EVALUATION OF THE CHARPY IMPACT MACHINE CALIBRATION DATA IN THE TESTING LABORATORIES

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Abstract

This work deals with the proposal for the new evaluation system of calibration data in the VÍTKOVICE STEEL Testing laboratories. The main purpose of this work is the best possible use of the information obtained during regular calibrations of Charpy impact machine performed according to standard ČSN EN ISO 148-2:2010 - Metallic materials - Charpy pendulum impact test - Part 2: Verification of testing machines, and ASTM E23 - 16 Standard test methods for notched bar impact testing of metallic materials. The results of a direct calibration of geometric properties of Charpy impact machine, as well as the results of indirect calibration obtained by testing of prepared etalons will be taken into consideration.

Keywords: Calibration, Charpy impact machine, etalon, testing laboratories

1. INTRODUCTION

The manufacturer of the product guarantees the declared quality of his product or service not only within the warranty period according to the legislation, but also morally is responsible for ensuring that the product will serve as long as possible for its determination to meet the customer's requirements to the maximum extent possible. In the case of a metallurgical companies, quality characteristic are not only dimensional parameters but also physical properties of steel alloys, such as: hardness, tensile strength, compressive strength, impact strength, extension, elasticity and plasticity. In order for the manufacturer to declare the correct values of these properties for each batch of products, they must be subject to different evaluations. To ensure that the tests were carried out correctly and independently according to the standards under defined fixed conditions and the interpretation of the results of these materials tests (e.g. steel, iron, aluminium and others) has been objectively and correctly understood, the tests are carried out in accredited testing laboratories equipped with appropriate test Machines serviced by experienced staff. Steel tests can be carried out non-destructively where there is no permanent change in the shape, chemical composition or structure of the steel material (microscopy, ultrasonic defectoscopy, radiological tests) [1].

The second options are destructive tests, which leads to permanent degradation of samples. These tests are carried out to test the mechanical properties of steel, which include, in particular, elasticity; strength; hardness; formability; toughness. Each test should be performed independently and should be completed by the test report [2].

2. CALIBRATION AND UNCERTAINTY

If a test laboratory wants to be successful on the market, it must demonstrate that it is acceptable to customers. Such laboratory must be at least accredited according to ISO / IEC 17025. This standard requires an evaluation of measurement uncertainty during calibration of any measurement or control device. Calibration must be repeated at appropriate intervals. These intervals, referred to as recalibration periods, are determined by the requirements (standards, customer) or chosen by the testing laboratory itself. The methods for determining the recalibration period are based on statistical processing of measurement errors, random error or absolute values, and comparison with standard deviations of already performed calibrations. These methods focus on time-based errors, ie, to detect dependence of error values over a long period of time and display them

graphically using a calibration curve [3]. The aim of the calibration is also to confirm that the target value of measurement uncertainty can be achieved. Target value can be defined by a standard, customer, or the laboratory itself. Measurement uncertainty is therefore a parameter associated to the measurement result that characterizes the range of values in which the true value (with defined probability) of the measured characteristic lies. There are 4 types of measurement uncertainties totally that are generally labelled u. Type A uncertainty is affected only by the random variables. Its calculation results from a statistical analysis [4]:

$$u(x_i) = s_g = \sqrt{\frac{\sum_{i=1}^{n}(x_i - \bar{x})^2}{n-1}} \quad (1)$$

Type B uncertainty is an expert estimate derived from available information and experience. The most frequent used information is:

- gauge manufacturer's data,
- experience from previous measurements,
- experience with the properties of the used materials and techniques,
- data obtained from certificates,
- the uncertainties of the reference materials and the uncertainty of the standard.

Type C uncertainty is a combined standard uncertainty of measurement obtained by combining Type A and type B uncertainty [15]:

$$u(y) = \sqrt{\sum_{i=1}^{n} u(x_i)^2} = \sqrt{u(x_1)^2 + u(x_2)^2 + u(x_3)^2 + \ldots} \quad (2)$$

Extended uncertainty (type D) is the combined standard uncertainty multiplied by the coefficient k. For Normal distribution, the most commonly used value is k = 2, which represents a 95%confidence interval.

VÍTKOVICE TESTING CENTER Ltd. provides comprehensive services in the field of materials testing and gauges calibration. These laboratories test the mechanical and technological properties of steel, alloys and non-ferrous metals and provide other special services according to customer requirements and regulations. These are e.g. tensile tests, impact tests, bend tests, hardness tests, weld metal bend tests, and DWTT etc.

Figure 1 PH Version CHV 200 Charpy hammer

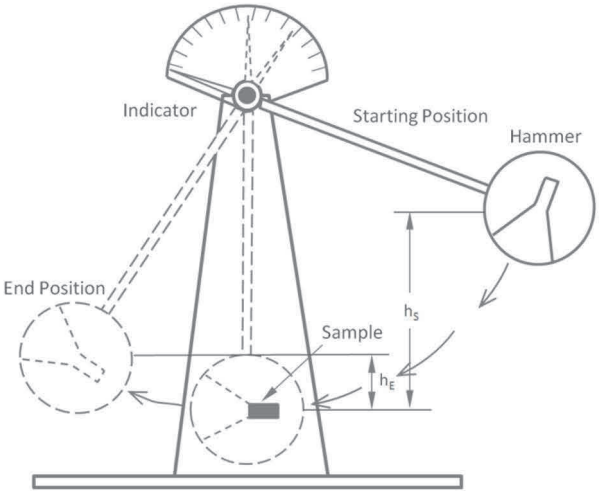

Figure 2 Charpy hammer testing principle

Calibration of the "Pendulum Impact Testing Machine" or Charpy Hammer (**Figure 1** and **Figure 2**) is carried out once a year - according to standard EN ISO 148-2: 2010 " Metallic materials - Charpy pendulum impact

test - Part 2: Verification of testing machines " and according to the American Standard ASTM E23 - 16b" Standard Test Methods for Notched Bar Impact Testing of Metallic Materials " [5].

Direct calibration is realized, consisting of measurement of geometric values and evaluation of the physical properties of parts of the test equipment, and indirect calibration during which a set of etalons prepared according to the above standards for a given type of testing. These etalons must be prepared to cover the entire testing range of the Charpy hammer (0 - 400 J). In the first part a direct calibration is performed. The following geometric characteristics of the device are measured and calculated (**Table 1**)

Table 1 Calibration data evaluated on the Pendulum Impact Testing Machine

Input variables	Output variables	Other variables
Force F developed by a pendulum	The values of absorbed energy KV_n	Deviations between the calculated energy Kcalc and the indicated energy KS.
The distance L_2	Repeatability b	Extended uncertainty U
Angle α of pendulum fall	Systematic error B_v	The probability of random error
Initial potential energy K_p		
Pendulum speed v		
The distance L_1		
Total friction losses		
Absorption power error K_s		

Table 2 Table of absorption power error Ks

Calibration date Cal. List No.	**Table B: Absorption power error Ks**					
16.8.2012	Scale value [J]	45	90	180	225	270
	Deviation [J]	-1.8	-2.078	-1.78	-1.949	-1.337
	Uncertainty U [%]	0.5	0.6	0.6	0.8	0.6
3.1.2013 001-13	Identified K_S [J]	44.9	88.7	133.1	222.7	315.9
	Calculated K_{CALC} [J]	45.09	88.9	134.2	223.7	316.9
	Deviation [J]	-0.19	-0.2	-1.1	-1	-1
	Extended uncertainty U [J]	0.88	1.6	1.8	1.9	1.7
⋮	⋮	. . .	. . .	⋮	⋮	⋮
14.12.2015 489-15	Identified KS [J]	55	93	138	228	310
	Calculated K_{CALC} [J]	55.2	92.6	138.2	228.4	312.6
	Deviation [J]	-0.2	0.4	-0.2	-0.4	-2.6
	Extended uncertainty U [J]	1.7	1.7	1.6	1.4	1.1
12.12.2016 595-16	Identified KS [J]	55	93	138	228	310
	Calculated K_{CALC} [J]	55.4	92.8	138.3	228.6	312.6
	Deviation [J]	-0.4	0.2	-0.3	-0.6	-2.6
	Extended uncertainty U [J]	2	1.9	1.9	1.8	1.9

3. CALIBRATION DATA EVALUATION PROPOSAL

Immediately after each calibration or during the calibration, the lab staff will record the values of the monitored variables into the prepared electronic form (**Table 2**).

For easier orientation, are the calibration data tables designed to be as similar as possible to the tables in the calibration sheets. We assume that easy orientation will reduce the risk of wrong data recording. Based on these tables, it is possible to evaluate the calibration data. Validation of the hypothesis whether are the calibration data normally distributed is an important and necessary part of the analysis that will first be subjected to input and output variables (**Figure 3**) [6]. It is also important to identify outliers using a box and whisker plot (**Figure 4**).

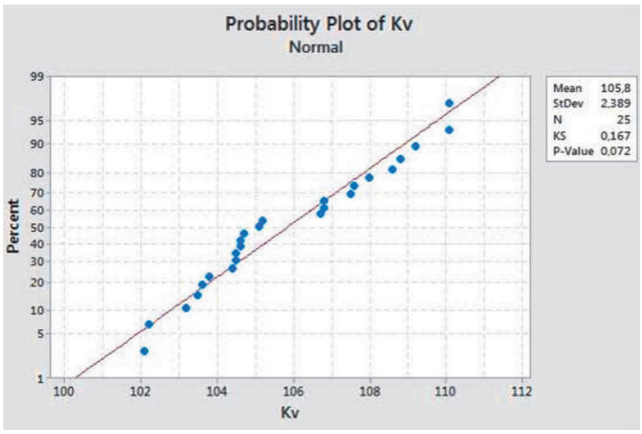

Figure 3 Normality test for Kv

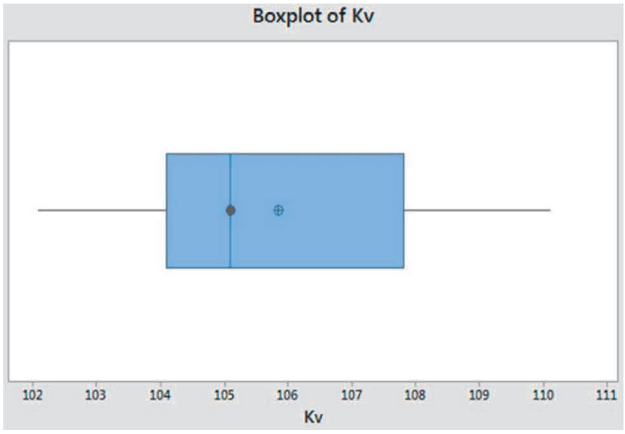

Figure 4 Homogeneity test for Kv

In the calibration process, we must consider not only a simple linear regression in which one independent variable X and one dependent response variable Y are defined. But we also have to take into consideration the multiple linear regression model with regression function:

$$Y = \beta_0 + \beta_1 x_1 + \beta_2 x_2 + \cdots + \beta_n x_n + \varepsilon \tag{3}$$

An important use of a regression model is the prediction of future observations. For the value predictions are used very complex formulas that depend on the regression model found [7]. Therefore, predictions using exponential time series smoothing will be used for these purposes. Theoretical prediction values $\hat{Y}_t$ and actually observed values Y_t are recorded in the line graph in the form of two separate lines (**Figure 5**).

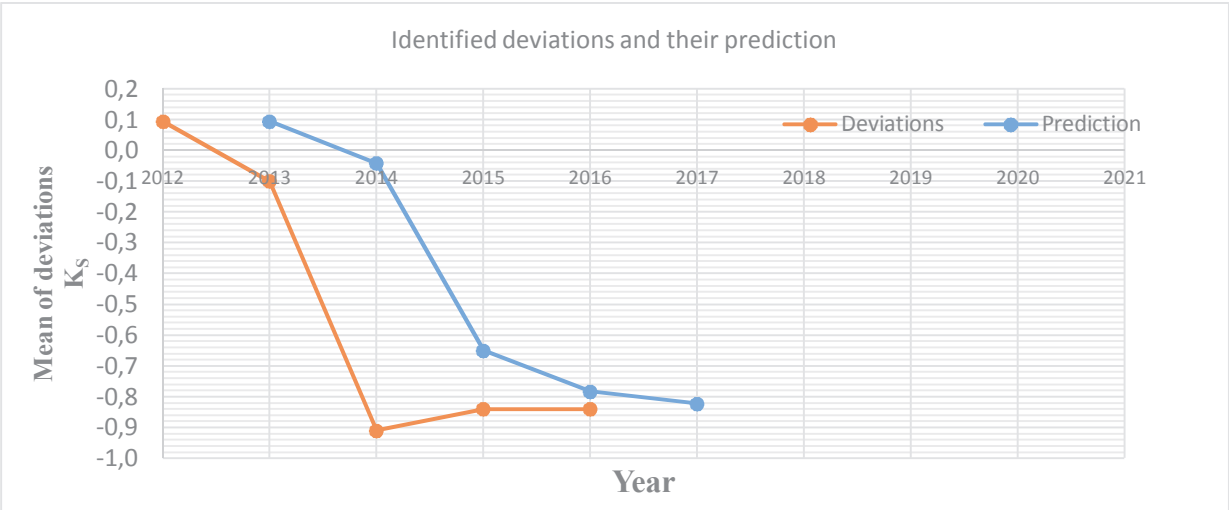

Figure 5 Prediction of absorption power error Ks values

4. MEASUREMENT SYSTEM STATISTICAL PROPERTIES EVALUATION

The effects of measurement errors and the extent of their impact can be detected and quantified [8]. The basis of the measurement system represents the difference between the mean of the repeated measurements of the same quality characteristic and the reference value. According to the calibration method, bias can be evaluated from indirect evaluation, where 5 repeated measurement results are obtained (**Table 3**). Before the any statistical property evaluation, the exploratory data analysis should be performed.

Table 3 Bias evaluation

Calibration date:	19.1.2013	3.1.2014	19.12.2014	14.12.2015	12.12.2016
Mean:	104.62	106.86	106.92	105.44	105.4
Bias B_i:	2.72	4.96	5.02	3.54	3.5
St. dev:	3.14	2.14	2.87	1.20	2.25
Lower conf. limit:	-1.184	2.290	1.451	2.049	0.692
Upper conf. limit:	6.624	7.629	8.588	5.030	6.307
Bias evaluation:	**Not significant**	**Significant**	**Significant**	**Significant**	**Significant**

The measurement system linearity study, which expresses the difference between the biases in the assumed operating range of the measurement system, proceeds in a similar way, as in the case of bias study [9]. In order to evaluate whether the linearity varies depending on the magnitude of the measured value, it is necessary to perform repeated measurements on several samples (standards) covering the assumed testing range. Evaluation of measurement system linearity should be carried out in the following steps:

- Calculation of deviations from the reference value,
- Calculation of the measurement system bias for individual samples,
- Construction of a scatterplot of dependencies between deviation from mean and reference value,
- Calculation of regression function,
- Testing the statistical significance of the regression coefficient graphically and using confidence intervals (**Figure 6**).

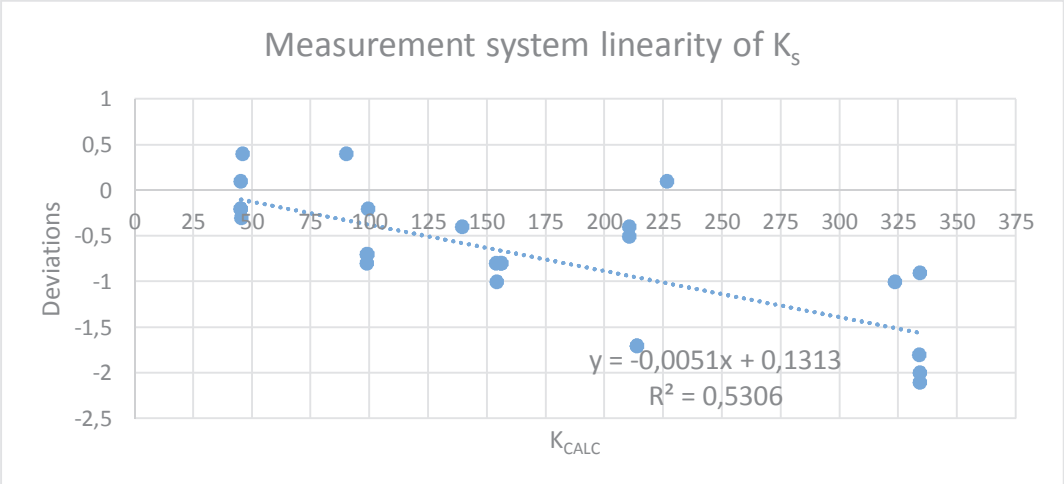

Figure 6 Measurement system linearity of absorption power error K_s

If the confidence intervals contain zero, then it can be assumed that the linearity of the measurement system is not statistically significant.

Depending on the shape of the regression line and the Determination Index value, it can be argued that there is a significant dependence between deviations and reference values. With increasing reference value, the magnitude of deviations in negative values is increasing.

5. CONCLUSION

The measured data are an essential basis for important decisions, such as product quality control, processes regulation, assessing the effectiveness of corrective actions and implementing improvement activities [10]. It can be stated that the introduction of statistical methods for the evaluation of calibration data is suitable for Vítkovice Steel testing centre. However, their use requires the development of an internal document which will set out how the activities will be carried out, their timing, responsibilities and required knowledge of laboratory staff. Expert approach, correct use of the information obtained from the evaluation as well as a responsible approach to continuous improvement will bring the expected benefits and will be reflected mainly on the market.

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