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Efficiency of diagnosing the condition of rolling bearings in real time

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Abstract

One of the control elements of a complex technological system is an information-and-measuring network, a significant part of which is represented by measuring transducers and sensors. Due to the design features, the sensors turn out to be unreliable elements of information-and-measuring systems. Distortions in sensor readings affect the quality of controlling the technical system. It is necessary to account for these distortions when assessing the efficiency of the diagnostics of mechanical components. This fact is especially significant when assessing the efficiency of diagnosing the condition of rolling bearings in real time.

It is proved that the efficiency of diagnosing the machine parts largely depends on the dynamics of the information-and-measuring system and the prompt detection of changes in the operation of this system. As a result of the experiments, the primary task to diagnose the machine parts was solved on the example of faulty rolling bearings, and the influence of the computing power of the equipment used, the sensitivity of the acceleration sensors, and practical feasibility of the network algorithms for automatic data processing in real time were assessed.

Keywords: ball bearings; reliability; efficiency of diagnostics; vibration measurements; real time.

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1. Introduction

Rapid development of data transmission methods and their implementation in the production process has a significant impact on a wide range of technologies in various fields. The emergence of high-speed and reliable communication channels allows you to remotely control production processes and monitor corresponding technological modes. The influence of digital technologies on the production sector requires the availability of an appropriate infrastructure, the basis of which consists of communication networks.

In industry, there are requirements for measuring the data transfer rate, compliance with which allows you to evaluate the bandwidth of communication channels. The integrity of communication channels ensures complete and timely transmission and receipt of information about managed production processes. In addition, there are increased requirements for the computing power of the equipment used, related to the real-time performance. This is due to the problems with small samples of observations.

Paper [1] presents a model based on a temporary convolutional network (TJN), which was used to diagnose a malfunction of the engine in real time. It is claimed that a small amount of data received within 5 seconds is sufficient for timely detection of a malfunction with high accuracy. However, not all components of the measurement uncertainty are accounted for, and even in the prediction mode of engine malfunction. In this paper, malfunctions are interestingly modelled, but the efficiency of detecting these defects has not been studied.

Paper [2] investigates dynamic phenomena related to the vibration, which have a destructive effect on industrial equipment. Torsional vibrations that can be caused by malfunctions of the machine parts are also described. However, the fact that torsional vibrations themselves cause the equipment wear is not presented in this study.

Study [3] provides the estimation of the possibility of introducing vibration standards of defects in the machine parts. It is stated that the confirmation of metrological characteristics of the equipment is not a convincing proof of the efficiency of test benches. The efficiency of the diagnostics has not been studied.

Articles [4, 5] discuss the possibility of creating virtual standards. To successfully identify defects in the diagnosed assemblies, it is suggested to use fault standards that will be used to diagnose measuring devices. In this case, the inverse problem of diagnostics is solved. For real technological processes, the primary task of diagnostics is more important, the result

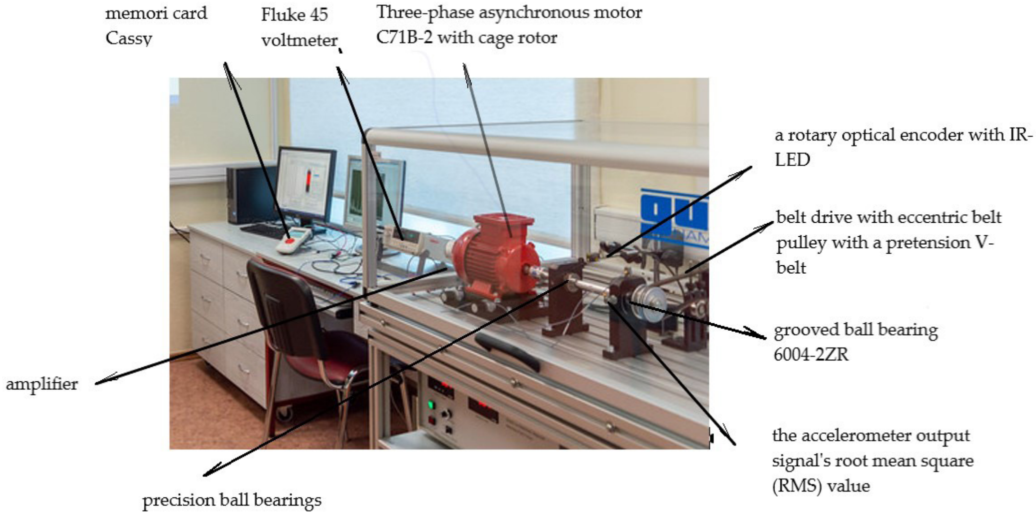

Fig. 1. Experimental test bench

of which is effective monitoring of the condition of mechanical assemblies in real time.

Study [6] proves that the efficiency of diagnosing a rotor journal malfunction increases with the use of the simplified global information fusion convolution neural network (SGIF-CNN). The idea of using SGIF-CNN can be good only when identifying unchangeable fault signs. In a real situation, vibration diagnostics of rotary mechanical assemblies should allow detecting defects at an early stage and prevent the occurrence of an emergency, reducing repair costs.

One of the control elements of a complex technological system is an information and measuring network, a significant part of which is represented by measuring transducers and sensors. Due to the design features, the sensors turn out to be unreliable elements of information and measuring systems.

Distortions in sensor readings affect the quality of controlling the technical system. It is necessary to account for these distortions in the budget of uncertainty when assessing the efficiency of the diagnostics of mechanical components. This fact is especially significant when assessing the efficiency of diagnosing the condition of rolling bearings in real time.

Paper [7] studies a dynamic model of a vibration test bench, which includes reference bearings with known types of malfunctions. According to the calibration tables of frequencies occurring due to the damage depending on the speed of the Roller bearing type 6004, prototypes of bearings with similar malfunctions were made. To diagnose the working prototype standard in monitoring mode, the user program *Lucia* was created. Using the Accelerometer Type 4513B-01, the value of the acceleration vector of vibrations of the control object was calculated alternately in two mutually perpendicular directions.

2. Experiments

It is proved that the efficiency of diagnosing the machine parts largely depends on the dynamics of the information-and-measuring system and the prompt detection of changes in the operation of this system [8–10]. As a result of the experiments, the primary task to diagnose the machine parts was solved on the example of faulty rolling bearings, and the influence of the computing power of the equipment used, reliability, and the practical feasibility of the network algorithms for automatic data processing in real time were assessed.

The equipment shown in Fig. 1 was used for the experiments. To evaluate the performance of automatic data processing, the user program applied in the work [7] was changed to organize the operation of the Fluke-45 meter in the RS-232 interface operation *Print-Only* mode. *Lucia* is a Windows desktop application that enables communication with FLUKE multi-meter that is connected to the computer via COM port. The communication interface is described in the FLUKE manual document. The program reads data from the COM port as a string, parses this string, and saves measurement values into a text file with timestamp labels. Further, this file can be opened in MS Excel and converted to an Excel table.

Simultaneously, data from two acceleration sensors were transmitted to the network database, subsequent transmitting the information via an Ethernet communication channel. Mobile-CASSY can only serve up to 4 WebSocket connections for transmitting live measured values. The functional diagram of the hardware and software parts of the reproduction and subsequent registration of vibration signals is presented in Fig. 2.

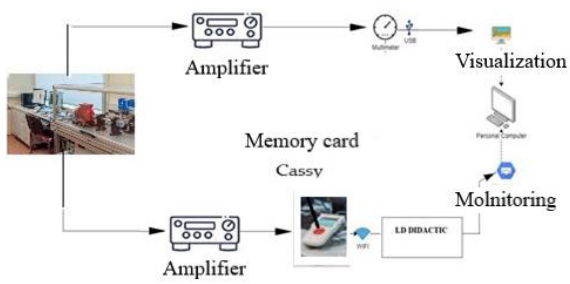

Fig. 2. Functional diagram

Table 1

Frequencies arising from the damage to the reference/etalon roller bearing

n	Outer ring		Inner ring		Ball		Cage		Belt	
In rpm	f_o in Hz	f_o in rpm	f_i in Hz	f_i in rpm	f_k in Hz	f_k in rpm	f_C in Hz	f_C in rpm	f_r in Hz	f_r in rpm
200	11.9	716	18.1	1084	15.6	935	1.3	80	0.7	43
300	17.9	1073	27.1	1627	23.4	1403	2.0	119	1.1	65

During the experiment, the actual amount of data, the reading rate of the meter and the duration of the interval required for transmitting this amount of data were measured. The duration between the outputs is determined by the reading rate of the meter.

The degree of coincidence of the signals (from a reference bearing and from a bearing with a known malfunction) was estimated using indirect and generalized indicators in the time and frequency areas.

To compare the signals, the following parameters of the time and frequency range were selected: instantaneous values U_{A_1} and I_{B_1}; the time-derivative (Equation 1); integral over time (Equation 2), FFT.

$$f_1 = \frac{dU_{A_1}}{dt}, \tag{1}$$

$$f_2 = \int I_{B_1} dt. \tag{2}$$

As the initial data for the experiment, temporary vibration signals were taken, obtained when scrolling a reference bearing having a defect on the inner ring of the cavity. The frequencies arising from the damage depending on the speed of the rotation of the Roller bearing type 6004 are shown in Table 1.

For subsequent tests, a prototype of a reference bearing was installed on the bench: a grooved ball bearing and a belt drive with an eccentric belt pulley with a V-belt pretension.

3. Results

Using the described equipment (Fig. 2), studies on reproduction of signals from the damaged machine parts were conducted. The recording of the reproduced signals was carried out using a measuring system in various ways. At first, using a user program, data were received immediately from the serial COM port and were printed out in one line with a pair of data from the corresponding acceleration sensors. The results are presented in Fig. 3.

Since the Cassy and Fluke meters have two inputs, one of which is the current meter, it was necessary to use an analogue integrated circuit to convert voltage signals into current signals. With the correct ratio of the resistances of the measuring object and the measuring device (Randomness from Cassy), it was possible to obtain acceptable results. With the correct value measure equal to 100, the maximum amplitude in Fig. 3 (c) corresponds to the peak amplitude level in Fig. 3 (a) and Fig. 3 (b).

The experiment showed (Fig. 4a) that the transmission of digital information about the measurement units of acceleration and volume via the Internet channels is associated with incomplete and untimely transmission and receipt of information. The Cassy module does not allow you to transfer a large amount of information if there are more than four computers within the network. Frequencies (100–122) Hz (Fig. 4a, Fig. 4b) correspond to the fault response when connected to the Cassy module.

The comparison of these results demonstrated that the diagnostic signs have significant differences in the frequency range (100–120 Hz). For the rest of the analysed frequencies, there is a coincidence in characteristics of spectral components, with permissible deviations in both amplitude and frequency occurring due to the damage to the Roller etalon bearing.

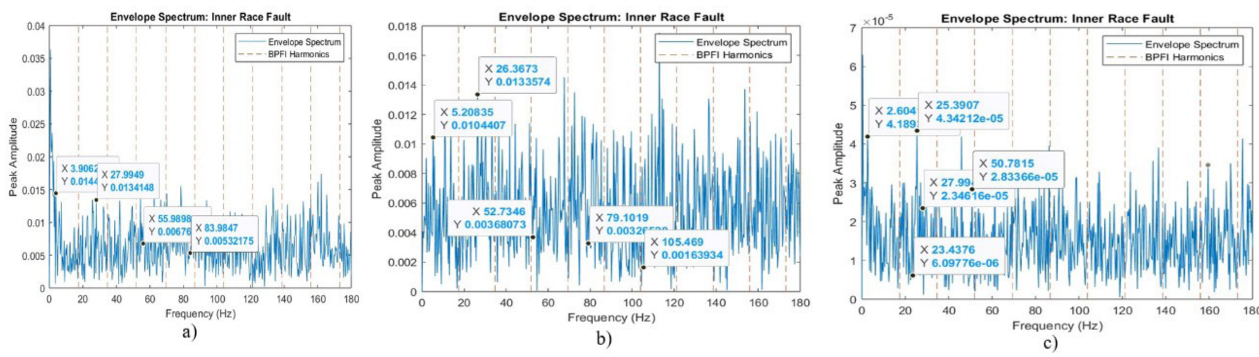

Fig. 3. a) Envelope Spectrum of the signals reproduced from the COM port connected to the voltmeter Fluke 45; b) Envelope Spectrum of the signals reproduced from the COM port connected to the Fluke 45 voltmeter while simultaneously reading data from two acceleration sensors; c) Envelope Spectrum of the signals reproduced from the COM port connected to the Fluke 45 ammeter while simultaneously reading data from two acceleration sensors.

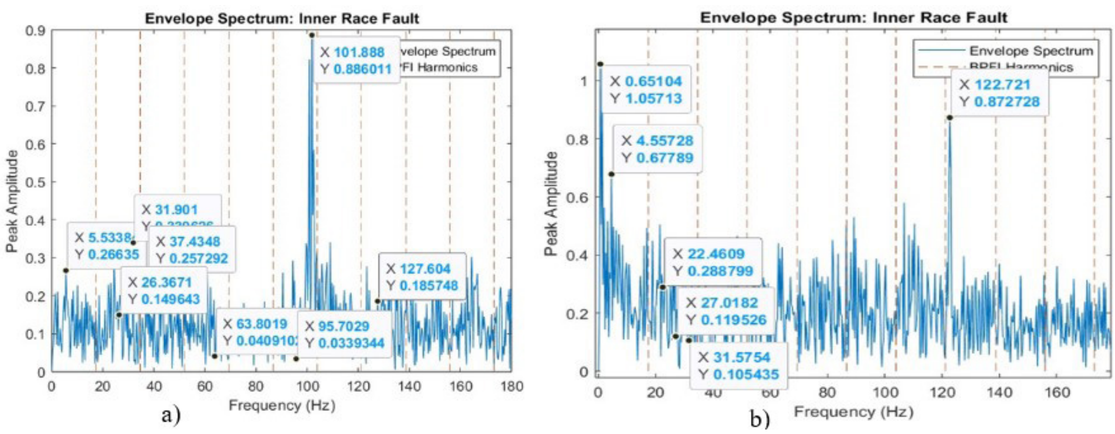

Fig. 4. a) Envelope spectrum of the signals transmitted over the Internet channels;
b) Envelope spectrum of the data transmitted over the Internet channels with a subsequent numerical differentiation

Table 2

Parameters of = frequency signals for a rolling bearing with a defect on the inner ring (cavity)

Fault response frequency f_i in Hz at the speed of rotation of the motor shift: n=300 rpm	Roller etalon bearing	Serial data transmission	Parallel data transmission		Data transmission over the Internet	Numerical differentiation
			1 channel	2 channel		
	27.1±1.6	27.99±1.8	26.37±1.7	25.39±1.7	31.90±2.1	27.01±1.8

Numerical differentiation of data carrying information about the damage increases the accuracy and efficiency of the diagnostics in real time.

Data for a comparative analysis of the efficiency of diagnosing the condition of rolling bearings in real time are presented in Table 2.

4. Conclusion

As a result of the experiments and calculations carried out, it can be concluded that the efficiency of monitoring the condition of mechanical components in real time depends on the data transfer rate, the sensitivity of acceleration sensors, and the amount of the memory of storage devices. The interval between the data does not significantly affect the accuracy of monitoring. Numerical differentiation of signals can be used to detect individual signs of malfunctions of mechanical components. Time and frequency signals can be taken as prototypes of standards of defects in mechanical components. To check the functionality of the diagnostic equipment, the presented methodology can be used.

Ефективність діагностики стану підшипників котіння в режимі реального часу

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Анотація

Одним з елементів управління складною технологічною системою є інформаційно-вимірювальна мережа, суттєву частину якої представлено вимірювальними перетворювачами. Через конструктивні особливості давачі виявляються ненадійними елементами інформаційно-вимірювальної системи. Спотворення в показах давачів впливають на якість управління технічної системи. Потрібно враховувати ці спотворення. Особливо важливу роль відіграє цей факт при оцінюванні ефективності діагностики стану підшипників котіння в режимі реального часу. Для оцінювання швидкодії автоматичної обробки даних було створено програму для користувачів, сумісну з MatLab r2022b. Одночасно передавалися дані з двох давачів пришвидшення в базу даних мережі з наступним передаванням інформації через канал зв'язку Ethernet. Доведено, що ефективність діагностики деталей машин значною мірою залежить від динаміки роботи інформаційно-вимірювальної системи та оперативного виявлення змін у роботі цієї системи. В експериментах було вирішено пряму задачу діагностики деталей машин на прикладі несправних підшипників котіння; зроблено оцінку впливу обчислювальної потужності використовуваного обладнання, швидкодії, практичної реалізованості мережевих алгоритмів автоматичної обробки даних у режимі реального часу. В результаті проведених експериментів і розрахунків можна зробити висновок, що ефективність моніторингу стану механічних вузлів у режимі реального часу залежить від швидкості передавання даних, від чутливості давачів пришвидшення, від обсягу пам'яті запам'ятовувальних пристроїв. Інтервал між даними не має суттєвого впливу на точність моніторингу. Чисельне диференціювання сигналів може бути використано для виявлення окремих ознак несправностей механічних вузлів. Часові та частотні сигнали можуть бути взяті за прототипи еталонів дефектів механічних вузлів. Для перевірки функціональних можливостей діагностичного обладнання може бути використано представлену методику.

Ключові слова: діагностика підшипників; режим реального часу; вимірювання вібрації; часовий сигнал; еталон.

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