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ANALYSIS OF DEVIATION IN THE MEASUREMENT OF VIBRATIONS

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Abstract

In order to achieve relevant and exact value in measurement of vibrations, it is necessary to add the corresponding value of deviation to the result of measurement. As the topic of determining the deviation is too complex and the scope of article is limited, we focus on the characteristic features and mathematical description of the basic types of deviations and some partial deviations which should betaken into account in measurement.

Key words

deviation, analysis, sources

INTRODUCTION

Deviation is reflected into the whole system of measurement of vibrations. The goal of any measurement, including the measurement of vibrations, is to objectively discover the real state of vibration emission of the measured object by measuring and subsequent calculating the respective determining quantities.

As in the other fields of technical measurement, we can also assume that the measurement will be not perfectly correct. Actually, the result of measurement is burdened by certain errors regulated by deviation of measurement. We can state that all errors become a source of deviation.

Deviation of measurement can be defined as a parameter which embraces the result of measurement and which gives interval values around the result of measurement, in which there is certain probability of presence of the right value of measured quantity.

DETERMINATION OF STANDARD DEVIATION IN THE MEASUREMENT

Deviation of measurement is a non-negative parameter which defines dispersion of the quantity values assigned to the measured quantity based on applied information.

"The basic (quantitative) feature of deviation is the standard deviation *u,* defined as the value of standard deviation" (1).

The corresponding deviation in general referred to as *u(y)* value of result quantity y, is determined from the summation of squared numbers of *m* components according to the basic relation which is known as the principle of propagation deviation.

$$u^2(y) = \sum_{j}^{m} A_j^2 * u^2(x_j) \,, \qquad [1]$$

where $u(x_j)$ are individual components of deviation,
A_j is coefficient of sensitivity of corresponding source.

It is a relation where transition of the standard input deviation of relevant model of measurement is transmitted into output quantities.
Then the output quantity *y* within the corresponding model of measurement is defined by the formula: (1)

$$y = f(x_1, x_2, \ldots., x_j, \ldots, x_k, \ldots. x_m) = f(x). \qquad [2]$$

In case that value of coefficient A_i is not known, it is determined as the partial derivate of function [2] according to the relevant input quantity x_i.

$$A_j = \frac{\partial y}{\partial x_j} = \frac{\partial f(x_1, x_2, \ldots\ldots x_m)}{\partial x_j}. \qquad [3]$$

Based on the shown findings, it is possible to mark relation [1] as general or so called the covariance principle of propagation of deviation (1).
The individual deviation consists of partial deviations that, according to the method of determination, can be divided into two basic groups:

- deviations which are determined by the method of type A,
- deviations which are determined by the method of type B (2).

DETERMINATION OF DEVIATION OF TYPE A

The method of this deviation type is based on the statistical analysis of a series of repeated measurement.

We assume that these measurements are independent on each other and carried out under the same conditions. In such measurement, *n* measured data is achieved, so x_1, x_2,..........x_j,........x_n, which are the result of measurement of the one parameter are statistically independent. The resulting value will be represented by the arithmetical average.

$$\bar{x} = \frac{1}{n}\sum_{i=1}^{n} x_i \text{ ,[4]}$$

where $\bar{x}$ is the sample average (2).

The standard deviation of type A of this result is marked $u_A(x)$ and is equal to the standard deviation of arithmetic or sample average S_x and is defined by the formula:

$$u_A(x) = s_{\bar{x}} = \frac{s_x}{\sqrt{n}} = \sqrt{\frac{1}{n(n-1)}\sum_{i=1}^{n}\left(x_i - \bar{x}\right)^2} \text{ .} \qquad [5]$$

In order to evaluate the deviation of type A, $n \geq 10$ measurement must be a true. Characteristic for this deviation is that the values with increasing number of repeated measurements are decreasing (2).

DETERMINATION OF DEVIATION OF TYPE B

The calculation of deviation of type B is therefore related to the known identifiable and quantifiable error sources. Therefore, it is important not to ignore the resources that can significantly affect the value of deviation u_B. In terms of physical measurements, identifiable and quantifiable components affecting the u_B include:

- characteristics of the used measuring instruments,
- properties of the used calibration instruments,
- measurement methods and procedures,
- effects caused by the conditions of measurement,
- environmental conditions.

Determination of deviation of the type B is therefore based on the determination of partial uncertainties of individual sources $u_{B,j}$. Estimation of fractional deviation taking into account the tolerances and deviations *j-th* source of deviation ($+Z_{max,j}$, - $Z_{max,j}$) is determined by the equation:

$$u_{B,j} = \frac{Z_{\max,j}}{k} \text{ ,} \qquad [6]$$

K is the coefficient of the expected probability distribution by which the relevant partial source of deviation is managed. In practice, Gaussian distribution of $k = 2$ (eventually $k = 3$) or even distribution with $k = 1.73$, or a bimodal - Dirac distribution with $k = 1$. (2), (3) are the most frequently used.

The resulting value of the standard deviation u_B that merges all intermediate deviations u_{Bj} of all sources (if there is no correlation among them) is determined by the equation:

$$u_B = \sqrt{\sum_{j=1}^{m} u_{B,j}^2} \text{ ,} \qquad [7]$$

where m is the total number of resources (1), (3).

The total resulting deviation is a value which merges both types of deviations A and B. This is the combined standard deviation which is calculated by the equation:

$$u_C^2 = u_A^2 + u_B^2. \qquad [8]$$

If it is considered that the difference between the actual - measured value and the true value does not exceed a determined standard deviation depends on the error distribution.

The likelihood of this difference in the normal distribution of errors represents 68.3 %. To increase the likelihood of actual values in the interval, consideration is given to the calculation of the expanded deviation *U*. The value of the expanded deviation is determined by the equation:

$$U = k_u * u(y), \qquad [9]$$

where k_u is the coefficient of extension,
u(y) is the combined standard deviation (1), (3), (4).

The value of coverage factor is chosen depending on the desired level of coverage probability. For $k_u = 2$, the probability is about 95 %.

In practice, it is not always possible to meet the requirement of normality of components and symmetry, then the probability value of less than 95 %.

SOURCES OF DEVIATION IN THE MEASUREMENT OF VIBRATION

To obtain representative values of vibration, the individual values of the standard deviation u_B estimate of individual elements assembled measurement chain.

Possible identifiable and quantifiable resources include:
- selection and sensor characteristics (analysis of uncertainties associated with the sensor),
- characteristics of the used vibration analyzers(analysis of uncertainties associated with the analyzer),
- characteristics of the used operational calibration instruments,
- impact to environment.

The balance of deviation comprises also the deviation of the measurement method, which is determined as the standard deviation of type A or B depending on the procedure of finding the assessed values determining the parameters of vibrations (1), (5).

DEVIATION OF ANALYSIS CONNECTED WITH SENSOR

In compilation of measuring chain, sensor represents the important input element, which further determines the accuracy of the values of vibration acceleration. For measurement, IEPE triaxial accelerometer model 356B21 by PCBPIEZOTRONICS manufacturer was used, which affect the measurement accuracy and can be summarized in the following deviations sensor:

Location and fixing the sensor – this type of partial uncertainty, respectively effects of unsuitable placement and fixing sensors are difficult to estimate, so it can be assumed that a qualified person who will carry out the measurement, follows all the necessary principles known for this type of measurement. Otherwise, the values of this deviation could independently move in the range of 50 to 100 %. Acceptance of these deficiencies would mean impairment of the whole measurement (6).

The fluctuation of sensitivity – the maximal deviation from the sensitivity of *1.02 mV/ms-2*, specified by the manufacturer is $Z_{max}= \pm 10$ %. By using the normal probabilistic division with *k =3*, the value of overall standard deviation of sensor sensitivity is $u_{Bc}=3.72$ %.

The deviation of calibration – the deviation of operational calibration specifies the error of calibration measurement chain (sensor, analyzer). The calculation of the resulting standard deviation is therefore included into the deviation of calibration using calibrator u_{Bka}, then the total deviation related to operational calibration $u_{Bk}=4.023$ %.

The effect of surrounding, especially temperature - in the temperature range *-54 to +121 °C*, the deviation from the fixed sensitivity values *1.02mV/ms-2* specified by the manufacturer within the range *±10 %*. The progress of this dependence is given in the manufacturer catalogue sheets.

ANALYSIS OF DEVIATION ASSOCIATED WITH THE ANALYZER

In terms of accuracy, the output signal processed by analyzer can be influenced by various sources of deviation. According to the are currently in use modern types of analyzers, there can be for the type of analyzer specify some sources of deviation:

The chang of power supply - in the case where the power supply is used as an adapter AC that transforms the mains voltage in the range from *100* to *240*, in the frequency range of *47- 440 Hz* for the necessary voltage *15 V*, the maximum deviation of transformation is considered ±*10 %*. Then the partial deviation AC adapter $u_{B(AC)}=5.78$ %.

The deviation of A/D converter - to the type of analyzer used converter *24 bit* A/D with a maximum deviation of *0.2 %*, where in the bimodal Dirac's dividing with k =1, the amount of deviation $u_{B2(A/D)}=0.2$ %.

The error of linearity– the maximum linearity error of amplitude characteristics is $Z_{max}=$ *0.5 %* then sub-deviation $u_{B\,L}$ with coefficient of coverage *k =1.73* u_{BL} is *0.29 %.*

BALANCE OF SOURCES OF DEVIATION

The next table summarizes balance of deviation, which was achieved from the individual elements of measuring sequence.

BALANCE OF SOURCES OF DEVIATION USING THE DEFINED ELEMENTS OF MEASURING SEQUENCE Table 1

The deviations coupled with a sensor			
Source of deviation	**Marking of deviation**	**Division of probability**	**Value of deviation [%]**
The fluctuation of sensitivity accelerometer, 356B21 model	u_{Bc}	normal	3.72
The fluctuation of frequency amplitude	u_{Bf}	uniform	4.09
The deviation of VC110 calibrator	u_{Bka}	normal	1.6
The precision reading of deviation from the VC110 calibrator	u_{Bkh}	bimodal	0.25

The A/D deviation of converter VC110 calibrator	$u_{B1(A/D)}$	bimodal	0.3
The deviation of calibration sensor according by the calibration certificate No. 1862.01	u_{BkS}	normal	3.67
The deviations coupled with an analyser			
The A/D deviation of CoCo - 80 converter	$u_{B2(A/D)}$	bimodal	0.2
The error of linearity	u_{BL}	uniform	0.29
The fluctuation of power supply /(AC adapter)	$u_{B(AC)}$	uniform	5.78
The fluctuation of temperature atmosphere	u_{BT}	uniform	0.231
The deviation of method of measurement			
The repeated measurements	u_A	true n >10	7.7711
The continual measurements	u_{Bkm}	uniform	3
The deviation of random effects	u_{Bn}	uniform	0.3
Consequential values of deviation			

Source of deviation	**Marking of deviation**	**Value of deviation [%]**
The standard deviation of sensor, 356B21 model	u_{BS}	6.87
The standard deviation of CoCo 80 analyser	u_{Ba}	5.8
The combined standard deviation	u_c	**10.65**
The expanded deviation	$U(y)$	**21.31**

CONCLUSION

Based on the achieved individual values of deviation which are shown in Table 1, resulting values of combined deviation u_c and the expanded deviation $U(y)$ were determined.

$U(y)$ represents the value *21.31 %* from the final value of absolute acceleration $a_{hv,Tn}$, which is repeatedly added to $a_{hv, Tn}$, Based on this, we achieved relevant and exact value of the resultant acceleration, which can be compared with the limit legislative specified values as the actuator value $a_{hv, 8h}$ and is $2.5 m.s^{-2}$ and the limit value $a_{hv, 8h,L}$ is $5 m.s^{-2}$ (according to NV SR No. 416/2005 Z. z.).Where $U(y)$ is presented together with the result of measurement, ± is added in front of the numerical value.

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