ON EXPRESSION OF HARDNESS MEASUREMENTS RESULTS UNCERTAINTY

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Approach to hardness measurements data processing has been examined. The basis of this approach is that the scales of hardness are, in accordance with the general measurements theory, scales of order. The advantage of the method consists in the fact that it is more adequate and simple which is characteristic of hardness measurements as such.

In the modern production, the process of estimating the quality and reliability of metal products and other articles , control over technological processes in different branches of economy is closely connected with materials mechanical testing and, in particular, with hardness measurements. One can measure hardness of metals, plastic materials, minerals, rubber, wood particle boards, paint coatings. Hardness measurements are simple and highly productive, they make it possible to carry out testing without involving any special specimens, just on the surface of the article without violating its strength.

Hardness in general is a property of a material (solid body) to resist to indentation, deformation, penetration into it of any other solid body. Physical theories of solid body fail to describe hardness because of uncertain variety of factors which influence hardness of different materials. Moreover, in actual practice, different types of this property are used for different materials. That is why the notion of “hardness” without giving the measurements method and conditions is rather uncertain. When we speak about hardness we do not mean a physical constant, but one of the quantities measured with the help of one or another method and depending not on material only, but on the conditions and method of measurement. Numbers of hardness measured by different methods and under different conditions are different quantities. All these values, however, refer to non-Archimedes values [1], and according to measurements theory [2] they are described by the scales of order [3]. Non- Archimedes values differ from usual scalars in that way that the notion of proportionality cannot be applied to them, i.e. there is no possibility to obtain information about what times one quantity is bigger or smaller than another. The presence of non-Archimedes values is sometimes comprehended with difficulty because of the habit to deal with arithmetic and algebraic notions, that is why let’s give some additional explanations on a concrete example of metal hardness. Hardness measurements are widely spread in all industrially developed countries and are performed in compliance with standardized both internationally and in Russia [4] Rockwell, Brinell, Vickers and Shore D scales. The obtained as a result of measurements on the basis of these scales hardness numbers are non-Archimedes quantities. There is no doubt that there is a relationship between equivalence and order as hardness increases on a concrete scale. Experimentally within one and the same measurements method, we can establish that two samples of metal have either similar (equivalent within the limits of measurements uncertainty) hardness or that one specimen is harder than the other one. It is impossible, however, to establish in how many times one specimen is harder than the other one. Logical situation is connected with the fact that there is no natural and clear criterion of zero manifestation of hardness of metal, and without zero it is impossible to speak about proportionality. It is also impossible to establish equal intervals of hardness level on various scale parts experimentally. That is why it is said that the property of “hardness” possesses in principle unavoidable disproportionality. There is no reason to believe that such non-Archimedes values can be in this or that way transformed into usual scalar ones. Since there is no possibility to establish equality of hardness intervals, it is senseless to speak about hardness measurement units and to attribute units of measurement to hardness numbers.
Specification (a set of defining points) of any hardness scale consists of standardized description of all main technical and operational elements of the experimental procedure and the method of

processing and presentation of the obtained in the course of experiment data in the form of hardness numbers. The type of the measured hardness is fully determined by a part of scale specification, which refers to the experimental procedure. This experimental procedure shall be fully, without any deviations implemented for any hardness measurement, since any changes in it mean transition to another type of the measured quantity. And any changes in the mode of experimental data processing and presentation do not lead to any change of the measured quantity type. In this aspect, random monotonous transformations, i.e. transformations which preserve the order as hardness increases, are possible.

Statistics of arithmetical mean $\bar{x}$ of $x_1, x_2, \ldots, x_n$ values of hardness number for the tested sample

$$\bar{x} = \frac{1}{n}\sum_{i=1}^{n} x_i$$

is inadequate due to the lack of scales of order proportionality, because the ratio

$$\frac{1}{n}\sum_{i=1}^{n} x_i = \frac{1}{n}\sum_{i=1}^{n} \tilde{x}_i$$

is, generally speaking, violated during monotonous transformations of x_i into $\tilde{x}_i$. In this case, there is an adequate statistics in the form of a median [2]. That is why median, i.e. (k+1) value among n= (2k+1) values located in the increasing order (for example, the third from the five or semi-sum of the fourth and fifth from the eight values of hardness located in the increasing order, is taken as a result of the measurement for scales of order. In comparison with arithmetical mean, median is invariant in relation to possible monotonous non-linear transformations of scales of order.

Arithmetical mean statistics inadequacy and, consequently, square deviation for the scales of order predetermine non-application of the recommended [5,6] algorithms of measurement results uncertainty calculation to the results of hardness measurements using any standardized scale. It is more correct to express uncertainty for such scales by the difference between the biggest and smallest value of the measured value. This method of presentation of measurements accuracy for the scales of hardness has been traditional in full compliance with applicable standards for decades. It follows from what has been said that one has to recognize that the example of calculation of Rockwell C hardness measurement uncertainty in Annex H.6 to the Manual [6] is incorrect, and it was pointed out in [7].

Let's study the example of international comparison of national hardness standards of Czech Republic, Germany, Poland, Romania and Russia [8] and examine two cases of estimating the hardness measurements uncertainty of hardness block №28/98 using Rockwell C scale (the results of ten measurements performed at the state primary metal hardness standard on Rockwell and Super Rockwell scales GET 30-94 are given in the Table below). The first **case** undertaken by a pilot laboratory for comparison is based on the generally accepted uncertainty calculation program. The second **case** is based on the proposed in the present article concept proceeding from measurement scales theory. Further in the article, we shall replace the generally accepted symbol of hardness, which is HRC, by H which is shorter.

Case 1. Aggregate standard uncertainty of hardness block measurement on the national standard block is determined as:

$$u_C = \sqrt{u_A^2 + u_B^2}\ , \qquad (1)$$

where u_A is uncertainty of *A* type, u_B is uncertainty of *B* type.

Uncertainty of the results of arithmetical mean $\overline{H}$, estimated by *A* type is:

$$u_A = \sqrt{\frac{1}{n(n-1)}\sum_{i=1}^{n}(H_i - \overline{H})^2} \ , \qquad (2)$$

where $\overline{H} = \sum_{i=1}^{n} H_i / n$, H_i are quantities of hardness numbers, obtained as a result of a set of measurements.

B type uncertainty was determined by the formula:

$$u_B = \frac{\Delta}{\sqrt{3}} \ , \qquad (3)$$

where Δ is the borders of uncertainty of the reproduction of the scale by the national standard.

For the national primary standard (GET 30-94), Δ HRC = 0,25 (data sheet for this standard is based on its metrological study results).

The extended uncertainty is determined as

$$U = ku_C, \qquad (4)$$

Where k = 2 is coverage factor.

Table

№ of measurement	1	2	3	4	5	6	7	8	9	10
HRC hardness number quantity	29,02	29,02	28,58	28,58	29,0	28,86	28,59	28,64	28,58	28,74

Medium HRC standard block hardness:

$$\overline{H} = 28{,}76 \ ,$$

type *A* uncertainty:

$$u_A = 0{,}06 \ ,$$

type *B* uncertainty:

$$u_B = 0{,}25 / \sqrt{3} \ .$$

Aggregate standard uncertainty:

$$u_C = \sqrt{0{,}06^2 + \frac{0{,}25^2}{3}} = 0{,}16 .$$

Extended uncertainty:

$$U = 2u_C = 0{,}32 .$$

Case 2. In accordance with measurements data given in the Table, hardness number of hardness block determined by median is:

HRC = (28,90+28,86)/2=28,93.

Naturally, this quantity is a bit different from $\overline{H}$, calculated on the basis of **Case 1**. It is proposed to express uncertainty for hardness scales in the form of the difference between the quantities of hardness numbers from H_{min} to H_{max}, changed up and down the scale by Δ which is the border of uncertainty of reproduction of the scale by the standard, i.e. from H_{min}–Δ to H_{max}+Δ. By adding measurement data, we obtain uncertainty of measurement of HRC from (28,58 – 0,25) to (29,02 + 0,25). Thus, HRC hardness number for hardness block №28/98 is 28,93 with upper and lower uncertainty border being 28,33 and 29,27 respectively.

In conclusion we would like to stress that the results of hardness measurements uncertainty estimate obtained by these two different methods are comparable. A half of uncertainty interval of **Case 2** shall, in principle, be close to $3u_C$ of **Case 1**. And in reality it is exactly like this:

$$(29{,}27 – 28{,}33) / 6 = 0{,}157 \approx 0{,}16.$$

As distinguished from **Case 2**, however, the estimate of data uncertainty by a generally accepted method (**Case 1**) does not take into consideration the real nature of hardness measurement scale. Moreover, one of the main advantages of the proposed method is the fact that all data processing operations can be performed fast and easily, as hardness measurements themselves.

The proposed method of uncertainty expression, based on measurement scales theory was taken during metrological characteristics research and preparation of the documentation for the new state hardness standard for metals hardness on Shore D scale [9] and for the relevant verification schedule.

BIBLIOGRAPHY

1. Doinikov A.S. Measured properties “Measuring instruments 2002, (is prepared for publication).
2. Pfantsgal I. Theory of Measurements, Moscow, “Mir” publishing House, 1976
3. Doinikov A.S .Bryanskii L.N. Krupin B.N. Recommendations. State System for Provision of Integrated Measurements. Measurement Scales. Basic provisions. Terms and Definitions. MI 2365-96.
4. Aslanyan E.G. Provision of Integrated Hardness Measurements in Russia. First Scientific and Technical Conference “Metrological Support to Arms and Military Equipment Testing", 2002. p.p. 22-24.
5. Sebekin A.B., Slaev V.A., Chunovkina A.G., Chursin A.V. Recommendations. Рекомендация. State System for Provision of Integrated Measurements. Application of «Instructions for Expression of Measurements Uncertainty Expression». MI 2552-99.
6. Guide to the Expression of Uncertainty in Measurement: First Edition, ISO, Switzerland, 1995.
7. Doinikov A.A., Doinikov A.S. International Guide for Expression of Measurement Uncertainty. Foreign Radio Electronics. Achievements of Modern Radio Electronics, 2000, № 3, p.p. 44-53.
8. Hardness Measurement Intercomparison within COOMET. Final Report No 813-ZV-A003-01. Czech Metrology Institute, 2001.
9. Aslanyan E.G., Balakhanov M.V., Gusyatinskaya N.S., Doinikov A.S., Kozlov V.I.., Safarov N.A., Shlegel V.R. New State Primary Hardness Standard On Shore D Hardness Scale. Measuring Instruments, 2002, №3, p.p. 3-6.