

## A NEW DESIGN AND AUTOMATION OF ROCKWELL HARDNESS STANDARD MACHINE

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**Abstract** – A new dead weight type Rockwell hardness standard machine with a laser interferometer optic system was designed for TSE (Turkish Standards Institution) in the scope of TÜBİTAK (The Scientific and Technological Research Council of Turkey) Project\* with project number 111G068. The scope of this project is mainly based on covering the requirements of a government agency by making R&D in the related field and it is funded by the TÜBİTAK.

A Rockwell hardness standard machine had been previously designed and established at UME (National Metrology Institute of Turkey) Hardness Laboratory as a National Standard to provide traceability for Rockwell hardness reference blocks calibration. In the new TÜBİTAK Project it is aimed to design a new Rockwell Hardness machine for the TSE with at least similar metrological performance to and more automatic hardness measurement capability than UME machine.

Traceability of each component constituting Rockwell Hardness scales such as force application, depth measurement and realization of testing cycle to national standards is provided by direct calibration. To realize performance tests of the machine as a whole, hardness reference blocks calibrated by the PTB (National Metrology Institute of Germany) and UME were planned to be used. In this paper, Rockwell Hardness Standard Machine designed by TÜBİTAK UME Hardness Laboratory for the TSE is introduced and its performance test results performed so far are interpreted.

**Keywords:** Rockwell, Hardness Standard Machine, Hardness

### 1. INTRODUCTION

With the demand of the TSE and in turn accredited calibration and testing laboratories a Rockwell hardness standard machine had been decided to be redesigned and established to provide traceability in the field of Rockwell Hardness measurements. In this new design the force

application system was considered to comprise mass stacks realizing force under the gravitational acceleration and a frame to transfer the realized force to the tip of the indenter, a very well known dead weight force application system. The frame was supposed to generate the 3 kgf and 10 kgf, separately, as the pre-load of Superficial Rockwell and Rockwell scales, respectively. The Rockwell scales are realized with a total of 6 mass stacks, in addition to two 2 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 sensed by measuring the force on the load cell instantaneously during load application and comparing the measured force values with the nominal values belonging to the scale and Force - Time relationship is recorded. Indenter approach and penetration speeds are measured via the laser system and Depth - Time correlation is taken from this system. Also the Force - Indenter velocity relation is figured out by the information instantaneously taken from the laser and load cell equipments.

### 2. DESIGN OF THE MACHINE

The machine body was designed to be rigid and sturdy to minimize side effects during realization of force application and depth of indentation measurement and every component constituting Rockwell Hardness is considered to be with the highest accuracy to attain the best outcome quantity hardness.

The machine was also designed to realize hardness measurement as automatic as possible. For this purpose a motorized XY\_stage is mounted onto the machine body and integrated to the control panel and in turn it is aimed to

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realize a series of hardness measurement automatically with predefined distances in between in X and Y directions, at locations and with number of measurements. Also a camera is adapted to the system to place locations of hardness measurements on the screen of the control pc through the automation software of the system. In Fig. 1 the Rockwell Hardness Standard Machine designed for the TSE is given.



Fig. 1. Rockwell Hardness Standard Machine Designed for the TSE

## 2.1. Force Application System

To realize the force with the highest accuracy and stability, deadweight type force application principle was preferred. It comprises mass stacks made up of stainless steel and a frame made of Aluminium to constitute the preload of the Rockwell and Superficial Rockwell scales. Force application is composed of two steps: preload and additional load is applied respectively 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].

The smaller preload (29,42 N) is realized by making use of an Aluminium frame. The 98,07 N preload is applied by adding a 7 kgf mass stack automatically to the frame to attain a total of 10 kgf as the preload of Rockwell scales from HRA to HRK. Beside these preloads, six mass stacks made up of 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 air bearings is square and the other is cylindrical shaped, both are working with (4-6) bar air pressure. In Fig. 2, the frame constituting the preloads and mass stacks constituting additional loads for HRC scale (1471 N) and air bearings are given.

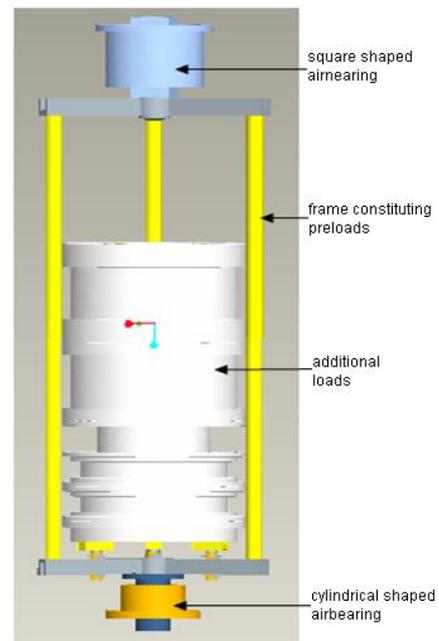


Fig. 2. The Frame and Masses of the Machine for 1471 N

## 2.2. Indentation Measurement System

For indentation depth measurement, a laser interferometer system was equipped on to the machine. The laser head/source was placed near the machine, the linear interferometer is placed on an adjustable plate on the machine in vertical coaxial with the indenter 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

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automation of the system and Depth - Time graph is plotted. In Fig. 3 indentation depth measurement principle is given.

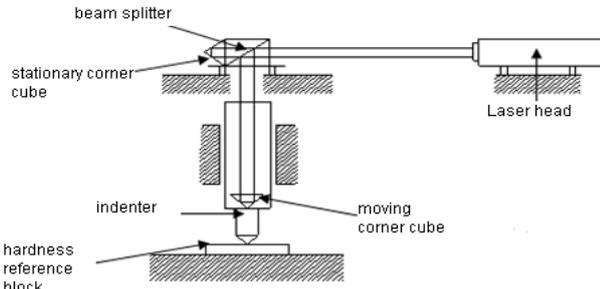


Fig. 3. Depth of Indentation Measurement Principle

With the laser system given in Fig. 3 the movement of the indenter is recorded. At the same time the speed of the indenters instantaneously is figured out and used in control of the machine. Depth - Time info recorded by the system is given in Fig. 4.

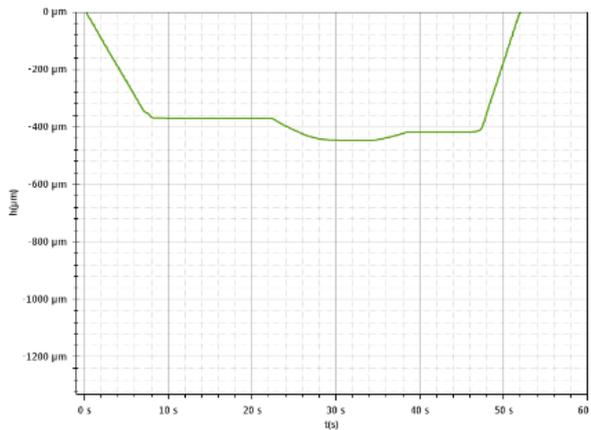


Fig. 4. Movement of the Indenter During Rockwell Test

### 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 speeds and durations should be controlled. 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 Speed - Time which taken from the laser system to figure out the Force - Speed which is effective on the measurement results. With this design force and speed of the indenter and time during a measurement cycle can be changed. Important parameters like final load application speed, total force application and dwell times, preload application and dwell times and percentage of force at which the speed is changed can also be set up. In Fig. 5 the very preliminary Force - Time graph attained for HRA scale is given. It is obvious that speed of force application can be changed at any time during the measurement cycle in a

closed loop manner in accordance with the force value taken from the load cell instantaneously.

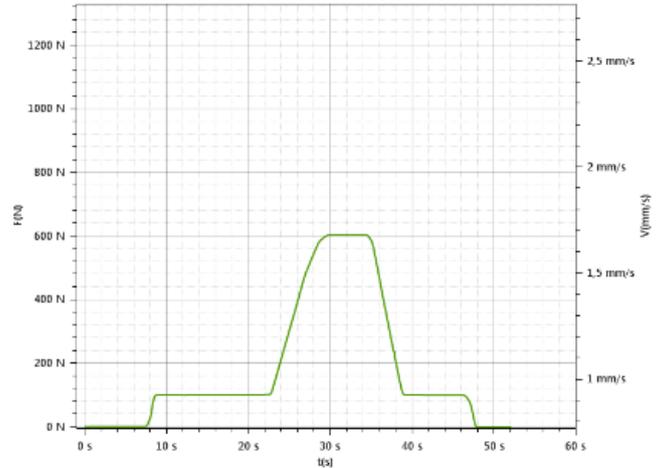


Fig. 5. Force - Time Graph for HRA Scale

### 3. AUTOMATION OF THE MACHINE

The machine is designed to perform the action from the scale selection to performing the hardness measurement automatically for all scales. Under this circumstances there are two main servo-motor integrated with the mechanical parts and controlled with a software; one for selection of masses and the other one for realization of indentation which moves the masses in the up and down direction for force application. A motorized XY\_stage is used to move the hardness block on the anvil for the next hardness measurement at the requested locations respectively, as many times as requested at the beginning of the test.

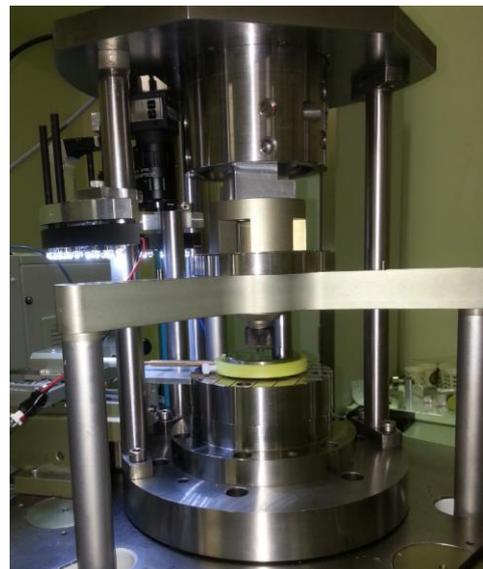


Fig. 6. Motorized XY\_Stage and Camera System

A camera as shown in Fig. 6 is mounted on top of the XY\_stage to view the block surface and select the number and locations of the indentations prior to the block calibration.

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## 4. CALIBRATION OF THE MACHINE

### 4.1. Force Calibration - Testing Cycle Verification

Mass stacks used in Rockwell Hardness Standard Machine were calibrated at UME Mass Laboratory at  $1 \times 10^{-5}$  level of uncertainty and the local gravitational acceleration at the location where the machine will be located is measured with a better level of uncertainty. After mounting the machine the force at the tip of the indenter was supposed to be calibrated/verified by another reference force measurement assembly.

Force application is automatically controlled by a servo motor. Since the mass stacks are applied by a frame hanged to a load cell 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.

### 4.2. 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.

### 4.3. Depth Measurement System

In this design the of depth of indentation and indenter speed are measured with a laser interferometer system. The laser head is calibrated by UME.

### 4.4. 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. We have a set of hardness reference blocks calibrated at PTB and UME and these blocks are used for performance test of the designed machine. Then, the measured values and the blocks' certified values are compared taking the certificates and measurement uncertainties into consideration. The results were compared by including the uncertainties via the  $E_n$  formula given below.

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

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

## 5. 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:

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

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,

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

The combined standard uncertainty is calculated by:

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

At the end the expended uncertainty is calculated by:

$$U = k u(H) \quad (5)$$

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:

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

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;

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

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

$$U = k u_b \quad (8)$$

## 6. CALIBRATION RESULTS

### 6.1. Force Calibration

The mass stacks were calibrated at Mass Laboratory of UME with a  $1 \times 10^{-5}$  uncertainty, but since it is not a pure dead weight system after mounting of the machine the force application system and testing cycle were calibrated by making use of a high accuracy two load cell-indicator force reference devices. The load cell was placed instead of the block and Rockwell tests for all scales were performed. The measured values are within the tolerances of the ISO 6508-3. Since the tolerances of the superficial Rockwell is smaller than the other scales, some examples from HR15N, HR30N and HR45N scales are given in Fig. 7 to Fig. 11 below.

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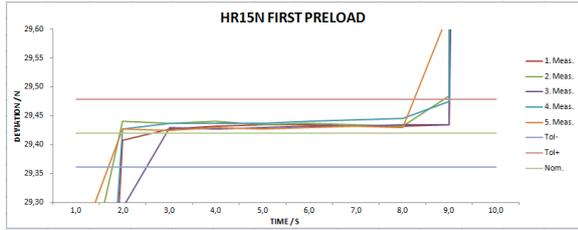


Fig. 7. HR15N First Preload Measurements

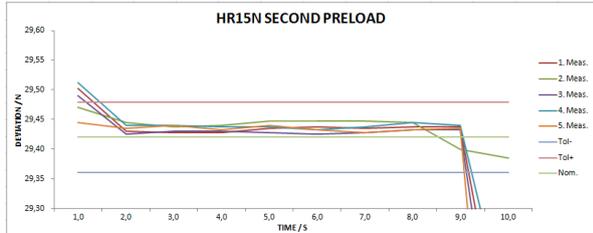


Fig. 8. HR15N Second Preload Measurements

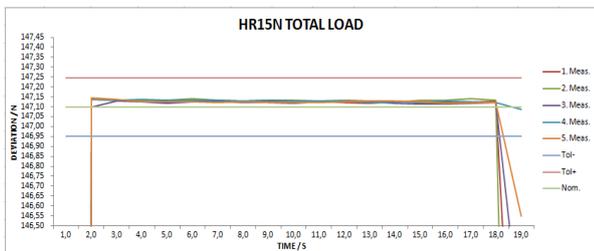


Fig. 9. HR15N Total Load Measurements

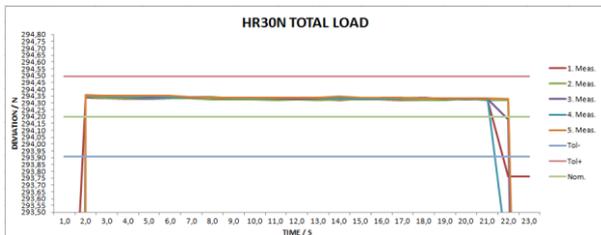


Fig. 10. HR30N Total Load Measurements

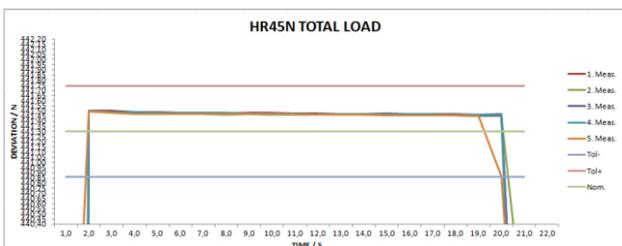


Fig. 11. HR45N Total Load Measurements

### 6.2. Calibration by Hardness Reference Blocks

To see performance of the machine as a whole, a set of hardness reference blocks were used. The blocks measurements were done only for HRA, HRB and HR15N scales for the very beginning of the performance. The performance tests of the machine has not been completed

yet but just to have a first idea for different force and preliminary force values and indenters these scales were preferred. Below in Fig. 12 to Fig. 14 you can see some examples for the very preliminary measurement results.



Fig. 12. Block Measurements for HRA Scale

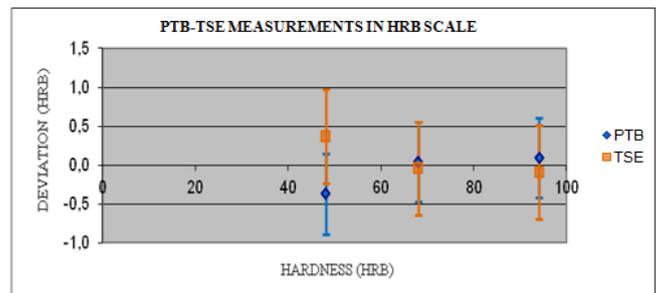


Fig. 13. Block Measurements for HRB Scale

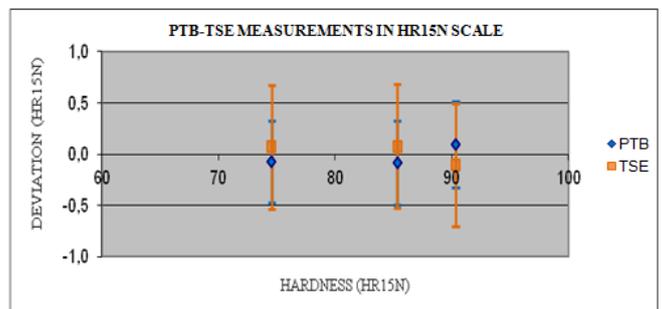


Fig. 14. Block Measurements for HR15N Scale

## 7. CONCLUSION

At the end of the work explained above we attained the following conclusions;

- We have redesigned and established a new Rockwell Hardness Machine in accordance with EN ISO 6508-1[2] and covering all hardness scales present in the standard.
- The scale selection, measurement cycle, performing a series of measurement and selection of the location and number of indentation through a camera are all automatically possible.
- With the very preliminary performance measurements done so far we reached good results.

\* This paper is issued as an outcome of a project supported and funded by the TÜBİTAK with Project Number 111G068.

## 8. REFERENCES

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