PAPER • **OPEN ACCESS**

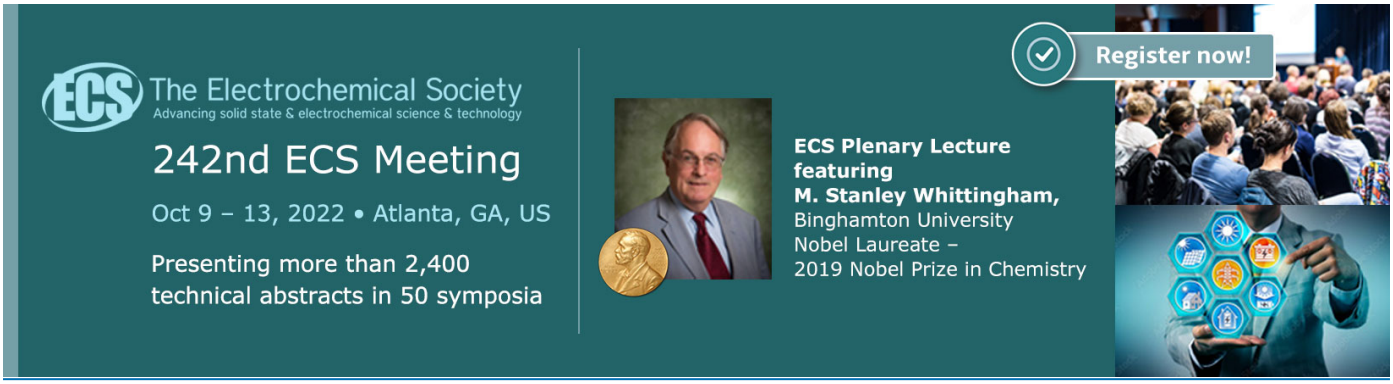
Method of prediction of vibration emissions and transition of the technical state of a centrifugal pumping unit

To cite this article: F A Bekchanov *et al* 2022 *IOP Conf. Ser.: Earth Environ. Sci.* **1076** 012037

View the article online for updates and enhancements.

You may also like

- Probability-driven identification mechanism for degradation of magnetic drive pumps
Ruijia Cao, Jianping Yuan, Fei Zhao et al.
- Volumetric Flow Observer For A Pumping Unit Without Backpressure With Induction Electric Drive
O A Lysenko and A V Simakov
- Operational monitoring of oil transport regimes for frequency regulation of the pump unit
M Y Zemenkova, A A Gladenko and Y D Zemenkov



This content was downloaded from IP address 213.230.109.7 on 05/10/2022 at 07:32

Method of prediction of vibration emissions and transition of the technical state of a centrifugal pumping unit

F A Bekchanov, A U Atajanov, L K Babajanov and F F Yusupov

Tashkent Institute of Irrigation and Agricultural Mechanization Engineers (National Research University), Kory Niyoziy str., 39, 100000, Tashkent, Uzbekistan

E-mail: faxriddinatabaevich@mail.ru

Abstract. From many factors, the reliable operation of a centrifugal pump unit largely depends on the reliability of the electric motor, which is the main link of the centrifugal pump unit and an important factor in the failure-free operation of the centrifugal pump unit, which depends on the reliability of rolling bearings. This article is devoted to the study of the methodology for predicting vibration emissions and the transition of the technical state of a centrifugal pump unit to the states "Requires action" and "Unacceptable". Experimentally tested and confirmed the operability of the method for isolating vibration emissions in the flow of measuring the vibration of a centrifugal pump unit, separating a smooth increase in vibration from its emission. The technique for detecting and controlling the process of staged accumulation of damage and failure of parts by increasing the amplitudes of vibration emissions has been tested, which provides long-term and prompt proactive diagnostics throughout the entire period of operation, and the performance of the proposed diagnostic method has been confirmed.

1. Introduction

Reliability and reliability in the operation of the electric motor rolling bearings is the main link, which is part of the centrifugal pump unit. At the water management enterprises of the country, centrifugal pumping units account for more than 70% of the total number of units of dynamic equipment controlled by monitoring and diagnostic systems. The operation of rolling bearings differs from plain bearings; they have constant mechanical contact between the parts of the electric motor. The resource of rolling bearings during manufacture allows them to work for a long time without being subjected to significant wear; fatigue phenomena accumulate in the parts of the rolling bearing, which ultimately lead to fatigue damage and failure. At present, the state control is carried out without taking into account the possible non-stationary nature of the development of malfunctions, which creates the problem of ensuring the control of the state of a centrifugal pump unit during operation in order to prevent sudden failures of units, assemblies and parts.

This article is devoted to the study of the failure processes of rolling bearing parts of a centrifugal pump unit, i.e. the development of control methods and the development of methods for identifying and predicting staged failure processes. The failure of a centrifugal pump unit due to fatigue failure of a rolling bearing does not occur suddenly and not instantly. First, some signs of the approach of this process appear, the nature of the vibroactivity of the aggregate 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

Content from this work may be used under the terms of the Creative Commons Attribution 3.0 licence. Any further distribution of this work must maintain attribution to the author(s) and the title of the work, journal citation and DOI.
Published under licence by IOP Publishing Ltd

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[1].

2. Methods

For research, a system was prepared for collecting experimental data in real time on vibration parameters during the operation of centrifugal pumping units in real conditions of water management production [2, 3].

To obtain data on the vibration level of centrifugal pump units, they are installed by mounting vibration sensors on the bearing assemblies of electric motors and pumps. The method of mounting the vibration sensors on the unit should ensure the normal operation of the unit, as well as an easy process of their dismantling before sending the unit for repair if necessary. To reduce the cost of the experimental data collection system and, at the same time, to facilitate the process personnel in monitoring the operation and maintenance of pumping units during operation, the number of sensors in the system is determined by the number of bearing units in the unit - one vibration sensor per one bearing unit. The minimum required number of vibration sensors is determined from the design features of the diagnosed centrifugal pumping units [4].

Currently, the most widely used methods for diagnosing rolling bearings in various frequency bands of the sound and ultrasonic range. Measurement of vibration in the frequency band from 2 Hz to 10-12 kHz allows you to monitor the condition of not only bearing assemblies, but also the condition of the entire centrifugal pump unit. In this frequency range, the general vibration level is normalized, which allows sorting pumping units according to their technical condition: “Good”, “Acceptable”, “Requires action”, “Unacceptable”. To determine the technical condition of centrifugal pump units and their components, it is advisable to control not only the overall level of vibration, but also the nature of the change in vibration parameters - an abrupt change in level, vibration emission, and a rapid increase in vibration parameters. For this, the experimental data collection system provides real-time automatic vibration measurement cycle and subsequent archiving of the obtained data (Figure 1) [5].

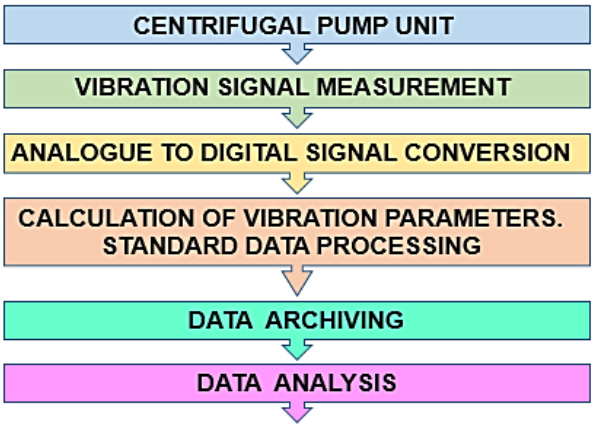


Figure 1. - Enlarged algorithm for converting experimental data.

The system for collecting experimental data provides the researcher with access to the archive of accumulated data for further analysis and identification of patterns of abrupt changes in the vibration of centrifugal pumping units.

To use the system at an oil refinery, certification was carried out according to the requirements for ensuring explosion protection of the equipment used in it: vibration sensors 0ExiaIICT6, measuring modules 0ExiaIICT5, diagnostic controller [Exia]IIC.

The equipment used in the experimental data acquisition system is certified for the type of explosion protection, as an intrinsically safe electrical circuit with a special explosion-proof level (ia), which allows it to be installed on any centrifugal pump unit at an oil refinery[7].

3. Results and discussion

To obtain reliable information on the level of vibration, the metrological parameters of the system for collecting experimental data were certified to ensure the measurement of vibration parameters with a specified error in the range of frequencies and amplitudes. In accordance with the technique for extracting outliers described in the dissertation paragraph, the system for collecting experimental data performs the extraction of vibration emissions.

Figure 2, shows a four-day section of the trend of the vibration parameter, recorded from a vibration sensor installed on the rear bearing assembly of the BAO2-450LB-2 electric motor equipped with an experimental setup to provide control at the initial stage of generation and subsequent tracking of the development of defects in the details of the rolling bearing, bearing assembly and the engine itself.

The presented results of the experiment clearly show that the vibration of the electric motor from the side of the rear bearing in section T_1 lasting 25 hours and 50 minutes is in the "Permissible" zone (Fig. 2, Trend I), while the level of vibration acceleration does not exceed 2.5 m/s^2.

Further, in the T_2 section, lasting 17 hours 50 minutes, the amplitude of the vibration parameter reaches the threshold level "Release" ($A_{release}$), which is an indicator of the presence of a vibration parameter outlier (Fig. 2, Trend I, Trend III). However, the amplitude of these vibration emissions does not reach threshold levels ("Permissible", "Requires action", "Unacceptable"). The appearance of outliers of the vibration parameter in section T_2 is a consequence of the origin of defects in the rolling bearing. The nucleation of defects is accompanied by an increase in the amplitudes of vibration parameter surges up to 8.2 m/s^2. However, in this case, after reaching a certain value of the emission level of vibration parameters, there was a subsequent decrease in the vibration level almost to the initial level corresponding to the level of section T_1.

I – vibration parameter trend;

II – moving average trend;

III– "outlier" threshold trend (20% more than the moving average) [8].

This phenomenon can be explained as follows: as a result of long-term operation in the parts of the rolling bearing, fatigue deformations accumulated in the mechanical bonds of the structure and their instantaneous destruction began. Due to the minor nature of these changes, the parts of the rolling bearing have been able to adapt to these changes. Parts were adjusted to the new operating conditions, the technical condition of the rolling bearing and the electric motor of the centrifugal pump unit almost returned to its original level. However, it should be noted that the changes that have occurred in parts and assemblies do not go unnoticed for its operational life. Therefore, in the T_3 section of the trend, lasting 19 hours and 20 minutes, a single outburst occurred (Fig. 2, section 14) and then in the T_4 section, lasting 8 hours 50 minutes, subsequent outliers occurred with a smaller amplitude, compared with the outliers recorded earlier in the section T_2. The physical essence of this phenomenon can be as follows.

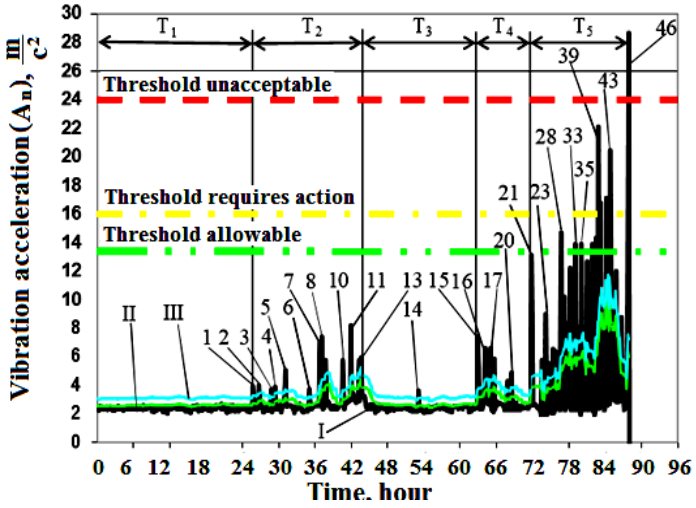


Figure 2. – Four-day trend of vibration from the system sensor mounted on the rear bearing (317) in the electric motor (BAO2-450LB-2, power 400 kW, rotational speed 2980 rpm) during normal operation, initiation and development of fatigue defects in details.

As a result of the accumulated fatigue phenomena in the structure, some mechanical connection or system of mechanical connections was destroyed. However, this destruction, the resulting defect, also turned out to be insignificant [9].

Therefore, a running-in process took place in the mechanical system, accompanied by vibration emissions of decreasing height. The mechanical system continues to maintain the normal mode of operation. This really happened in this mechanical system in a short time on the interval T_4. At the interval T_5, lasting 16 hours, the process of final failure of the rolling bearing parts began. The beginning of destruction is characterized by outbursts of increasing magnitude, which are greater than all previous outbursts. At the same time, the intensity of emissions increases and reaches the level "Unacceptable" at 46 emissions and the unit is taken out of service.

In accordance with the method for isolating vibration emissions, paragraph 2.4, on the presented result of the experiment (Fig. 2), 46 vibration emissions were recorded that accompanied the degradation process of the rolling bearing installed in the field bearing assembly of the BAO2-450LB-2 electric motor. The origin and intensive development of defects is shown, which is unacceptable for further operation of the unit.

When monitoring the level of vibration during operation of a centrifugal pump unit, control of the development of defects is ensured, that is, control of wear and degradation of parts during the operation of a centrifugal pump unit [10].

In accordance with the accepted standards, there are four levels of technical condition of centrifugal pumping units: “Good”, “Allowable”, “Requires action”, “Unacceptable”.

Based on the power and height of the center of the shaft axis of the pumping unit, specific threshold values are set for each measured vibration parameter: vibration acceleration, vibration velocity and vibration displacement (Fig. 2). In Figure 3, in sections T_1-T_4, the level of the vibration parameter does not exceed the threshold "Permissible", that is, according to the regulatory documents, there are no defects in the aggregate, at the same time, the trend shows vibration parameter outliers that indicate the presence of the process of nucleation and development defects in the details of the centrifugal pump unit.

In this regard, the thesis proposes the following methodology for assessing the stages of degradation of a centrifugal pump unit in the presence of vibration emissions:

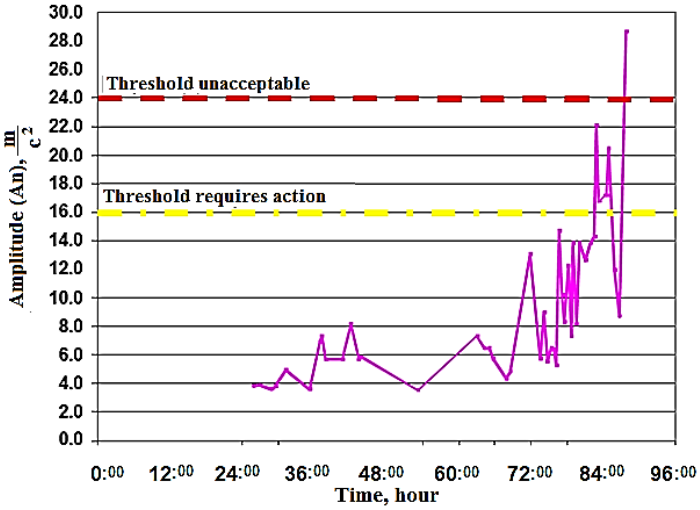


Figure 3. - Four-day trend of vibration emission amplitudes.

If the vibration level is up to the “Permissible” threshold and there are no vibration parameter emissions, the technical condition of the centrifugal pump corresponds to the “Good” rating (Fig. 2, section T_1), and if there are isolated vibration parameter emissions, the technical condition corresponds to the “Permissible” rating (Fig. 2, sections T_2, T_3, T_4).

At the level of vibration in the presence of emissions in the interval from the threshold "Permissible" to "Requires action", the technical condition of the centrifugal pump unit is "Permissible" (Fig. 2, section T_5, emissions 28, 33, 35, 37, 38) [11].

1. At the level of vibration in the presence of emissions in the interval from the threshold "Requires action" to the level "Unacceptable", the technical condition of the centrifugal pump unit corresponds to the level "Requires action" (Fig. 2, section T_5, emissions 39, 40, 42, 43).
2. If the vibration level is above the “Unacceptable” threshold, the technical condition of the centrifugal pump unit corresponds to the “Unacceptable” level (Fig. 2, section T_5, release 46).

Thus, when trends in vibration emissions are detected, in order to assess the technical condition of a centrifugal pump unit, it is necessary to exclude the “Good” rating and apply only three gradations.

"Allowable", "Requires action", "Unacceptable". To visualize the degradation process, we build a trend of vibration emission amplitudes (Fig. 3).

We apply a new algorithm for assessing the technical condition of a centrifugal pump unit in terms of vibration parameters (Fig. 4) [12].

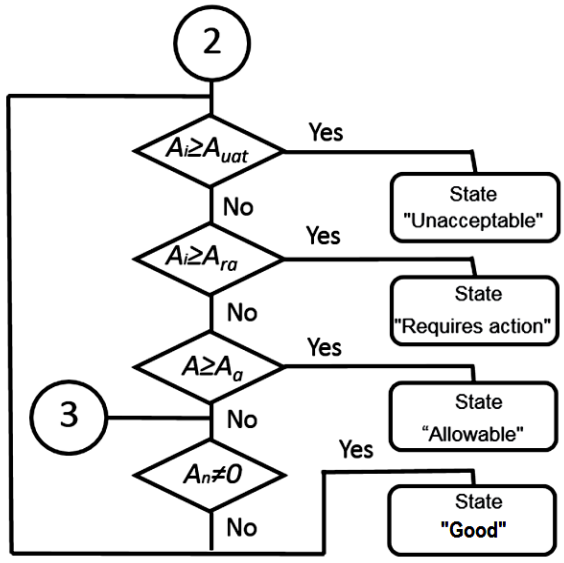


Figure 4. - Block diagram of the assessment of the technical condition of the centrifugal pumping unit in case of vibration emissions

The proposed technique makes it possible to pay attention to the stage of defect initiation and the beginning of degradation processes in parts and assemblies of a centrifugal pump unit.

The technique for controlling the staged accumulation of damage to parts by increasing the amplitudes of vibration emissions, in contrast to the traditional approach to controlling the vibration level, allows:

- fix vibration emissions, record them as stages of damage to parts and assemblies of a centrifugal pump unit during the entire period of its operation from repair to repair;
- set the initial (starting) level of damage to parts and assemblies of a centrifugal pump unit according to the amplitude of the first vibration emission (A_1) and, relative to the first emission, take into account the degree of damage to parts and assemblies throughout the entire life cycle of the pump unit;
- to determine the degree of damage to parts and assemblies of a centrifugal pump unit relative to the initial level, using the ratio of the amplitudes of subsequent vibration emissions (A_n) to the amplitude of the first vibration emission (A_1), to provide long-term diagnostics during the entire period of operation;
- to determine the degree of damage to parts and assemblies of the centrifugal pump unit relative to the previous stage of degradation, providing control over the change in the relative increment of the amplitudes of the subsequent vibration emission (A_n) to the amplitude of the previous

vibration emission (A_{n-1}), thereby providing operational diagnostics in the interval between two adjacent emissions ;
- exclude errors due to different initial technical condition of parts and assemblies of a centrifugal pump unit after the completion of the manufacturing or repair process, before starting operation;
- to visualize the staged degradation of parts and assemblies of a centrifugal pumping machine during its operation in a continuous technological process of oil refining by building trends in emission amplitudes (A_n), their ratios (B_n) and increments (C_n);
- monitor the degree of danger of damage to parts and assemblies of a centrifugal pump unit according to the established critical boundaries of the states "Requires action" and "Unacceptable";
- issue conclusions on the technical condition, stages of degradation and the degree of damage to parts and assemblies of the centrifugal pump unit during the period of its operation.

The proposed technique for controlling the staged accumulation of damage to parts by the duration of the intervals between emissions, in contrast to the traditional approach to controlling the vibration level, allows:
- fix vibration emissions, record them as stages of damage to parts during the entire period of operation from repair to repair;
- set the initial (starting) level of parts damage according to the duration of the first interval T_1 between the first and second vibration emissions;
- determine the degree of damage to parts by controlling the ratio of the duration of the interval between subsequent emissions to the duration of the first interval and carry out long-term proactive diagnostics during long-term operation, eliminating errors due to different initial technical conditions of parts and assemblies;
- fix the degree of damage to parts by monitoring the change in the duration of the intervals between emissions, which allows you to quickly judge the degradation from release to release;
- improve the accuracy of the diagnosis, since the measurement of the duration of time intervals between emissions has minor errors, compared with the measurement of vibration amplitudes at which the measurement error reaches 25%;
- to visualize the staged degradation process by constructing trends in the duration of the intervals between emissions (T_n) and the ratio of subsequent intervals to the first interval (I_n), reflecting the process of staged degradation of parts and assemblies during the operation of a centrifugal pump unit in an oil refinery;
- monitor the degree of danger of damage to parts and assemblies of a centrifugal pump unit according to the established critical boundaries
- "Requires action" and "Unacceptable";
- issue conclusions on the technical condition, stages of degradation and the degree of damage to parts and assemblies of a centrifugal pump unit throughout the entire period of its operation.

4. Conclusions

As a result of the conducted experimental studies:
- A system for collecting experimental data has been developed, configuration and operation modes have been selected and substantiated, providing tracking of vibration emissions during the operation of centrifugal pumping units at the site of operation.
- Experimentally tested and confirmed the operability of the method for isolating vibration emissions in the flow of measuring the vibration of a centrifugal pump unit, separating a smooth increase in vibration from its emission.
- The technique for detecting and controlling the process of staged accumulation of damage and failure of parts by increasing the amplitudes of vibration emissions has been tested, which

provides long-term and prompt proactive diagnostics throughout the entire period of operation, and the performance of the proposed diagnostic method has been confirmed.

- The method for detecting and controlling the process of staged accumulation of damage and failure of parts was tested by changing the duration of the intervals between vibration emissions and the operability of the proposed diagnostic method was confirmed.
- The method for predicting the time of occurrence of vibration emissions and the operating time of a centrifugal pump unit before the transition to the technical state "Requires action" and "Unacceptable" for vibration emissions has been experimentally tested. The error in predicting the service life averaged no more than 53 minutes (1.5%).
- The concept of technical condition has been clarified. When trends in vibration emissions are detected, in order to assess the technical condition of a centrifugal pump unit, it is necessary to exclude the “Good” rating and apply only three gradations “Allowable”, “Requires action”, “Unacceptable”.

References

[1] Ergashev R, Bekchanov F, Atajanov A, Khudaev I and Yusupov F 2021 *E3S Web of Conferences* **264** 04026
[2] Antonova E, Ivanov I and Stepanov O 1998 *Monitoring of power units at compressor stations* (Chekardovsky. - OAO Publishing House "Nedra")
[3] Barkov A, Barkova N and Azovtsev A 2000 *Monitoring and diagnostics of rotary machines by vibration* (St. Petersburg State Marine Technical University)
[4] GOST R ISO 10816-3-99. 2000. Vibration. Evaluation of the condition of machines based on the results of vibration measurements on non-rotating parts. *Part 3. - Introduced from 01.07.00. – M.: IPK Publishing house of standards, - 10* (in Russian).
[5] GOST 32106-2013. 2014. Condition monitoring and diagnostics of machines. Monitoring of the state of equipment of hazardous industries. Vibration of centrifugal pump and compressor units. - *Introduced from 01.11.14 – M.: FSUE "Standartinform" - 8* (in Russian)
[6] GOST R ISO 7919-3-99. 2000. Vibration. Assessment of the state of machines based on the results of vibration measurements on rotating shafts. - *Introduced from 01.07.00. - M.: IPK Standards Publishing House, Part 3. - 10* (in Russian).
[7] Bekchanov F, Yusupov F, Kholbutaev M, Khayitov B and Ulashov Q 2021 *IOP Conf. Series: Earth and Environmental Science* **868** 012039
[8] Makhutov N and Gadenin M 2011 *Technical diagnostics of residual resource and safety* (M.: Publishing House)
[9] Kostyukov V, Tarasov E, Kostyukov A and Boychenko S 2017 / *Pat. 2606164 RF*, Bull. - No. **1**. (in Russian).
[10] Guericke V 1999 *Monitoring and diagnostics of the technical condition of machine units* (Kemerovo: KuzSTU*)*
[11] Tarasov E 2018 Monitoring of rolling bearings under conditions of multi-stage failures based on the analysis of vibration acceleration trends. *Thesis for the degree of candidate of technical sciences. Omsk - 170* (in Russian).