Analyzing the bearing wear using direct spectrum method when transferring the torque motion from the machine

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Abstract. The present article examines rolling bearings with varying degrees of wear using direct spectrum method when operating from a machine drive. To achieve this purpose, a narrow-band spectrum analyzer was used. Also, several experiments were carried out to determine the effects of different types of bearing wear on the frequency characteristics of the vibroacoustic signal, which allows to predict the occurrence of defects in the bearing structure. Eventually, data were gathered on the increase in vibroacoustic noise in different types of wear and conclusions were drawn about the possibility of using the spectral method to predict failures during the operation of bearings. The results showed the lack of lubrication in the bearing and the presence of corrosion leads to an increase in amplitude frequencies in the high frequency range of 4000 - 10000 Hz. Moreover, the amplitude of the bearing without lubrication is about 35% higher than the amplitude of the worn bearing. Finally, due to the research carried out, it becomes possible to create a method for determining the type and nature of wear of rolling bearings of metal-cutting and other equipment. This will allow in the future to create a system for monitoring malfunctions directly during the operation of technological equipment without disassembling its units, reduce the cost of repair work and prevent emergency failures.

1. Introduction
Rolling bearing is an important element of rotating machinery, which is extensively used in the different industries (i.e., automotive, airplane, mechanics, petrochemical, nuclear engineering and so on). This critical component is subjected to various types of loads (i.e., axial, angular, and radial loads) to its design specifications. The early bearing failure occurs at very high speed, very low/high temperature, and very heavy loading conditions. In fact, when the design does not meet the requirement, it will lead to high temperature, high frictional torque, excessive deflection, and consequently unwanted vibration [1]. Detection of the running state of bearing and error diagnosis are essential since its working condition directly affects the function and operation of equipment [2]. In this regard, the operational reliability and availability of the machine can be increased by monitoring faults in the bearing [3]. The problem statement of the present study is due to the widespread use of rolling bearings in mechanisms and machines, as well as the need for further development of effective methods and tools for error diagnostics of bearings in the different working conditions. In the realities of production, the modern techniques of error diagnostics allows avoiding frequent repairs of equipment, in which defects in rolling bearings are one of the dominant causes of breakdowns [4]. The common faults that usually occur for rolling bear are inner and outer ring fault, cage damage, and rolling body fault. Therefore, industries aim at finding an effective and efficient diagnosis system to predict the condition and consistent lead time of the machine [5]. Determination of a diagnostic parameter that makes it possible to predict the failure
time of rolling bearings without disassembling technological equipment is an important task in mechanical engineering, automotive and other fields of technology. In addition to the usual physical wear, the cause of the destruction and seizure of rolling bearings is often insufficient lubrication, corrosion, and the ingress of particles from machine parts. One of the requirements for the diagnostic parameter is the ability to determine the type of wear. All this will make it possible to create a system for monitoring malfunctions of technological equipment during its operation and reduce the cost of repair work and prevent emergency failures due to timely detection and elimination of defects. According to some studies, about 35% of bearing failures are related to insufficient amount of lubricant, inadequate selection of lubricant, and aged lubricant. In addition, wear and corrosion are also considered as the main causes of bearing damage [6]. The most important and prominent types of wear in rolling bearings includes surface fatigue wear, adhesive wear and abrasive wear followed by erosive, fretting, and corrosive wear. Detection of the dominant type of wear makes it easier to measures and provide solutions to reduce or eliminate the errors, which can extend the service lifetime of the rolling bearings [7].

Existence of some mechanical problems, such as unbalance, misalignment, worn gears or bearings, and looseness, leads to increase machine vibration level [8]. However, one of the main factors that has a great impact on the accuracy of fault diagnosis is environmental noise [9]. Vibration analysis plays an important role to detect the fault in rotating machine. Moreover, the frequency band, includes the characteristics of modulation, nonlinear, and non-Gauss [10]. According to the traditional diagnosis technology to recognize the fault, the time domain or the frequency domain features of vibration signals should be studied. Therefore, finding an appropriate method to enhance the resolution and extract the characteristic frequency plays an important role in realizing the fault diagnosis of bearing. Especially, the onset prediction of a bearing failure is of great practical importance [11]. Some important, reliable, and well-known methods that are frequently applied to analysis the bearing failure are acoustic emission technique, high frequency resonance technique, sound measurement technique, and localized current method. In this regard, the health of bearing is identified by parameters such as: power, crest factor, kurtosis, overall RMS, spectrum etc. [12-14]. Goncharov has investigated the possibility of using the vibroacoustic method to diagnose engine malfunctions [15]. In this research, the author proposed that to improve measurement accuracy, five spectrograms in five ranges should be analyzed. Furthermore, the causes and effects of vibration on various types of surface treatments have been investigated. It also uses the method of vibroacoustic analysis to diagnose malfunctions, improve the stability, and quality of the machined surface [16, 17]. Using this method, the authors have proven the effectiveness of vibration diagnostics and the possibility of using the method during the operation of the machine. Moreover, the authors have stated that this method made it possible to make a choice in favor of the direct spectrum method and have proven the advisability of its applicability during the transmission of the torque motion from the machine tool. Actually, the spectral analysis is the main method of vibration diagnostics, allowing you to detect a number of pronounced periodic frequency components directly related to the dynamics of the interaction of parts of the machine or desired part, as well as components caused by certain defects in working parts [2,18].

Based on above, the main problem statement of the study is related to the diagnosing the bearing wear using the direct spectrum method and prove the advisability of its use during the transmission of the torque motion from the machine tool.

In the present research, the study is carried out by the method of analysis of the direct spectrum - identifying the frequency of the appearance of amplitude bursts, obtained using a vibration analyzer. The amplitude bursts observed in the spectra provide useful information, since they allow one to draw a conclusion about the presence of defects in the equipment under study. In this case, each type of defect corresponds to its own set of amplitude bursts, which are unambiguously calculated depending on the operating parameters of the equipment [19, 20]. In this method, the presence of a certain defect in the spectrum is determined by the presence of a certain defect, and by the amplitude of the spectrum fluctuation, the degree of its development. Compared to other conventional methods, this method has low error rates and high information content. In summary, the main advantage of spectral analysis is the
possibility of detecting a defect at the stage of its inception, which allows taking timely measures and avoiding emergencies.

The main tasks of the study are:

- Determination of a diagnostic parameter to determine the moment of failure of the rolling bearing;
- Investigating the sensitivity of the diagnostic parameter to various types of rolling bearing wear;
- Revealing the influence of vibrations and noise from the main drive of the lathe on the diagnostic parameter;
- Making a conclusion about the possibility of using the developed method for detecting wear of rolling bearings while the equipment is in operation.

To this end, the paper is organized as follows: in section 2 the experimental study is performed. Six rolling bearings with different forms of wear were used (see Table 1). Machining processes were carried out on the lathe machine 16K20 by setting the required operational mode. The spectrum analyzer A17-U8 was applied to record the vibration-acoustic signals of each tested rolling bearings. In section 3 the results obtained during experimental studies are shown for each examined rolling bearing and the results were compared and discussed. Finally, in section 4 the conclusion is derived which indicates that the criteria for comparing the spectra make it possible to detect defects at a significantly lower amplitude of the bearing signal or at a late stage of the development of defects.

2. Materials and methods

A spectrum analyzer A17-U8 and its accessories include vibration sensors, microphones, and speed sensors were used to carry out a bearing laboratory study. The vibration signal is analyzed by a narrow-band spectrum analyzer and the occurrence and development of bearing defects can be identified by the frequency composition of the spectrum.

The tests were carried out on rolling bearings with different forms of wear according to Table 1. Also, the different groups of tested bearings are shown in Figure 1.

| №  | Rolling bearings with different forms of wear                                      |
|----|----------------------------------------------------------------------------------|
| 1  | with separator and seal deformation due to mechanical shocks                       |
| 2  | with the presence of chips arising from the physical wear of machine parts         |
| 3  | with the presence of chips arising from the physical wear of machine parts         |
| 4  | in bearing grease                                                                  |
| 5  | without wear                                                                      |
| 6  | with traces of corrosion                                                           |

Figure 1. Different forms of wear (Table 1) on the rolling bearings with the aim of conducting experiments
Figure 2. (a) Accelerometer position installation of the test sample (b) Conducting experiments on the machine 16K20

All experiments were carried out on a lathe machine type 16K20 (Figure 2). And the steps of the test are shown in Figure 3:

**Fig. 3. Steps of the test**

3. Results and discussion

The graphs of vibroacoustics as a results of the experiments are demonstrated in Figure 4. From this figure, the influence of the type of bearing wear on the frequency characteristics of the vibroacoustic signal is clear. Bearing wear in the form of mechanical wear leads to an increase in the noise level in the low frequency range of 0.1 - 0.25 Hz. The results show that the noise amplitude of a worn bearing 59 is 2% higher than that of a worn 58 bearing. Moreover, the lack of lubrication in the bearing and the presence of corrosion leads to an increase in amplitude frequencies in the high frequency range of 4000
- 10000 Hz. The amplitude of the bearing without lubrication is 104, and the bearing with corrosion is 106, which is 35% and 36% higher than the amplitude of the worn bearing, respectively. The presence of a small amount of abrasive chips in the bearing lubricant at an early stage of clogging increases the amplitudes (48 dB) in the low frequency ranges of 0.25 - 1 Hz, while the presence of a significant amount of chips in the lubricant increases the amplitudes at all frequencies, but this is especially noticeable in the range of medium frequencies (100 - 1000 Hz).

Figure 4. Vibroacoustics measurements for different samples including: bi means- sample with no wear; bs - means sample without lubrication; i - means sample with wear; s1 - means sample with shavings 1; s2 - means sample with shavings 2; and cr - means sample with traces of corrosion

4. Conclusion
In this research, the effect of various common forms of wear on the vibrational characteristics of rolling bearings has been investigated to detect the defects with higher accuracy. The analysis of the obtained data showed that the criteria for comparing the spectra make it possible to detect defects at a significantly lower amplitude of the bearing signal or at a late stage of the development of defects. Also, they are not applicable for early diagnostics of rolling bearings, while the criteria for comparing spectra are suitable for monitoring bearings. The main advantage of the proposed method is the ability to diagnose bearings on working equipment. In other words, for successful diagnostics, bearing removal is not required since the method minimizes interference, and the bearing design does not have complex moving components.

5. References
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