422. Investigation of uncertainty in vibromonitoring of rotating systems transient modes

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(Received:17September; accepted: 02 December)

Abstract. Earlier uncertainty investigation in vibration monitoring of rotating systems showed that uncertainty in stationary and periodic monitoring systems have different character. Uncertainty of stationary vibromonitoring systems of rotating systems have insignificant statistical component, while this uncertainty component plays main role while analyzing periodic vibration monitoring systems.

This investigation expands the uncertainty analysis in stationary vibromonitoring systems adding transient mode. Uncertainty analysis is performed for different time and distribution intervals in order to determine whether statistical component of uncertainty still remains insignificant due to measurements quantity.

Keywords: vibration monitoring of rotating machinery, measurement uncertainty

Introduction

The reliability of measurements is usually evaluated by measurement uncertainty. In its value the main role usually is played by the components, determined by characteristics of electronic measurement devices and statistical sand, which depends on measurement data. When the measurements are performed by monitoring system, the data structure becomes more complicated, as it includes various operating modes, for example, operating and off mode, change of unit operating mode, origin of significant disturbance, etc. For evaluation of uncertainty, this information is usually concentrated in one statistical component. The data structure complexity is a well known problem and it can be analyzed using various methods of data fusion [1, 2]. As uncertainty is usually evaluated using statistical methods, though there are other methods suggested, the methods, used in this paper, still are based on statistics theory. In earlier works [3, 4] we have analyzed the uncertainty in rotating machinery vibration monitoring, paying attention to measurement data gathered using different techniques: stationary monitoring and periodic monitoring. The investigation showed that the characteristics of the measurement data are significantly different, and those techniques usually can by characterised by different environment, operation modes during the measurement, periodicity of measurements, and this reveals the reliability of the measurement itself through the value of uncertainty.

Problem formulation

Stationary vibration monitoring systems works all the period after installing them on the monitored machine till its end of exploitation. In contrast to periodic monitoring, the data of machine parameters is collected even during the periods, when machine is not working. In this way, when analysing the whole data set, the mean and standard deviation values, used in uncertainty evaluation, might be incorrect if the equipment was rarely used, or over long periods in the “off” mode.

The purpose of this paper is to extend the analysis of statistical uncertainty in vibration monitoring systems, by changing data structure of stationary system: taking the whole data set, and working with it by eliminating data gathered when the unit was in off or transient modes.

The data of two different type of machinery was analyzed: slow speed machinery and high speed machinery.

As in earlier investigations the conclusion about the insignificance of statistical uncertainty component was made, one of the assumption was that the cause may be in the data structure of low-speed machinery monitoring. So, in order to evaluate the change of insignificance of machinery vibration monitoring uncertainty in both, distinguishing slow-speed machinery and high-speed machinery, additional analysis was made.

Methodology

The data of the slow-speed rotating machinery (120 rpm), analyzed in this paper, was gathered in 4 years period, measuring vibration speed of the hydro aggregates. 12 transducers were used, but only 7 data sets were analyzed. The same data was used in earlier investigations [3, 4] but the problem analyzed there was to compare stationary and periodic monitoring data structure and the difference of their uncertainty values.

The data of the high-speed machine (6000-7000 rpm), analyzed in this paper was gathered in one-year period, measuring vibration speed of the large pumps. The data of 2 transducers were analyzed.

In low-speed machine case, "significant" data was excluded i.e., the data of the operating mode. All the data sets of the transducers measurement were analysed separately. For data exclusion, the threshold was used.

In case of the high-speed machine, three variables were analyzed. Three steps for data modification:

1 step – initial data set analyzed,

2 step – eliminating "off" mode, i.e. zero values;

3 step – eliminating "run-up" mode values, i.e. values similar to zero, and significantly (by half) different than stationary process (working mode) data.

The threshold used for data selection was 0.5. This number was approximately chosen, regarding to the values in all analyzed data sets. The analysed and compared parameters are:

N - the initial data set volume; in this case it is 11486;

$\bar{x}$ - the mean of initial set; mm/s;

σ - standard deviation of the initial set, mm/s;

u_{stat} - statistical uncertainty sand, mm/s; is calculated according to the formula:

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

Results

The data sets of different transducers in slow-speed rotating machinery monitoring are denoted VSi, $i = \overline{1,7}$

To make analysis, the above mentioned parameters are calculated for all the sets then the change of their distribution is analyzed.

The statistical parameters of the slow-speed machinery monitoring system are presented in the table 1.

Table 1. Statistical parameters of the slow-speed machinery vibromonitoring data

Var.	Parameters						
	$\bar{x}$	σ	u_{stat}	$\hat{N}$	$\hat{\bar{x}}$	$\hat{\sigma}$	$\hat{u}_{stat}$
VS1	0.58	0.55	0.005	6128	1.05	0.55	0.007
VS2	0.16	0.1	0.0009	4820	0.28	0.073	0.001
VS3	0.45	0.47	0.004	5256	1.029	0.22	0.003
VS4	0.89	0.89	0.0074	6095	1.85	0.51	0.0067
VS5	0.46	0.48	0.004	5332	1.097	0.16	0.002
VS6	0.4	0.45	0.0037	5313	0.93	0.37	0.005
VS7	0.63	0.66	0.0055	6069	1.32	0.54	0.007

Here

$\hat{N}$ - the new size of modified data set (without values below threshold);

$\hat{\bar{x}}$ - average of the modified data set, mm/s;

$\hat{\sigma}$ - standard deviation of the modified data set, mm/s;

$\hat{u}_{stat}$ - statistical uncertainty component of the modified data set mm/s.

The Fig. 1 is graphic representation of the relative changes of the parameters. Each bar represents the different data set, the group of the bars represent the change of the specified statistical parameter (average, standard deviation, standard uncertainty component and data set volume). It shows that the number of quantities in the sets reduce significantly, and according to the (1) formula, the statistical uncertainty component should also decrease. And despite the decrease of standard deviation, the behaviour of the statistical uncertainty component is ambiguous (in some cases it decreases, in some case it increases). Though, comparing to the values of statistical uncertainty, provided in [3], it still remains insignificant. The contribution of the measurement device uncertainty component to the overall uncertainty still remains the most significant.

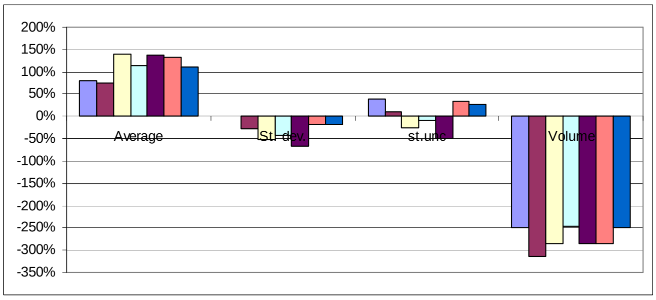

Fig. 1. Graphic representation of changes in parameters of slow-speed machinery monitoring data (average, standard deviation, standard uncertainty, data set volume) after removing the values below the threshold

The Fig. 2 and the Fig. 3 provides the visual picture of the changes in data distribution of the slow-speed machinery vibration monitoring. When comparing Fig. 2 and Fig 3, it is obvious, that the character of those two distributions is slightly different. The modification is just removing the left bards in the histogram and the mean value moves to the right, the standard deviation, which has influence to statistical uncertainty component and is characterized by the form of distribution also changes, though this change is not significant.

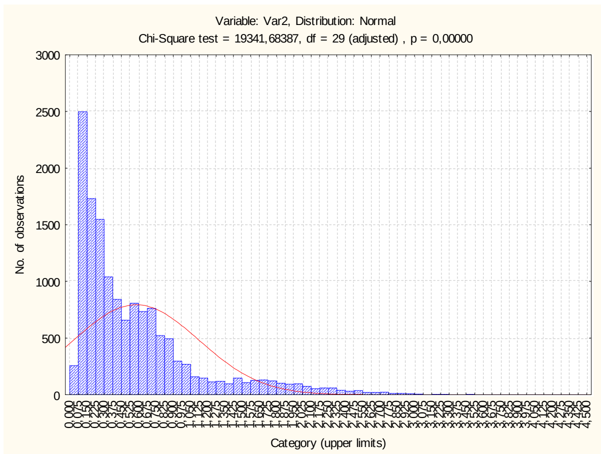

Fig. 2. Statistical distribution of initial slow-speed machinery monitoring data

The similar analysis was made with the data of high-speed rotating machinery vibration monitoring.

The data sets of different transducers in high-speed rotating machinery monitoring are VHj, $j=\overline{1,3}$.

To make analysis, the statistical parameters are calculated for all the sets then the changes of their distribution are analyzed.

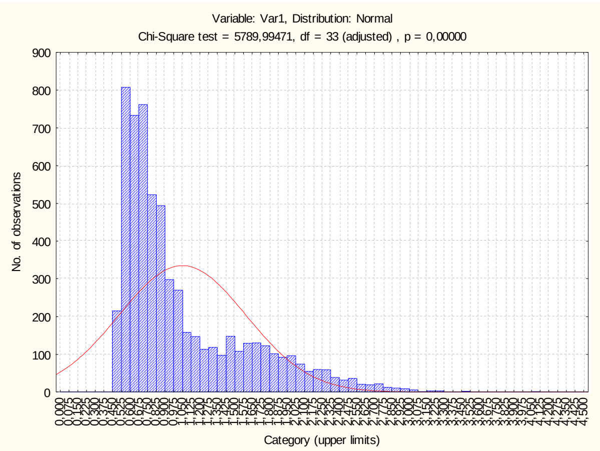

Fig. 3. Statistical distribution of changed slow-speed machinery monitoring data

The statistical parameters of the high-speed machinery monitoring system are presented in the table 2.

Table 2. Statistical parameters of the slow-speed machinery vibromonitoring data

	N	$\bar{x}$	σ	u_{stat}
$VH1$	1024	8.059	2.32	0.073
$VH2$	1024	7.6	2.8	0.087
$VH3$	1029	7.54	2.85	0.089
$\hat{V}H1$	999	8.26	1.96	0.062
$\hat{V}H2$	992	7.84	2.48	0.079
$\hat{V}H3$	990	7.84	2.47	0.078
$\hat{\hat{V}}H1$	965	8.54	1.3	0.042
$\hat{\hat{V}}H2$	964	8.06	2.15	0.069
$\hat{\hat{V}}H3$	961	8.06	2.13	0.069

Here the $\hat{V}H1$, $\hat{V}H2$, $\hat{V}H3$ are data sets without zero values (2 set); $\hat{\hat{V}}H1$, $\hat{\hat{V}}H2$, $\hat{\hat{V}}H3$ denotes data sets without zero and transient mode values (3 set).

The Fig. 4 is graphic representation of the relative changes of the parameters in high-speed rotating machinery vibration monitoring data. Each bar represents the different comparison data set, i.e. the first bar represents the comparison of 1 set with 2 set, the second bar represents the comparison of 2 set with 3 set and the third bar represent the comparison of 1 set with 3 set (then the change is the biggest). The group of the bars represent the change of the specified statistical parameter (average, standard deviation, standard uncertainty component and data set volume). It shows that the quantities of values in the sets reduce most insignificantly, and the most significant change is the relative change of the decrease of standard deviation and statistical uncertainty component.

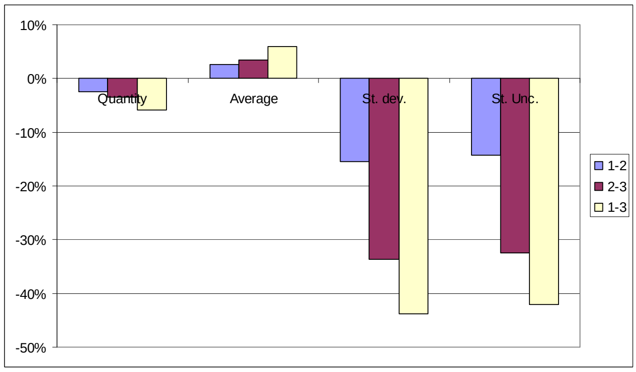

Fig. 4. Graphic representation of changes in parameters of slow-speed machinery monitoring data (average, standard deviation, standard uncertainty, data set volume) after removing the zero (2 set) and transient mode (3 set) values

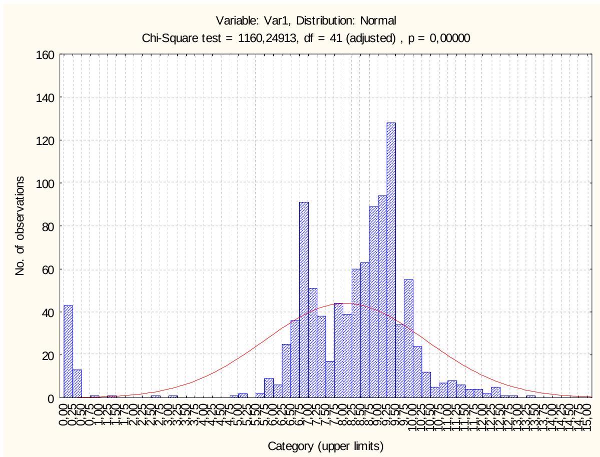

Fig. 5. Statistical distribution of initial high-speed machinery monitoring data

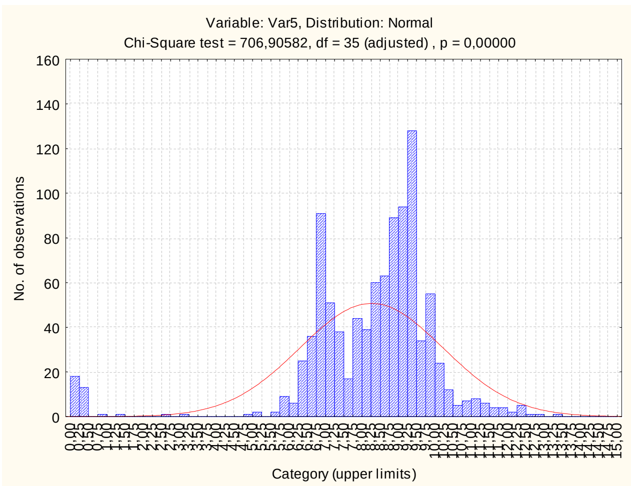

Fig. 6. Statistical distribution of changed high-speed machinery monitoring data (without zero values)

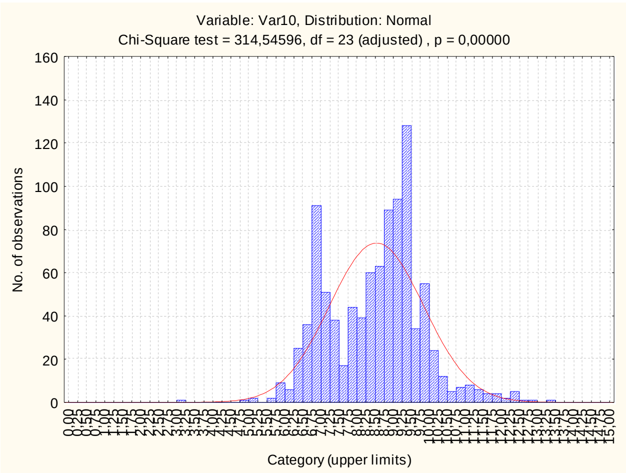

Fig. 7. Statistical distribution of changed slow-speed machinery monitoring data (without zero values and transient mode values)

The Fig. 5, Fig. 6 and Fig. 7 provides the visual picture of the changes in data distribution of the high-speed machinery vibration monitoring. When comparing Fig. 6 and Fig 7, it is obvious, that the character of those two distribution is almost indifferent. But when comparing the change presented in Fig 7, it is obvious, that the character of the distribution has changed significantly - by the mean, which is represented at the position of the highest value of distribution, and the standard deviation represented by the form of the distribution changes significantly.

Conclusions

1. The overall uncertainty value used in the basic diagnosis rule, should reflect the stationary regime, as it best corresponds to the mean value used in decision making.

2. Measurement uncertainty of low speed stationary rotating machinery vibration monitoring systems depends on the data structure, modified by extracting data related to various operating modes. But independently of highly reduced measurement quantity it still remains insignificant at the aspect of overall measurement uncertainty.

3. Measurement uncertainty of high speed stationary rotating machinery vibration monitoring system diminishes when modifying data by extracting data, related to "off" and run-up mode.

4. The analysis of statistical uncertainty component shows that as it doesn‘t have significant influence on the value of overall uncertainty component. Thus, it can be concluded that the change calculated uncertainty reflect, probably, the changes in electronic measurement devices measurement capabilities.

References

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