system is mounted on to the Microvickers Hardness Calibration Machine and originally used for measurement of microvickers indentations, but available for Vickers indentations as well. The lenses present on this system are 10X, 50X and 100X. This system can perform only manual measurements and measurement of indentations with diagonals up to 1 mm length can be done.

Fig. 3. Indentation Measurement System

Calibrations of both systems for the lenses used were made with a calibrated line scale having an uncertainty 0,04 µm. The results were consistent with related ISO Hardness Standards Part-3[3,5]. Some calibration results of both indentation measurement systems are given in Fig. 4 to 9.

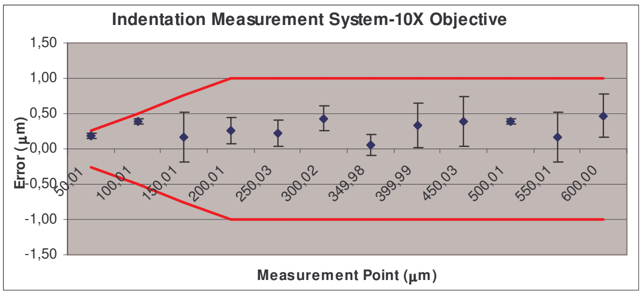

Fig. 4. Microvickers Indentation Measurement Sys.-10X Lens

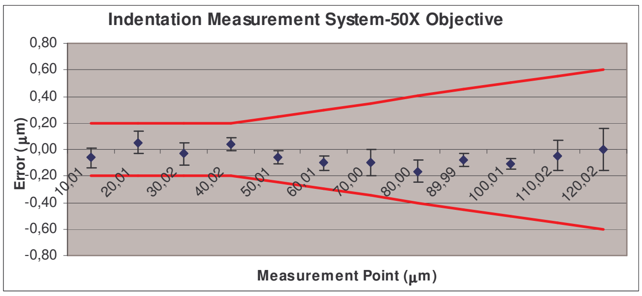

Fig. 5. Microvickers Indentation Measurement Sys.-50X Lens

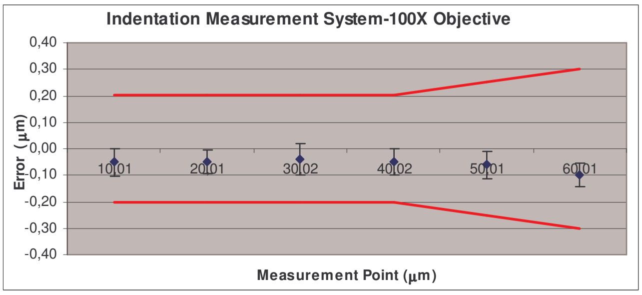

Fig. 6. Microvickers Indentation Measurement Sys.-100X Lens

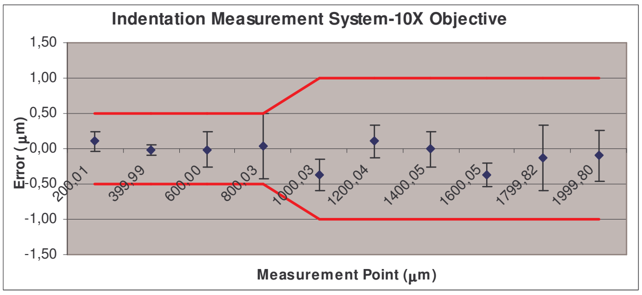

Fig. 7. UME Indentation Measurement Sys.-10X Lens

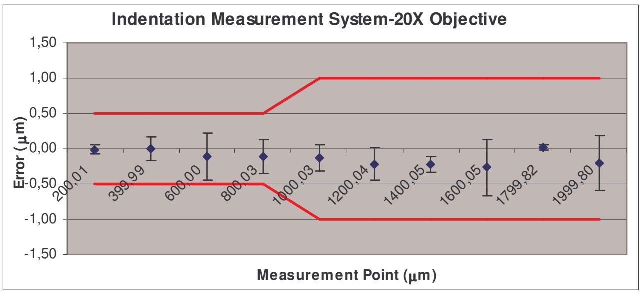

Fig. 8. UME Indentation Measurement Sys.-20X Lens

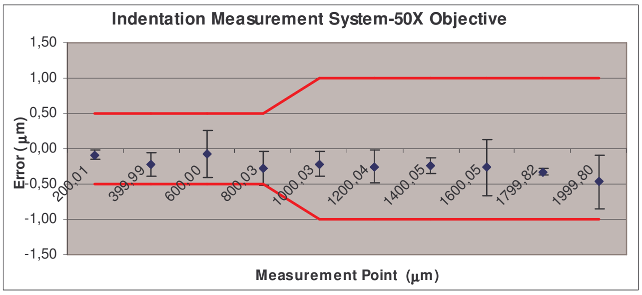

Fig. 9. UME Indentation Measurement Sys.-50X Lens

It can be seen from measurement results all lenses of both systems are in accordance with ISO Part-3[3,5] specifications.

5. INDIRECT CALIBRATION

After calibration/verification of each component constituting a hardness scale, the hardness machine should be checked by hardness reference blocks to figure out its performance including non-measurable effects. We have calibrated a set of hardness reference blocks at PTB. We made measurements of the same blocks with UME Brinell and Vickers hardness standard systems. We compared the measurement results with certificate values of the blocks and we saw a significant consistency between the results. The results were compared by including the uncertainties via the E_n formula given below (see [1]).

$$E_n = \frac{|H_{PTB} - H_{UME}|}{\sqrt{U_{PTB}^2 + U_{UME}^2}} \quad (1)$$

Here H_{PTB} and H_{UME} are the hardness measurements, U_{PTB} and U_{UME} are the uncertainties belonging to PTB and UME, respectively. E_n calculated for every block and the achievement results are obtained as $E_n \leq 1$ for each block, as given in Table 3.

Table 3. Vickers Hardness Scales Established On Two Different Dead Weight Machines

Scale	H_{PTB}	H_{UME}	U_{PTB}	U_{UME}	E_n
HV0,1	198,4	201,2	7,8	9,9	-0,2
	622,6	634,0	33,6	51,0	-0,2
	829,9	858,7	50,3	83,2	-0,3
HV1	100,8	100,6	1,3	1,4	0,1
	509,4	508,6	10,5	13,8	0,0
	945,3	923,8	23,1	30,1	0,6
HV10	104,0	103,7	0,9	0,6	0,3
	509,4	507,3	5,0	3,1	0,4
	905,6	906,7	10,6	8,9	-0,1
HV30	103,7	103,3	0,9	0,8	0,3
	506,5	507,3	4,7	4,9	-0,1
	895,9	901,6	8,7	8,2	-0,5
HBW 2,5/62,5	97,6	98,4	1,0	0,8	-0,6
	334,0	334,4	2,5	2,1	-0,1
	530,0	532,9	3,3	3,3	-0,6
HBW 2,5/187,5	171,5	173,0	1,2	0,8	-1,0
	346,2	347,4	2,8	1,3	-0,4
	530,1	527,5	5,0	3,1	0,4
HBW 10/3000	153,9	153,9	1,2	0,8	0,0
	533,1	533,4	3,4	1,7	-0,1

The uncertainties of measurements were calculated by using EA Guidelines on the Estimation of Uncertainty in Hardness Measurement (EA – 10/16) [1]. The graphical views of the results for some scales all together are given in Fig. 10 to 16.

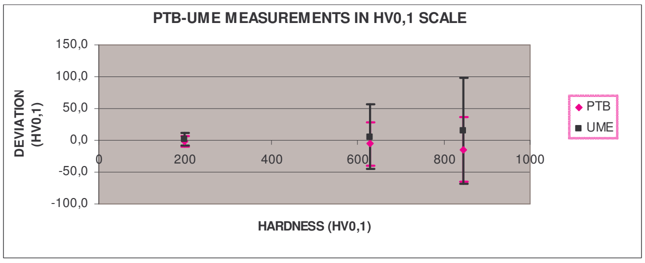

Fig. 10. Hardness Reference Blocks Measurements For HV0,1

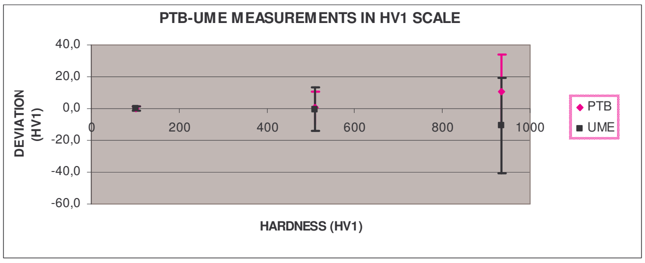

Fig. 11. Hardness Reference Blocks Measurements For HV1

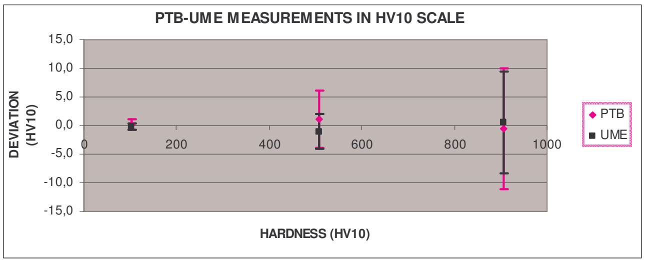

Fig. 12. Hardness Reference Blocks Measurements For HV10

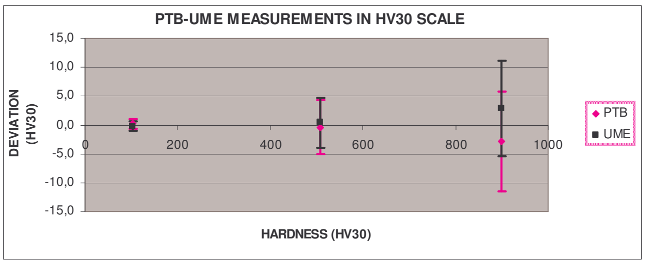

Fig. 13. Hardness Reference Blocks Measurements For HV30

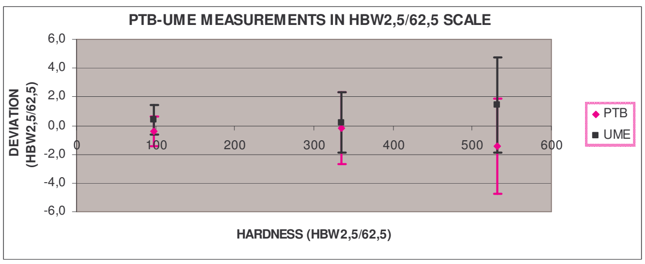

Fig. 14. Hardness Reference Blocks Measurements For HBW2,5/62,5

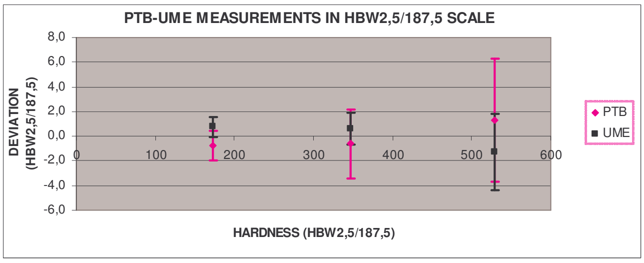

Fig. 15. Hardness Reference Blocks Measurements For HBW2,5/187,5

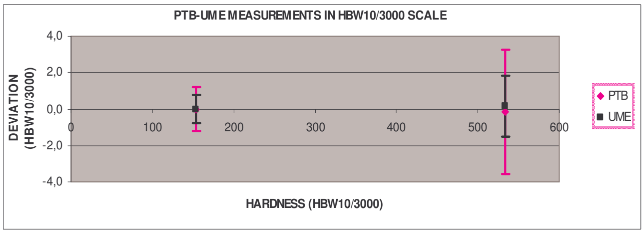

Fig. 16. Hardness Reference Blocks Measurements For HBW10/3000

6. UNCERTAINTY CALCULATIONS

Measurement uncertainty of the hardness standards is estimated in accordance with EA/4-02 [6] and EA 10/16 [2]. The destination quantity hardness can be defined as a function of influencing parameters as follows:

$$H = f(x_1, x_2, \dots, x_N) \qquad (2)$$

where H is the hardness measured and $x_1, x_2, \dots, x_N$ are the influencing parameters. The sensitivity coefficients, c_i, can be determined by either partial derivation of the model function f or empirical investigation of the relationship $H = f(x_i)$. If the standard uncertainty of each parameter, $u(x_i)$, then contribution of each parameter is calculated by,

$$u_i(H) = c_i u(x_i) \qquad (3)$$

The combined standard uncertainty is calculated by:

$$u^2(H) = \sum_{i=1}^{N} u_i^2(H) \qquad (4)$$

At the end the expended uncertainty is calculated by:

$$U = ku(H) \qquad (5)$$

where k is the expansion factor. The influencing parameters for Brinell Hardness Standard Machine is given Table 4 and for Vickers Hardness Standard Machine is given in Table 5.

Once the uncertainty of the machine is calculated then the uncertainty of the blocks is calculated by taking the uncertainty of the machine and the standard deviation of the blocks into account as follows:

$$u(s_b) = \frac{t \times s_b}{\sqrt{5}} \qquad (6)$$

where $u(s_b)$ is uncertainty of the mean of 5 hardness measurement mae on the block and t is the coefficient coming from the Student-T for n=5. Then the combined uncertainty of the block is calculated by;

$$u_b = \sqrt{u_m^{\,2} + u(s_b)^2} \qquad (7)$$

where u_m is the uncertainty of the HSM and expended uncertainty of the block is,

$$U = k\, u_b \qquad (8)$$

Table 4. Influencing Parameters For Brinell Hardness Standard Machine

Test force, F
Indentation diameter, d
Indentation ball diameter, D
Test force application time, t_1
Test force duration time, t_2

Table 5. Influencing Parameters For Vickers Hardness Standard Machine

Test force, F
Indentation diagonal length, d
Plane angle of the indenter, α
Tip radius of the indenter, Δc
Length of the line of junction Δc

7. CONCLUSION

At the end of this study explained above it can inferred the following conclusions;

- UME has completed the establishment of Brinell and Vickers hardness scales.
- At the end of direct calibration of the machines, it was seen that all scales meet the EN ISO Hardness Standards Part:3 requirements.
- With the measurements done with hardness reference blocks calibrated by PTB we obtained good results.

ACKNOWLEDGEMENTS

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