Control method for stage degradation of centrifugal pump unit parts in the system of technical condition monitoring and automatic diagnosis

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Abstract. Reliable operation of a centrifugal pump unit, as an electric motor, which is a reliable link in the composition of a centrifugal pump unit, depends on many factors, as well as an important factor in the trouble-free operation of a centrifugal pump unit is the reliability of rolling bearings. The presented work is devoted to the study of the processes of multi-stage failure of the parts of the rolling bearing of a centrifugal pump unit, i.e., repeatedly occurring self-eliminating failures of the same nature - intermittent failures, establishing the dependences of vibration changes in the degradation process, developing control methods and developing methods for identifying and predicting staged failure processes.

1 Introduction

In Uzbekistan and abroad, the production of pumping units is concentrated at large enterprises that produce the entire range of units in demand in the oil refining industry. Of the variety of pumping units, the most common type can be distinguished by centrifugal pumping units.

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The reliable operation of a centrifugal pump unit depends on many factors. The electric motor is a reliable link in the composition of a centrifugal pump unit, the operating conditions of which are debugged and normalized. Another important factor in the trouble-free operation of a centrifugal pump unit is the reliability of rolling bearings.

Centrifugal pumping units account for more than 70% of the total number of dynamic equipment units controlled by monitoring and diagnostic systems at oil refineries. In contrast to plain bearings, features of the operation of rolling bearings are the presence of constant mechanical contact between its parts. Even though the life of rolling bearings built into the manufacture allows them to operate for a long time, practically without being subjected to significant wear, fatigue phenomena accumulate in the parts of the rolling bearing, leading to fatigue failures. Currently, in the vast majority of cases, condition monitoring is carried out without taking into account the possible non-stationary nature of the development of faults, which creates the problem of ensuring control of the state of a

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centrifugal pump unit during operation to prevent sudden failures of the units. Therefore, an urgent task is to develop new and develop existing methods for monitoring the condition, diagnosing and monitoring a centrifugal pump unit, taking into account the identification, control, and prediction of damage accumulation processes in parts and multi-stage failure of rolling bearings [1].

2 Methods

The technological process of an oil refinery is continuous. All refinery equipment operates 24 hours a day, 365 days a year, excluding the time of scheduled overhauls of technological complexes, carried out according to a pre-planned schedule. When operating dynamic equipment in continuous technological production, one of the key issues is the timely detection and trouble-free decommissioning of units with a high degree of degradation of parts and assemblies before their destruction and jamming. [2]. The main working link in the technological chain of an oil refinery is a centrifugal pump unit [3]. The number of centrifugal pumping units at water management enterprises varies from thousands to tens of thousands of units. At water management enterprises, centrifugal pumping units pump a large amount of river water.

From this list, it can be seen that the pumped liquids are explosive and flammable. In the event of an emergency, they can not only harm the environment and pollute the environment but also lead to fire, explosion with possible loss of life, and cause economic damage to the enterprise [4,5]. To ensure monitoring of the technical condition of round-the-clock dynamic equipment, water management enterprises widely use systems for monitoring the technical condition and automatic diagnostics that provide real-time control over the operation. A typical set of diagnostic parameters of the monitoring system are the following parameters: vibration (vibration acceleration, vibration velocity, vibration displacement), rolling bearing temperature, and current consumption by the drive motor. If possible, it is advisable to additionally apply technological parameters: pressure at the inlet/outlet of the pump, head, flow rate, etc.

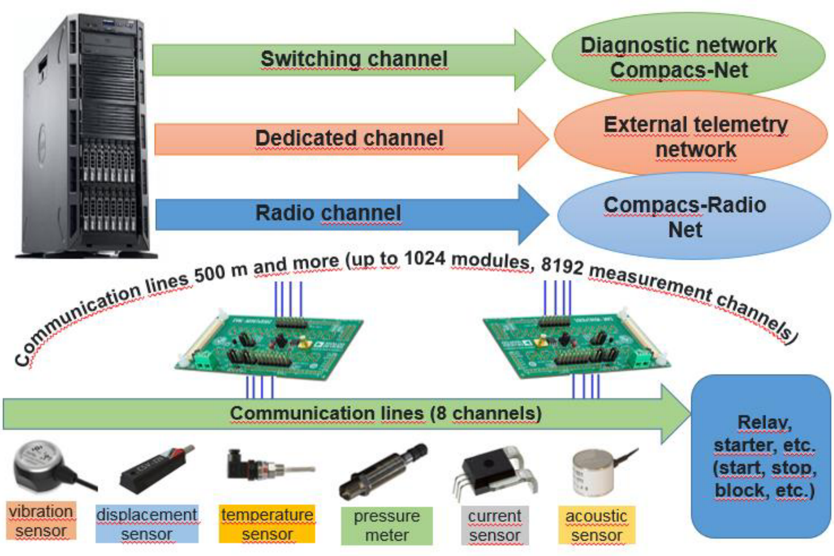

Fig. 1. Structural system diagram for monitoring the technical condition and automatic diagnostics of centrifugal pumping units.

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The use of the system for monitoring the technical condition and automatic diagnostics COMPACS® makes it possible to ensure the stability of the process by monitoring the technical condition of pumping equipment in real time. The system allows obtaining data on controlled centrifugal pumping units using a sufficient number of measuring channels to which sensors of various physical quantities are connected, such as vibration, temperature, current, pressure, etc. (Fig. 1) [6].

Sensors are installed directly on the controlled centrifugal pumping unit in certain places on the body to obtain initial data on the unit's state. Sensors convert the measured parameters of various physical quantities (vibration, temperature, current, pressure, etc.) into an electrical signal. Piezo accelerometers are used as vibration sensors, the output signal of which is proportional to vibration acceleration. COMPACS® systems use two designs of vibration sensors, AB-311FRU, and AB-321FK, which allow monitoring the vibration of units of various designs. To mount vibration sensors on a diagnosed centrifugal pump unit, sensor holders are used, the installation of which is carried out without making changes to the unit's design (Fig. 2).

Fig. 2. Option to install a vibration sensor on a cantilever centrifugal pump

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The electrical signal from the sensors via cable communication lines enters the programmable interface modules installed near the units, where the signal is amplified and further transmitted via the main communication lines to the diagnostic station for its final processing. Real-time visualization of the obtained measurement results is performed; storage of the received data of automatic diagnostics and the visual display is provided (Fig. 3, 4).

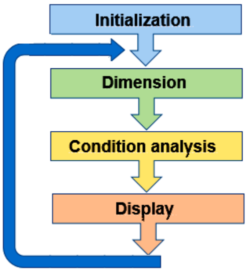

Fig. 3. The algorithm of the software for the diagnostic system of centrifugal pumping units

The measured parameters are accumulated in the system databases for various time intervals: 12 hours, 4 days, 40 days, etc. The system automatically processes the received data and provides information on the status of centrifugal pumping units in the form of voice messages, color icons, and test messages. An event log is kept in automatic mode, which tracks all events that occur with the diagnosed pumping equipment, the system's operation, electronic components, software, and the operation of the built-in expert system. The system allows you to receive reports of various types on databases (parameter trends) and the event log. The monitoring system implements five main modes of operation: "Monitor", "Trend", "Analysis", "Analysis log", "System", and the auxiliary mode "Oscillograph" (Fig. 4).

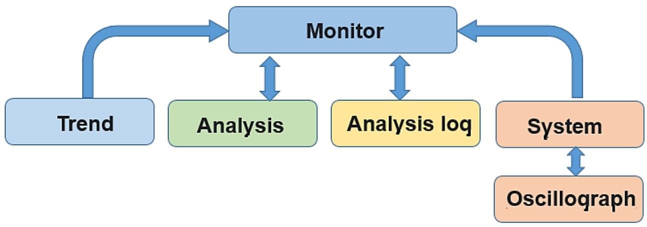

Fig. 4. The main modes of operation of the monitoring system for centrifugal pumping units.

The controlled centrifugal pump units are presented on the "Monitor" screen of the monitoring system [7, 8]. The rectangle's color corresponds to the controlled unit's technical condition: green - Permissible, yellow - Requires action, red - Inadmissible, gray - reserve, brown - repair. The upper left of the screen shows the diagnostic parameters for each subject of the pumping unit. In the upper right part of the "Monitor" screen, text expert messages are displayed, which are issued by the expert system to ensure the trouble-free operation of pumping equipment. When the technical state of the centrifugal pumping unit goes into the "Unacceptable" state, the unit issues a warning using a voice message to take immediate measures to ensure the trouble-free operation of the equipment.

The values of diagnostic parameters recorded in the database can be visualized in the "Trend" mode, where the changes in diagnostic parameters for various time intervals are presented in graphical form: 12 hours, 4 days, 40 days, etc.

The monitoring system software also contains the "Analysis log" mode - the events database. In automatic mode, the events occurring with centrifugal pumping units are recorded, such as turning the pumping unit on or off, the current technical condition of the unit or its changes, the appearance of expert warnings, and other events.

The equipment of the monitoring system is certified according to the type of explosion protection, as an intrinsically safe electrical circuit with a special explosion-proof level (ia):

- vibration sensors 0ExiaIICT6;
- programmable interface modules 0ExiaIICT5;
- diagnostic controller [Exia]IIC.

Implementation of algorithms for monitoring the process of staged accumulation of damage and degradation of parts of a centrifugal pump unit by increasing the amplitudes of vibration emissions, by changing the duration of intervals between vibration emissions into the COMPACS® system monitoring program, as well as forecasting the time of occurrence of vibration emissions and the transition of the technical state of the centrifugal pump unit to "Requires action" and "Unacceptable" for vibration emissions, which made it possible to expand the diagnostic capabilities of the COMPACS® system and provide a prediction of the technical conditions of the unit during its operation [9, 10].

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3 Results and Discussion

The developed methods are implemented in the systems for monitoring the technical condition and automatic diagnostics. Consider an example of the operation of a system for monitoring the technical condition and automatic diagnostics based on algorithms for monitoring the process of staged accumulation of damage and degradation of parts of a centrifugal pump unit [11].

Example. The vibration trend in Fig. 10 shows the degradation of a rolling bearing (46318) over 3 days. The first vibration emission occurred at 33:22 with an amplitude of 6.4 m/s^2, followed by a decreased vibration to its original values. The vibration release showed that a defect is developing in the front bearing of the pump; according to the methodology for determining the technical condition, we classify the technical condition of the pump as "Permissible" and with subsequent emissions 2 - 20 (Fig. 5, 6).

Vibration emissions 21 - 26 correspond to the technical state "Requires action" and emissions 27, 28 correspond to the state "Unacceptable". With the 28th release at 72:08, the unit's operation was stopped (Fig. 5, 6).

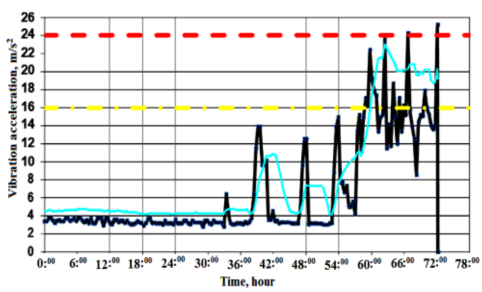

Fig. 5. Trend of vibration changes during 3 days of operation of a centrifugal pump (CVP 600-200, power 400 kW, rotation speed 2980 rpm

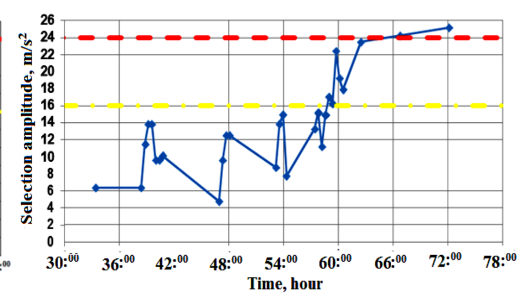

Fig.6. Trend of vibration emissions

Already at the third vibration emission at 38:47, diagnostic signs of detection and control of the process of staged accumulation of damage and degradation of parts of a centrifugal pump unit by increasing the amplitudes of vibration emissions and changing the duration of the intervals between vibration emissions showed that the technical condition of the pump is "Unacceptable" and must be taken measures to stop its operation (Fig. 7, 8, 9, 10). Thus, for all four diagnostic signs of staged degradation, 33 hours before the shutdown of the pumping unit, the system warned the personnel about the need to stop its operation.

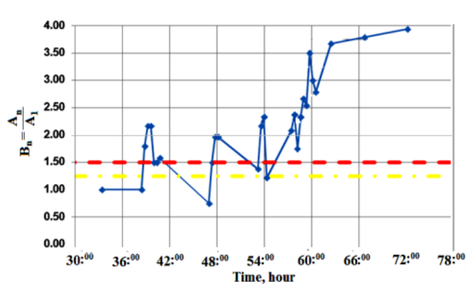

Fig. 7. Trend of relative amplitude (Bn) of

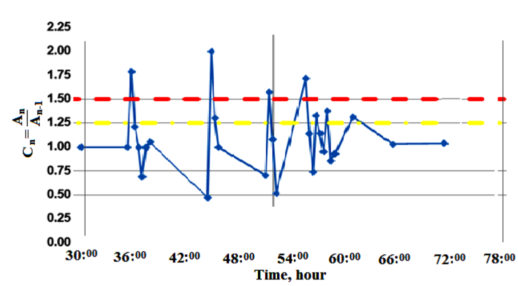

Fig. 8. Trend of the relative increment of

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vibration emissions

amplitudes (Cn) of vibration emissions

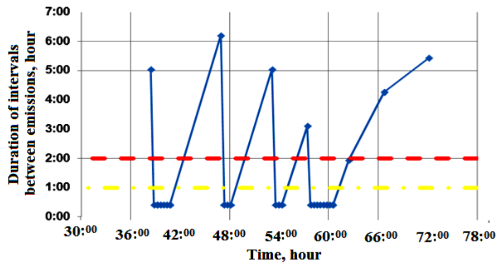

Fig.9. Trend of duration of intervals between vibration emissions

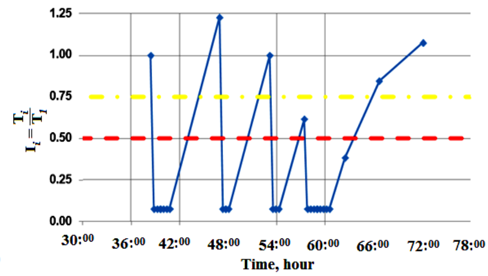

Fig.10. Trend of ratios of intervals (In) of subsequent outbursts to the duration of the first interval

With a long-term forecast, the average error in the time of appearance of outliers was 1.7% (1:02:38) and 2.7% (1:35:12) for the transition to the technical state "Requires action" and "Unacceptable". Based on 28 emissions in the long-term forecast, 15 accurate predictions of vibration emissions were made. The forecast technique makes it possible to calculate subsequent outliers after the appearance of the second outlier. For 18 emissions, the predicted emissions are beyond the period of operation of the pumping unit

With an operational forecast, the average error in the time of occurrence of outliers was 1.1% (0:35:22) and 1.2% (0:44:49) for the transition to the technical state "Requires action" and "Unacceptable". Based on the data of 28 emissions during the operational forecast, 32 accurate forecasts of vibration emissions were made; for 1 emission, the forecast goes beyond the period of operation of the pumping unit, and for 4 emissions, the condition is not met Ai > Ai-1.

The method for predicting the time of occurrence of vibration emissions and the transition of the technical state of a centrifugal pump unit to the states "Requires action" and "Unacceptable" based on vibration emissions made it possible to calculate 22 vibration emissions with an average error in calculating the operating time before the emission of 59:30 minutes (1.7%) [12, 13].

The presented example showed the results of the industrial application of the developed methods for detecting and controlling the process of staged damage accumulation and degradation of parts of a centrifugal pump unit, on the growth of amplitudes of vibration emissions and the change in the duration of the intervals between vibration emissions, forecasting the time of occurrence of vibration emissions and the transition of the technical state of the centrifugal pumping unit into "Requires action" and "Unacceptable" [14].

4 Conclusions

Failure of a centrifugal pump unit due to fatigue failure of a rolling bearing does not occur suddenly or instantly. First, some signs of the approach to this process appear, and the nature of the vibration activity of the unit changes. Against the background of a stable vibration level, some outliers of vibration trends appear. The study of the sequence and intensity of these emissions is important information not only about the approach of the moment of destruction of the rolling bearing parts but also about the operating time that the operating personnel still have to take measures to eliminate an emergency and complete catastrophic destruction.

The conducted studies of the process of changing the vibration of centrifugal pumping units showed what is in operation, identifying patterns of multi-stage failure processes of rolling bearing parts by vibration trend emissions, using patterns of vibration trend emissions, starting from the first stage of the appearance of degradation, and subsequent monitoring of the development of defects for a timely assessment of the technical condition of the unit.

Acknowledgments

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References

1. R.Ergashev, F.Bekchanov, A.Atajanov, I.Khudaev, F.Yusupov. Vibrodiagnostic method of water pump control. In E3S Web of Conferences **264**, (2021) https://doi.org/10.1051/e3sconf/202126404026.
2. Kostyukov V.N. Monitoring of production safety. Moscow, (2002). p. 224.
3. Makhutov V.N. Kostyukov A.V. Kostyukov. Monitoring of the state and risks of equipment operation in real time is the basis of industrial safety. Federal reference book. 26. pp. 321-326 (2012)
4. A. V. Kostyukov, V. N. Kostyukov. Improving the operational efficiency of enterprises based on real-time monitoring. Moscow (2009) p. 192
5. V. N. Kostyukov, S. N. Boychenko, A. V. Kostyukov. Automated control systems for the safe resource-saving operation of equipment for oil refining and petrochemical industries. (ACS BER - COMPACS), Moscow (1999) p. 163
6. V. N. Kostyukov, A. A. Shatalov, V. F. Anisimov E. V. Tarasov. There are no "sudden" accidents. Improving the efficiency of the operation of the "21-10/ZM" installation based on monitoring the technical condition of the equipment". **7**, pp. 78-81 (2006)
7. Stepin P.A. Strength of materials: textbook. for non-machine building. (Moscow 1997), p. 320
8. V. N. Tarasov, G. N. Boyarkin. Impact theory in theoretical mechanics and its application in construction. Omsk: Publishing House of OmSTU, (1999) p. 120
9. Glovatsky O. Ya., Ergashev R. R., Bekchanov F. A., Sharipov S. M. Hybrid installations in pumping stations based on the use of renewable energy sources. Applied Solar Energy **48**(4), pp. 266-268 (2012)
10. F. Bekchanov, F. Yusupov, M. Kholbutaev, B. Khayitov, Q. Ulashov. Diagnostic model of great irrigation pump units. In IOP Conf. Series: Earth and Environmental Science **868** (2021) doi:10.1088/1755-1315/868/1/012039
11. Bekchanov F.A., Ergashev R. R., Mavlanov T.M., Glovatskiy O.Y. Mathematical model of vibrating air pump unit. In XXII International Scientific Conference on Advanced in Civil Engineering. pp. 122-126, Tashkent (2019)
12. R. Ergashev, F. Bekchanov, Sh. Akmalov, B. Shodiev, B. Kholbutaev. New methods for geoinformation systems of tests and analysis of causes of failure elements of pumping stations. In IOP Conf. Series: Materials Science and Engineering **883**, (2020) doi:10.1088/1757-899X/883/1/012015
13. O. Glovatsky, F. Bekchanov, B. Hamidov, A. Saparov. Strengthening technology and modeling of dams from reinforced soil. In IOP Conf. Series: Materials Science and Engineering **1030**, (2021) doi:10.1088/1757-899X/1030/1/012155.
14. Tarasov E.V. Monitoring of rolling bearings under conditions of multi-stage failures based on the analysis of vibration acceleration trends. p. 170, Omsk -2018.