Analysis the amount of lubrication and roughness of raceways on dynamic behavior on the ball bearing

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Abstract. The operating principle of rolling bearings generates vibrations that come from the periodic change in the stiffness of the bearing. The vibration level of the bearing depends on a large number of factors such as waviness, surface roughness of the raceways, deviation of the raceway radius, exploitation conditions, amount of lubrication in the bearing and other. This paper presents the influence of the roughness of the raceways and the amount of lubrication on the level of vibrations of the ball bearing, designation 6006. The determination of the influence of these parameters was done experimentally. The experiment was performed according conditions prescribed by ISO 15242-2, and the analysis of the measured signals was performed according to the guidelines given by the standard ISO 15242-1.

1 Introduction

Rolling bearings are widely used in rotary systems, and their role is to allow the relative movement of rotary parts while simultaneously transferring loads between them and ensuring the accuracy of their position. The bearings have an important role in every rotary system. Requirements for continuous improvement of bearing characteristics encourage researchers to research, model and mathematically describe the dynamic behavior of the bearings. Dynamic behavior of roller bearings is the result of the action of external and internal forces due to various effects during exploitation, which cause oscillatory movement of bearing elements, at different amplitudes and oscillation frequencies [1].

Under the external forces, due to the rotation of the bearing elements there is a periodic change in the elastic deformation of the raceways, which leads to the appearance of the vibration of the bearing. In practice, however, the greatest vibrations are due to the imperfection of the internal bearing geometry, as well as due to the deviation of the roughness and waviness of the raceways [2]. One of the main causes of vibration

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appearance in rolling bearings is the discrete structure of the elements and the kinematics of rolling bearings. Transferring the load from the inner to the outer ring takes place over a certain number of discrete rolling elements, whose angle position, in relation to the direction of the external loading effect changes during time. Changing the position of the rolling elements causes a change in the mutual position of the inner and outer ring of the bearing, which is periodically appear by rotating the cage. Therefore, the axis of the inner ring, in relation to the external, constantly oscillates during the operation of the bearing.

The next reason for the vibration of the bearing is to change the stiffness at the contact point of the raceways and the rolling elements. The stiffness change occurs as a result of the load transfer between the raceways and the rolling elements, where the contact between them can be described by Hertz's theory of contact [3].

Another reason for the appearance of bearing vibration is the geometrical imperfection of the bearing elements. Manufacturing errors are usually classified into two groups: errors in the macro and micro geometry of the surfaces of the rolling bearing. The errors of the macro geometry are deviation from the form and dimensions of the bearing rings and cage, as well as deviation from the form and dimensions of the raceways and rolling elements of the bearing. Errors of micro geometry arise from the machining of the rolling elements and raceways. Typical representatives of these errors are the waviness, roughness and variation of the diameter of the ball [4].

The roughness of the raceways is an important source of vibration when their level is higher than the thickness of the oil film, which is between the rolling elements and the raceways. Under these conditions, the peaks of the surface roughness interrupt the oil film so that contact between the rolling elements and the raceways occurs at these points. As a result, vibrations consist of a series of random impulses that evoke all of their own modes of bearing and the whole assembly. Some models of the prediction of the working life of the bearing, as a significant factor take into account the relation between the thickness of the oil film and the surface roughness [5].

In this paper, the influence of surface roughness and lubrication on the level of vibration of bearing 6006 based on the experimental measurements and analysis of measured signals using the method of Fast Fourier transformation (FFT) is considered.

In the paper [6], the procedure for determining the thickness of the oil film for bearings 6007, 6207, 6307 and 6407 in elastohydrodynamic lubrication is presented, using Hertz's theory of contact. It is shown that the thickness of the oil film depends on the bearing load, the resistance that occurs in the rolling bearing and the characteristics of the lubricant.

2 Experiment description

Experimental measurement were carried out on the device for measuring the bearing vibration level, Fig. 1. Bearing Vibration Measurement is a technique used to determine the quality class of the bearing, and can be used to determine the working ability of the system with rolling bearings, or to determine the causes of potential failure of the system. The Vibration Measurement and Control System is installed on a measuring instrument for testing, analyzing and diagnosing rolling bearings and is based on vibration measurement of rolling bearings using an electrodynamic speed encoder (pickup). Measuring - control device is used for diagnostics of deviation in micro and macro geometry of bearings, as well as for detection of damage of bearings elements during production or assembly of bearings.

The bearing is mounted over the inner ring to the spindle, which is supported by hydrodynamic bearings. The spindle speed is constant during the measurement (n = 1800 RPM). The outer ring is stationary and loaded with axial force over the pneumatic cylinder. The basic element in the vibration measurement chain is the velocity sensor
(electrodynamic pickup), (Fig. 2), which generates a voltage at its output whose amplitude and frequency is proportional to the vibration level generated by the observed rolling bearing. Since the amplitude of the signal obtained from the used velocity sensor is small for digital processing and the displaying, signal is amplified by an amplifier. Block diagram of the measurement-control system for testing rolling bearing vibrations is shown in Fig. 3.

![Fig 2. Schematic view of measuring principle of electrodynamic pickup [7]](image)

Elements whose task is analog signal processing are an amplifier and a filter bandwidth. The amplifier has the task of increasing the signal level from the velocity sensor to a level that is suitable for digital processing and display. An amplifier with an amplification of 1500 was used, which provides sufficient signal amplitude for digital processing. The frequency range of the signal which is of interest for testing vibrations of rolling bearings is from 20 Hz to 10 kHz. The filter has the task of limiting the spectrum of the signal received from the amplifier to the given range. The projected filter introduces a relatively small attenuation of wave oscillations in one or more frequency bands and a relatively large attenuation for oscillations of other frequencies (below 20 Hz and above 10 kHz) according to standard ISO 15242-1 (Rolling bearings - Measuring methods for vibration - Part 1: Fundamentals). The bandwidth of the filters is also defined based on the above standard. Digitalization of the signal is done using the NI DAQ USB-6009 measuring system. The sampling frequency is 48 kHz, while the resolution of the internal A/D converter is 13 bit. In this way, the quality preparation of the signal obtained by applying the velocity sensor and its digitalization for further computer processing is provided.

![Fig 3. Block diagram of measuring device](image)

### 3 Results and discussion

Table 1 gives the results of the experimental testing carried out on a sample of 5 ball bearings, designation 6006 belong to the class C0 (normal clearance). The tested bearings have a radial internal clearance of 10 μm. The bearings are 12, 13, 61, 64 and 65. For each bearing, surface roughness for external (Rae) and inner (Rai) ring is given. The roughness of the rolling elements has not been considered. Measurements for different quantities of grease were performed for each bearing. The first measurement was carried out without lubrication, followed by 0.7 g of grease, then with 1.4, 2.1 and a maximum grease quantity of 2.8 g. During the measurement, the axial force was changed from 200 N to 1000 N with a step of 100 N. The results of measurements are given in Table 1. The results shown in
Table 1 apply to a bearing loaded with an axial force of 200 N. By processing of measured signals, the vibration speeds were obtained in three bands that are analyzed for smaller dimensions bearings (50 - 300, 300 - 1800, 1800 - 10000 Hz).

**Table 1.** Class quality of bearings according to the surface roughness of raceways.

| Bearing designation | Internal clearance µm | Class quality | Grease quantity g | R_{ae} µm | R_{ai} µm | \( \frac{R_{ae} \cdot R_{ai}}{R_{ae} + R_{ai}} \) |
|---------------------|-----------------------|---------------|-------------------|-----------|-----------|----------------------------------|
| 61                  | 10                    | Q6            | 0                 | 0.09      | 0.073     | 0.0403                           |
| 65                  | 10                    | Q6            | 0.7               | 0.072     | 0.157     | 0.04936                          |
| 64                  | 10                    | Q6            | 1.4               | 0.152     | 0.179     | 0.0822                           |
| 12                  | 10                    | Q7            | 2.1               | 0.125     | 0.271     | 0.0855                           |
| 13                  | 10                    | Q7            | 2.8               | 0.168     | 0.279     | 0.10485                          |

The measurement results were compared with the recommended limits for determining bearing quality obtained from the manufacturer of rolling bearings that were tested. According to the recommendations, rolling bearings are divided into three quality classes Q5, Q6 and Q7, and the prescribed limits for bearing 6006 are given in Table 2 and apply for the number of revolutions 1800 RPM and the axial force of 200N.

By comparing measured vibration values for characteristic areas, with allowed values, the bearing quality class is determined. Table 1 shows the changes in the bearing quality class with the change in the amount of grease compared to the roughness of the raceways. The influence of the surface roughness of the raceways of rings (relative roughness) is given as the ratio of the product and the sum of the roughness and is given in Table 1.

**Table 2.** Permitted vibration velocity for class quality

| Class quality | Low band frequencies/vibration velocity µm/s | Medium band frequencies/vibration velocity µm/s | High band frequencies/vibration velocity µm/s |
|---------------|---------------------------------------------|-----------------------------------------------|----------------------------------------------|
| Q5            | 56                                          | 80                                            | 112                                          |
| Q6            | 112                                         | 80                                            | 224                                          |
| Q7            | 224                                         | 160                                           | 450                                          |

On the basis of the obtained results, it can be concluded that the bearings with greater relative roughness belong to the quality class Q7 (the worst quality). As the relative roughness decreases, the bearings cross the Q6 quality class. For bearings 61, 64 and 65 whose roughness ratio is less than 0.0822, it can be seen that with only one amount of grease, the quality of Q7 is exceeded. Bearing 12 with roughness ratio 0.0855 for the first three quantities of grease is in Q7 quality. When the amount of grease becomes large enough to form an oil film that separates rolling elements and raceways, then the level of vibration of the bearing is reduced and it belongs to Q6 quality. Bearing 13 has the highest relative roughness that increases the bearing vibration amplitude. The roughness is such that grease does not cover the picks with any amount of grease and for this reason bearing belongs to the quality Q7. The load transfer in this case is achieved through the peaks of the raceways of both the rings and the rolling elements.
Fig. 4 and Fig. 5 show diagrams of vibrations velocity amplitude changing for bearings 12 and 61 in the first band (50-300 Hz), for the quantities of grease 0, 0.7, 1.4, 2.1 and 2.8 g, and for an axial force between 200 to 1000 N.

![Fig. 4 and Fig. 5](image)

**Fig. 4.** Dependences of amplitudes, grease quantity and axial force for bearing 12 in the low band frequency (50 Hz – 300 Hz).

**Fig. 5.** Dependences of amplitudes, grease quantity and axial force for bearing 61 in the low band frequency (50 Hz – 300 Hz).

On the diagrams it can be noticed an increase in vibration amplitude with the increase in axial force, for all quantities of grease. For bearing 12 it can be noticed a significant change in the level of vibration with the change in the amount of grease. Bearing 61 has less change in the vibration amplitude when changing the amount of grease relative to the bearing 12, which is due to the less surface roughness of the outer and inner ring of bearing 61 (Table 1). Vibration amplitudes at a maximum force of 1000 N are less for bearings 61 than bearing 12, which can be explained by the lower surface roughness of the raceways. Based on the results of the measurements shown in the diagrams, it can be concluded that for both bearings the optimum grease amount is 1.4 g, especially if the intensity of vibrations is compared at a higher load, which is expected in exploitation conditions. This
observation is in accordance with the work shown in [8] and the recommendations made by the bearing manufacturer in relation to the recommended amount of grease in this type of bearings.

4 Conclusion

The performed analysis shows that there is a dependence between the surface roughness of the outer and inner ring of the ball bearing and the level of vibration, which is in accordance with the results of other researchers. In this paper, the effect of the amount of lubrication on the dynamic behavior of the bearing, regarding the level of vibration, is indicated. It has been shown that the load size affects the vibration level of the ball bearing. Bearings with higher surface roughness produce vibrations that classify them in the Q7 quality class. According to the results shown, bearings with a lower surface roughness of the raceways produce vibrations that classify them in the Q6 quality class. The analyzed bearings do not meet the requirements in order to be classified in Q5 quality class. The tested bearings have the same radial clearance to eliminate its impact on the test results. The influence of the amount of lubrication on the bearing vibration level is shown on bearings 12 and 61, while the same conclusions apply to other tested bearings. It has been shown that the level of vibration of the bearing increases with the increase in bearing load. Based on the results shown, an optimal amount of grease can be determined for each tested bearing. In most cases it is 1.4 g. What should be noted is, that the results of the experimental test are shown, and that in addition to the roughness of the raceways, all the tested bearings have different other geometric parameters of the outer and inner ring, such as waviness, deviation from circular form, etc. and these parameters may have impact to the level of vibration of the bearing.

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