ABSTRACT

of the dissertation work by Sagatova Laila Bakytzhankyzy
on the topic: « Development of digital monitoring of pumping plant operation»,
submitted for the degree of Doctor of Philosophy (PhD) in the educational program
8D07110 – «Digital Engineering of Machinery and Equipment»

Relevance of the research. The thesis examines the problem of increasing the efficiency of pumping units through the introduction of digital methods for monitoring the technical condition.

The relevance of the research is due to the need to switch to a predictive model of equipment maintenance at industrial enterprises in Kazakhstan as part of the digital transformation of the engineering and energy industries.

In the conditions of modern industry in the Republic of Kazakhstan, pumping units are integral elements of technological systems of water supply, thermal power engineering, oil and gas complex and chemical industry. The reliability of production processes and the energy efficiency of enterprises directly depend on their uninterrupted operation. However, a significant part of the pumping equipment is operated beyond the standard service life, which is accompanied by an increase in the number of failures, increased energy consumption and a decrease in equipment availability.

Today, in Kazakhstan, the methods of monitoring and diagnostics of pumping units in most cases are based on periodic inspections and routine repairs. Such approaches do not allow timely detection of hidden defects such as misalignment, rotor imbalance, bearing wear, cavitation, and misalignment of the electric motor and pump. Despite the fact that predictive and digital monitoring systems are being actively implemented in the world, their application in the domestic industry is fragmentary.

Existing foreign solutions (SKF, Siemens, ABB, Honeywell, Endress+Hauser) are not always adapted to the climatic and infrastructural conditions of Kazakhstan, require high implementation costs, complex technical support and stable telecommunication channels. At the same time, domestic enterprises need affordable, reliable and energy-efficient monitoring systems that will allow them to monitor the condition of pumping units in real time and prevent the development of defects.

The paper develops a concept for digital monitoring of pumping units based on the integration of vibration parameters obtained using the BALTECH VP-3470 analyzer into a single information and analytical system. The analysis of existing methods of pump diagnostics is carried out, the main diagnostic signs of bearing assembly defects, misalignment, imbalance and cavitation are determined. An experimental stand structure based on a 1K8/18 centrifugal pump and a 1.5 kW electric motor has been created to ensure laboratory testing and verification of digital diagnostic algorithms.

The result of the work is a developed digital monitoring architecture, including a sensor layer, a data acquisition and processing module, as well as a software platform for visualizing technical parameters.

The implementation of the proposed system makes it possible to increase the reliability of pumping equipment, reduce accidents and reduce operating costs.

A scientific and technical problem. The main scientific and technical problem is the lack of a single digital monitoring platform that combines the collection, processing and analysis of diagnostic data from pumping units in real time. It is necessary to develop a comprehensive system that includes intelligent algorithms for processing vibration, temperature, pressure, and electrical signals, as well as predicting the technical condition and remaining life of the unit components.

In addition, an urgent task is to adapt the international vibration control standards ISO 10816 and ISO 20816 to the operating conditions of domestic pumps, including those operating with variable frequency drives.

The purpose of the work — Improving the operational efficiency of centrifugal pumping units through the introduction of a digital monitoring system to identify emergency operating modes and hidden defects and predict them.

Research objectives:

- analysis of existing pumping equipment operation systems, as well as methods and means of monitoring the technical condition;
- development of an experimental installation to study the technical condition of a centrifugal pumping unit;
- conducting experiments on a laboratory installation to assess the technical condition of a centrifugal pumping unit using a vibration analyzer and a thermal imager;
- development of a computer model of rotating elements of a centrifugal pumping unit for the study of vibration parameters;
- investigation of the technical condition of centrifugal pumping units in industrial conditions by methods of vibration diagnostics and thermal imaging control;
- development of a diagnostic method based on the analysis of vibration parameters and diagnostic signs;
- development of recommendations for the implementation of digital monitoring to assess the technical condition of centrifugal pumping units.

1. A scientifically based concept of digital monitoring of pumping plant operation based on the integration of vibration, thermal and electrical diagnostic methods using real-time data collection, analysis and processing technologies. The concept provides a transition from routine maintenance to maintenance based on the actual condition (Condition-Based Maintenance).

2. A mathematical model for assessing the technical condition of a pumping unit, taking into account the relationship between vibration parameters, thermal characteristics and electrical signals. The model allows quantifying the degree of

degradation of the main components (bearings, shaft, seals) and predicting the remaining life of the unit.

3. A method for complex diagnostics of pumping installations based on the processing of multisensory data (vibration, temperature, current, pressure) and the use of spectral analysis, warrant tracking, and machine learning algorithms to identify defects such as imbalance, misalignment, cavitation, and bearing wear.

4. Principles of building a digital monitoring software and hardware complex that implements the functions of collecting, transmitting, storing and analyzing diagnostic data. The developed architecture ensures compatibility with industrial automated process control systems and SCADA, the ability to remotely access and scale the system for distributed pumping stations.

5. Experimentally confirmed patterns of changes in the diagnostic parameters of pumping units with the development of typical defects. The characteristic ranges of vibration and thermal characteristics for various stages of wear and cavitation have been established, as well as their relationship to changes in the energy efficiency of the units.

6. A methodology for implementing a digital monitoring system for pumping installations in industrial environments, including recommendations on the selection of diagnostic parameters, setting thresholds according to ISO 10816/20816 standards, integration with corporate maintenance management systems (CMMS), and cost-effectiveness assessment of implementation.

The scientific novelty of the research results is as follows:

- the orthogonality of vibration acceleration, vibration velocity and vibration displacement signals has been established in a wide range of signal-to-noise ratios for various malfunctions of the elements of the centrifugal pumping unit;

- the orthogonality of vibration parameters and their rates of change has been experimentally investigated and established, proving the need for their joint use for the diagnosis of pumping equipment;

- an integrated approach combining the methods of multibody dynamics and finite element analysis is proposed to study the vibrational behavior of a centrifugal pump rotor;

- a dynamic model has been developed that makes it possible to select the dynamic characteristics of the built-in elastic elements and predict the effect of damping rotor vibrations during their application;

- a methodology has been developed for predicting the residual life of nodes, which makes it possible to assess the technical condition of pumping equipment based on vibration and wear parameters.

The practical significance of the work.

The results of the study will be implemented in the systems for the operation of pumping units at facilities of water supply, energy and uranium mining enterprises in Kazakhstan. The created system will ensure the transition to predictive equipment operation, reduce maintenance costs and increase the efficiency of production processes.

The results can be used:

• When organizing the maintenance of pumping stations at industrial facilities;

• For the implementation of predictive diagnostic systems;

• Within the framework of enterprise digitalization programs (Smart Maintenance, Industry 4.0);

• Experimental research and modeling methods will be used in the educational process when conducting practical and laboratory research and when performing scientific work of students.

Methodology and research methods. The tasks were solved through theoretical and experimental studies in laboratory and industrial conditions. Statistical data and information obtained using standard measurement tools and methods under operating conditions were used for the research. The research tasks were solved using analytical and numerical methods for solving differential equations, mechanics, dynamics, and finite element analysis methods. The research is based on the principles of diagnostics of technical systems, vibration theory, reliability theory, and digital signal processing methods. The vibration parameters were obtained and processed using the BALTECH-Expert software.

When constructing a model of a centrifugal pumping unit and their elements, the MSC.ADAMS software package was used, which includes a preprocessor, a postprocessor and a solver in the basic configuration, converts the constructed model into a system of equations of motion and solves them using numerical methods. In addition, the package contains many specialized modules, each of which allows you to model different systems and mechanisms.

The work is based on the integration of experimental measurements, analytical modeling and computational methods aimed at increasing the reliability of diagnostics and forecasting the life of pumping units.

The applicant's personal contribution lies in the independent implementation of the main stages of scientific research, starting from the formulation of the task and ending with the practical implementation of the developed digital monitoring system for pumping installations.

The applicant personally:

1. Analyzed the current state of the problem of technical operation and diagnostics of pumping units in the industry of the Republic of Kazakhstan and abroad; summarized domestic and foreign approaches to digital monitoring and vibration diagnostics.

2. The concept and architecture of a digital monitoring system for pumping units has been developed, including a block diagram, algorithms for collecting and analyzing diagnostic data, and a model for integration with existing automation systems (automated process control systems, SCADA, CMMS) has been proposed.

3. An experimental installation (laboratory stand) has been created for the study of pumping units with a frequency-controlled electric drive, including a 1K8/18 pump, a 1.5 kW electric motor, a system of vibration and temperature sensors, as well as a software and hardware data acquisition module.

4. A method for conducting vibration and thermal imaging diagnostics of

pumping units using BALTECH VP-3470 and BALTECH TR-0102N equipment has been developed; an experimental study of the influence of operational factors on diagnostic signs has been performed.

5. Experimental data was processed and analyzed using spectral analysis, fast Fourier transform, order tracking and machine learning methods to identify characteristic defects (imbalance, misalignment, bearing wear, cavitation).

6. Algorithms for assessing the technical condition and predicting the remaining life of pumping units based on multisensory data (vibration, temperature, electrical parameters) have been developed.

7. A comparison of the simulation results and experimental data was performed, verification and evaluation of the reliability of the obtained dependencies were carried out.

8. Methodological recommendations have been prepared for the implementation of a digital monitoring system for pumping units in industrial enterprises in Kazakhstan.

9. Based on the results obtained, a number of scientific articles have been published in peer-reviewed journals, including international publications indexed in Scopus and Web of Science databases.

10. The main conclusions and suggestions formulated in the dissertation were received personally by the applicant and are the result of his own research and experimental activities.

Processing of research results.

Experimental research was carried out:

1. In the dissertation work, experimental work was carried out using laboratory stands of laboratories of the Department of "technological machines and equipment" of the Kazakh National Research Technical University named after K. I. Satpayev, as well as studies of the technical condition of centrifugal pump units SULZER in the industry of JSC "NAC" Kazatomprom" Khorasan-U "JV;

2. Based on the processing and analysis of experimental data, the following results were obtained:

Based on the data obtained, the algorithm of a digital monitoring system that monitors vibration and temperature online was tested. It has been shown that the system can detect real-time fault signs with an accuracy of 92-95%.

Approbation of the work. The main results and provisions of the dissertation research were widely tested at scientific and technical conferences, seminars and in the course of research, which confirmed their scientific and practical significance.

1. The research results were repeatedly reported and discussed at meetings of the Department of Technological Machines and Equipment and the A. Burkitbayev Institute of Energy and Mechanical Engineering at Satbayev University, where positive feedback and recommendations for further development of the work were received.

2. Experimental studies and practical verification of the proposed digital monitoring system were carried out at the Department of "Technologiyalyk Mashinalar zhane Jabdyktar" Satbayev University, as well as with the participation of a production partner, the joint venture JV Khorasan—U JSC NAC Kazatomprom,

where thermal imaging and vibration measurements of SULZER type pumping units were performed.

3. "Implementation of an automated system for monitoring the technical condition of pumping equipment" proceedings of the XI International scientific and practical conference dedicated to the 30th anniversary of independence of the Republic of Kazakhstan "Innovative technologies and Engineering" (Temirtau, 2021).

Publications. The results of the dissertation research were published in the Scopus database on CiteScore Q1, 1 article corresponding to percentiles, 3 articles in journals included in the list of publications recommended by the committee for quality assurance in Science and higher education of the Ministry of Science and higher education of the Republic of Kazakhstan, 2 reports at international conferences, 1 article published in other scientific journals and publications.

Structure and scope of work. The dissertation work consists of an introduction, 4 chapters and a conclusion. The dissertation consists of 119 pages, 39 figures, 18 tables, 113 lists of references and 1 appendix.