

CONFIRMATION OF THE MEASUREMENT UNCERTAINTY ESTIMATION

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Abstract: The paper presents calculation of measurement uncertainty for measuring hardness by use of Vickers method based on ISO Guide to the Expression of Uncertainty in Measurement (GUM) and by method of Monte Carlo simulations (MCS). Finally, confirmation of correctness of measurement uncertainty calculation is obtained with participation in proficiency test.

Keywords: Vickers hardness, Measurement Uncertainty, Proficiency Test.

1. INTRODUCTION

Civil Engineering Institute of Croatia - IGH Zagreb has 19 testing laboratories from which 14 possesses accreditation according to HRN EN ISO/IEC 17025:1999. One of the accredited laboratories is Laboratory of Department for steel structures, that deals with testing of metal and non-metal materials by use of destructive, as well as non-destructive methods.

With procurement of accreditation for selected testing methods according to standard HRN EN ISO/IEC 17025:1999, the Laboratory took upon a commitment to calculate measurement uncertainties for testing results.

The paper presents calculation of measurement uncertainty for measuring hardness by use of Vickers method based on guidelines for calculation of measurement uncertainty - ISO Guide to the Expression of Uncertainty in Measurement (GUM). The value obtained by calculation is confirmed by method of Monte Carlo simulations (MCS method). The MCS method is based on random number generation from the probability density functions for each input value and forming of experimental probability density function of the output value.

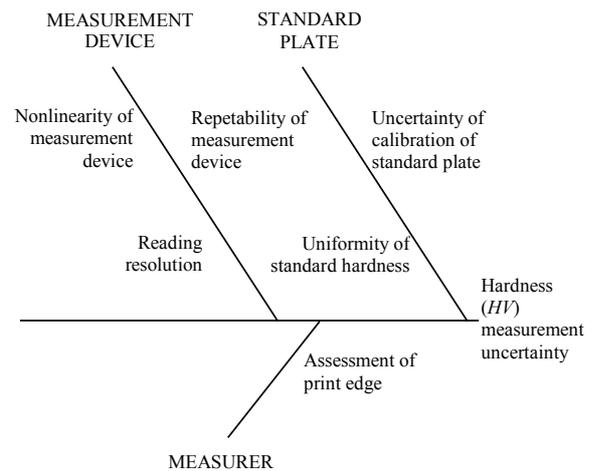
Finally, confirmation of correctness of measurement uncertainty calculation is obtained with participation of Laboratory in comparison measurement (proficiency test). For each laboratory, the organizer of proficiency test has expressed the value of measurement uncertainty based on comparison, as well as variation of the results for all participants in the comparison.

2. ANALYSIS OF INFLUENCING PARAMETERS

Measurement of hardness by use of Vickers method is based on the size of prism mark that is being pressed into

testing material by selected force. The length of diagonal of the prism mark determines hardness of testing material. Testing procedure is defined with Standard HRN EN ISO 6507-1:1999.

There is a series of quantities that influence on the uncertainty of measurement result. In order to define mathematical model of measurement, influencing quantities have been analyzed by use of Ishikawa diagram (Figure 1), providing that are taken those quantities that are considered to have the largest influence on uncertainty of the result, and



that can be numerically estimated or calculated.

Fig. 1. Ishikawa diagram

Calculation has been carried out through measurements performed on standard plate (tablet) (Type A evaluation of standard uncertainty) and by evaluation of Type B standard uncertainty.

Mathematical model represent the way of how influencing quantities influence on error of tested hardness. The error of tested hardness E_{HV} equals:

$$E_{HV} = HV - HV_s - \Delta_b - \Delta HV_{mjer} - \Delta HV_r - \Delta HV_R \quad (1)$$

Where:

- HV - Hardness value obtained by measurements on standard plate
- HV_s - Hardness value of the standard plate according to its certificate
- Δ_b - Standard plate hardness inequality

- ΔHV_{mjer} - Difference of measured hardness values caused by operators
 ΔHV_r - Difference of measured hardness values due to repeatability of the measuring device
 ΔHV_R - Difference of measured hardness values due to reproducibility of the measurement

HV hardness is being calculated according to expression (2):

$$HV = 0,102 \cdot [2F \sin(136^\circ / 2)] / d^2 \approx 0,1891F / d^2 \quad (2)$$

Where:

- F - Testing force, N
 d - Average length of the print's diagonal
 $D=(d_1+d_2)/2$, mm
 $d_1=a_1 \times 0,1 + b_1 \times 0,02$
 $d_2=a_2 \times 0,1 + b_2 \times 0,02$
 A - Number of full lines visible in microscope's eyepiece
 B - Readings on micrometers scale of the microscope

3. UNCERTAINTY BUDGET CALCULATION

3.1. Uncertainty of tested hardness on Standard Plate

In order to estimate values of measurement repeatability and reproducibility, measurement of hardness has been performed on standard plate with excellent uniformity of hardness. The force of pressing was equal to $F=49,02$ N (HV 5). Measurement was repeated five times (five prints).

Standard uncertainty of measured hardness has been calculated from the estimated standard deviation of hardness results obtained in five prints, as follows:

$$u(HV) = \frac{s(HV)}{\sqrt{5}} = 1,703 \text{ HV5}$$

3.2. Uncertainty caused by operators

Measurement of hardness has been performed on standard plate in five prints. Three operators have read each print.

Estimated standard deviation of measurement of the same print, by various operators, can be calculated from the expression for variance according to:

$$s_M^2 = \frac{\sum_1^N \nu_i \cdot s(M)_i^2}{\sum_1^N \nu_i} = \frac{\sum_1^N 2 \cdot s(M)_i^2}{\sum_1^N 2} = \frac{2 \sum_1^N s(M)_i^2}{5 \cdot 2} = 5,485$$

$$s_M = 2,342 \text{ HV5}$$

For five measuring sequences the number of degrees of freedom equals: $\nu=5-1=4$.

Student's t_{95} distribution factor for $\nu=4$ and $p=95\%$, equals 2,78. Follows:

$$u(\Delta HV_M) = \frac{2,342}{2,78} = 0,842 \text{ HV5}$$

3.3. Repeatability of measuring lines positioning

Positioning of measuring lines on the edges of print has been carried out in the eyepiece of measuring device, on one print, in five repeated measurements. Each time the length of the diagonal print has been read. For five measured values follows:

$$u(\Delta HV_r) = \frac{s(\Delta HV_r)}{\sqrt{5}} = 0,767 \text{ HV5}$$

3.4. Repeatability of hardness measuring results

Within regular annual calibration of measuring device – hardness tester, measurement of hardness on standard plate, in five prints, is performed. For assessment of the uncertainty budget calculation, results from last three years, on the same standard plate, have been taken.

Estimated standard deviation, due to measurement reproducibility, can be calculated from the expression for variance according to:

$$s_R^2 = \frac{\sum_1^N \nu_i \cdot s_i^2}{\sum_1^N \nu_i} = \frac{\sum_1^N 4 \cdot s_i^2}{\sum_1^N 4} = \frac{4 \sum_1^N s_i^2}{3 \cdot 4} = 6,183$$

$$s_R = 2,487 \text{ HV5}$$

For three measuring sequences, the number of degrees of freedom equals: $\nu=3-1=2$.

T distribution factor t_{95} for $\nu=2$ and $p=95\%$, equals 4,30. Follows:

$$u(\Delta HV_R) = \frac{s(\Delta HV_R)}{4,30} = 0,578 \text{ HV5}$$

3.5. Uncertainty of standard plate

For measuring purposes standard plate: MPA NRW 34238.1097 with hardness $235 \pm 3,0$ HV 5 have been used.

The plate has Calibration Certificate issued by DKD-K-02603 No. 97-10 year 1997.

In Calibration Certificate, calibration uncertainty of standard plate is expressed through relative repeatability. Relative repeatability is equal to:

$$r=0,3 \%, \quad r = \frac{\Delta HV_S}{235} = 0,003, \quad \Delta HV_S=0,705 \text{ HV5}$$

$$u(\Delta HV_S) = \frac{0,705}{\sqrt{3}} = 0,407 \text{ HV5}, \text{ with assumption of}$$

rectangular distribution.

3.6. Hardness dissipation of the standard plate

Hardness dissipation of the standard plate, according to Calibration Certificate, is equal to $\pm 3,0$ HV 5 expressed on the level of 2 sigma. Therefore, standard uncertainty of hardness dissipation equals:

$$u(\Delta_b) = \frac{3}{2} = 1,5 \text{ HV5}$$

3.7. Expanded measurement uncertainty

After calculation of every input quantity, along with their sensitivity coefficients, the value of standard uncertainty equals to:

$$u = 2,64 \text{ HV } 5$$

Expanded measurement uncertainty with probability of 95%, coverage factor $k=2$ equals:

$$U=5,3 \text{ HV } 5 \text{ or } U= 5,3 \text{ HV } 5/235 \text{ HV } 5 \text{ i.e.:}$$

$$U=2,3\%$$

4. MONTE CARLO METHOD

Calculation of measurement uncertainty for measuring hardness by use of Vickers method has been performed applying Monte Carlo simulations (MCS). MCS method is usable for calculation of measurement uncertainty as well as for validation of the results obtained by GUM procedure, and especially, for determination of the interval for specific (given) probability P . In this paper the estimation of measurement uncertainty by MCS method was performed by use of MathCad program. Probability density function of the output quantity was obtained by convolution of input quantities distribution and use of $M = 100000$ simulations.

Probability density function of the output quantity E_{HV} has been simulated by use of MCS method, according to expression (1). Input quantities x_i are defined with probability density functions $g(x_i)$ shown in Table 1.

Table 1. Input quantities and probability density function in simulation of E_{HV} quantity.

Input quantities x_i		Probability density function $g(x_i)$
Influence of measured hardness on standard plate	HV	Normal distribution (M; 0 HV 5; 1,703 HV 5)
Influence of calibration of standard plate	HV_S	Rectangular distribution (M; -0,705 HV 5; 0,705 HV 5)
Influence of hardness dissipation of standard plate	Δ_b	Normal distribution (M; 0 HV 5; 1,500 HV 5)
Influence of operators	ΔHV_{mjer}	Normal distribution (M; 0 HV 5; 0,842 HV 5)
Influence of measurement result repeatability	ΔHV_r	Normal distribution (M; 0 HV 5; 0,767 HV 5)
Influence of measurement result reproducibility	ΔHV_R	Normal distribution (M; 0 HV 5; 0,578 HV 5)

Probability density function of the output quantity E_{HV} is shown in Figure 2.

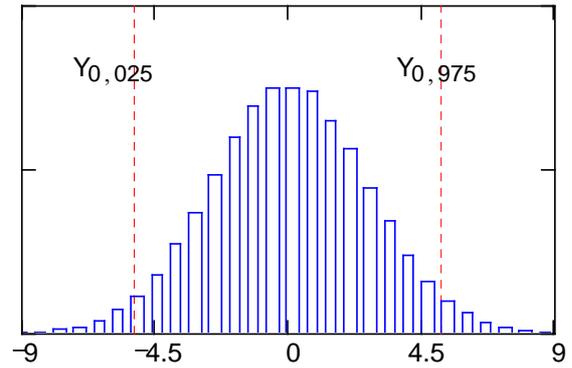


Fig. 2. Density distribution function $g(E_{HV})$

Estimated standard deviation of the output quantity E_{HV} equals 2,638 HV 5. Output quantity E_{HV} lies within the interval:

$$(Y_{0,025} = -5,16 \text{ HV } 5; Y_{0,975} = 5,20 \text{ HV } 5) \text{ with } P = 95\%.$$

Expanded measurement uncertainty estimated by MCS method equals:

$$U = 5,2 \text{ HV } 5; k = 2; P = 95\%$$

Hereby, the result of measurement uncertainty obtained by means of GUM method has been confirmed, as well as normal distributions for output quantities E .

5. PROFICIENCY TEST

Laboratory of Department for steel structures IGH applied for participation on international comparison measurement (Proficiency Test) of hardness by use of Vickers method HV 1 and HV10, in March 2004. Proficiency Test was organized by Institut für Eignungsprüfung, Herten, Germany. 93 laboratories from 21 states have participated in Proficiency Test.

The organizer of the Proficiency Test has estimated, for every laboratory, value of expanded measurement uncertainty of result based on testing results. Estimation of uncertainty for HV 10 result was equal to 2,65% that matches with uncertainties obtained by GUM and MCS methods (the same object glass have been used for purpose of testing HV 5 and HV 10 – enlargement 100×).

Estimation of uncertainty for HV 1 result was equal to 9,45%. The size of HV 1 hardness result print is rather small, therefore the reading uncertainty with the same object glass as in measurements of HV 10 is remarkably major. Based on that experience, Laboratory has as corrective action purchase object glass with greater enlargement (500X).

6. CONCLUSION

To estimate measurement uncertainty, first step is definition of mathematical model that represent the measurand on the best way, as expression of each influence separately.

Does that model describes measurand good enough, and are all relevant influences included in procedure of

uncertainty calculation, cannot be known solely by repeating and reproducing measurement results within laboratory.

The only way to verify and confirm expressed measurement uncertainties is through participation in comparison measurements with other laboratories.

Based on accomplished results, for HV 10 hardness, it can be found great compatibility between given value of measurement uncertainty expressed by organizer of the Proficiency Test and values of uncertainty that arise from uncertainty calculation made by IGH Laboratory.

On the other hand, comparison of HV 1 hardness has pointed out relatively great difference between estimated and realized measurement uncertainties.

Based on that experience, Laboratory took corrective actions in order to decrease measurement uncertainty in measurement of HV 1 hardness.

Confirmation of expressed measurement uncertainty can be verified in the following comparison measurement.

REFERENCES

- [1] BIPM, IEC, IFCC, ISO, IUPAC, IUPAP, OIML, Guide to the Expression of Uncertainty in Measurement, 1995.
- [2] V.Mudronja, B.Runje, Z.Baršić, "Reproducibility of Measurement Results of Gauge Blocks over a Period of 15 Years V, Proceedings of the XVI IMEKO World Congress, Volume V, TC-7, TC-8, TC-11, Vienna, Austria, 2000. pp. 277-280.
- [3] COX, M.; HARRIS, P.: The planned supplemental guide to the GUM: Numerical Methods for Propagation Distributions, Euromet Length Workshop, Oct 2001.
- [4] ISO/DGuide 99998, Guide to the Expression of Uncertainty in Measurement (GUM) – Supplement 1: Numerical Methods for the Propagation of Distributions, September 2004.
- [5] Z.Baršić, B.Runje, G.Baršić: "Estimation of measurement uncertainty for measuring hardness by use of Vickers method", Proceedings of International symposium: Competence of laboratories-CROLAB, Cavtat, Croatia, November 2005.