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Monitoring of the technical condition of the rotating machines

N.T. Mardanov *

"Azercosmos" Open Joint Stock Company

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A B S T R A C T

The article studies data-driven approaches to predicting and diagnosing defects in machines. In order to detect problems at an early stage, regular monitoring of machines can prevent unplanned downtime, increase performance and reliability. The purpose of the study is to investigate the operation of rotating equipment and to justify the relevance of the timely determination of their technical condition. The study investigates the main causes of failures by collecting data from sensors from different parts of the unit. The result of the study is systematization of the causes of accidents and other factors on the devices. The time-domain graphs of vibration signals are constructed in the study, and the amplitudes of the corresponding vibration signals in different technical situations are investigated. The necessity of planned technical diagnostics of units and devices is justified.

1. Introduction

It is well known that rotating equipment are one of the most important devices in the industry and it is impossible to imagine the technology without them. The components of these machines are subject to significant wear and tear over time due to harsh operating conditions. It is required to provide efficient operation of machines to minimize downtime and noticeable material losses due to such causes. Monitoring of the technical condition of such machines, various assemblies and parts is essential and mandatory in many industries to reduce productivity losses and improve sustainable operation. Technical literature analysis shows that during technical monitoring, the measurement of parametric data, signal processing techniques and a number of other methods are used for the analysis of vibration signals of rotating equipment [1, 2].

Over time, the complexity of machine parts increases in terms of quantity and functionality, which makes the process of monitoring of the technical condition harder and more complicated. Recently, data-driven methods of technical condition monitoring have been developed to reduce data complexity in data assessment, and machine monitoring is focused entirely on data-based methods [3, 4].

It is well-known that reduction of significant maintenance and repair costs is required to ensure reliable operation of vital systems, including power supply systems (e.g. power, gas, oil, etc.), water and sewer pipelines, and communication systems. Especially in large-scale systems, spatial sensors

* *E-mail addresses:* nail.mardanov@azercosmos.az (N.T. Mardanov)

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have a significant role to play in determining the technical state of the data, systems, and in the timely detection of accidents, extreme events and failures. Today, scalability and expandability of sensor networks are of particular importance. Because there was a need to cluster and expand the sensor networks by adding any number of sensors to the monitoring systems. This will facilitate the development of structural monitoring of the technical condition. Structural Health Monitoring (SHM), the ultimate goal of using sensors, is to improve decision-making to safely protect the structure in the event of a problem [5].

The main idea in the paper is to collect sensory data in computer memory and to evaluate the technical condition for the detection and diagnosis of fails and defects using a data-driven method. Later, data-driven methods, such as machine learning and data mining have traditionally been used for statistical data analysis [6-8].

2. Problem statement

The prototype of a portable laboratory device is provided in the research to provide a complete and full assessment of the current technical state of the controlled data. The paper shows how the condition of the machines can be predicted. The proposed technique improves the reliability of equipment, efficiency of repair costs, operational safety and the overall competitiveness of the enterprise, along with the continuous complex development of real-time data collection, database formation using sensors to assess the technical condition.

SHM systems with various defect detection and decision-making algorithms have been well studied for many years. Different monitoring systems are applied by different institutes, scientists, companies and these facilitate operation. One of the main tasks of monitoring systems is to identify defects and retrieve data from data monitoring systems by decision-making algorithms, which then separates the data according to the technical condition of the device, which facilitates maintenance planning, imitation of defect repair, and rational decision-making for structural modernization. The literature, as well as the Strategic Studies Program for the next decades in America and China shows that, among other things, the application of SHMs to real structures has not been fully proven and the development of the subject remains relevant [5]. Thus, defect detection and decision-making algorithms must be implemented at least by many dimensions:

- micro-sized defective mechanisms;
- diagnostics of local defects on component level;
- structural global assessment of technical conditions.

Taking into account the aforementioned, a goal was set to conduct similar experiments, compare the results obtained and make observations as an experiment in the real environment. It is known that, specifically, transmission diagnostic simulators (DDS) are often used to simulate errors in rotating equipment. Note that technical condition based monitoring (CBM – condition based monitoring) and operative condition prediction monitoring (PHM – prognostic health monitoring) systems for various machines have also been developed, implemented and are being operated and used in the industry [9].

Operation in critical mode, intensity of failure, availability of different measuring factors (vibrations, temperatures, etc.) that cause damage, have made the rotating equipment particularly interesting for monitoring. Other important categories include stress components, corrosion surfaces, hotspots, etc. Sensor measurements that detect defect diagnostics in critical systems can also be considered from two different perspectives: static or process-related measurements such as temperature, velocity, position change, pressure and consumption, and their parameters specified by high throughput capacity (for example, high-frequency components). In illustration of the latter category, we shall indicate ultrasound measurements, vibration measurements, acoustic notes, alternative currents or voltages [9].

In the case under review, the experimental device presented includes a hurricane pump, which receives rotation from an electric motor via a muff coupling that can change the number of rotations, a pipe of fixed length for transmission of fluid connected to the pump output tube, fittings allowing to increase and decrease discharge pressure regulating thus discharge pressure and consumption (figure 1). Vibration data obtained from observations on the experimental devices simulating real devices show the feasibility of this method.

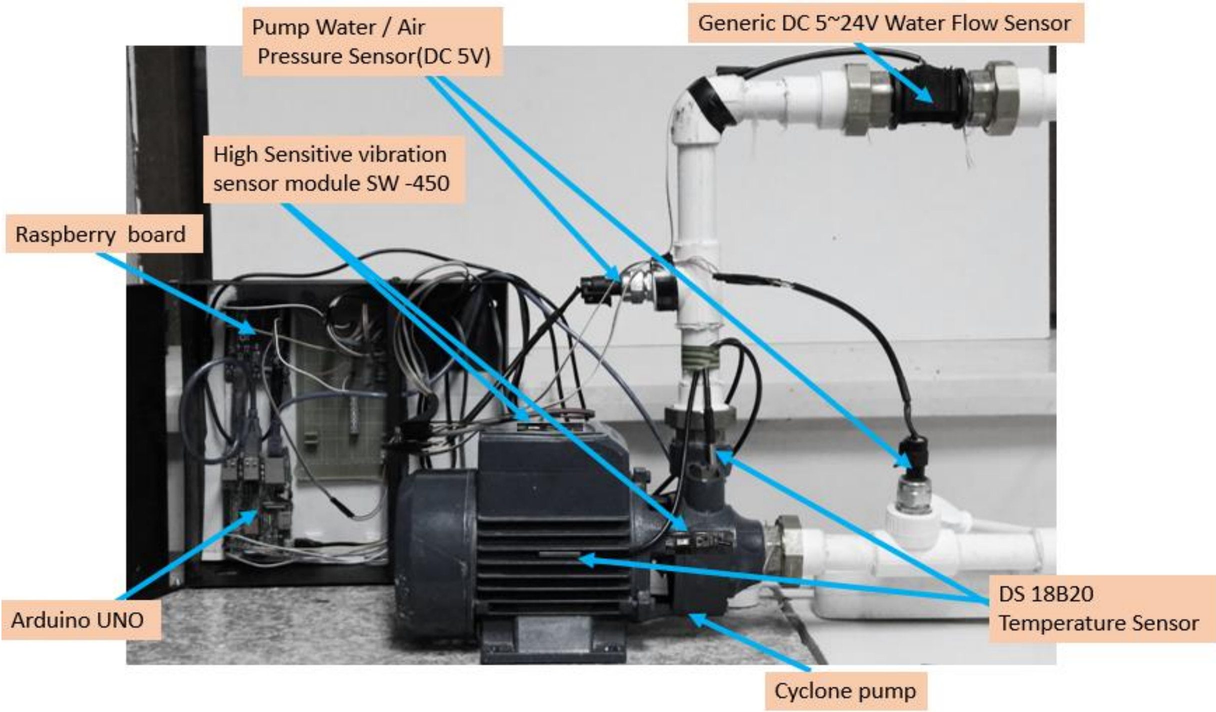

Fig. 1. Sensor measurement of vibration signals

2 sensors (“DS 18B20 Temperature Sensor MANYEE 1M/39.37"Waterproof Digital Temperature Temp Sensor Thermal Probe with Stainless Steel Tube Probe -55°c ~ +125°c for Arduino / Raspberry Pi / Car Refriger”), and 2 vibration sensors ("High Sensitive vibration sensor module SW-450" (at 90 degrees between axes of surface [10])) were installed on the monitoring unit. The sensors connect to the Arduino UNO and Raspberry boards, and the boards are controlled by connecting to the computer interface.

When viewed, the sensor logs are transmitted to the Raspberry board memory device in real-time mode. It is possible to record these data to a csv file on the computer and transfer it to the software modules via the services. The recording of the sensors on the device memory is regulated by the PuTTY software module. PuTTY is a network file sharing program with open code, free terminal emulator. PuTTY is a universal tool for remote access to other computers by supporting SCP, SSH, Telnet, rlogin and several network protocols [11, 12].

3. Result

After monitoring data is collected on a Raspberry storage device, the WinCSP software module is transferred to the hard disk of the computer by entering the device memory. WinSCP (Windows Secure Copy) is an open and free SFTP, FTP, WebDAV, Amazon S3 and SCP client protocol for Microsoft Windows. Its main task is to provide reliable, secure file sharing between local and remote computers. WinSCP was developed in the 2000s and continues to evolve [13, 14].

Table 1

Parametric data from the sensors and vibration signals

Time	Temperature, C	Voltage 1, V	P1, kPa	Voltage 2, V	P2, kPa	Consumption, l/s	Vibration
01:37:46	36,81	0,89	164,22	18,6	310	51101	30
01:37:07	36,56	0,9	168,13	18,8	313	14329	2938
01:37:10	36,56	0,9	166,18	18,8	314	14643	668
01:37:13	36,63	0,9	166,18	18,8	314	14957	388
01:37:16	36,63	0,9	166,18	18,6	310	15267	730
01:37:18	36,63	0,9	168,13	18,8	314	15581	373
01:37:21	36,69	0,9	168,13	18,8	314	48314	766
01:37:24	36,69	0,91	170,08	18,8	314	48628	865
01:37:27	36,69	0,9	166,18	18,6	310	48938	865
01:37:30	36,69	0,9	168,13	18,4	307	49245	885
01:37:32	36,75	0,9	168,13	18,3	306	49551	2353
01:37:35	36,75	0,92	175,94	18,6	310	49861	1956
01:37:38	36,75	0,9	166,18	18,6	310	50171	281
01:37:41	36,81	0,9	168,13	18,6	310	50481	638
01:37:44	36,81	0,9	166,18	18,6	310	50791	925
01:37:46	36,81	0,89	164,22	18,6	310	51101	0

Table 1 shows the format of the raw data file where the sensor records are given. The data were prepared for further analysis following the initial processing procedure. The following graph shows the time dependence of vibration signals (time domain):

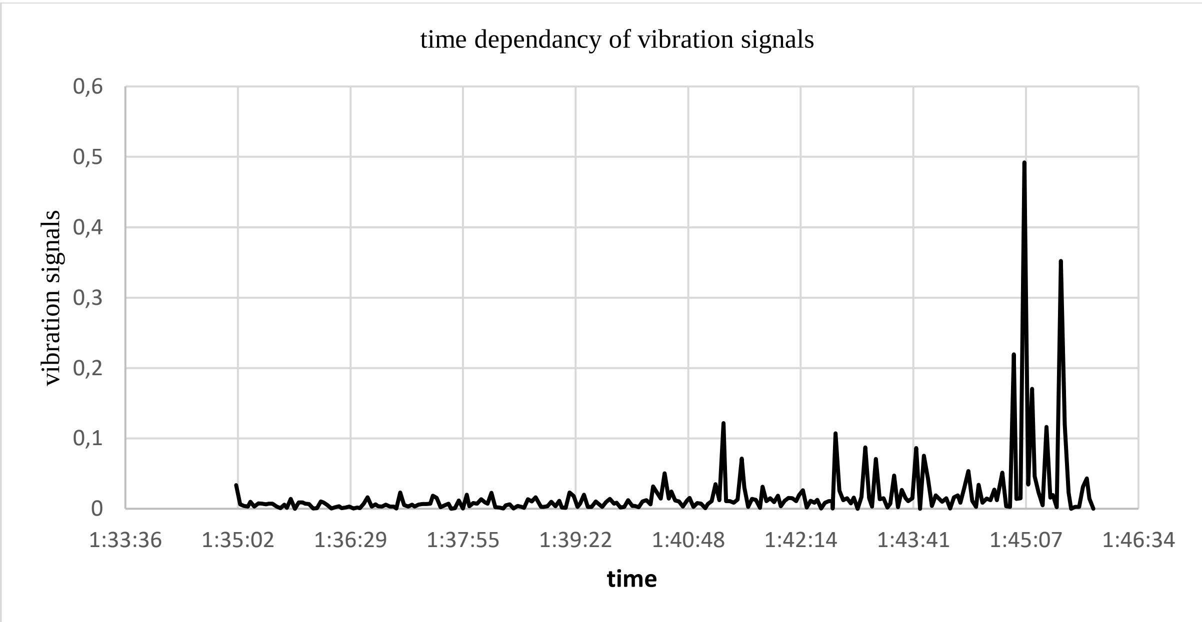

Fig. 2. Time dependency graph for a 20-minute time interval of vibration signals

In their investigations Vytautas Bučinskas, Nikolaj Šešok and others [15] measured vibration signals using sensors (transducers) and constructed a graph of the time dependence function based on the acquired data. Figure 2 shows the time domain vibration dependence for the 20-min time interval, and Figure 3 for the 5-minute time interval, according to the results of the experiment.

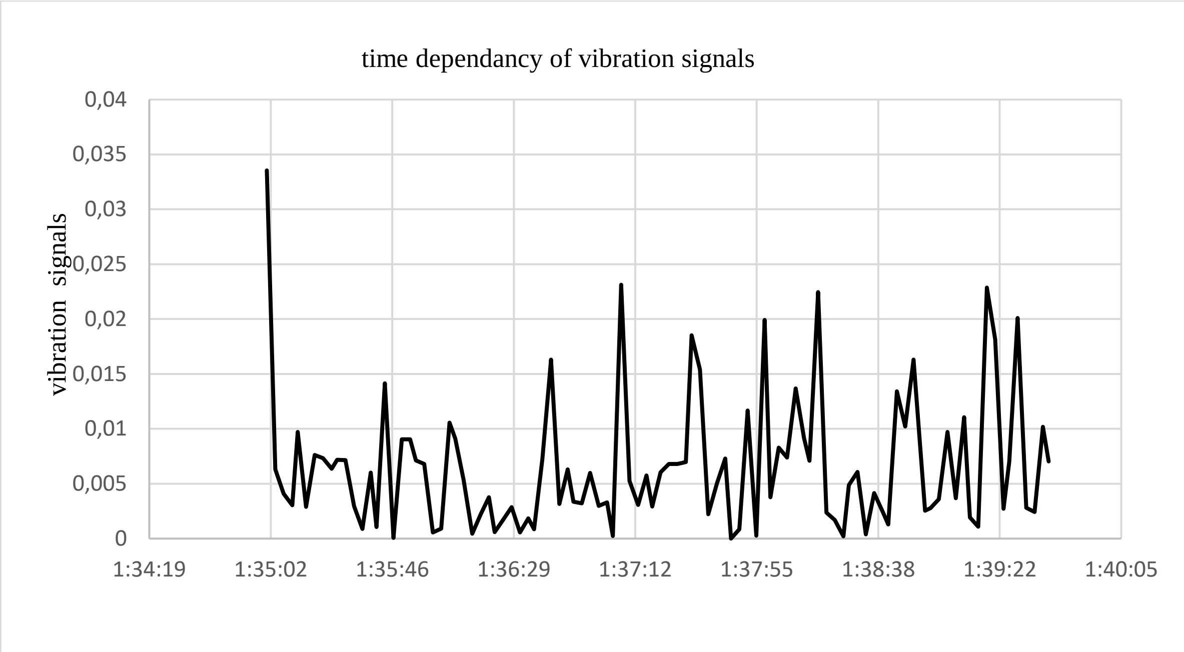

Fig. 3. Time-dependency graph for a 6-minute time interval of vibration signals

It is known that in order to get more accurate results, white and gray signals must be sorted out, and useful and useless information must be separated. Also, the methods described must be tested and applied in real systems before they can be used [16, 17]. Experimental data has been converted into qualitative data, and useless data has been cleared. Subsequently, dependence on relatively short time intervals has been established based on better data. As a result, the vibration signals in Figure 2 are relatively clear, periodically reaching and exceeding the threshold signals, and varying the peak thresholds every time indicating the technical condition of the pump unit mounted on a real load.

Based on the classification of the technical condition of the roller bearings 6 in the research of Asoke K. Nandi1, Chao Liu1 and M. L. Dennis Wong, it is possible to say that defects in the inner track of the bearings are being investigated in our experimental facility from Figure 2 and Figure 3.

To control the technical status of the unit, the overall level of vibration was measured, which allows evaluating the current state of the unit. Dynamics of the overall level of vibration allows to track the level dynamics of the device and to timely detect defects. Measurement of the general level of vibration is called level 1 and allows monitoring of various types of devices by conducting general vibration diagnostics. However, at this level, the time domain measurements are not sufficient to detect the defect; detailed spectral analysis of the device vibration is required to localize the defect. Most of the sources of defects are found in the frequency domain that is typical of them. In order to conduct vibration diagnostics at the second level, it is usually required to perform it through vibration analyzers normally using a fast Fourier transform method for vibration signals [18]. The research also carried out the transformation of Time domain signals in the Phyton programming language to the frequency spectrum using the matplotlib.phyton and numpy.fft libraries. Defining error-free classification of different structures is a difficult task. The Fourier transform of signals received for this purpose is studied in detail. The main idea of our study is the statistical analysis of vibration signals or their high derivatives [19].

4. Conclusion

During operation, different types of tension arise from the impact of static, dynamic and alternate loads on the machine's details. Many units are in critical operating mode under the influence of an abrasive and aggressive environment. A number of devices operate in high and sharply changing temperature conditions. All these factors reduce the lifetime of the equipment and lead to downtimes. However, if we can timely detect failures at early stages of the formation phase, we can eliminate the causes of the failures and increase the lifespan of the unit. Therefore, the technical condition of the aggregates shall be regularly assessed and monitored to reduce the risk of failures as well as to maintain operations. For this purpose, using sensors attached to different sensitive parts of the devices we can measure the above-mentioned parameters and collect the information in databases for intelligent processing and use them in decision-making.

As is seen from above, general signals of vibration have been obtained and graphic dependence is constructed. The data and graphs obtained help to form a preliminary picture for the initial assessment of the machine's technical condition. It is possible to assess the technical condition by matching the data obtained with the baseline data obtained from practice [19]. Also, referring to a number of studies, it is possible to determine the technical condition of the aggregate itself and of the parts individually by matching graphs obtained from practice with those given in literature using the program taking into account classification of defects in rotating machines [20].

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