ACTA IMEKO
ISSN: 2221-870X
December 2020, Volume 9, Number 5, 240 - 246

GUM'S ROCKWELL HARDNESS STANDARD MACHINES AFTER MODERNISATION

J. D. Fidelus[1], M. Kożuchowski[2]

[1] GUM, Central Office of Measures, 00139 Warsaw, Poland, janusz.fidelus@gum.gov.pl
[2] MERICORE, 02654 Warsaw, Poland, m.kozuchowski@mericore.com

Abstract:
This article describes two twin deadweight-type Rockwell hardness standard machines (HSMs – HSM-S02 and HSM-NT) of GUM after modernisation. A new control system for the station with database, a hydraulic pump, a displacement measuring system and an application enabling the operator to operate the measuring station are described. The adjustment process of the HSM-S02 with entering automatic compensation (correction) enabling the improvement of the measured result in real time is presented.

Keywords: Rockwell hardness standard machine; deadweight-type machines; adjustment; industry 4.0, LabVIEW, database

1. INTRODUCTION

The GUM HSMs were designed and manufactured in the 1970s by Ernst Leitz GmbH Wetzlar (Germany). In order for the systems to work in a fully automatic mode and in accordance with Industry 4.0 requirements [1], their modernisation was necessary. The proper and precise functioning of the HSMs requires their accurate adjustment and calibration. Although there is a precise procedure for calibrating the reference standard blocks, there is no such procedure for the HSMs.

2. GUM'S ROCKWELL HARDNESS STANDARD MACHINES

In cooperation between GUM (Główny Urząd Miar/Central Office of Measures) as the National Metrology Institute of Poland for standardisation of hardness measurement and MERICORE, a concept has been developed for the automation and modernisation of two twin HSMs - scale A, B, C, D, E, F, G, H, K (HSM-S02) and scale N, T (HSM-NT), in accordance with PN-EN ISO 6508-3 [2, 3]. As part of the modernisation process, a new control system for the station, a hydraulic pump, a displacement measuring system and an application enabling the operator to operate the measuring station were made, see Figure 1.

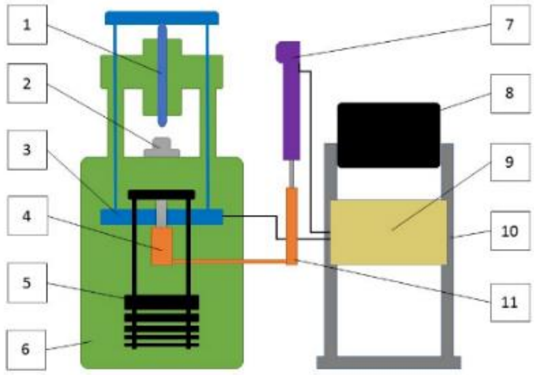

Figure 1: GUM's Rockwell hardness standard machine composed of the following elements:

1. Indenter
2. Specimen support
3. Preliminary load
4. Hydraulic cylinder
5. Weights
6. Body of the hardness tester
7. Electric drive of the pump actuator
8. Monitor
9. Electric control cabinet
10. Controller's rack
11. Hydraulic cylinder of the pump

The station controller was built in accordance with industrial and laboratory standards, combining reliability and precision required in laboratory equipment. The use of the latest solutions made it possible to prepare the station to be networked in accordance with the idea of Industry 4.0.

The use of an industrial computer, a system of distributed islands for the acquisition of signals from sensors, LAN communication with individual executive systems of the system, and a 22-inch, touch screen monitor creates an extremely efficient and convenient to use facility.

The hydraulic pump uses an electrically controlled actuator to control the piston position with single micrometre resolution. This makes it possible to control the movement of the overlap of individual loads unheard of in commercial workstations. Due to the fact that the modernised stations date back to the 1970s, it was necessary to replace the original sensing of the mechanical systems. Contact ends and switches were replaced by inductive proximity sensors which, thanks to the absence of moving parts and contacts, ensure failure-free operation even in the case of contamination or flooding with oil.

Depth displacement is measured using the Renishaw RESOLUTE system, which consists of an optical encoder (head) and a stainless steel belt scale with laser-engraved absolute code (Figure 2). The system used has a measurement resolution of 1 nm and an error of 3.5 µm per metre of scale length. When measuring displacements of 200 µm, the scale error is negligible. The head has its own electronics, which controls the optoelectronics of the reading but also monitors whether the setting of the optical axis to the scale is correct. If any deviation is detected, the measuring system sends information to the control application that the reading surfaces must be adjusted or cleaned. In combination with the digital readout transmission, this makes the system extremely resistant to interference and errors.

Figure 2: GUM’s Rockwell hardness standard machine equipped with the Renishaw RESOLUTE system, which consists of an optical encoder (head) and a stainless steel belt scale with laser-engraved absolute code

The software for the workplace control has been developed from scratch in the LabVIEW environment, which is dedicated to creating applications in laboratory and industrial applications. In particular, it is dedicated to the operation of measuring systems due to the implemented functions of hardware operation and data analysis and archiving capabilities.

The control application enables the measurement to be carried out and also includes an equipment diagnostic module. Thanks to it the user can easily check the correctness of operation of particular systems. In addition, the application will make it impossible to switch on the station or perform a measurement if it finds that any of the systems are not working properly or return values outside the accepted control limits.

Each station has its own database in which all data of orders placed as well as the results of conducted tests are stored. For the convenience of users, the database is accessible through a specially created program in LabVIEW using a web browser. This makes it possible to enter and modify data from any computer in the same network (Figure 3).

Figure 3: A computer with dedicated software (control and device diagnostics application written in LabVIEW) for data analysis and archiving

In accordance with the requirements of safety standards, the controller has been equipped with a certified safety controller and an emergency stop button, thanks to which the user can stop the hydraulic pump operation at any time, protecting himself or his equipment. Resumption of the workstation is only possible after the appropriate safety system restart procedure.

3. HSM-S02 – FORCE CALIBRATION AND MECHANICAL STUDY

3.1. Force Calibration

The force calibration of the machines using the force-proving instrument composed of the force transducer (type Z3H2 R, Hottinger) and the measuring amplifier (type DMP41-T2, HBM). Data archiving and analysis was carried out, i.e. using HBM (Catman) software. The exact description of the force calibration will be the subject of a separate work.

3.2. Preliminary Hardness Measurements

In order to verify the indications of the Rockwell hardness standard machine (HSM-S02), a number of hardness blocks measurements were made for the HRC scale, which are shown in Table 1. Each sample was measured at five points and then the average value was determined, which was compared with the valued of the measured standard. Based on the measurements carried out, a statistical analysis was performed to adjust the characteristics of the HSM-S02 to the hardness reference blocks. Thanks to this, the automatic compensation (correction) entered into the system can correct the measurement result in real time.

Table 1. Measurements of Rockwell hardness C without compensation

Hardness blocks		Measurements (HRC)							Difference
Designation	**HRC**	**1**	**2**	**3**	**4**	**5**	**Average**	**Uniformity**	
MPA NRW 1214601.1006	21.62	22.95	22.80	22.93	22.86	23.00	22.91	0.20	1.29
MPA NRW 863401.0206	30.20	30.91	31.08	31.10	31.06	30.98	31.03	0.19	0.83
MPA NRW 6975302.0916	44.71	44.91	44.82	44.70	44.64	44.74	44.76	0.27	0.05
AS 2271/98	55.90	56.39	56.22	56.29	55.9	56.08	56.18	0.49	0.28
MPA NRW 900809.0306	61.13	60.87	60.83	60.69	60.88	60.66	60.79	0.22	-0.34
MPA NRW 863905.0206	64.94	64.51	64.50	64.50	64.51	64.60	64.52	0.10	-0.42

First, a plot was made where measurement values were placed on the X axis, while the hardness values of the tested blocks were placed on the Y axis. Figure 3 presents a graph of this relationship.

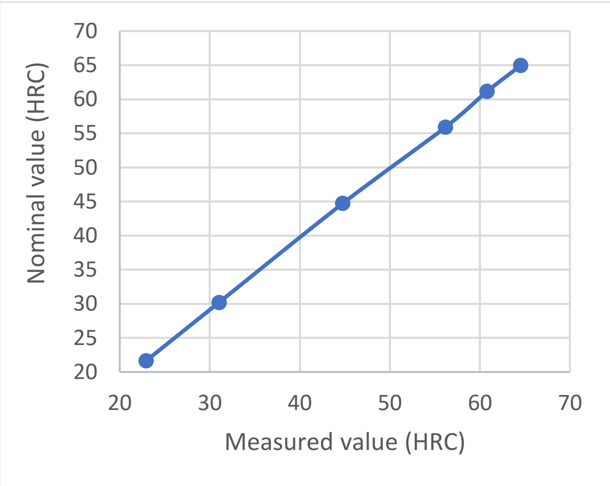

Figure 3: The graph presents the relationship between the hardness values measured on the HSM-S02 and the nominal hardness values of the HRC blocks

Then, a trend line was determined which was finally fitted using a 3rd degree polynomial (R^2 = 0.999), given in equation (1).

$$HRC = 0.00006 \cdot X^3 - 0.0077 \cdot X^2 + 1.3469 \cdot X - 5.8 \quad (1)$$

where the X value is the raw result of the hardness measurement at the HSM-S02.

After taking into account equation (1) in the calculations of the HRC result value from the measurements according to Table 1, the relation between the deviations of the values calculated from the measurements and the nominal values was obtained (Figure 4).

As shown in Figure 4, the distribution of deviation values is quite random and their values do not exceed ± 0.5 HRC. Therefore, it was decided to compensate the remaining deviation values by creating a table of correction values in specific intervals. The results are shown in Table 2.

Table 2: Summary of final corrections

Interval number	HRC hardness range	Correction accepted
1	0-30	-0.15
2	30-35	-0.1
3	35-40	+0.1
4	40-47.5	+0.2
5	47.5-50	+0.1
6	50-53.5	-0.1
7	53.5-58	-0.25
8	58-60	-0.1
9	60-62.5	+0.0
10	62.5-68	-0.3

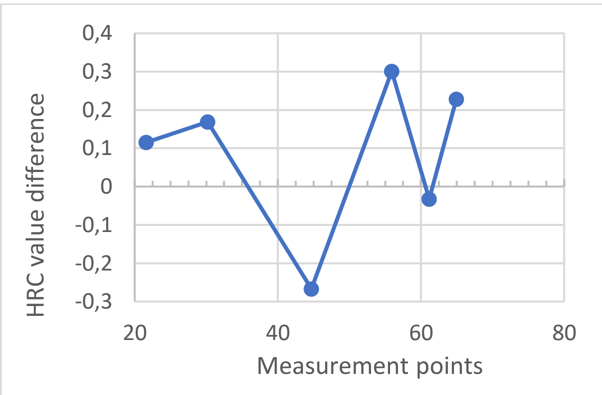

Figure 4: Deviations of the measurement HRC values from the nominal values after applying the compensation equation

In order to verify the correct operation of the HSM-S02 with the compensation equation and table of corrections, after 3 months from the first measurements summarised in Table 1, a series of measurements were made on the same hardness blocks. Measurement were made at 23 °C ± 0.5 °C using the same indenter. The results of the verification measurements are summarised in Table 3.

Table 3. Hardness measurements of HRC blocks with active compensation

Hardness blocks		**Measurements (HRC)**							**Difference**
Designation	**HRC**	**1**	**2**	**3**	**4**	**5**	**Average**	**Uniformity**	
MPA NRW 1214601.1006	21.62	21.50	21.51	21.36	21.53	21.55	21.49	0.19	-0.13
MPA NRW 863401.0206	30.20	30.25	30.21	30.19	30.07	30.28	30.20	0.21	0.00
MPA NRW 6975302.0916	44.71	44.99	44.75	44.84	44.80	44.77	44.83	0.24	0.12
AS 2271/98	55.90	55.89	56.06	56.05	55.70	55.68	55.88	0.38	-0.02
MPA NRW 900809.0306	61.13	60.99	61.25	61.04	61.15	61.18	61.12	0.26	-0.01
MPA NRW 863905.0206	64.94	65.01	64.88	65.01	65.00	65.12	65.00	0.24	0.06

The results of the introduced compensation are shown in Figure 5 and Figure 6. Figure 5 shows the deviations of the calculated values of the five measurements with and without active compensation, while Figure 6 shows a comparison of the uniformity values of both measurement series.

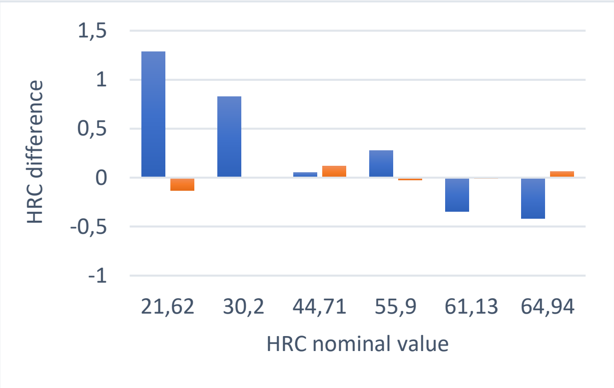

Figure 5: Difference of measured hardness value and HRC nominal hardness blocks value. Comparison of average values from the measurement series without compensation (in blue) and with active compensation (in orange)

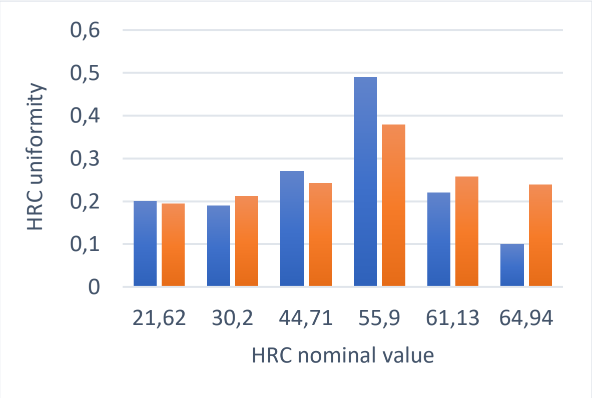

Figure 6: Uniformity for individual measurement series (measurements without compensation – in blue; measurements with compensation – in orange)

As shown in Figure 5, measurement results with active compensation differ much less from the reference blocks than in a series of measurements without compensation. By reading the difference in Table 3, the average hardness measurements of each block do not differ by more than 0.15 HRC from its nominal value.

Figure 6 summarises the values of measurement spread for measurement series made before and after the introduction of deviation compensation. In both cases, we can see that the scatter values for individual blocks for both measurement series are very similar and oscillate around 0.2-0.25 HRC. The exception are the uniformities when measuring the blocks with a value of 55.9 HRC, which shows higher uniformity (older generation block with higher uniformity of surface hardness).

The final stage of verification of the correctness of the HSM-S02 stand and the compensation used was the performance of the third series of measurements on other blocks than those used in the first two tests with a maximum uncertainty of 0.4 HRC.

Table 4 summarises the results from the measurements of the third series. These measurements were carried out on the same day as series 2 to eliminate the effect of time on possible position instability.

Figure 7 shows the difference between the HRC value of the block and the average value of its five measurements. The measurements were performed with active compensation taking into account the table with corrections to maintain consistency with the second measurement series.

Analysis of the results showed that the values of uniformities and average of individual measurements are acceptable. The block 22.73 HRC is an exception.

Table 4. Results of measurements of 3rd series made on additional blocks with a maximum measurement uncertainty of 0.4 HRC

Hardness blocks		Measurements (HRC)							Difference
Designation	HRC	1	2	3	4	5	Average	Uniformity	
19776 D-K	22.73	21.42	21.52	21.25	21.33	21.47	21.40	0.27	-1.33
PRESS-9794	35.80	36.07	35.96	35.90	35.99	35.91	35.97	0.16	0.17
19777 D-K	45.91	45.56	45.64	45.57	45.59	45.66	45.61	0.10	-0.30
AS4322/85	50.50	50.76	51.00	50.81	51.01	50.95	50.91	0.25	0.41
AS 60/98	61.00	60.73	60.64	60.54	60.92	60.75	60.72	0.38	-0.28
19778 D-K	65.86	65.52	65.49	65.49	65.65	65.57	65.54	0.16	-0.32

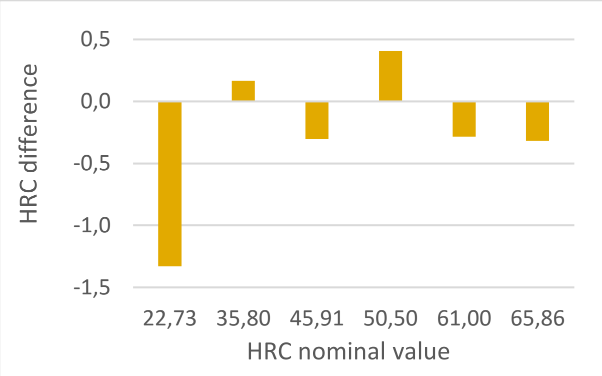

Figure 7: The values of the difference between the mean value of the measurements and the value of the hardness block in the 3rd series. Measurements with active compensation

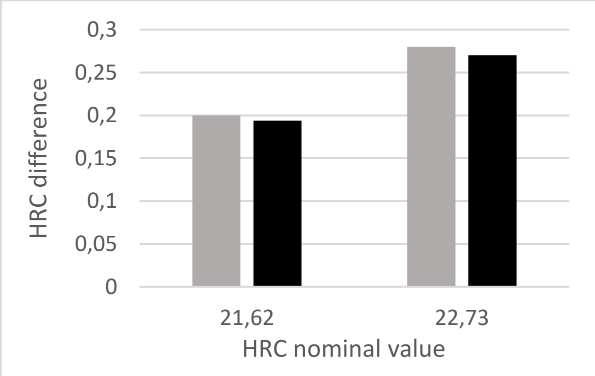

Figure 8: Uniformities for comparable test results at HSM-S01 (in grey) and HSM-S02 (in black) stands

The average values of measurements for all blocks, except the block with the lowest hardness, are within 0.4 HRC according to the documentation of blocks. The average value of the measurements for the 22.73 HRC block measured on the HSM-S02 stand is 1.33 HRC too small in relation to its nominal value.

Compared with the measurements from the first series of the 21.62 HRC block, it can be seen that they were 1.29 HRC too high in relation to its nominal value. Therefore (to check the uniformity of the soft 21.62 HRC block), a comparative study was conducted with the HSM-S01 stand, which uses the same type of indenters and is very similar in construction. The results for both blocks and stands (HSM-S01, HSM-S02) are presented in Table 5.

First, the values of uniformities were analysed. According to Figure 8, the dispersion values are comparable and according to the data from Table 5 for individual standards, they do not differ by more than 0.01 HRC, which can be considered a negligible value.

In addition, the scatter values for both blocks are small, which suggests that both blocks have similar uniformity and the positions are repeatable and stable.

The following conclusions can be drawn from the conducted tests:

1. It should be assumed that the block with a value of 21.62 HRC has a different actual value than the declared nominal value.
2. Assuming no fatal error in the measurements at the HSM-S01 and HSM-S02 stands and theirstability on the basis of the uniformities shown in Table 5 and Figure 8, it is suggested to take the actual value of the hardness of the 21.62 HRC block as the average of the measurements on the HSM-S01 stand and measurements from the first series on the HSM-S02 stand without compensation, giving a calculated average difference of 1.062 HRC.
3. If it is assumed that the average value of the 21.62 HRC block measurements taken on the HSM-S02 stand in the first series without compensation should be corrected by the calculated average value from comparative measurements according to point 2, then the average value from the results of the block with the 22.73 HRC value is -0.269 HRC. This value is close to the value measured at the HSM-S01 stand.

After introducing a change in compensation and correction value, the current graph in Figure 7 is shown in Figure 9.

Final calibration and corrections on HSM-S02 (and HSM-S01) stands will be introduced after conducting bilateral comparative tests with the National Institute of Metrological Research (INRiM, Italy) [4].

Table 5. Comparison of measurement results for the 21.62 HRC and 22.73 HRC blocks at HSM-S01 and HSM-S02

Hardness blocks		Measurements (HRC)							Difference
Designation	**HRC**	**1**	**2**	**3**	**4**	**5**	**Average**	**Uniformity**	
				HSM-S01					
MPA NRW 1214601.1006	21.62	22.36	22.36	22.56	22.56	22.44	22.46	0.20	0.84
19776 D-K	22.73	22.64	22.56	22.60	22.48	22.76	22.61	0.28	-0.12
				HSM-S02					
MPA NRW 1214601.1006	21.62	21.50	21.51	21.36	21.53	21.55	21.49	0.19	-0.13
19776 D-K	22.73	21.42	21.52	21.25	21.33	21.47	21.40	0.27	-1.33

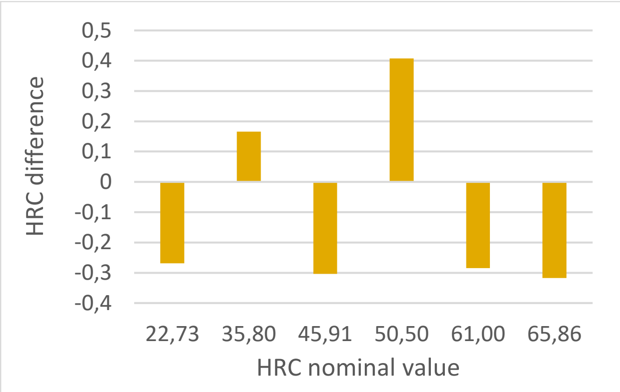

Figure 9: Measurement results of the 3rd series after updating the correction value for the 0-30 HRC range. Measurements with active compensation

The presented way of the adjustment HSM-S02 with the introduction of automatic compensation (correction) allows to improve the measured result (hardness) in real time.

On this basis, an uncertainty budget will be developed for the stand without using plate hardness standards. The compensation algorithm can be used to adjust the characteristics of the indenter or the system for measuring the displacement of the indenter if comparative measurements made with the laser interferometer showed its non-linearity or offset.

It is planned to use the HSMs (the hysteresis / Rockwell hardness investigations) in the EMPIR project with the acronym ComTraForce.

4. SUMMARY

GUM's deadweight-type Rockwell hardness standard machines were modernised in accordance with Industry 4.0 requirements.

At the stage of preparing the article, the stand was not yet ready to conduct the final research and determine the uncertainty budget. The stand was manufactured in 1975 and has been used sporadically in recent years, which raised concerns about its technical condition. After the modernisation, its stability and repeatability had to be determined and the developed algorithm to compensate for measurement deviations had to be tested. For this purpose, hardness blocks were used, which were measured under reproducible conditions with an interval of three months. The obtained measurements, which were used in the article, confirmed that the station's mechanisms work properly, and the compensating algorithm allows correction of any deviations to the level of 0.05 HRC for the entire scale range.

5. ACKNOWLEDGEMENTS

Modernisation works of the HSMs were financed from funds for investment tasks for the GUM in 2019.

As a part this work had been carried out in the framework of the project with the title “Comprehensive traceability for force metrology services”. The 18SIB08 ComTraForce project has received funding from the EMPIR programme co-financed by the Participating States and from the European Union's Horizon 2020 research and innovation programme.

EMPIR EURAMET

The EMPIR initiative is co-funded by the European Union's Horizon 2020 research and innovation programme and the EMPIR Participating States

6. REFERENCES

[1] Klaus Schwab, The Fourth Industrial Revolution, 2016 https://luminariaz.files.wordpress.com/2017/11/the-fourth-industrial-revolution-2016-21.pdf

[2] EN ISO 6508-1/2/3: Metallic Materials- Rockwell hardness.

[3] J. D. Fidelus, Participation of the Central Office of Measures in the European industrial project EMPIR in the field of force, Metrology and Hallmarking - the Bulletin of the Central Office of Measures, 1 (24) / 2020, 7-14. BazTech.

[4] A. Germak, J. D. Fidelus, C. Origlia, Bilateral comparison in Rockwell C hardness scale between INRiM and GUM, ongoing study.