IMPROVEMENTS OF THE NATIONAL HARDNESS PRIMARY STANDARD MACHINE ON VICKERS SCALES

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Abstract – The present paper discusses the results of the research conducted during the improvement of the national hardness primary standard machine on Vickers scales. The improvement consisted in the creation of an automated complex for measuring the indentation diagonal length through the indentation transfer via a digital camera to the computer controlling the measurement process. The peculiarities scales of order were taken into account while examining the hardness primary standard machine and determining the metrological characteristics. The modernization of the national primary standard machine allowed to minimize measurement uncertainty, increase productivity and improve working conditions on the standard machine.

Keywords: hardness primary standard machine, Vickers scales COOMET regional key comparison

1. INTRODUCTION

The necessity to control the quality of metal products requires constant improvement of the ways to ensure the uniformity of metal hardness measurements on different scales [1], including Vickers scale, that is mainly used for testing high-hardness metals, light-gauge details or thin outer layers – cemented, nitrided, etc.

The national hardness primary standard machine on Vickers scales was developed, created and tested in FSUE "VNIIFTRI" by means of modifying the previous standard machine GET 31-79. HV values on Vickers scales, reproduced by the primary standard machine, range between 8 and 2000. Expanded standard uncertainty of the measurement results is no more than 3%, depending on the load and the hardness range.

During the primary standard machine improvement, special equipment and a new way to measure the indentation diagonal length were created instead of a microscope used for measuring the indentation diagonal. This way, the operator's error has been reduced to a minimum.

2. DESCRIPTION OF STANDARD AND ITS COMPOSITION

The national hardness primary standard machine on Vickers scales has been designed to reproduce Vickers scales and transfer them to working measuring instruments via reference hardness test blocks in order to ensure the uniformity of measurements. The national hardness primary standard machine consists of the following measuring devices:
-   dead-weight hardness standard machine with a set of special weights providing loads starting from 49,03; up to 980,7 H and a PMT-3 microscope with a nominal scale division of 0,3 and 1,2 μm;
-   dead-weight hardness standard machine with a set of special weights providing loads starting from 9,807; up to 98,07 H and a PMT-3 microscope with a nominal scale division of 0,2; 0,3; 1,2 μm;
-   dead-weight hardness standard machine with a set of special weights providing loads starting from 0,09807; up to 9,807 H and a microscope with a nominal scale division of 0,1 μm;
-   automated complex for measuring the indentation diagonal length comprising: a) NIKON D100 digital camera; b) adapter; c) personal computer with a set of special "VideoTest Size 5.0" software for image processing.

Constructive improvement of the standard machine lies in the following. Opto-mechanical adapter, designed

specifically for NIKON D100 digital camera, is installed instead of the PMT-3 microscope sensor head. With the help of an ocular, built into the opto-mechanical adapter, and the setting system of the microscope, the operator sets the system onto the surface of the hardness test block under examination. The beam splitter switches to the photographing mode. In real-time regime the indentation digital photo is transferred to the PC via USB interface. Shortly after that the indentation image appears on the PC in the window of NIKON D100 supporting software. It is then transferred to the field of the "VideoTest Size 5.0" program, where the indentation diagonal length is measured. Five special lenses are used in the work of the automated measuring subsystem. 70 – 90 % coverage of the digital photo surface by the indentation image serves as a criterion for effective lens use.

3. METROLOGICAL STUDY OF STANDARD

Basic quantities influencing hardness measurement uncertainty on Vickers scales are listed in Table 1.

Table 2 demonstrates the results of correction and measurement uncertainty calculations on the national hardness primary standard machine for a test block of 240 HV1. Guidelines [2] and [3] were taken as the calculation basis.

Table 1. Basic quantities contributing to measurement uncertainty.

Influencing quantity X_i	Symbol	Unit	Reference value	Maximum permissible deviation
Load	F	H	0,09807	5×10^{-4}
			0,4903 - 0,9807	5×10^{-3}
			1,9614 - 4,903	$7,5 \times 10^{-3}$
			9,807 - 49,03	1×10^{-2}
			98,07 - 294,3	$1,5 \times 10^{-2}$
			490,3	2×10^{-2}
			980,7	3×10^{-2}
Indentation diagonal length	D	mm	0,02…0,08	3×10^{-4}
			0,08…0,4	4×10^{-4}
			0,4…0,7	6×10^{-4}
Indenter plane angle	α	…^{o}	136°	1'
Tip radius	r	mm	0	5×10^{-4}
Length of line of junction	c	mm	0	5×10^{-4}

Table 2. Procedure of correction calculations ΔH and estimation of hardness measurement results expanded uncertainty $U(H)$

Influencing quantity X_i	Symbol	Unit	Value	Δx_i	s_i	a_i	$u^2(x_i)$	c_i	ΔH	$u^2(y_i)$	v_i	$u_i^4(y)/v_i$
Test force F	**F**	N	**9,81**	0,000		1,50E-02	7,5E-05	2,4E+01	0,0E+00	4,4E-02	8	2,5E-04
Indentation diagonal length	**d**	mm	**0,088**	0		0,0008	2,1E-07	5,5E+03	0,0E+00	6,5E+00	9	4,6E+00
Plane angle α	α	°	136	2,0E-02		0,01	3,3E-05	4,8E+01	9,7E-01	7,8E-02	10	6,0E-04
Tip radius Δr	r	mm		5,0E-04		1,0E-04	3,3E-09	-3,0E+03	-1,5E+00	3,0E-02	10	9,0E-05
Length of line of junction Δc	c	mm		5,0E-04		1,0E-04	3,3E-09	3,8E+03	1,9E+00	4,8E-02	10	2,3E-04
Total									**1,36**	6,7E+00		4,6E+00
Combined standard uncertainty $u(H)$										2,6E+00	v_{eff}	9
Confidence level										95%		
Coverage factor										2,3		
Expanded standard uncertainty $U(H)$										**5,8**	**HV**	
Expanded standard uncertainty $U(H)+I\Delta HI$										**7,2**	**HV**	
Relative Expanded standard uncertainty $U_{rel}(H)$										**3,0**	**%**	
Hardness		**238,8**	**HV**									

Where: X_i – quantities influencing hardness H measurement results, Δx_i – inherent error of the measured quantity X_i, C_i - sensitivity coefficients.

The results analysis shows that the biggest contribution to the combined uncertainty is made by the error of indentation diagonal length measurements.

Table 3 shows calibration results of hardness test blocks used in PTB-VNIIFTRI bilateral comparisons on Vickers scales within the framework of COOMET program.

Below is given an example of an alternative uncertainty calculation based on the fact that the analyzed metal hardness scales are the scales of order for which the application of arithmetic mean and root mean square deviations is inadequate. For these scales it is correct to use the median as the hardness measurement result. This method was introduced in paper [4] and was applied during the metrological research of the national Shore D scale hardness standard [5]. It is suggested to express the uncertainty for hardness scales through the repeatability R of hardness numbers from H_{min} to H_{max} , expanded up and down the scale by Δ_m uncertainty limits of the scale expression by the primary standard machine, i.e. from $H_{min}-\Delta_m$ to $H_{max}+\Delta_m$.

According to the findings of Table 3, for the test block of 238,8 HV1 we get $\Delta_m = |\Delta H| + R = 2,73+1,36=4,09$, and the hardness number 238,8 HV with an uncertainty HV from 234,7 to 242,9.

The results of uncertainty calculation that have been received differently are quite comparable. The half-range according to the second method of calculation should be close to 2 u_{bm} according to the first method, which is indeed the case $(242,9-234,7)/4=2,03\approx2,61$.

4. RESULTS OF INTERNATIONAL COMPARISONS

Metrological characteristics of the improved hardness primary standard machine were tested during two PTB/VNIIFTRI comparisons within the framework of COOMET program (PTB being the pilot). In these comparisons PTB served as a connecting institution with KCRV on Vickers scales, since it took part in CCM H-K1 key comparisons.

The comparisons were carried out on three sets of hardness test blocks for Vickers scales HV30, HV1 (comparison 1) and HV0,2 (comparison 2), each of which comprised three test blocks of 240 HV, 540 HV and 840 HV. The comparison results of the two institutes match well and are listed in Table 4.

Table 3. Results of uncertainty calculations of hardness test blocks calibration on the national hardness primary standard machine
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Test block average value, HV	Repeatability, R, HV	Primary hardness machine standard uncertainty u_m	RMSD of 8 measurements s_b	Uncertainty of test block calibration on primary standard machine $u_{bm}=\sqrt{u_m^2+s_b^2}$
249,2 HV 02	5,2	3,2	0,73	3,28
533,9 HV 02	3,6	7,7	0,62	7.7
846,5 HV 02	10,5	15,1	4,1	15,65
238,8 HV1	2,73	2,6	0,32	2,61
534,5 HV1	6,00	6,6	0,76	6,61
830,6 HV1	3,00	9,0	0,53	9,0
238,52 HV30	1,49	0,9	0,19	0,93
524,37 HV30	6,00	3,0	0,50	3,07
818,1 HV30	7,0	5,9	0,79	5,97

Table 4: Results of PTB-VNIIFTRI bilateral comparisons on Vickers scales HV 0,2; HV1; HV30

Test block hardness value	PTB values	PTB uncertainty	VNIIFTRI values	VNIIFTRI uncertainty	Difference (VNIIFTRI-PTB)
			HV		
240 HV 0,2	252,27	8,3	249,20	8,1	-3,07
240 HV1	244,06	7,5	238,80	7,2	-5,26
240 HV30	238,00	2,1	238,52	2,3	0 ,52

540 HV 0,2	540,63	16,2	533,93	21,2	-6,70
540 HV1	539,03	17,9	534,50	18,2	-4,53
540 HV30	522,89	6,9	524,38	9,2	1,49
840 HV 0,2	858,07	31,3	846,48	42,5	-11,59
840 HV1	831,49	30,1	830,63	25,3	-0,86
840 HV30	817,86	9,9	818,13	17,1	0,27

5. CONCLUSION

The improvement of the hardness primary standard machine has led to an increase in the accuracy of indentation diagonal length measurements, particularly within the ranges of 20-60 μm and 300-700 μm. The efficiency of hardness test blocks calibration has risen by five times. The operator influence on the results of test blocks calibration has been reduced to a minimum. The load range has been expanded from 9,807 H to 0,098 H. It has become possible to archive the most important measurements in form of indentation digital photos recorded on CDs.

PTB-VNIIFTRI comparison results on Vickers scales match well with the reference values obtained during CCM H-K1 key comparisons.

At the moment VNIIFTRI acts as a pilot in regional key comparisons of national hardness primary standard machines on Vickers and Brinell scales (comparison codes COOMET.M.H-K1.b and COOMET.M.H-K1.c).

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