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Analysis of influence of data quantity to measurement uncertainty in vibration monitoring systems

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Abstract

The paper analyzes the measurement uncertainty in periodic and permanent vibration monitoring systems, its variation due to measurement data. The factor which can be used to evaluate the significance of random uncertainty component was suggested. The varation of this factor was analyzed and its dependence on data quantity. The results of numerical experiment based on data collected with real periodic and permanent monitoring systems are provided.

Keywords: Vibromonitoring systems, data quantity, uncertainty, random component.

Introduction

According to the results of measurements of monitoring and diagnostic systems, the state of an object, separate equipment or machinery is evaluated and the decision is made about further operating activities. The reliability of measurement result depends on many factors – these may be the features of the observed object, structure of the measurement system, environment of aggregate or machinery, work of operator. The modern systems of monitoring and diagnostics often are the part of automated control systems of the object, equipment or machinery. Thus reliable operation of the mentioned subsystem is the element influencing the reliability and efficiency of the whole object. Therefore the measurements in the monitoring system are performed with a specific uncertainty.

The state of a rotor machinery technical state may be described using various parameters. In the literature which analyses vibration monitoring and diagnostic systems it is emphasized that there are five main non-destructive control methods applied during state monitoring, that is: vibration monitoring, termography, tribology and visual inspection. In this case vibration monitoring and diagnostics is the main method used to observe the equipment as exactly as this mean allows to determine and evaluate the problems and defects emerging in an operating equipment.

Information quantity here also plays the main role, as with more information more reliable decision can be made. This may also influence the measurement uncertainty.

Evaluation of measurement uncertainty

The measurement uncertainty is usually evaluated using the procedure descibed in the “Guide to the Expression of Uncertainty in measurement”. Here the measurement uncertainty is defined as the parameter related to the measurement result and variance of values which can be reasonably attached to the measurand. The measurement uncertainty consists of these components:

- uncertainty due to measurement equipment error;
- uncertainty due to environment factors influencing measurement result;
- uncertainty of the standard;
- uncertainty due to assumptions of the measurement methods [1,2].

To analyse multichannel vibration measurement system, the assumption is made that it is a set of measurement systems consisting of n similar vibration measurement channels. The assumption that the channels which measure the same vibration parameter are operating in the same conditions and the response of measurement equipment to the environment influence is the same, thus the uncertainty in separate channels is the same and differs only by random uncertainty component.

Vibration measurement influence factors according to their nature can be distinguished to:

- Measurement equipment uncertainty components;
- Environmental influence components;
- Time components;

Also another classification may be applied, distinguishing components according their character into random and systematic [1].

The random uncertainty component strictly depends on the collected data and the systemic uncertainty component depends on the measurement equipment and systematic component changes due to other parameters, therefore the influence of data quantity may esentially affect the random uncertainty component.

Usually vibration monitoring and diagnostic system performs measurements in specific periods. If these measurements are made quite often, the set volume N grows and a random uncertainty component is calculated according the formula:

$$u_{rand} = \frac{\sigma}{\sqrt{N}}, \qquad (1)$$

here σ is the standard deviation of the data set; N is the data set volume.

The random component uncertainty component decreases when the value of N increases. One should notice that the standard deviation also depends on the set volume. This equation might be written as:

$$u_{rand} = \frac{\sqrt{\frac{\sum (x_i - \bar{x})^2}{N}}}{\sqrt{N}} \approx \frac{\sqrt{\sum (x_i - \bar{x})^2}}{N}, \qquad (2)$$

where x_i is the measurement set member; $\bar{x}$ is the average of the set.

If the variation of the process is significantly large, then the random uncertainty component might be big and significant while calculating the general uncertainty value. As the assumption that the vibration measurement result set in the case of a stationary monitoring is stationary process is made, and then $x_i - \bar{x} = \Delta x_i$ might be assumed to be a fixed value and the Eq.2 may be expressed as:

$$u_{rand} \approx \frac{\sqrt{N\Delta x^2}}{N} = \frac{|\Delta x|}{\sqrt{N}}. \qquad (3)$$

Knowing the limit when the uncertainty component may be disposed as unsignificant, let us mark this factor as b, thus we can calculate the necessary data volume in order to get an insignificant uncertainty component:

$$\text{if} \quad \frac{|N\Delta x|}{\sqrt{N}} \le b, \text{ then } \sqrt{N} \ge \frac{|\Delta x|}{b} \text{ or } |N| \ge \left(\frac{\Delta x}{b}\right)^2. \qquad (4)$$

Measurement uncertainty in vibration monitoring systems

According to [2], the vibration monitoring systems can be distinguished into two main categories: permanently installed and periodic.

The main difference between permanent and periodic monitoring systems referring to uncertainty attributes is that here the main roles are played by different error types. In the stationary system the measurements are performed constantly and the random uncertainty component is very small, as the number of N is large, but the measurement equipment is calibrated periodically, for example, once per year. Influence factors, determined during calibration, still affect the measurement procedure if it is performed in environmental conditions other than of calibration. So the systematic error here plays the main role more than the random. In the case of the periodic monitoring system, the measurement equipment calibration is usually performed before every measurement set. But in contrary, as the measurements are rarer, their variance is bigger and the volume of data set is very small – the random error dominates in uncertainty value.

Applying this to different vibration monitoring systems, one should notice that in the permanent vibration monitoring systems the variance of the normal distribution will be small enough due to large data sets, so in critical cases, the uncertainty influence will show the effect immediately. In the case of the periodic monitoring system, the data sets are small and variance is much bigger. Due to that, the uncertainty might have a big influence to decision making with the periodic monitoring systems having raw data. The data set might be expanded using the particular methodology [3], while a transformation function will enlarge data set, in this way reducing the random uncertainty component. Using this method an additional uncertainty contribution should be added, which calculates the impact of the increase of the set to measurement reliability. On the other hand, this contribution has a less impact than the difference between the primal random uncertainties and uncertainties calculated after the transformation.

Factor variation due to the changes in data quantity

The data were collected by the vibromonitoring system which is installed in Kaunas water power station [4]. The vibromonitoring system for each hydro-aggregate measures 12 vibration velocity quantities simultaneously. The results of the first vibration velocity set of data were analyzed by dividing the data into groups by month and the average and the standard deviation of the group was calculated.

These data were analysed to evaluate the significance of the threshold b.

The example of the periodic monitoring system was the vibration measurements made for the leak cleaning equipment compressor.

Table 1 **The values of threshold b_i in permanent monitoring and diagnostics system**

Threshold	b_1	b_2	b_7	b_8
Value	$5.68 \cdot 10^{-5}$	0.00136	$1.728 \cdot 10^{-4}$	$2.48 \cdot 10^{-4}$
Threshold	b_9	b_{10}	b_{11}	b_{12}
Value	$8.75 \cdot 10^{-4}$	$6 \cdot 10^{-4}$	0,0044	0,0036

The threshold was also analyzed in the case of the periodic monitoring system (Table 2). The intial data set had 9 members, and using the transformation the set of 1000 members was generated. The results showed that the threshold did not change much and in this case the random component of the uncertainty is significant and still plays the main role in the measurement uncertainty model.

Table 2. **The values of threshold b_i in the periodic monitoring and diagnostics system**

Measurement set	Threshold before transformation	Threshold after transformation
V_1	0,096	0,082
V_2	0,58	0,422
V_3	0,036	0,031
V_4	0,075	0,063
V_5	0,051	0,043
V_6	0,04	0,034
V_7	0,13	0,11
V_8	0,070	0,42
V_9	0,044	0,038
V_{10}	0,045	0,038
V_{11}	0,14	0,12
V_{12}	0,026	0,022

In order to evaluate the effect of data volume change to the threshold *b* the graph was made in Fig. 1.

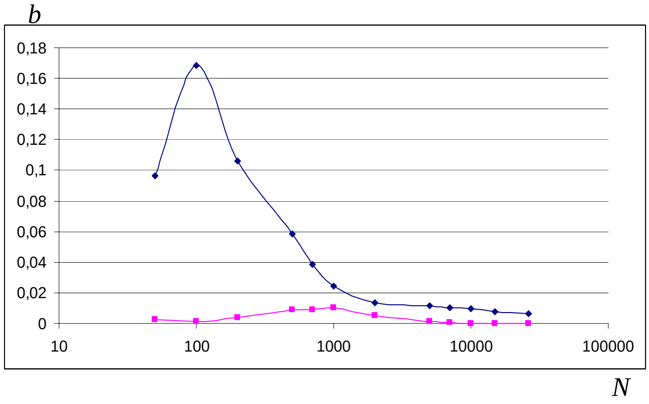

Fig. 1. **The dependence of threshold b_i to measurement amount *N***

The analysis was made dividing the data of the permanent monitoring system of two vibration speed measurement sets into several increasing data sets and to each set the corresponding factor *b* value was calculated. The peak in the upper line shows that there was a bigger value of the standard deviation, but still the increase of data quantity results in decrease of the factor *b* value. The data quantity scale in this graph was chosen to be logarithmic.

Conclusions

1. The factor *b* was evaluated which allows evaluation of the significance of a measurement uncertainty random component. This factor *b* depends on the quantity of measurement data. When the quantity increases, the variable *b* decreases. The rate of decreasing depends on the standard deviation of the data set. If the standard deviation is large, then the decrease rate might be insufficient and then the measurement uncertainty is different in each measurement channel as the random uncertainty component is quite large.

2. For the periodic vibration monitoring data the data transformation method is used to increase data quantity. The investigation showed that despite the increased quantity of data the random component did not became insignificant due to the too small initial data set.

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Duomenų kiekio įtakos neapibrėžties įverčiui vibracinės stebėsenos sistemose analizė

Reziumė

Nagrinėjamas periodinių ir nuolatinių vibracijų matavimo neapibrėžties įverčio kitimas stebėsenos sistemose dėl atsitiktinės dedamosios, priklausančios nuo duomenų kiekio. Pateikiami skaičiavimai ir pasiūlytas parametras, kuriuo remiantis nustatomas neapibrėžties įverčio atsitiktinės dedamosios reikšmingumas. Analizuojamas šio parametro kitimas ir priklausomybė nuo duomenų kiekio. Pateikti skaitinio eksperimento rezultatai, gauti remiantis duomenimis, surinktais realiose nuolatinės ir periodinės stebėsenos sistemose.

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