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A NEW APPROACH TO FORCE TRACEABILITY IN HARDNESS MEASUREMENTS

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Abstract:

Force traceability in hardness measurements is provided via force measurement devices which are requested to have an accuracy Class 0,5 for hardness calibration machines, an accuracy Class 1 or accuracy of 0.2 % for hardness testing machines according to ISO 376 as indicated in the relevant ISO hardness standards. The most accurate way of having force traceability is to have the force measurement device calibrated against high accurate force standard systems. In this paper investigation and results of providing force traceability of force measurement instruments calibrated against deadweight type hardness standard machines is explained in detail.

Keywords: hardness; force; traceability; deadweight; measurement

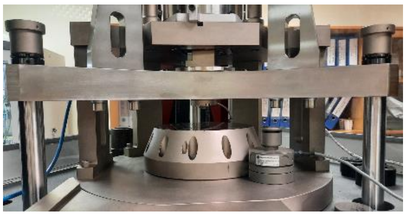
1. INTRODUCTION

Traceability in hardness measurements can be managed both in *direct* and *indirect* ways. In the direct way it is realised by providing traceability of each component constituting the hardness scale such as force, indenter, measurement cycle and indentation measurement system. In the indirect way the calibration/testing machines shall be traceable via hardness reference blocks to take the non-measurable parameters into account and check the machine as a whole. Force traceability in hardness measurements is provided via force measurement devices (force transducers, load cells etc.) which are requested to have an accuracy Class 0,5 for hardness calibration machines, an accuracy Class 1 or 0.2 % accuracy for hardness testing machines according to ISO 376 [1] as indicated in the relevant ISO hardness standards [2], [3], [4], [5], [6], [7]. The most accurate way of having force traceability is to have the force measurement devices calibrated against high accurate force standard systems. In this paper the possibility of providing traceability for the force measuring instruments by making use of deadweight type hardness standard machines is investigated. It is aimed to provide a possibility to calibrate the force measurement instruments for the same force values as those used for the relevant hardness scales with a much shorter calibration procedure. In this case the force instrument can be calibrated for the scales that the instrument is to be used for by taking only a few measurements for each scale to shorten the calibration procedure as well as (if possible) to have even better uncertainty values for the force values subject to calibration by eliminating some of the parameters affecting the measurement uncertainty take place in the ordinary calibration performed according to ISO 376.

2. CALIBRATION METHOD

In this method the deadweight type hardness standard machine (HSM) is used as reference for calibration of force measurement instrument. So the HSM is prepared as to be used for calibration of hardness reference block and instead of the block the force measurement instrument is placed underneath the indenter as shown in Figure 1(a) and Figure 1(b).

(a)



(b)

Figure 1: Placement of force measurement instrument instead of hardness block at TÜBİTAK UME HSM

A spare block/sample is placed on top of the force instrument and the test cycle is realised as the block calibration is performed. The force measured by the instrument is recorded with a data acquisition software. In this method the force, force application time and force dwell time are all recorded. This cycle is repeated five times and the relevant calculations can be made and compared with the reference machine force value, force application times and force dwell times.

2.1. Calibration of Force

In the claimed shorter force calibration procedure the force measurement instrument is calibrated for the force values it is supposed to be used for by the client. Since some parameters of the force measurement instrument (i.e. interpolation error, reversibility error, zero error etc,) are eliminated the calibration uncertainty of the instrument might be smaller than the ordinary calibration according to ISO 376 for some force ranges. The force instrument is calibrated for the exact force values of the hardness scales. So, if force traceability will be provided for only hardness calibrations the instrument can be calibrated for the points needed.

In the calibration procedure three force measurement devices with full capacities of 200 N, 5 kN and 50 kN calibrated via force standard machines are used. These transducers are calibrated via deadweight type HSMs recently developed by TÜBİTAK UME Hardness Laboratory; Rockwell-Brinell-Vickers hardness standard machine (RBVHSM) and high load Brinell hardness standard machine (HLBHSM). The load values subject to calibration are 3 kgf, 10 kgf, 50 kgf, 100 kgf and 150 kgf of RBVHSM; 500 kgf, 1500 kgf and 3000 kgf of HLBHSM. The procedure applied can be described as follows:

1. Five force measurements are made for every scale for *repeatability*.
2. The force transducer is removed and replaced three times and the same measurements are applied for *reproducibility*.
3. The mean of the force values are calculated to calculate the deviation of the transducer from the reference values.

At the end of the measurements the errors and uncertainty components given below are taken into consideration to calculate the force measurement results.

1. repeatability (u_{REPE})
2. reproducibility (u_{REPR})
3. creep (u_{CREEP})
4. resolution (u_{RES})
5. uncertainty of the HSM (u_{REF})

Examples for error calculation and the uncertainty budget are given in Table 1, Table 2, and Table 3.

Table 1: Error and uncertainty calculation for 50 kgf

50 kgf / N	Mean / N	u_{REPE} / N	u_{RES} / N	u_{CREEP} / N	u_{REPR} / N	u_{REF} / N	U (k = 2) / N	U (k = 2) / %
490.4040								
490.4104								
490.3268	490.3869	0.0199	0.0007	0.0085	0.0191	0.0049	0.0585	0.012
490.4234								
490.3697								

Table 2: Error and uncertainty calculation for 150 kgf

150 kgf / N	Mean / N	u_{REPE} / N	u_{RES} / N	u_{CREEP} / N	u_{REPR} / N	u_{REF} / N	U (k = 2) / N	U (k = 2) / %
1471.0862								
1471.0540								
1471.0417	1470.9965	0.0458	0.0021	0.0255	0.0224	0.0147	0.1177	0.008
1470.8865								
1470.9141								

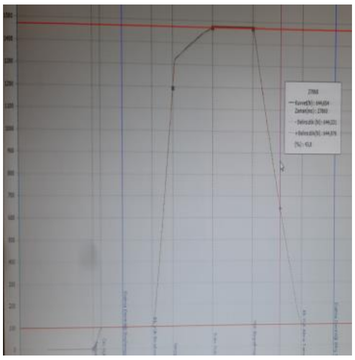
The calibration of the transducer are made for some force values and the results are calculated as given in Table 1 to Table 2 as examples and the results are compared with the force measurement instrument calibration values made according to ISO 376 and ASTM E74 [8]. The results are given in Table 3.

Table 3: Error and uncertainty calculation for force values in between 3 kgf – 3000 kgf

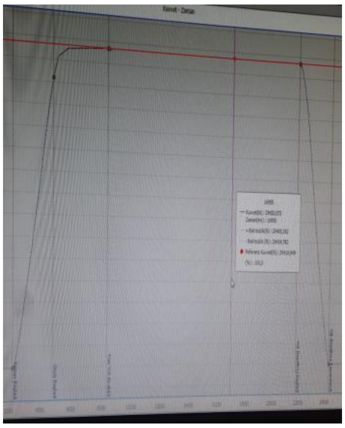
HSM calibration		FSM calibration to ISO 376 (Cases A to D) and to ASTM E74					
Hardness scale	U_{SHORT} (k = 2) / %	$U_{\text{ISO 376 / ASTM E74}}$ (k = 2) / % A	B	C	D	E74	Force value
3 kgf	0.021	0.029	0.035	0.030	0.036	0.015	20 N
10 kgf	0.020	0.027	0.029	0.027	0.029	0.012	100 N
50 kgf	0.012	0.013	0.026	0.024	0.033	0.015	0.5 kN
100 kgf	0.009	0.009	0.021	0.011	0.022	0.008	1.0 kN
150 kgf	0.008	0.010	0.019	0.010	0.019	0.007	1.5 kN
500 kgf	0.015	0.024	0.027	0.024	0.027	0.025	5 kN
1500 kgf	0.008	0.005	0.006	0.015	0.015	0.009	15 kN
3000 kgf	0.010	0.007	0.007	0.008	0.007	0.005	30 kN

2.2. Calibration of Measurement Cycle

The measurement cycle calibration of the software (where possible) is made in the same measurement cycle as made for force calibration. For application times (for preliminary loads of Rockwell and total loads of all Rockwell, Brinell and Vickers) and dwell times the same procedure is applied and calibration of the measurement cycle is realised. For realisation of the measurement cycle at HSM of TÜBİTAK UME data acquisition frequency is 1 kHz. All measurable quantities are plotted in graphical demonstration and especially the *force* – *time* cycle is constituted with high accuracy by making use of the force transducer equipped onto the HSM. Example screenshots of measurement cycles for Rockwell and Brinell – Vickers scales are shown in Figure 2.



(a)



(b)

Figure 2: Rockwell (a) and Brinell – Vickers (b) Reference Measurement Cycle of TÜBİTAK UME HSM

Regarding calibration of measurement cycle of force measurement software where possible, the following parameters were taken into consideration to constitute the measurement cycle uncertainty budget:

1. reference timer (u_{REF})
2. response time of the force device (u_{RESP})
3. repeatability (u_{REPE})
4. resolution (u_{RES})

At the end of the calibration of the measurement cycle, the measurement results given in Table 4 and Table 5 were obtained.

Table 4: Error and uncertainty calculation for load application time

Time / s	**Mean / s**	$\boldsymbol{u_{\mathrm{REPE}}}$ **/ s**	$\boldsymbol{u_{\mathrm{RES}}}$ **/ s**	$\boldsymbol{u_{\mathrm{REF}}}$ **/ s**	$\boldsymbol{u_{\mathrm{RESP}}}$ **/ s**	$\boldsymbol{U\ (k = 2)}$ **/ s**
7.95						
7.45						
7.65	7.79	0.129	0.087	0.000	0.014	0.312
8.10						
7.80						

Table 5: Error and uncertainty calculation for load dwell time

Time / s	**Mean / s**	$\boldsymbol{u_{\mathrm{REPE}}}$ **/ s**	$\boldsymbol{u_{\mathrm{RES}}}$ **/ s**	$\boldsymbol{u_{\mathrm{REF}}}$ **/ s**	$\boldsymbol{u_{\mathrm{RESP}}}$ **/ s**	$\boldsymbol{U\ (k = 2)}$ **/ s**
13.80						
14.10						
13.65	13.70	0.134	0.087	0.000	0.014	0.32
13.45						
13.50						

3. HSM TO BE USED AS REFERENCE

There are two HSMs to be used as reference for calibration of force measurement instruments in terms of force and measurement cycle as shown in Figure 3 and Figure 4. One is the Rockwell-Brinell-Vickers HSM and the other one is High Load Brinell HSM, covering a range from 3 kgf to 3000 kgf, with the possibility of calibration for all hardness scales in between these limit values. The force uncertainty of these machines is as good as 1×10^{-5} and measurement cycle is as good as 0.3 s. These machines can apply the force application cycle in accordance with the relevant ISO and ASTM hardness standards [2], [3], [4], [5], [6], [7], [9], [10], [11], [12], [13], [14].

Figure 3: Rockwell-Brinell-Vickers Hardness Standard Machine of TÜBİTAK UME

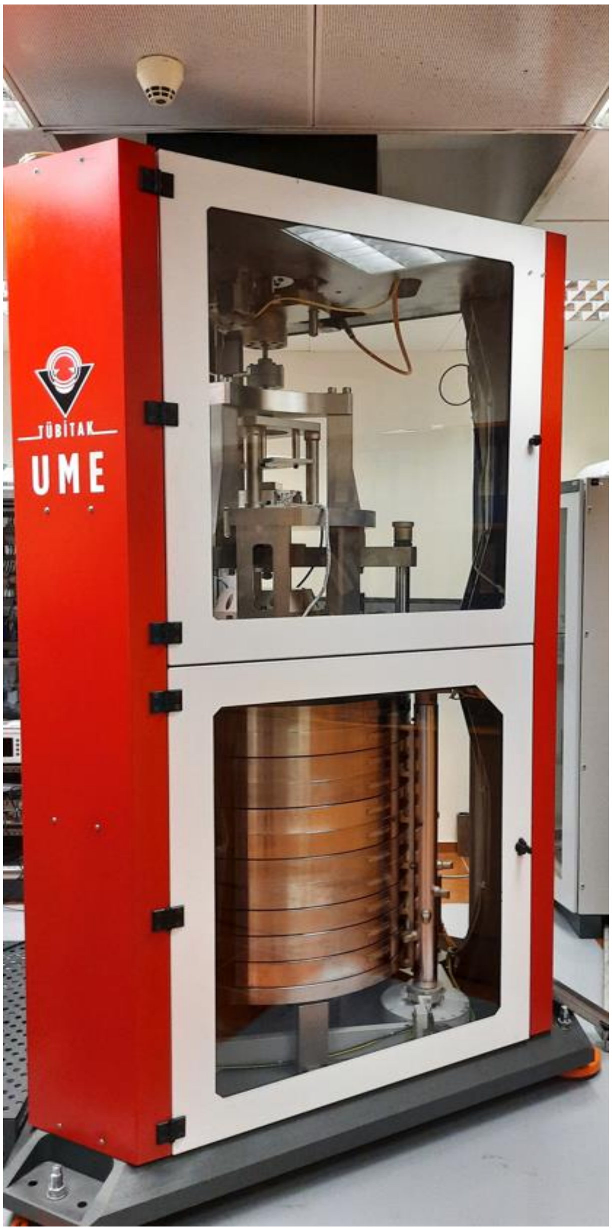


Figure 4: High Load Brinell Hardness Standard Machine of TÜBİTAK UME

4. ADVANTAGES OF THE METHOD

Accurate deadweight type hardness standard machines have advantages not only in calibration of hardness reference blocks but also in calibration of force measurement instruments used for calibration and verification of hardness testing and calibration machines. These advantages can be summarised as follows:

- Calibration of as many points as the client needs is possible.
- Force accuracy same as the force standard machines is possible.
- Similar way of force application cycle as the hardness testing/calibration machines (particularly from dwell time and force application time point of view) is available only by the HSMs.
- Automatic force calibration is possible.
- Verification of test cycle for the force instrument having automatic calibration capability (data acquisition) is possible.
- Exact force values of hardness scales to be calibrated are possible.
- Less time and manpower consuming procedure compared to the ordinary force calibration procedure is possible.

5. SUMMARY

Calibration of force measurement devices used for verification and calibration of hardness calibration and testing machines can be made very easily by making use of deadweight type hardness standard machines. Besides, if the force measurement instrument has a data acquisition software used to verify the measurement cycle also this software can be verified against the verified measurement cycle of the hardness standard machine. This calibration method can be applied at TÜBİTAK UME Hardness Laboratory for the range 3 kgf – 3000 kgf by making use of the recently developed deadweight type HSMs with very user-friendliness from design and automation point of view. The measurement results presented in this paper are preliminary ones and this method is still open to be improved.

6. REFERENCES

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