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ESTABLISHMENT OF ROCKWELL HARDNESS SCALES AT UME

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Abstract: A dead weight type Rockwell Hardness Standard Machine with a laser interferometer optic system was established to provide traceability in the field of hardness measurement for Rockwell Hardness scales at UME (National Metrology Institute of Turkey). Traceability of each component constituting Rockwell scales such as force, depth measuring system and testing cycle to national standards was provided by direct calibration. To realize performance tests of the machine as a whole, hardness reference blocks calibrated by PTB were used. In this paper, Rockwell Hardness Standard Machine of TÜBİTAK UME Hardness Laboratory is introduced and its performance test results are interpreted.

Keywords: Rockwell, Hardness Standard Machine, Hardness

1. INTRODUCTION

With the demand of Turkish Industry a Rockwell hardness standard machine had been decided to be established to provide traceability in the field of Rockwell Hardness measurements.

In this project the force application system was decided to comprise mass stacks realizing force under the gravitational acceleration and a frame transferring this force to tip of the indenter. The frame was designed to apply 3 kgf and 10 kgf, separately, as the pre-load of Superficial Rockwell and Rockwell scales, respectively. The forces of all Rockwell scales are realized with 6 mass stacks and two additional preliminary loads provided by the frame connecting the masses to the indenter, including the indenter itself.

A laser interferometer optic system is integrated to the machine as an indentation depth measurement unit. The depth measurement system is composed of laser head, linear interferometer and suitable optics mounted on top of the indenter.

Testing cycle is managed by making use of a load cell to which the whole force application system is mounted. The force application durations are measured with the change in the force value of the load cell and Force-Time relation is recorded. Indenter approach and penetration speeds are measured by the laser system and Depth-Time information is taken from this system. Also the Force-Velocity relation is figured out by the information instantaneously taken from the laser and load cell equipments.

To realize performance of the machine as a whole, in which non-measurable parameters are also taken into consideration, hardness reference blocks calibrated by PTB were used. Hardness measurement results and calculated uncertainties were compared with blocks' certified values and uncertainties.

2. DESIGN OF THE MACHINE

It was planned to design the machine such that every component constituting Rockwell Hardness to be with highest accuracy and minimizing side effect during force application and depth of indentation measurement. Furthermore, all parameters affecting Rockwell hardness measurements were aimed to be controlled and adjusted by automation of the system.

2.1. Force Application System

To realize the force with the highest accuracy and stability, deadweight type application system design was preferred. Force application is composed of two steps: preload and additional load to attain a certain amount of total load. The force values are realized by 2 preloads and 6 additional mass stacks to cover all scales present in ISO 6508-1 [2] are given in Table1.

Table 1. Forces Generated by the Rockwell Machine

Pre-load (N)	Add. Load (N)	Tot. Load (N)	Hardness Scales
98.07 98.07 98.07	490.3 882.6 1373	588.4 980.7 1471	HRA, HRF, HRH HRB, HRD, HRE HRC, HRG, HRK
29.42 29.42 29.42	117.7 264.8 411.9	147.1 294.2 441.3	HR15N, HR15T HR30N, HR30T HR45N, HR45T

The smaller preload (29.42 N) is realized by making use of a hardened Aluminium frame. The 98.07 N preload is applied by mounting three masses, each having 7/3 kgf, to the three legs of the frame manually to make a total of 10 kgf preload. Beside these preloads, six mass stacks made up of AISI 304 stainless steel are added to the frame as additional loads. To prevent the frame from any pendulum and rotational motions during load application which will affect penetration performance of the indenter, it was guided by two air bearings at the two ends. One of the two airbearings is square and the other is cylindrical shaped, both are working with (4-6) bar air pressure. In Figure 1, the frame constituting the preloads and mass stacks constituting additional loads for HRC scale (1471 N) and air bearings are given.

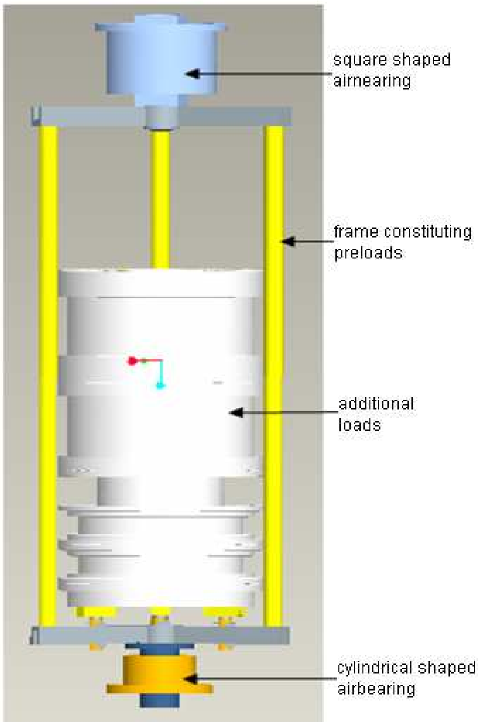

Fig. 1. The frame and masses of the machine for 1471 N

2.2. Indentation Measurement System

For indentation depth measurement, a laser interferometer optic system was equipped on to the machine. The laser head was placed on its original tripod holder near the machine, the linear interferometer is placed on an adjustable plate on the machine and a corner cube which is supposed to move as far as the indenter moves was placed on to the indenter and fastened to the indenter. By this manner, movement of the indenter is recorded by automation system of the machine and Depth–Time graph is plotted. Velocity of the indenter penetration is also taken from this system In Figure 2 indentation depth measurement principle is given.

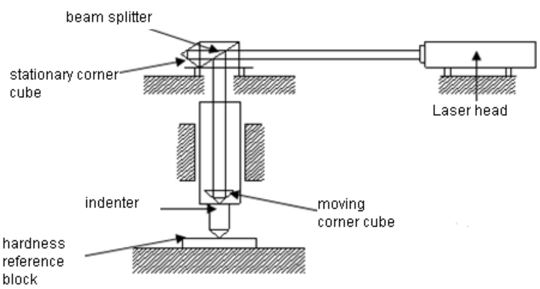

Fig. 2. Depth of Indentation Measurement Principle

With the laser system, movement of the indenter can be recorded and all information present in Figure 3 can be controlled. Here V represents velocity and T duration of the indenter movement.

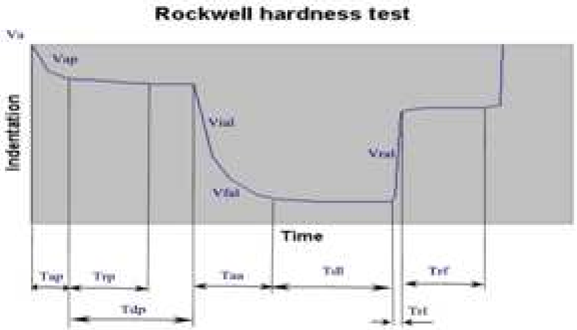

Fig. 3. Movement of the Indenter During Rockwell Test

2.3. Testing Cycle

Beside the force applied on the indenter and depth measurement, the cycle through which the test is realized is also critical and has effects on measurement results. For this reason, some velocities and durations should be controlled and standardized. To make such a control and an adjustment a load cell is equipped on to the machine and by making use of this load cell, force application times are recorded. Force–Time is matched with Velocity-Time which is taken from the laser system to figure out the Force-Velocity which is effective on the measurement result. In this way, one can check the final application velocity between 80% - 99% of the total force. With this force application manner it is possible to realize the testing cycle given in Figure 4.

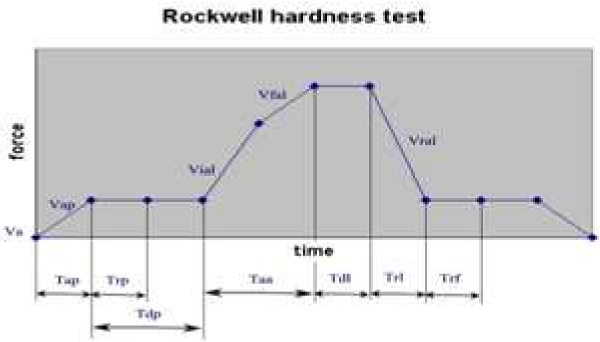

Fig. 4. Force-Time Graph Possible by the Machine

3. CALIBRATION OF THE MACHINE

3.1. Force Calibration – Testing Cycle Verification

Mass stacks used in Rockwell Hardness Standard Machine were calibrated at UME Mass Laboratory at $1x10^{-5}$ level of uncertainty. After mounting the machine the force at the tip of the indenter was checked by another load cell-indicator assembly.

Force application is automatically controlled by a servo motor. Since the mass stacks are applied by a frame hanged to a load cell as shown in Figure 5, the preload/load application and dwell times in Rockwell scales can be controlled. Indenter approach and load application speeds are also controlled by the servo motor and can be adjusted.

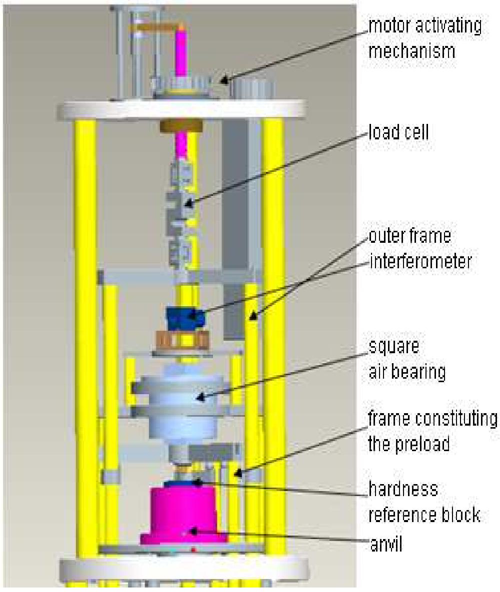

Fig. 5. Force Application System of the Machine

3.2. Indenters

Tungsten carbide ball and sphero-conical diamond indenters in accordance with EN ISO 6508-3 standard [4] were used. The ball indenters with 1,5875 mm and 3,175 mm diameter and sphero-conical diamond indenters were all calibrated at UME in accordance with EN ISO 6508-3.

3.3. Depth Measurement System

In Rockwell method hardness is determined by measurement of depth of indentation and it is realized with a laser interferometer optic system. For calibration of this assembly another laser interferometer optic system is used as a reference and by movement of the frame displacement of the indenter is recorded by the two lasers and compared.

3.4. Calibration By Hardness Reference Blocks

After calibration/verification of each component constituting Rockwell hardness scale, the hardness machine should be checked by hardness reference blocks to figure out its performance including non-measurable effects. A set of hardness reference blocks calibrated at PTB were used to check the performance of the machine. All measurements of the same set of blocks were made with UME Rockwell Hardness Standard Machine. Measurement results were compared 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.

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

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 were accepted for $E_n \leq 1$ for each block.

4. UNCERTAINTY CALCULATIONS

Measurement uncertainty of the hardness standards is estimated in accordance with EURAMET/cg-16/v.01:2007 [5]. The destination quantity hardness can be defined as a function of influencing parameters as follows:

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

where H is the hardness measured and $x_1, x_2, \ldots, x_N$ 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:

$$U = k.u(H) \qquad (5)$$

where k is the expansion factor.

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, u_b is combined uncertainty of the block.

E

xpended uncertainty of the block is,

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

5. CALIBRATION RESULTS

5.1. Force Calibration

Although the masses were calibrated at Mass Laboratory of UME, after mounting of the machine the force application system and testing cycle were calibrated by making use of a load cell-indicator assembly. The load cell was placed instead of the block and Rockwell tests for all scales were performed. Measurement results belonging for different forces are given below.

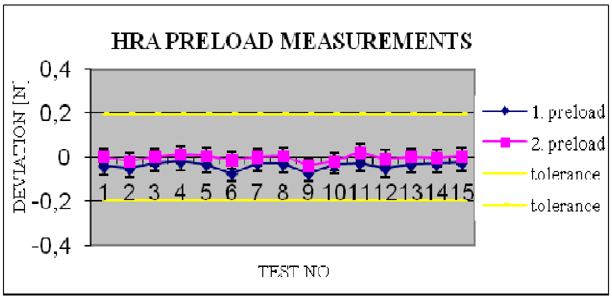

Fig. 6. Preloads Measurements for HRA Scale

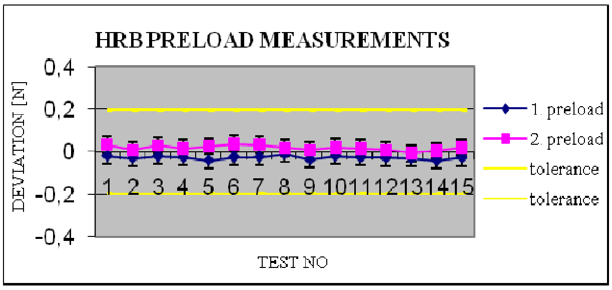

Fig. 7. Preloads Measurements for HRB Scale

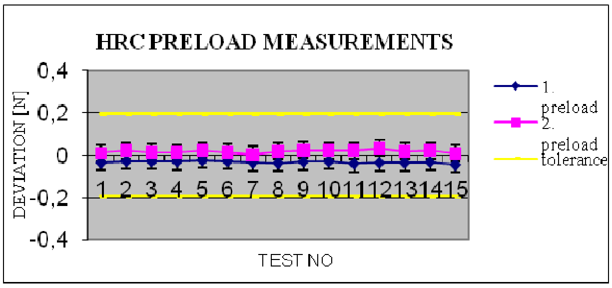

Fig. 8. Preloads Measurements for HRC Scale

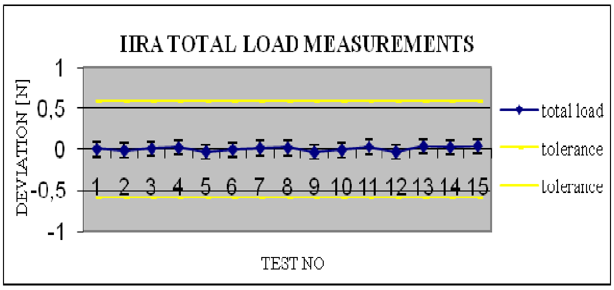

Fig. 9. Total Load Measurements for HRA Scale

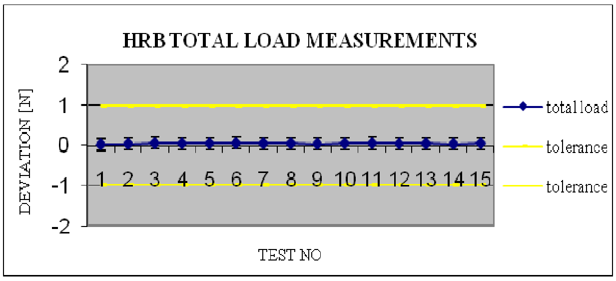

Fig. 10. Total Load Measurements for HRB Scale

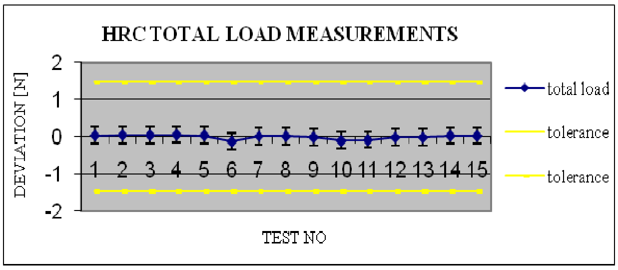

Fig. 11. Total Load Measurements for HRC Scale

5.2. Calibration by Hardness Reference Block

To see performance of the machine as a whole, a set of hardness reference block was used. Below the E_n numbers and graphical view for each block are given.

Table 2. E_n Values Between UME and PTB

Scale	H_{PTB}	H_{UME}	U_{PTB}	U_{UME}	E_n
HRA	23,12	23,42	0,32	0,4	0,59
	57,35	57,45	0,30	0,4	0,20
	71,54	71,65	0,30	0,4	0,22
	87,12	87,44	0,30	0,4	0,64
HRB	29,71	30,22	0,54	0,6	0,63
	50,76	50,47	0,51	0,6	0,37
	73,52	73,95	0,50	0,6	0,55
	100,37	100,55	0,50	0,6	0,23
HRC	19,85	20,10	0,31	0,4	0,49
	35,47	35,59	0,30	0,4	0,24
	45,69	45,80	0,31	0,4	0,22
	57,60	57,87	0,31	0,4	0,53
	70,30	70,60	0,31	0,4	0,59
HR15N	74,55	74,63	0,40	0,6	0,11
	85,25	85,40	0,40	0,6	0,21
	90,38	90,24	0,41	0,6	0,19
HR30N	50,83	50,89	0,42	0,6	0,08
	68,67	68,92	0,40	0,6	0,35
	77,93	78,35	0,42	0,6	0,57

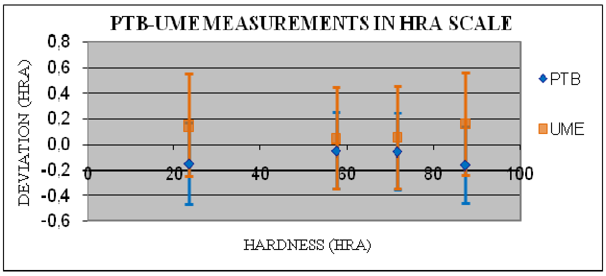

Fig. 12. Block Measurements for HRA Scale

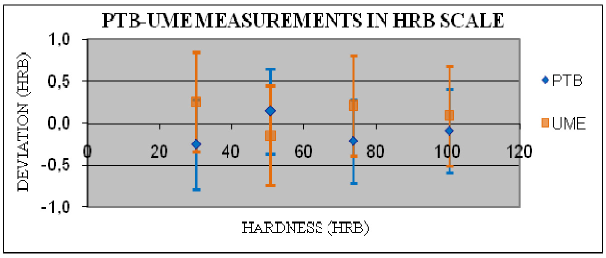

Fig. 13. Block Measurements for HRB Scale

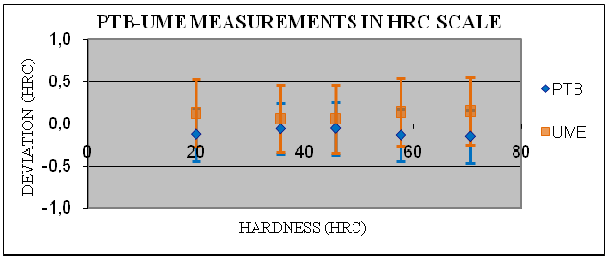

Fig. 14. Block Measurements for HRC Scale

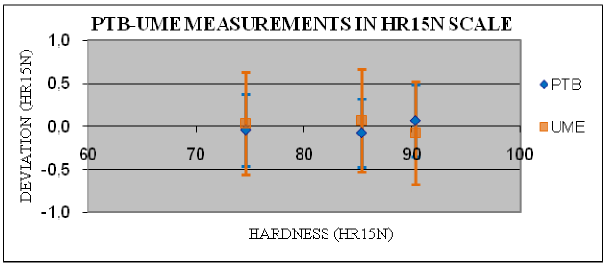

Fig. 15. Block Measurements for HR15N Scale

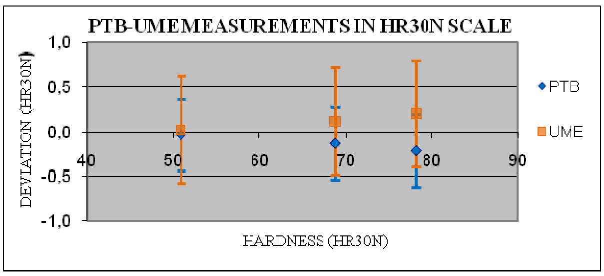

Fig. 16. Block Measurements for HR30N Scale

6. CONCLUSION

At the end of the work explained above we ended with the following conclusions;

- We have completed the establishment of Rockwell hardness scales.
- At the end of direct calibration of the machines, we saw all scales met the EN ISO Hardness Standards Part:3 Requirements.
- With the measurements done with hardness reference blocks we reached good results.

7. REFERENCES

[1] EN ISO/IEC 17043: 2010. Conformity assessment - General requirements for proficiency testing, 2010

[2] EN ISO 6508-1: 2005. Metallic Materials – Rockwell Hardness Test - Part1: Test Method (scales A, B, C, D, E, F, G, H, K, N, T).

[3] EN ISO 6508-2: 2005. Metallic Materials - Rockwell Hardness Test - Part2: Verification and Calibration of Testing Machines (scales A, B, C, D, E, F, G, H, K, N, T).

[4] EN ISO 6508-3: 2005. Metallic Materials - Rockwell Hardness Test – Part3: Calibration of Reference Blocks (scales A, B, C, D, E, F, G, H, K, N, T).

[5] EURAMET/cg-16/v.01:2007. Guidelines on the Estimation of Uncertainty in Hardness Measurements