Method for diagnosing the state of bearings of spindle units by the energy of the vibration signal

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Abstract. The work considers improved approach to assessing the serviceability of bearing assemblies of spindle groups of metal-cutting machines. As a basic malfunction, we looking a variant of the defect of the outer ring of the rolling bearing separator. For this task the calculated values of the vibration frequencies were obtained, and a full-scale experiment was conducted with the evaluation of the vibration signal on a large spectrum of frequencies. The results of the experiment showed that it is possible to assess the degree of bearing damage both from the spectrum of signal amplitudes and from the rms value of the vibration signal (RMS). However, studies have shown that the most beneficial, from the point of view of diagnostics, is to consider RMS not for the entire vibration signal, but only in the frequency range corresponding to the diagnosed bearing malfunction.

1. Introduction
The problem of analyzing the state of the main load-bearing systems of metal-cutting machines is extremely urgent today from a scientific, scientific and practical point of view. A lot of research is devoted to the assessment of the influence of vibrations on the state of metal processing by cutting [1-2]. Some studies consider the question of assessing vibrational activity from the point of view of the influence of temperature on it in the zone of vibration formation [3]. A number of works consider the effect of tool wear in metal-cutting equipment on the vibrational dynamics of the cutting process [4]. Most modern Russian researchers note the importance of controlling vibrational dynamics when processing metals on metal-cutting machines [5-7]. Here, authors lookin the diagnostics of processing processes during cutting, both during turning [5] and during milling [6], issues of general diagnostics of processes through analysis of a vibration signal are considered in [7]. On the whole, all these works show the ever-increasing role of vibration signal analysis as an information channel illustrating the processes occurring in the equipment under study.

2. Conditions for conducting experiments and mathematical methods used for analysis
When conducting the experiment, we must proceed from the fact that it is necessary to eliminate defects in the outer ring of the separator. An example of such a damage is shown in figure 1.
In the example presented in Figure 1, we are interested in the case of a defect in the outer ring of the bearing separator. For this, we used the SKF 6207-2z bearing, which is of Swedish origin, but today it is produced in our country. In order to diagnose a malfunction in this bearing in the form of a defect in the outer ring of the separator, we deformed him by hard blow. For the experiment, a specialized balancing machine was used, on which sensors for measuring vibration acceleration, manufactured by Vibroprribor, DVST, were installed in the bearing mountings. The appearance of the experimental setup with installed sensors is shown in Figure 2.

As can be seen from Figure 2, the sensors are mounted directly on the bearings, an engine belt is used to drive the rotor, and an optical speed sensor was used to measure the speed. To assess the influence of the dynamics of the machine associated with cutting, in which the cutting force acts on the spindle, we introduced an imbalance on the rotor, as shown in Figure 3.
Let us consider that the introduction of an imbalance in the rotor will allow to simulate the cutting process, as it happens on the real spindle of the metal cutter. Frequency of the beats connected with an imbalance will be connected with the frequency of rotation of a rotor which in an experiment we will establish in 2000 revolutions per minute, or in 33.33 Hz which further we will designate as $f_0$. For further calculations we will need to know the speed of rotation of the separator, which can be calculated according to the following expression:

$$f_c = \frac{1}{2} f_0 (1 - \frac{d_w}{d_c} \cos \alpha) ,$$

(1)

Where $d_w$ — is diameter of rotation bodies (balls), $d_c$ — is diameter of separator, $\alpha$ is angle of bearing tension, in our case it is equal to zero. Based on our bearing SKF 6207-2z, $f_c$ ranges from 12 to 14 Hz. However, in our case, it is not this chastota itself that is of interest, but the frequency of rolling of the bodies of revolution (bearing balls) through the outer ring of the separator, which is defined as:

$$f_h = f_c \cdot z ,$$

(2)

Where $z$ - is the number of bodies of rotation, in our case 9, which gives a frequency of 117 Hz. It is in the vicinity of this frequency that we have to control the vibrations on the bearing, to estimate the test (diagnose) fault.

3. Results of the experiment and discussion

The conducted experiment can be estimated both from the signal itself, which will be presented below, also by the amplitude spectrum of the signal in the frequency range close to the value calculated by us. Figure 4 shows the vibration signal removed from the vibration inverter on the is-right bearing, as well as the part of the signal that can be obtained from it if you subtract the RMS signal. For the numerical evaluation of the instrument vibration signal RMS, we used the following integral indicator:
\[ VA = \frac{1}{T_v} \left( \int_0^{T_v} da(t) \right)^2 dt \]  

Where \( a(t) \) - is the vibration signal itself (vibration acceleration), and \( T_v \) - the period of signal observation.

As can be seen from Figure 4 a), the visual analysis of what is happening on the test bearing is not amenable, however, it is of interest between the vibration signals of a serviceable and a unserviceable bearing, in our case the vibration signal from a unserviceable bearing is shown in Figure 4 b). A comparison of Figures 4 a) and 4 b) allows us to see only the fact that the vibrations on a unserviceable bearing are higher (greater) in amplitude, but how much more they are from the figure is not clear, just as it is not clear what exactly leads to this difference in signals. To determine the cause of the amplitude difference of the oscillation signals on a serviceable and a unserviceable bearing, it is convenient to consider the amplitude spectrum of the signal taken from a unserviceable bearing, which we presented in Fig. 5 for the case of an experiment without imbalance.

**Figure 4.** Vibration acceleration and its peak values: a) serviceable bearing, b) faulty bearing.

**Figure 5.** Spectrum of signal removed from unserviceable bearing, without unbalance
As can be seen from Figure 5, two main frequencies of amplitude peak are present in the frequency range of the signal. The frequency is 48 Hz, which is associated with the vibration of the drive belt and the frequency of 116 Hz, which, according to our calculations, is associated with a bearing defect. As can be seen from Figure 5, the amplitude spectrum power here is greatest. In order to assess the impact of the fault on the RMS vibration signal, we passed the measured signal through a frequency filter, with a window from 100 to 140 Hz, and calculated the value of the signal energy using the expression (3). Results for the serviceable VA=793 mm/s² bearing, and for a case of the unserviceable bearing were VA=5823 mm/s², gain of energy of vibrations much more seven times that is not visible from comparison of figures 4 a) and 4 b). For order to evaluate the operation of this approach in conditions close to processing conditions, we will consider the amplitude spectrum of the signal removed from the unit with unbalance on the rotor (see Figure 6).

As can be seen from Figure 6 as compared to Figure 5, there are significant run-outs at the rotor speed, but the run-outs associated with the diagnosed fault, if changed, are extremely insignificant.

4. Conclusions
The article presents a method for solving the problems of diagnosing bearings of spindle assemblies of metal-cutting machines that have defects in the outer rings of the separator. The paper proposes approaches to such an analysis based on the determination of frequency ranges and fixing faults and estimates of the RMS of the vibration signal in this frequency range. Studies have shown that the difference between the serviceable and unserviceable bearings in a predetermined private window of the oscillatory signal can be more than seven times, which, in our opinion, is quite enough for the correct determination of the occurrence of malfunctions.

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References
[1] Lapshin V, Moiseev D, Minakov V 2019 AIP Conference Proceedings. Vol. 2188.
[2] Zakovorotny V L et al. 2019 E3S Web of Conferences. EDP Sciences. Vol. 104.
[3] Lapshin V P et al. 2020 Russian Engineering Research. Vol. 40. P. 259-265.
[4] Lapshin V P, Babenko T S, Moiseev D V 2018 *International Conference on Industrial Engineering*. Springer, Cham. P. 853-859.

[5] Kozochkin M P et al. 2018 IEEE International Conference *Quality Management, Transport and Information Security, Information Technologies (IT&QM&IS)*. P. 458-461.

[6] Sabirov F S, Vainer L G, Rivkin A V 2015 *Russian Engineering Research*. Vol. 35. P. 458-461.

[7] Porvatov A N et al. 2015 *Mechanics & Industry*. Vol. 16. P. 707.