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Comparative study of selected bearing vibration measuring systems

Badania porównawcze wybranych systemów pomiarowych drgań łożysk tocznych

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Roller bearing manufacturers have individual bearing vibration monitoring systems, consisting of several key components. Despite the fact that the principle of operation of these systems is the same, they differ from each other with some constructional solutions, whereas the type of construction used has an impact on the accuracy of measuring vibrations of a rolling bearing.

KEYWORDS: measurements, vibrations, rolling bearings

Measurement of vibrations generated by the rolling bearing is one of the most important elements of quality control [1, 2]. Leading bearing manufacturers use self-made measuring equipment or a specific supplier.

Fig. 1 presents a diagram illustrating the principle of industrial measurement of vibrations of rolling bearings [3]. The measurement consists in recording the radial vibrations of the bearing superimposed on the shaft rotating at a specified speed. For the most part, an electro-dynamic sensor that generates a signal proportional to the vibration velocity is used for this purpose. The rolling bearing during axial load is axially loaded with a force with a force corresponding to the type and size of the bearing. To obtain accurate information on the state of the object being studied, the measurement signal is filtered into three frequency bands. In each of the bands, the effective vibration value is calculated, informing whether the examined bearing has significant defects [2, 4, 5].

The level of vibration generated by the bearing should meet the client's expectations. Standards concerning vibration measurement of rolling bearings are determined only by the general measurement conditions, such as: the rotational speed of the inner ring of the bearing, the clamping force of the outer ring or the method of filtering the obtained signal [6, 7]. There are no standards setting limits, which should not be exceeded by the level of vibrations. Usually this is a matter of internal company standards or a reconciliation between the producer and the recipient. Standards also do not determine how to provide measurement conditions technically.

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The existing systems differ, therefore, in some structural solutions of their subassemblies. Each of these components has a greater or lesser impact on the accuracy of the measurement.

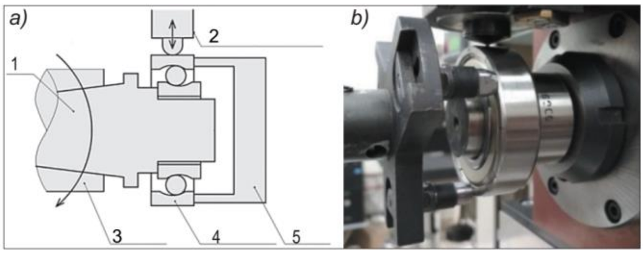

Fig. 1. Scheme of the principle of operation of the rolling bearing vibration measurement system: 1 – shaft, 2 - vibration speed sensor, 3 – spindle, 4 – rolling bearing, 5 – pressure [3] (a); head of an industrial system for measuring vibrations of rolling bearings (b)

Tested vibration measurement systems for rolling bearings

Different solutions of these components are used. On the basis of the analysis of only some of the available devices [3, 8-10], it can be noticed that they differ from each other: spindle type (hydrodynamic or fully air-bearing type), pressure type (pneumatic, spring - realized coaxially in compact structure or tilting, for example for the time of bearing replacement), contact type of the bearing with the outer ring of the bearing (three-point contact or the whole circumference), motor positioning (directly after the spindle or separated from the rest of the system), sensor mounting (stationary sensor be added for the duration of the measurement) or the method of processing the signal obtained from the measurement (analog or analog-digital).

The aim of the research is to select a system that in further tests can be considered as a model.

The comparison of the measurement results is doubly problematic. First of all, the result of vibration measurement is unknown and very difficult to determine accurately. There are no reference bearings in which the magnitude of generated vibrations would be known exactly. It is possible to calibrate the measuring path of the sensor, measure the pressure eccentric or spindle run, but it will not reflect the correct value of the vibration level of the tested bearing. Secondly, the result of one measurement is three numbers associated with different frequency bands. In the case of discrepancies, the problem arises to select the appropriate frequency range.

TABLE I. Characteristics of the most important components database systems

Subassembly		System 1	System 2	System 3
Spindle		Hydrodynamic bearing	Air-bearing	– Hydrodynamic bearing
Pressure	Type	Pneumatic on the tilting arm	Pneumatic, constantly coaxial	Pneumatic, constantly coaxial
	Contact with bearing	Three-point	Three-point	Peripheral
Sensor		Fixed	Fixed	Added during measurement
Signal processing		Analog-Digital	Analog	Analog-Digital

Three industrial vibration measuring systems for rolling bearings were subjected to comparative tests. Their characteristics are presented in the tab. I.

Methodology of measurements and results

The tests were carried out on one 62062Z bearing. Between successive measurements, pneumatic clamps were released and then re-activated. The rotational speed, in accordance with the accepted standards, was 1800 revolutions per minute, while the pressing force - 60 N. The obtained measurement signal was filtered into three frequency bands: low 50÷300 Hz (LB), average 300÷1800 Hz (MB) and high 1800÷10,000 Hz (HB). In each frequency band, the effective vibration value expressed in special units - anderon - was used, mainly used in the bearing industry. This size is closely related to the adopted rotational speed.

The relationship between the output unit of vibration velocity (μm/s) and anderon (And) [2, 5] describes the formula:

$$1\ \mathrm{And} = 2\pi \cdot 30 \sqrt{\log_2 \frac{f_h}{f_l}}\ \mu\mathrm{m/s}$$

where: f_h - upper limit of the frequency band, Hz; f_l - lower limit of the frequency band, Hz.

Measurements of bearing vibrations at one point

On the outer ring of the bearing, a measuring point is marked as the place where the sensor contacts the bearing. Then, on each system 40 times the vibration level of the tested bearing was measured at the selected point. The arithmetic means of measurement, mean-square errors and the range of results for each band were calculated. The results can be found in the tab. II.

It is difficult to suggest differences in arithmetic means in this case, because the correct vibration level of the tested rolling bearing is not known. Theoretically, the same size is measured (assuming that each time the balls are turned, the basket and the inner ring during the movement cause the same vibrations). It can therefore be assumed that the smaller the spread and the range of results, the greater the fidelity of the system.

TABLE II. Results of bearing measurements at one point

	Band	Arithmetic mean, And	Mean square error, And	Range, And
System 1	LB	5,74	0,44	1,7
	MB	7,4	0,25	1,1
	HB	5,22	0,34	1,7
System 2	LB	5,45	0,21	0,77
	MB	7,13	0,19	1
	HB	6,98	0,4	1,46
System 3	LB	4,37	0,19	0,7
	MB	6,86	0,25	1,15
	HB	6,58	0,4	1,75

On the basis of the analysis of the results, there is a lack of consistency and there is a different position in each frequency band. One should therefore choose one band and set a reference system on this basis. The only suggestion here can be the physical quantity measured directly.

Analysis of the amplitude dependencies between displacement, velocity and acceleration in the case of a sine wave indicates that in the low frequency band the best detectable amplitude has displacement, while in the very high frequency band the highest amplitudes reach acceleration. The vibration velocity is best measured in the medium frequency band.

The measuring systems use electrodynamic sensors, thanks to which a signal proportional to vibration velocity can be obtained. Thus, the selected vibration signal can be considered as the most representative of the actual bearing vibrations in the medium band. Both the mean square error and the range indicate the most accurate result in the middle band for the system 2.

Measurements of bearing vibrations at many points

To determine the nature of the relationship between the results obtained from the tested systems, 20 measuring points were spaced at the same intervals on the outer ring of the tested bearing. Three measurements were taken at each point, and the arithmetic averages of the results were used to build graphs (fig. 2).

The level of vibration at a given point of the bearing depends primarily on the geometrical structure of the treadmill of its outer ring. This is due to the fact that as an element of contact with the sensor it is stationary. The other components of the rolling bearing (inner ring, basket and balls) perform cyclic rotary movements. Thus, if the systems do not cause changes in the result of their operation, then one can expect a correlation between specific points.

Pearson correlation coefficients between systems were calculated and the results are given in the tab. III. In this case, the low frequency band is of particular interest since the shape errors of the outer ring are visible in this frequency range. They should have the greatest impact on the difference in results depending on the point at which the vibration is measured.

Correlation analysis shows that systems 2 and 3 are the best correlated. In the low- and medium-frequency band, the relationship between these systems is strong, and in the high-frequency band - even very strong. System 1 in the first two bands weakly correlates with both system 2 and system 3. At this stage it can be concluded that system 1 will not be taken into account as a model.

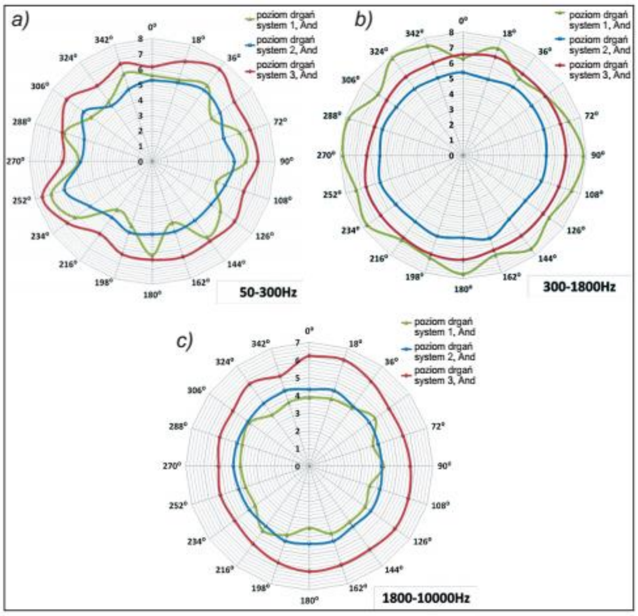

Fig. 2. Results of the measurement of the effective value of vibrations at points on the perimeter of the outer ring: a) low frequencies, b) medium frequencies, c) high frequencies

The diagrams in fig. 2 show that the variability of the result has different causes than in the case of systems 2 and 3.

TABLE III. Pearson's correlation coefficient between the results obtained from the tested systems

Band	Correlation for a combination of systems		
	1↔2	1↔3	2↔3
LB	0,38	0,25	0,83
MB	0,25	0,31	0,85
HB	0,79	0,73	0,93

The peaks appearing in the spectrum largely correspond to the frequencies characteristic for this type of rolling bearing (at a specific rotational speed). The tested bearing is brand new and emits vibrations at a relatively low level.

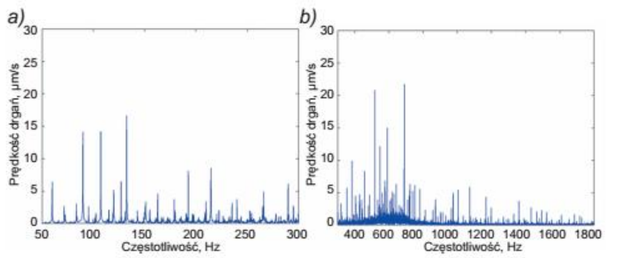

Fig. 3. Discrete amplitude spectrum of the vibration speed signal of the tested bearing: a) low frequency band, b) medium frequency band

Fig. 3 shows the low and medium frequencies. In the area of the first (108 Hz) and second (216 Hz) harmonic frequency of the outer ring, peaks with amplitude of 14.2 μm/s and 214.5 μm/s are visible successively. They are not higher than others, and the amplitude is close to the neighboring peaks of amplitudes originating, among others from rotational frequency (14.9 μm/s) or spheres (16.7 μm/s). It can therefore be assumed that there are no significant defects on the outer ring, which may result in a large difference in the result of measurements at various points.

It is known that the result may be different depending on the point at which the measurement is performed and the correlation on the two systems indicates that this may be due to the structure of the geometric surface of the outer ring. This allows the assumption that the range system should be minimal in the reference system. Larger ranges of results on the perimeter may indicate the unwanted operation of the measurement system.

The range was calculated, and the results can be found in the tab. IV.

TABLE IV. Range of the effective value of vibration on the circumference of the outer ring

	Measuring system	Range, And		
		LB	MB	HB
Obverse of bearing	1	3	1,6	1,1
	2	1,5	0,65	0,4
	3	1,7	0,75	1,17
Reverse of bearing	1	3,6	1,9	2,5
	2	1,35	0,75	0,85
	3	2,3	0,93	0,96

The assumption with the smallest spacing meets the system 2 - in each frequency band on one and the other side of the bearing. The analysis allows you to sublimate this system as a model. This is additionally advantageous due to the fact that the device is an analogical prototype of the other two newer systems.

Conclusions

Determination of the reference system is crucial for further research to determine the metrological properties of various rolling bearing vibration measurement systems. The presented method uses the simplest statistical tools and is of a pivotal nature. It can therefore be used for quick selection of the reference system.

The tests were carried out on one bearing for which no significant damage was found. Further research should therefore extend both the number of bearings and the testing of rolling bearings of various types and sizes.

Research aimed at comparing systems may be of interest to bearing customers, who for various reasons (e.g. switching supplier) would like to verify the performance parameters of the products they receive.

In a simple example, such as multiple measurement of one bearing, it can be seen that despite the use of patterned devices there are differences in the results of measurements. Differences in the construction of measuring stations are too large to be able to determine the recommended construction solutions at this stage. Understanding the causes of differences in measurement results will be a valuable guideline when choosing design solutions that ensure the construction of a measurement station that accurately determines the vibrations generated by the rolling bearing.

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