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MONITORING OF MACHINERY COMPONENTS DURING THEIR LIFE CYCLE

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Abstract: The article deals with determining the operating state of machinery and its components by processing trend characteristics through measuring mechanical vibration, which determine the end of the lifetime cycle of machine components. It focuses mainly on the area of spinning headstocks and proposes a methodology for permanent monitoring of the dynamic behaviour of the bearings of spinning units. The elaborate the methodology for monitoring bearings leads to an increase in the service lifetime of machinery components. It analyses the causes and frequency and time distribution of vibration.

KEYWORDS: Vibration, monitoring, trend characteristic, spinning headstock, service lifetime.

1 Introduction

In machines and machine systems, one of the most important components are the bearings, which enable the rotational movement of the shaft and at the same time transfer dynamic forces to the machine structure and it's mounting. The operability and service lifetime of these mechanical systems is therefore largely dependent on the operating condition of the bearings and their service lifetime. With high-quality bearings and the corresponding dynamic load, their service lifetime is usually equal to the service lifetime of the machine, but this is not the case for spinning headstocks. Therefore, it is necessary to monitor the trend characteristics of vibration (or noise) in spinning headstocks and ensure that they do not exceed the set acceptable limits by replacing them in time (Fig. 1). Otherwise, their dynamic overload occurs, and thus also shortens their service lifetime. Using vibro-acoustic diagnostics, it is possible to determine the time when the bearing is just before the end of its service lifetime and when the optimal time for its replacement occurs [6, 9]. This will eliminate the premature and unnecessary replacement of bearings performed on the basis of the established time of operation and maintenance. Diagnostics therefore increase certainty, reliability and service lifetime, or the time between two repairs, which also reduces operating costs and material recycling costs. At the same time, it should be emphasized that reducing the dynamic load of the machine increases the lifetime of the machine itself, and the noise level in operation also decreases, which has a positive effect on the health of employees [7].

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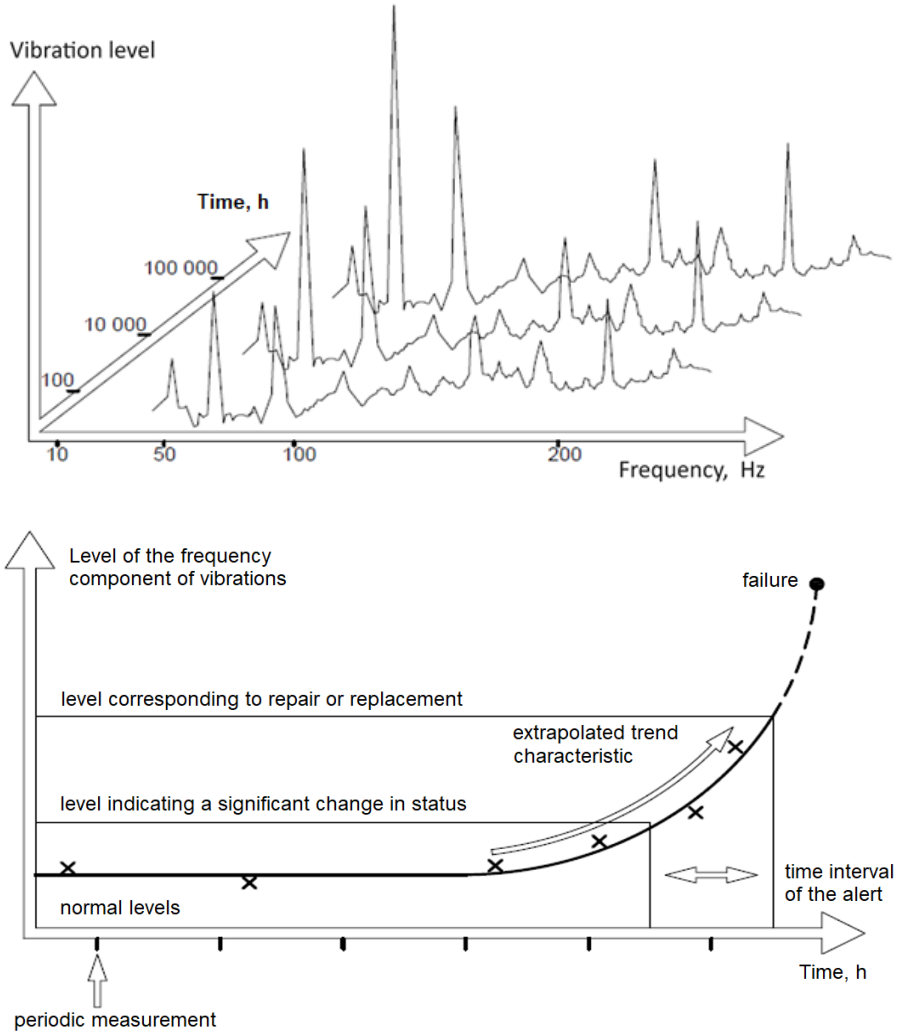


Fig. 1 Trend characteristic of the machine component and trends of changes in the frequency spectrum of the machine system electric motor – pump [6, 22]

From all of the previously mentioned areas of application of vibro-diagnostic methods, the most frequently employed methods seem to be those ones which determine the actual operating state of bearings (rolling, sliding), or the mounting of bearing rotors. According to an estimate, there are approximately 18 billion pieces of rolling bearings in operation in the world [9]. The good and effective diagnostics can prevent damage to other parts of the machine and ultimately accidents, thus significantly reducing the cost of repairing and recycling machine components. A representative example can be, in machine systems, spinning headstocks used in the textile industry, where A-weighting noise levels normally exceed the value of 90 dB, primarily depending on the degree of bearing fault and therefore a timely replacement of the bearings of the spinning unit reduces noise in the working environment and extends the service lifetime of the assigned components of the given machinery and, in case of insufficient vibration isolation, also of nearby building structures [3].

The absence of monitoring or incorrect monitoring of the operational state of bearings can also result in the other extreme, when bearings are replaced or renewed prematurely (sliding), based on an inappropriately determined time interval between repairs. When choosing the right diagnostic method and/or device, it is important to first clarify what damage can occur when using rolling or sliding bearings, and what is the percentage of individual causes in the total

number of fault bearings. The largest share of bearing faults is caused by the lubricant and/or the lubrication method, in almost 55 % of the total number of known causes [6, 9].

The monitoring of the operating state is based on the ability to monitor the current operating condition of the mechanical system and to predict the future condition of this system during its further operation. It means that information must be obtained on the basis of external manifestations of the mechanical system caused by internal causes during its operation.

2 Objectives, methodology and measurement technique

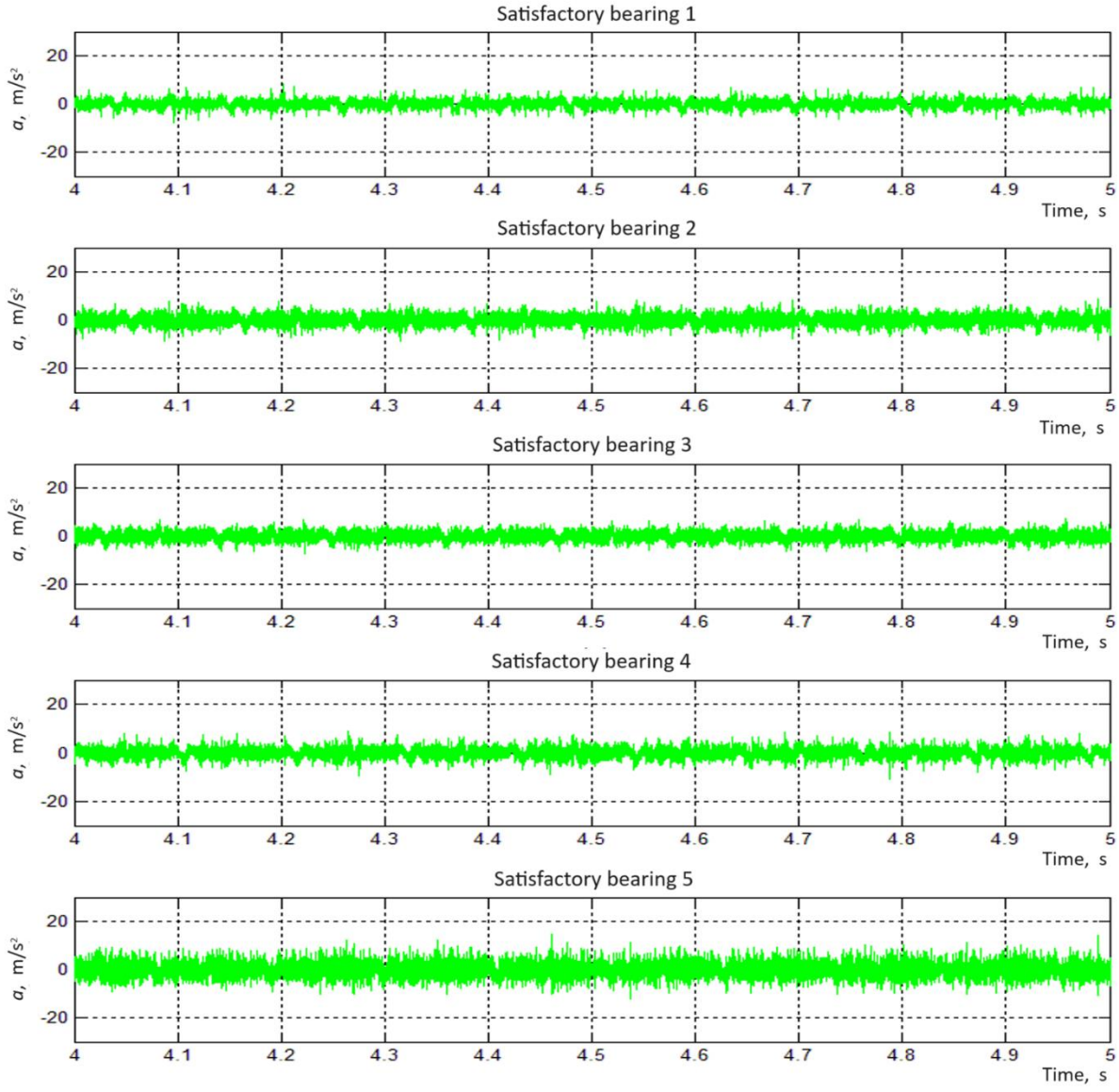
The aim of the experimental measurements was to determine the magnitude of the dynamic load on the bearing of spinning headstocks with different types of lubricant and different operating rotational frequency during its planned lifetime using diagnostic sensors that are in direct contact with the outer ring of the bearing [1]. This method is based on the assumption that a fault or worn bearing of the spinning headstock will show a greater dynamic load on the machine system and the environment (vibration, noise) and therefore a greater power consumption. In addition to the increased dynamic load on the spinning headstock bearing, this will also be manifested by an increase in the temperature of the headstock body, which has, so far, been the only indicator of the operating state of the spinning units, but not completely reliable [2]. The aim of the experimental measurements was also the analysis of the influence of external sources generating vibrations affecting the dynamic load of the spinning headstock bearing.

The procedure for evaluating the operational quality of bearings in terms of their noise is based on the dynamic behaviour of the bearings, that is, on the evaluation of the parameters of the mechanical vibration quantities. The aim of measuring the acceleration and magnitude of the periodic dynamic load (vibration) was to analyses the magnitude of the kinematic quantities of acceleration and vibration velocity acting on the bearing flange, respectively its mounting in the mechanical system. The acoustic power level of the headstock was calculated from the severity vibration, which makes it possible to assess and predict the acoustic environment of the workplace [8]. Vibration quantities are not affected by ambient vibration as in the case of sound signal sensing, which is more or less affected by background noise when determining the acoustic power level of the spinning headstock itself [8]. The methodologies therefore use a clear connection between mechanical and acoustic vibration. The methodology for evaluating the quality of mounted bearings in rotary components of a mechanical system must unambiguously and reliably evaluate satisfactory and non-satisfactory bearings with repeatability and/or reproducibility [4]. The goal was also to find out the frequency distribution of the significant unwanted dynamic load of the equipment and the working environment and its causes.

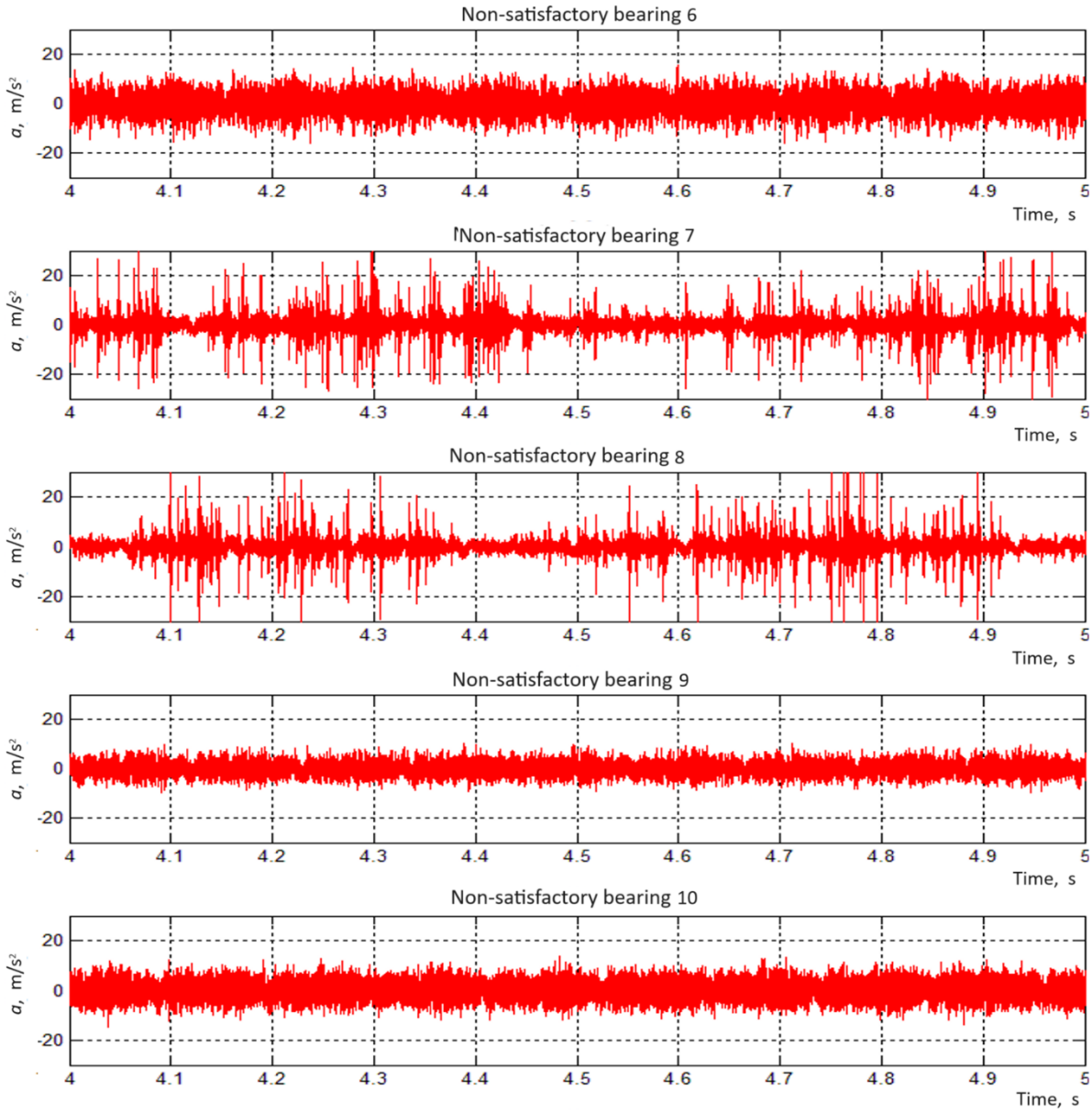
When measuring mechanical and acoustic vibration, the most modern measuring technique was used from the renowned Bruel & Kjaer (B&K) company, namely the 12-channel B&K PULSE measuring card; accelerometers with usable frequency ranges of 0.2 Hz – 12 800 Hz; sound analyser with a usable frequency range up to 25 600 Hz for control recording of measured signals, including residual noise. The attachment of the sensor to the investigated objects was in accordance with the requirements of ISO 5348 [23] on the accelerometer as well as in accordance with the previous experience of the researchers [2-6, 10-21]. The aim was to ensure that the accelerometer correctly reproduces the movement of the analysed component without interfering with its sound. In addition to the frequency range, it was also very important to choose a suitable averaging method for the signal type and the number of averaging per time unit, as well as a suitable time window [6]. For this reason, the Hanning window with linear averaging and 66.67 % overlap that provides completely uniform weighting was chosen, as it is was deemed useful for analysing generated signals.

3 Dynamic bearing load and trend characteristics

Time history: The time history of the measured vibration accelerations of the new bearings (Fig. 2) represent a selection from a significant statistical sample from the dynamic load generated by the satisfactory (a) and non-satisfactory (b) bearings. The time history of vibration acceleration is approximately constant with a small amplitude in high-quality bearings, compared to substandard bearings, where the amplitude of vibration acceleration is on average several times greater with more pronounced regular and irregular maximum amplitudes. These amplitudes reach high values of vibration acceleration characteristic of, for example, pulse stuttering. These deterministic or random maximum signal amplitudes exhibit the fault to the bearing´s orbits or its components and they are only usable only for re-use of the material. A closer specification is possible with the use of frequency analysis, which allows detecting the causes and types of bearing fault. Abnormal temporal dynamic behaviour of the bearing through the maximum value of vibration acceleration is one of the criteria for the objective assessment of the quality of bearings [3, 5]. Closer specification is possible with the use of frequency analysis, which allows to detect the causes and types of bearing fault and, based on the type of fault in production, to detect the type of production operation where the fault occurs.



(a)



(b)

Fig. 2 Time histories of the dynamic load of the headstock bearings: (a) satisfactory and (b) non-satisfactory

Frequency analysis: From the measured time courses, a frequency spectrum was processed to identify the exact rotational frequency, which was 75 600 r/min at the set rotation frequency of 85 000 r/min (Fig. 3). Based on the rotational frequency, the characteristic frequencies belonging to individual components of the bearing were calculated and the causes of bearing fault were analysed. This analysis provides the manufacturer to take appropriate measures.

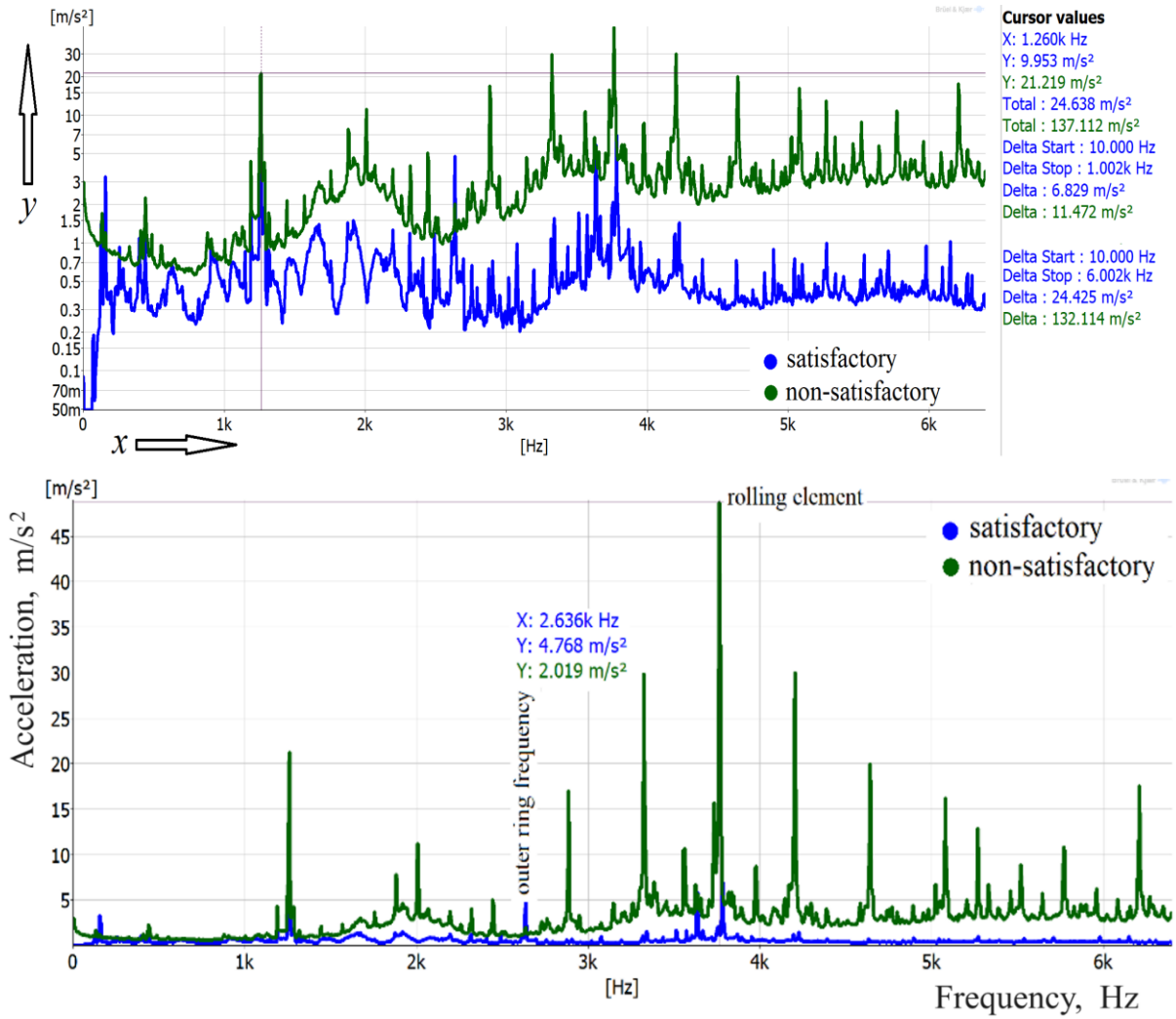


Fig. 3 Frequency spectrum of bearings of a satisfactory and non-satisfactory spinning headstock in logarithmic and linear scale

Trend characteristics of spinning headstocks: Based on the measured or calculated values obtained from the operational monitoring of the spinning headstock bearings, their trend characteristics were processed, either on the basis of the measured vibration values (Fig. 4) or on the basis of the calculated values of the acoustic power level with the measured severity vibration (Fig. 5) [12]. The use of vibration acceleration is advantageous from the point of view of the lifetime of other machinery components and the use of acoustic power levels presents an obvious benefit in ensuring the required working conditions for employees with regard to noise exposures [7].

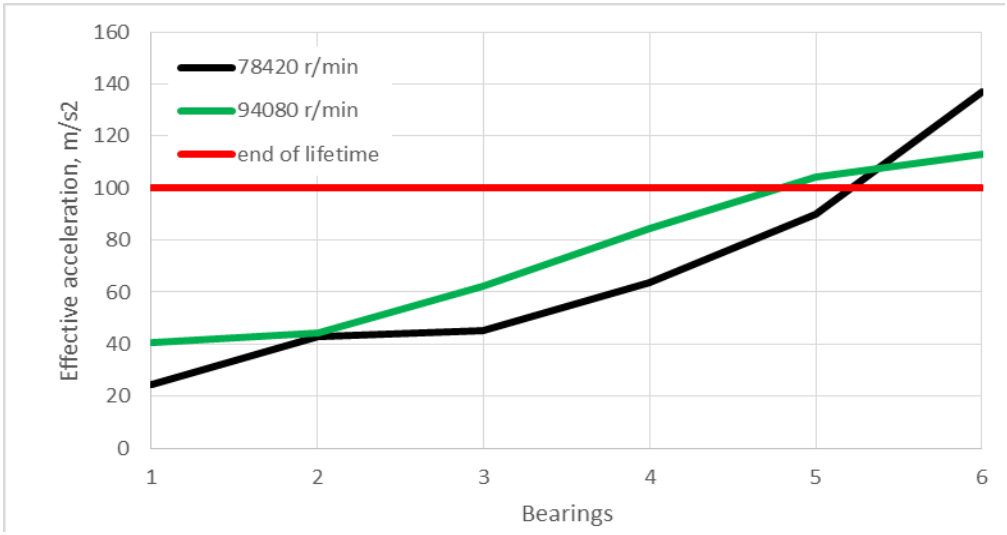
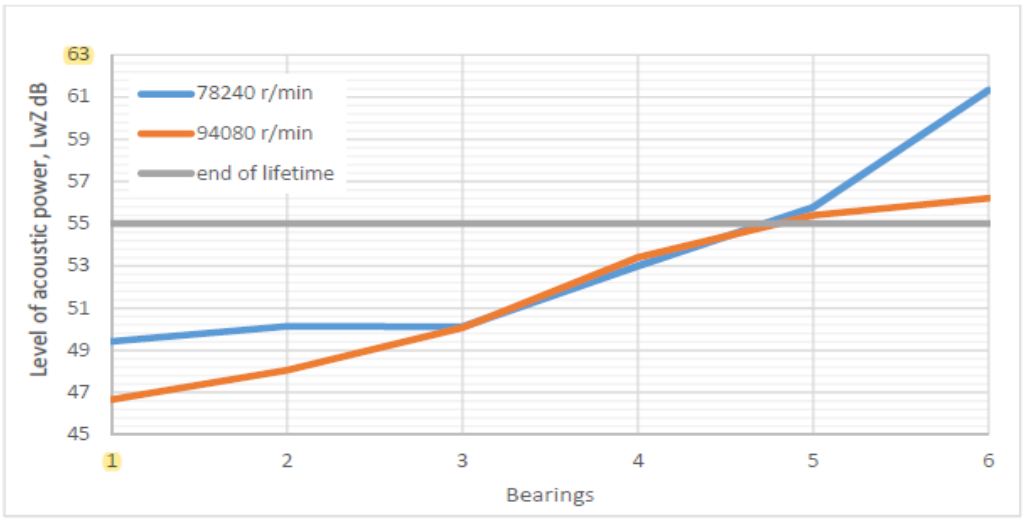
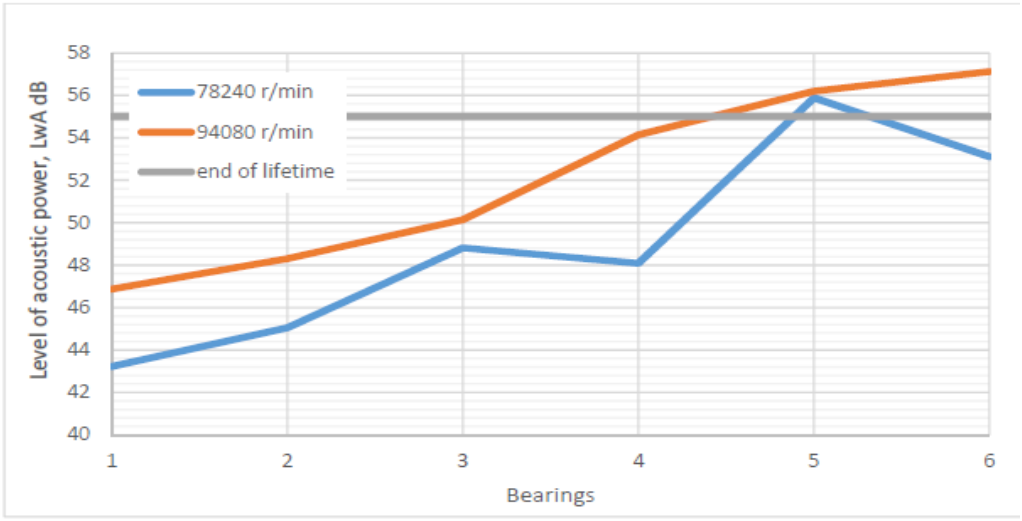


Fig. 4 Trend characteristics of bearings from the measurement of the acceleration of vibration of spinning headstocks with a recommended lifetime limit



(a)



(b)

Fig. 5 The bearing trend characteristics from calculated Z-weighted (a) and A-weighted (b) acoustic power levels of spinning headstocks with a recommended lifetime limit

DISCUSSION AND CONCLUSION

In cases where the monitored machinery occupies a key position in production and has a decisive influence on its creation, and thus also on the economic side as well as on the safety and health of workers/employees, it is recommended to introduce diagnostic systems for monitoring the operating state of the machinery bearings. This may be done by using vibration monitors that immediately indicate changes in the operating state of the monitored machinery. It is estimated that operational monitoring brings around 60 % savings in maintenance [9]. Therefore, experts recommend maintenance according to the operating state because the potential failure of the machine or machine system is predicted on the basis of regular monitoring of its operating state, and maintenance is carried out at the optimum time. This has economic advantages compared to post-failure or preventive maintenance, but requires a reliable approach to operating state monitoring, which, by measuring vibrations or other methods of technical diagnostics, is able not only to determine the current operating state, but also to give rational predictions for the remaining operating lifetime.

This method of maintenance deals with each machine separately. Instead of maintenance work at fixed intervals, measurements are taken periodically, the results of which enable the operating state of each individual machine and/or rotating component to be monitored precisely. Since mechanical vibration is a very good indicator of the operating state of mechanical systems, it is appropriate to base the method of monitoring the operating state of mechanical systems on vibration measurements and to use the corresponding results as indicators of their operating states. The principle of maintenance based on monitoring the operating state of mechanical systems states that maintenance work should be carried out only when measurements show that it is necessary to carry it out. Finally, practice and personal experience show that it is not advisable to interfere with a perfectly working machine because its technical state may deteriorate even further, as illustrated in Figure 6.

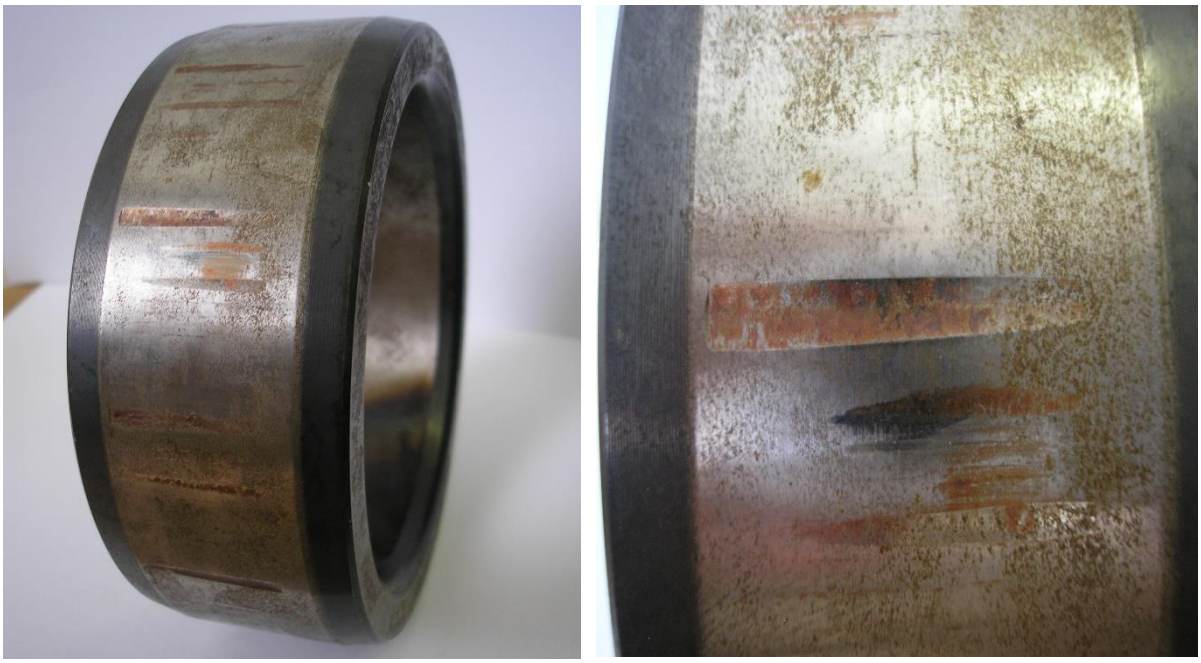


Fig. 6 Destruction to an electromotor rotor bearing during maintenance

By regularly measuring the mechanical vibration, the beginning of damage (or the beginning of a future failure) can be detected and its development monitored. The measurement results can be extrapolated to estimate the time when vibration levels reach unacceptable values and

when maintenance will be required. This method is called the trend-following method and allows long-term planning of repairs (see Fig. 1).

The maintenance method based on monitoring the operating state has had positive results. When this method has been used for a long time and applied correctly, maintenance costs have been significantly reduced [9]. Great successes have been achieved in industries where machines have been operated for long periods of time without stopping, such as generators in power plants and mechanical systems in the petrochemical industry. Machines and machine systems in such industrial plants usually operate at a constant rotational frequency with a constant load, and thus the technical problems associated with monitoring the operating condition are greatly reduced. This progressive method can be advantageously used in the petrochemical and paper industries, in hydroelectric power plants in nuclear and other types of power plants, in the diagnosis of wind turbines, food processing and spinning machinery systems, and other more complex mechanical systems, and this method has also been effectively used in the water industry, compressor stations, high-speed components and also in mobile technology [10-21]. In practice, it is desirable to apply a wide range of procedures based on vibration analysis, namely all four phases of monitoring the operating state of a machine, namely diagnosis of causes, fault detection and diagnosis, and fault prognosis (prediction of remaining operating lifetime). This significantly reduces the replacement and/or restoration of damaged machine components and especially bearings, which positively contributes to the living and working environment of a human.

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