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PROCEDURE FOR QUANTIFICATION THE MEASUREMENT UNCERTAINTY IN DETERMINING PROCESS OF TENSILE STRENGTH

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Abstract

This paper presents the measurement uncertainty analysis procedure during laboratory tests, using the example of determining the tensile strength of wire from steel ropes for the haulage facilities in mining. Assessment of measurement uncertainty is one of the basic requirements of the SRPS ISO/IEC 17025:2017 standard for accredited laboratories. To this end, the measurement quantities and identification the cause of uncertainty during test were defined, then the measurement uncertainty quantification for each source individually, and finally calculation the total and extended measurement uncertainty.

Keywords: *uncertainty in measurement, tensile strength, steel wire, ropes for haulage facilities in mining*

1. INTRODUCTION

In general, when making a measurement of any kind, one thing is certain, the measurement result will never be accurate. Even with the best equipment use in the laboratories, there will always be a measurement error. The measurement error could be defined as the difference between the measured and actual quantitative value. The Standard ISO/IEC Guide 99-2007 introduces the term reference value and defines the measurement error as the difference between the measured value and reference value. Generally, in practice, the measurement error is unknown. The measurement uncertainty is given as a quantitative indicator of the measurement results.

The measurement uncertainty is an estimate of the characteristic range of values in which the actual value is located and it would be one of definitions the measurement uncertainty. When issuing a report of measurement results of any size, it is mandatory that some quantitative indicator the quality of result is given, so that those who use it can assess its reliability. Without such an indication, the measurement results cannot be compared, either with each other or reference values given by the specification or standard.

The aim of this paper is to summarize the basic concepts related to the measurement uncertainty and procedure for its analysis, considering that the analysis of measurement uncertainty is one of the explicit requirements of the Standard SRPS ISI/IEC 17025:2017 for accredited laboratories, which, among other things, deal with the testing of steel ropes for the haulage facilities in mining, elevators, cable cars, etc. Metallic Materials, Tensile Testing, Part 1: The room temperature test method is a standard test method that requires the use of CWA 15261-2:2005 - Uncertainty of Measurement in Mechanical Testing of Metallic Materials, Part 2: Evaluation of Uncertainty in Tensile Testing.

2. EXPERIMENTAL

In the process of assessing the measurement uncertainty when determining the tensile strength, a steel rope of construction 18x7+FC for the haulage facilities in mining of the company Serbia Zijin Mining d.o.o., was used. Bor. In order to obtain the adequate samples for testing, a suitable length of rope was cut and the wires were unraveled. After degreasing and marking, wires of the same nominal diameter were mixed well and eight samples were randomly selected. The initial diameters of wires were measured and the mean value of diameter was determined representing the best indicator for the available number of measurements, as shown in Table 1.

Table 1. *Statistical processing the experimental results of tensile strength tests*

No. of samples	Wire diameter, d_o (mm)	Breaking force, Fm (N)	Tensile strength, Rm (N/mm^2)
1	1.98	5253	1706
2	1.98	5259	1708
3	1.98	5268	1711
4	1.98	5265	1710
5	1.98	5256	1707
6	1.99	5259	1691
7	1.99	5249	1688
8	1.99	5253	1689
$\overline{X}$	1.98375	5252.875	1699.625
STDEV	0.005175492	18.122	13.07055
RSD %	0.26	0.344	0.769

3. RESULTS AND DISCUSSION

Determination of measurement uncertainty is achieved through the four necessary steps: specification of measurement quantities, identification of all sources of uncertainty during testing, quantification of uncertainty components and calculation the total and expanded measurement uncertainty.

The specification of measured quantities implies their identification and listing, as well as a connection between them, and parameters on which they depend.

Identification the uncertainty sources involves making a list of possible sources of measurement uncertainty during testing. For this step, a good knowledge on measuring equipment, test method, as well as its practical application is necessary. Typical sources of measurement uncertainty are: the effect of an instrument - the precision of instrument used, uncertainty of the reference material, uncertainty from the point of view of systematic errors of operator when reading analog instruments, variations of the measured value during repeated measurements under the same conditions, etc.

The contribution from each source of measurement uncertainty is expressed through the value of standard deviation, which is calculated on the basis of the type of distribution the measurement quantity. The basic types of distribution used to estimate the value of standard deviation are: rectangular, triangular and normal distribution. The normal distribution is used if the assessment is based on repeated tests, and on the basis of random variables, when the measurement uncertainty is equal to the value of standard deviation S(x), as it is in this case.

Input quantities that are determined from a series of repeated measurements have a measurement uncertainty of type A, labeled $u_A(x)$, which represents a dispersion of the results through the values of experimentally determined standard deviation and it is calculated as:

$$u_A(x) = S(x) = \sqrt{\frac{1}{n-1}\sum_{i=1}^{n}(x_i - \bar{x})^2} \tag{1}$$

In the case of direct measurements, as it is the case in this paper, the total measurement uncertainty, labeled $u_C(x)$, is the standard uncertainty of the result that was created from the sum of several different values and it is calculated as the square root of the sum of variances of all identified contributions:

$$u_C(x) = \sqrt{u_A(x)^2 + u_B(x)^2} \tag{2}$$

Where: $u_B(x)^2$ measurement uncertainty obtained on the basis of measurement data

For individual measurements, it is necessary to express the extended measurement uncertainty U, which defines the interval around the result of one measurement, which can be attributed to the measured value. It is calculated as follows:

$$U = k\, u_C(x) \tag{3}$$

where k is a coverage factor that represents a value that depends on the type of distribution and level of acceptance. For an acceptance level of 95% and normal distribution, k = 2 is valid.

As an illustration of the measurement uncertainty analysis procedure, this paper shows the example of determining the tensile strength of wire from the steel ropes according to the requirements of the Standard CWA 15261:2005.

The tensile strength of the steel wire is determined by a calculation that takes into account directly measured values, or a combination of directly measured values and calculated values of certain sizes.

The dimension that is directly measured is: d_0 - initial diameter of steel wire (mm).

The quantities arrived at by calculation are: S_0 – cross-sectional area of wire, $S_0 = d_0^2\pi/4$ (mm), and Rm – tensile strength of wire, $Rm = Fm/S_0$ (N/mm^2).

It can be seen from Table 1cthat the mean value of the measured wire diameters is $x_{sr} = 1.98375$ (mm).

The standard deviation, according to formula (1), is $S_x = 0.005175492$ (mm).

The standard uncertainty corresponding to the standard deviations of mean value has the value of $U_{d_0 sr} = 0.001976$ (mm).

The measurement uncertainty of the gauge used for measurements is $U_{mk} = 0.00235$ (mm) (value taken from the Certificate of calibration of the gauge).

Further, the measurement uncertainty of measurement the initial diameter of wire is calculated according to formula 4:

$$U_{d_0} = \sqrt{U_{d_0 sr}^2 + U_{mk}^2} \quad \text{mm} \tag{4}$$

and has the value of 0.0031 mm.

The measurement uncertainty when determining the initial cross-sectional area of steel wire is determined from formula 5 and has value of 0.0096 mm^2:

$$U_{S_0} = \sqrt{\frac{d_0^2\bar{u}^2}{4} U_{d_0}^2} = 0.0096\ \text{mm}^2 \tag{5}$$

So, in the end, there is the calculation of combined measurement uncertainty of tensile strength according to formula 6:

$$U_{R_m} = \sqrt{\left(\frac{1}{S_0}\right)^2 U_{Fm}^2 + \left(\frac{F_m}{S_0^2}\right)^2 U_{S_0}^2} \ \mathrm{N/mm^2} \quad (6)$$

where, F_m – maximum breaking force, and U_{F_m}– standard uncertainty of the measurement uncertainty of force and the value is taken from the Certificate of calibration the tensile testing device.

By substituting the corresponding values in formula, the value for combined measurement uncertainty of tensile strength of steel wire is obtained, which is 6.1 N/mm^2.

The expanded measurement uncertainty of tensile strength in the steel wire tension test is calculated by formula 7:

$$U = 2 \cdot u_C(x) = 2 \cdot 6{,}1 = 12.2 \ \mathrm{N/mm^2} \quad (7)$$

Therefore, the interval in which the greater part of distribution the tensile strength, which can be expected during tensioning of steel wire, is expressed by the final result of measurement: $R_m \pm U \left(\frac{N}{mm2}\right)$; $R_m = 1699.625 \pm 12.2 \ \mathrm{N/mm^2}$.

4. CONCLUSION

The measurement uncertainty assessment procedure is a complex process. However, the once estimated measurement uncertainty for one test method and sample type can be applied to all further tests that are carried out according to this procedure in the Materials Testing Laboratory, Mining and Metallurgy Institute Bor. In addition to satisfying one of the basic requirements of the Standard SRPS ISO/IEC 17025, determining the size of contribution the individual sources of uncertainty to the variation of final result is an important source of information when modifying the method in order to further reduce the measurement uncertainty.

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