Measurement of vibrations occurring in rolling bearings

Metody pomiaru drgań łożysk tocznych

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There are three criteria the vibration measurement methods as applied at each stage of the rolling-element bearing life period could be classified to. Analysis of these methods is suggested for better understanding of the rolling bearing operating problems and of the issues related to dynamic measurements.
KEYWORDS: rolling bearings, vibration measurements

Roller bearings are a very important part of the machine parts, and because they determine the durability and reliability of mechanical devices, they should be controlled for vibration generation at each stage of their service life. The rolling bearing vibrations are measured by the manufacturing company - after completion of all bearing parts and then by the user - after the bearing has been purchased (measurement of unmounted or already mounted bearing) and during its operation (periodic measurements until the bearings are lost) [1]. Vibration can be implemented in various ways, which can be divided due to:
- measured value - measurement of vibration displacement, vibration velocity measurement, vibration acceleration measurement;
- reference: relative (relative) vibration measurement, absolute (absolute) vibration measurement;
- contact: contact measurement, non-contact measurement.

Influence of the measured vibration magnitude on the measurement result

As with any kind of vibration motion, it is characterized by displacement, velocity or acceleration - their time waveforms can be recorded using measuring systems. The term „vibration measurement" should be understood as a measure of one of these magnitudes. Theoretically it is sufficient to measure one of these, the remaining two can be obtained by integration or differentiation. These operations are easy to implement by analytical methods. Integration or differentiation is most often performed directly during the measurement, using electronic circuitry, but this results in an error in the amplitude of the resulting magnitude (especially when the integration or differential is performed twice). There is also the determined phase shift between the signal obtained and measured at the output of the measurement system [2]. Roller bearing is a vibration emitter emitting a very wide amplitude spectrum. Sensors should detect vibrations that may result from bearing wear or subsequent wear. The best detection for low frequency ranges is displacement amplitude. The method based on displacement measurement is used, for example, in the measurement of low-speed bearing vibrations and in measurements of the roundness and waving of bearing elements. Very high frequency pulses can be easily detected by the method of recording a signal proportional to the acceleration of vibration over time. During high-frequency vibration measurements, acceleration has the highest measurable amplitude, while amplitudes of speed and especially displacement disappear due to the noise of the instrument. The best solution for the intermediate frequency range is to use a method based on the measurement of velocity. Apart from the fact that velocity measurement is a kind of compromise, there is another argument in favor of the use of such sensors - the sound induced in man is proportional to the velocity of the vibrating surface [3].

Relative and absolute methods of bearing vibration measurement

The methods of measuring the vibration of rolling bearings can be classified depending on whether the relative (relative) or absolute (absolute) vibrations are measured. This relative vibration of the vibration of the bearing, measured relative to a fixed reference point - for example. Relative to the sensor mounting electrodynamic used in quality control operations producing rolling bearings.

Another example of a reference point is a stationary Doppler laser pointer positioned on the rack whose beam records the vibrations of the bearing mounted in the structure.

Fig. 1 (as well as fig. 3 and fig. 5) showing the head of anderometer STPPD [4], developed at the Świętokrzyski Technical University. The presented test bench can be adapted to measure the vibration of rolling bearings by a variety of methods, including the measurement of relative vibration velocity. Tested bearing (undeveloped or placed in a special housing) is deposited on a rotating shaft. On the outer ring of the bearing an axial load acts asked by a three-point pressure. The pressing load of the axial bearings are protected by a patent [5]. Generated during operation of the bearing radial vibrations are recorded by different sensors.

The STPPD test stand is equipped with an electrodynamic sensor in which the movable mandrel on which the coil is wound contacts the working bearing. The sensor housing is located in the fixing system (stationary), which is the reference system. Inside the sensor is a permanent magnet - in its field, under the influence of bearing vibrations, the winding moves and causes an electromotive force. If the length of a coil and induction produced by

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a permanent magnet remains unchanged, the resulting force is proportional solely to the velocity of the vibrating object [6].

Fig. 2 shows an example of the measurement of the bearing 6204 by the electrodynamic sensor SG 4.3 (internal ring rotational speed was 1800 rpm).

Absolute vibrations of the rolling bearings can be recorded directly by the vibration sensor attached to, for example, the housing of the test bearing. The sensor vibrates in the same way as the bearing and allows vibration measurement without any reference point. Sensors for the measurement of absolute vibration include electrodynamic sensors with seismic mass, which record a signal proportional to the vibration velocity of the bearing, as well as piezoelectric accelerometers, which record a signal proportional to the acceleration of the vibration. An example of a piezoelectric sensor is a 608A11 sensor from PCB Piezotronics, whose selected technical data are listed in Table I.

Fig. 3 shows a bearing mounted on a shaft, mounted in a special measuring casing, to which a piezoelectric accelerometer is attached. This sensor allows the recording of absolute vibration. The principle of operation of the accelerometer is as follows: the bearing vibrations are transferred to the housing with a rigidly mounted sensor. The accelerometer contains piezoelectric plates on which the mass rests. The acceleration acting on the sensor is proportional to the charge generated in piezoelectrics due to the force of mass inertia [7].

A sample of the 6204 piezoelectric sensor 608A11 (internal ring rotational speed was 1800 rpm) is shown in fig. 4.

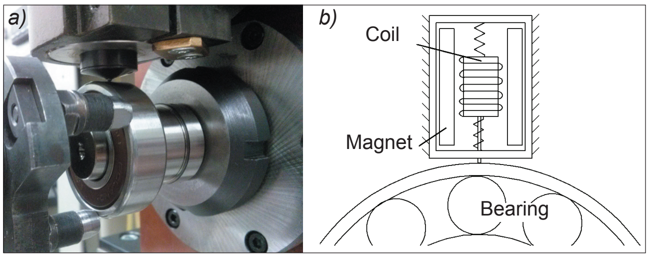

Fig. 1. STPPD anderometer equipped with an electrodynamic sensor (a) and a diagram of the relative velocity measurement (b)

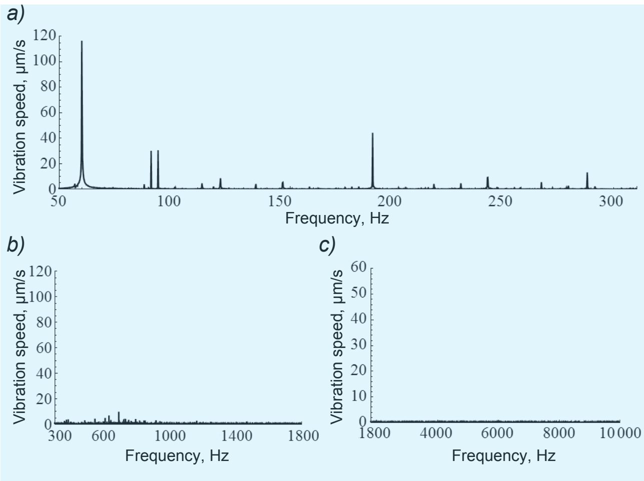

Fig. 2. Spectrum of velocity of rolling bearing type 6204 - electrodynamic sensor measurement SG 4.3: a) low frequency band, b) medium frequency band, c) high frequency band

TABLE I. Selected specifications of piezoelectric sensor 608A11 [6]

Measured value	Acceleration
Sensitivity, mV/(m/s²)	10,2
Resonant frequency, Hz	22 000
Range of measured frequencies, Hz	0,5÷100 000
Resolution, μm/s²	3,434
Maximum measurable amplitude, m/s²	490

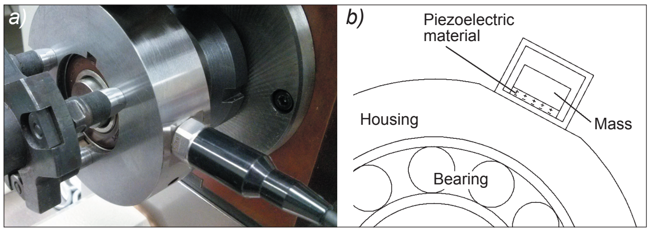

Fig. 3. STPPD measuring station equipped with piezoelectric accelerometer (a) and the scheme of absolute vibration acceleration measurement (b)

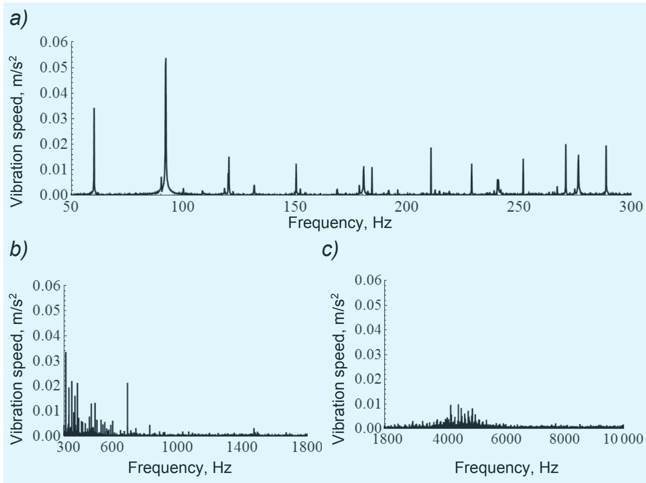

Fig. 4. Spectrum of the vibration speed of a type 6204 rolling bearing mounted in a housing - piezoelectric sensor measurement 608A11: a) low frequency band, b) medium frequency band, c) high frequency band

The greatest advantage of the sensors for absolute measurement is that the vibration measured by them is identical to the vibration of the bearing. The disadvantage is the way of mounting the sensors, which significantly influences the measurement result. Sensors used for relative measurement are much simpler to install, but they can detect not only the signals generated by the bearing, but also from the system in which the bearing works.

Characterization of contact and contactless methods

The contact methods for measuring the vibration of rolling bearings are that the vibration sensor is in direct contact with the outer ring of the undeveloped bearing or bearing housing. Sensors that perform contact measurement can include, for example, electrodes and piezoelectric accelerometers, and differential displacement sensors for relative displacement. As mentioned, vibration measurements are very rarely used to measure vibration of a bearing.

Non-contact methods of measuring vibration of rolling bearings include methods in which the vibration signal recording device has no physical contact with any rolling element or its housing. Non-contact measurement can be performed, for example, with a laser vibrometer, which competes with typical electrodynamic sensors.

Fig. 5 shows the bearing mounted on the anderometer. The vibration velocity of the bearing is recorded by the laser pointer positioned next to it. Measurement with a laser vibrometer is a comparison - by a precise interferometer - of the laser beam generated by the beamed device from the vibrating object. If the subject is moving, the frequency of light reflected from the surface of the object changes as a result of the Doppler effect. The wave frequency increases when the object is approaching the source, and decreases as the object moves away. When the frequency difference is known, the object's vibration velocity can be determined directly [8]. Table II presents the selected technical specifications of the PSV-500 laser vibrometer, and in fig. 6, an exemplary measurement of this bearing device 6204 (internal ring rotational speed was 1800 rpm).

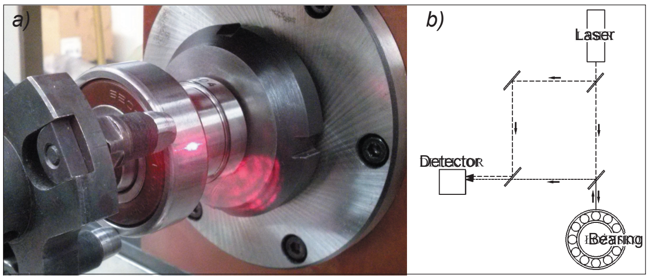

Figure 5. Contactless measurement of vibration speed with a laser vibrometer, the beam of which is visible on the outer ring of the rolling bearing (a), and the principle of measurement (b

TABLE II. Selected specifications of the PSV-500 laser vibrometer [9]

Measured value	Speed
Laser type	He-Ne (633 nm)
Measurement distance, m	0,125÷100
Range of measured frequencies	0÷50 000
Resolution, μm/s	0,02
Maximum measurable amplitude, m/s	10

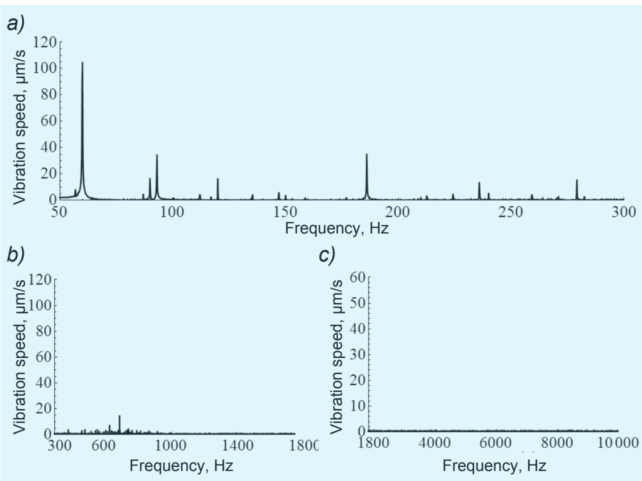

Fig. 6. Spectrum of velocity of rolling bearing type 6204 - measurement by PSV-500 laser vibrometer: a) low frequency band, b) medium frequency band, c) high frequency band

An interesting alternative to the measurement of vibration displacements by differential transformers could be the use of contactless confocal-chromatic displacement sensors, which are useful, for example, in the measurement of geometric features of the surface layer [10]. As industry practice shows, contact measurements are widely used for both the inspection and diagnostics of rolling bearings. Contact methods allow to measure all the vibration values, as well as relative and absolute vibration measurements.

The use of contact measurement sensors often requires good access to the bearing and the use of an exact mounting system. All contactors are subject to wear.

Contactless methods of measuring the vibration of rolling bearings are rarely used in the control of rolling bearings, but more often in their diagnostics. The advantage of these methods is that the measurement system does not affect the test bearing (no load on the sensor mass) and the measuring procedure does not force the precise and laborious installation of the sensor. Increasing popularity of modern vibration measurement methods may in the future result in the replacement of contact methods with non-contact methods.

Conclusions

The measurement result is strongly dependent on the method used. The classification shows how the term „vibration measurement" is general. Each time a particular method is chosen, the constraints associated with it must be considered. Research on the methods and parameters determining the size of bearing vibrations are very important. The vibration measurement results in key information on other features of the bearing such as its durability or torque. It is also worth emphasizing that the vibrations of rolling bearings are unavoidable and are not due solely to malfunction or damage. In addition to the production and operating vibration sources, structural vibrations are also distinguished, the causes of which lie in the construction of the rolling bearing itself.

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