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Reducing vibration of pumping units of reclamation systems

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Abstract. The article presents the results of scientific research on the operation of pumping equipment at reclamation pumping stations. In pumping stations, more and more attention is being paid to measures to maintain the reliability and efficiency of pumping units and reduce the negative impact of factors of various origins. One of the most significant factors affecting the service life of the equipment is the increased vibration of the pumping unit. According to the analysis of failures of pumping equipment at pumping stations in Uzbekistan for 2010-2021, more than 40% of the pump stops occurred due to increased vibration. The most common cause of vibration of pumping equipment is waterjet and cavitation wear of the impeller, destruction of seals, wear, and temperature rise of the bearing. The greatest vibration occurs when the equipment is operated in heavy and non-optimal modes. As a result of the generalization of the research results, active methods and means of reducing the vibration of pumping units were identified.

1 Introduction

The problem of ensuring the reliability of systems of machine irrigation of agricultural crops in Uzbekistan is currently one of the most urgent. Issues of the technical condition of hydraulic, mechanical, and electrical pumping station equipment and improving their reliability are the subject of many research works [1, 2]. To date, several research areas have been formed in improving the reliability and assessing the technical condition of equipment for machine water lifting systems [3, 4]. One of the reasons leading to a decrease in reliability and an increase in the number of failures of pumping stations can be the wear of equipment elements and assemblies. This can lead to the appearance of an increasing level of pump vibration, a decrease in pressure characteristics, a general technical condition of the system, and low operating life of the pumps. Increased vibrations result from malfunctions that have appeared and, therefore, the cause of failures. Based on the analysis of failures of pumping equipment at pumping stations in Uzbekistan for 2010-2021. more than 40% of pump stops were due to increased vibration [5, 6]. The fight against vibrations

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of the pumping unit is one of the most important problems. Vibration reduction is necessary to increase the reliability and durability of structures and reduce the duration of repairs. Developing effective means for these purposes is impossible without knowledge of the sources of vibration and the causes of its occurrence. The vibration of pumping units is caused by causes of mechanical, electrical, and hydrodynamic origin. The least studied and predictable vibration of hydrodynamic origin occurs when pumps operate under severe conditions. Under such operating conditions, an intense dynamic effect occurs on the hydraulic part of the pumps, which is perceived by the mechanical part and transmitted to the bearing units, housing, and foundations of the units.

2 Methods

The article uses methods of hydraulic research to prevent the vibration of pumping equipment at main pumping stations. Reliability profits, in the course of a theoretical study, the reliability of the mathematical effectiveness of testing the effectiveness of the results of experiments and natural studies.

3 Results and Discussion

One of the most common causes of vibration in a rotating impeller is imbalance. It occurs when the impeller is manufactured incorrectly, and the shaft of the electric motor and the impeller are misaligned with shaft curvature or due to the difference in the masses of structural elements located on diametrically opposite sides of the impeller. It also appears due to prolonged operation of the shafts when the design of the elements mounted on the shaft is worn.

Imbalances can occur due to distortions in fitting the impellers onto the shaft. Even when mounted on balanced rotor bearings with different-walled inner races, a dynamic imbalance may occur due to the appearance of a new axis of rotation due to the eccentricity of the pump units (PU) [7, 8].

The main sign of imbalance is the appearance of a dominant peak in the vibration signal spectrum at the shaft rotation frequency (reverse frequency). Due to the procession, a peak at this frequency also appears in the signal envelope spectrum. If an imbalance occurs on the shafts between the supports, then both signs appear on both supports. If the imbalance occurs on the cantilevered impellers, then these signs appear mainly on the support closest to the impeller [9, 10].

As a result of the appearance of vibration, failure of the pump unit occurs. Failures are divided into complete failures, which lead to a complete loss of system performance, and partial failures, which lead to the loss of only some system functions. To determine it, a periodic audit of the units is carried out. An indirect state assessment is also possible when determining the number of parameters [11, 12].

The papers directly address the issues of the technical condition of pumps and methods for diagnostics and monitoring [13, 14]. The study of the parameters determined by the hydroabrasive wear of pumps is of great interest. Methods for express diagnostics of pumps in irrigation systems are closely related to changes in their technical condition during operation, which directly depends on the degree and intensity of hydroabrasive wear of pump elements, particularly the impeller.

The method and means of vibroacoustic examination depends on the objects' structural, functional, and vibrational state.

The structural state is characterized by a set of structural properties - the geometry of the elements and the relationships between them. This state of the object is reflected mainly by periodic oscillatory processes; An adequate method for the physical nature of such processes is the method of tracking spectral analysis.

According to the order of vibration harmonics in rotary action mechanisms, its sources can be identified: the amplitudes of these harmonics characterize the energy distribution associated with the object's state [15, 16].

The authors studied hydrodynamic disturbances in the operation of pumps at pumping stations (PS) in the Samarkand and Bukhara regions.

One of the reasons for the vibration of centrifugal pumps is cavitation, which occurs due to the pressure drop in the fluid flow below the saturation (boiling) pressure; it occurs in areas with high fluid velocities, in particular, as a result of insufficient backwater at the pump intake. During the transition from the non-cavitational operation of the pump to the regime with gas cavitation, there is a sharp increase in vibration. Cavitation causes an increase in vibration, mainly in the frequency range (1...10 kHz). The vibration spectrum, unlike other faults, is continuous.

Following the recommendations currently in force, the assessment of the operability of PU, at nominal modes is carried out following the vibration standards given in Table 1 [17, 18].

Table 1. Vibration standards for bearing assemblies of scientific equipment operating at nominal conditions

RMS vibration velocity, mm/s	Assessment of the vibration state of the unit	Estimation of the duration of operation
Up to 2.8	Excellent	Long
Over 2.8 to 4.5	Good	Long
Over 4.5 to 7.1	Satisfactory, needs improvement	Limited
Over 7.1	Unsatisfactory	Unacceptable

As an estimated vibration parameter, the RMS of the vibration velocity is used, which is determined for the frequency range of 10 ... 1000 Hz by the formula:

$$V_{скк} = \sqrt{\frac{1}{T}\int_{O}^{T} V(t)dt} \quad (1)$$

where V(t) is vibration velocity, measured in the frequency band 10.. 1000 Hz; T is the averaging time.

RMS of vibration velocity of bearing assemblies of SE in the frequency range of 10...1000 Hz are measured by stationary monitoring and signaling vibration equipment (CSA) and portable vibrometry tools. Vibration control is carried out in vertical (Z), horizontal-transverse (Y), and horizontal-axial (X) directions.

The vertical vibration component is measured at the top of the bearing cap above the middle of the bearing shell length; the horizontal-transverse and horizontal-axial vibration components are measured at the level of the rotor shaft axis against the middle of the support insert length.

A significant amount of additional information about the vibration characteristics of the SE can be obtained from the characteristics measured in transient modes - acceleration and run-out when the rotational speed of the rotor system changes smoothly. At the same time, the frequencies of the main driving dynamic forces associated with the rotational speed of the rotor system (rotor unbalance, misalignment, bearing defects, etc.) also change. In contrast, the frequencies of discrete vibration components that are not related to the rotational speed of the rotor system do not change (resonances of rotors and bearings, power supply frequency, etc.).

Modern digital spectrum analyzers allow measuring and storing signal spectra at specified time intervals. Groups of spectra measured during the transient process are called multispectra [18,19].

The time during which the multispectrum can be measured is determined by the following relationships:

$$T_m = \Delta t_{dig} \cdot N \tag{2}$$

where: Δt_{dig} is measurement interval of single spectra, s; N is the number of single spectra in the multispectrum.

$$\Delta t_{dig} \geq \Delta t_{aver} \tag{3}$$

where Δt_{aver} is averaging time of single spectra, s;

The number of spectra forming a multispectrum depends on the spectrum analyzer's frequency bands and storage capacity.

Since the vibration amplitude of the PU in transient modes can change significantly and quickly, it is proposed to use exponential averaging when measuring the multispectra of the vibration velocity of an accelerating or running out unit.

For the analysis of multispectra, it is proposed to use:

- three-dimensional graphical representation of the multisection in the form of waterfall graphs in the coordinates amplitude - frequency - time;
- diagrams of RMS signal development;
- diagrams of the development of signal amplitudes in 1/3-octave frequency bands;
- signal spectra determined from the vibration velocity development diagrams at the characteristic time points of the studied transient process.

The three-dimensional representation of multispectra makes it possible to trace the dynamics of development of all discrete components simultaneously, to determine the characteristic features of the formation of individual stages of the process, and to determine discrete components whose frequencies change with time and whose frequencies do not depend on time.

The RMS development diagram allows you to track the change in time of the integral assessment of the process under study, determine its maximum value, identify the presence of patterns in the development of the process (for example, the presence of low-frequency oscillations), determine the characteristic time points of the development of the process (turning on and stopping individual nodes, the passage of resonances, etc.). Diagrams of the development of signal amplitudes in 1/3-octave frequency bands make it possible to trace the change in time of individual discrete components of the spectrum of the process under study. When comparing these diagrams with the diagram of the development of the RMS, it is possible to determine which discrete components contribute to the formation of the RMS of the process at certain characteristic stages of its development [20,21].

Based on individual spectra, the main discrete components of the spectrum of the process under study are determined at characteristic moments of time.

Therefore, to implement the tasks of preventing the occurrence of vibration of pumping units, it is necessary to use the created original (at the level of inventions) designs at pumping stations with a lower flow of driftwood, suspended and bottom sediments, to identify and eliminate the causes of excess energy consumption due to unfavorable operating modes of the pumping station. Optimal forms of pump inlets are created based on ensuring maximum efficiency values, minimum permissible cavitation reserves, and low levels of dynamic perturbing effects of the flow with minimum dimensions of the inlets in plan and height, taking into account special operational requirements [22,23].

Depending on the type, design, and operating conditions, various forms of inlets are used for large pumps.

The presence of increased flow turbulence or hydraulic vortex funnels at the inlet openings of the water intake, caused by an uneven velocity field, the flow on the approach, can significantly affect the operation of the pumps, increasing their vibration and changing the feed. So, when the flow is swirled at the pump inlet in the same direction as the rotor of the unit rotates, the pressure developed by the pump decreases, and the flow decreases accordingly, and when the flow is swirled in the direction opposite to the direction of rotation of the rotor, the pressure increases.

The purpose of the new design is to increase the water intake efficiency due to the combined effect on the flow of a number of interacting flow-forming elements [2,15]. The set goal is solved by installing flow-forming elements, one of which is located at the top of the initial section, preventing air from being sucked through whirlpool funnels (Figure 1).

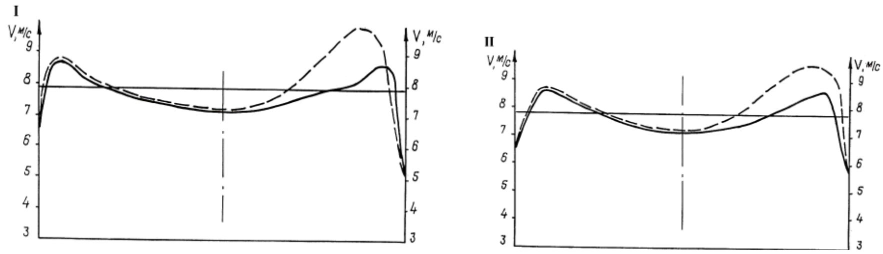
Fig. 1. Surface guide of flow forming elements

The second element is located at the end of the confuser, forming, due to the vertical compression of the flow, an improved picture of the distribution of velocities in front of the impeller (PI) of the pump.

Experimental testing of fabricated structures included testing of guiding elements, and the flow part of pumps, taking into account the influence of flow distribution in the fore chamber [11, 24].

Investigation of the flow structure under the pump's PI included measuring the flow velocity components: axial υ_a, radial υ_r, circumferential υ_c; calculation based on the measurement of pump delivery rates; estimation of the uniformity of speeds.

According to the velocity distribution (axial) plots in the flow in front of the pump CV, velocity distribution diagrams were constructed (one diagram is the velocity distribution along the axes of the section in which the speeds were measured; the second diagram is the velocity distribution along the section). The first diagram represents the distribution of absolute velocities; the second diagram represents the distribution of relative velocities, Figure 2. The choice of data for plotting from all available determined the following conditions:



— Diagram of the distribution of absolute velocities along the axis of the section perpendicular to the axis of the suction pipe; – – – the same coinciding with the axis of the suction pipe; $I\alpha = -2°;\ 2.Q = 40.9\frac{m3}{s};\ 3.\ H = 18.6\ m;\ 4.Hs = -3.5m;\ 5.\ V_{av} = 7.9\ m/s;\ II\ \alpha = -2°;\ 2.Q = 40.4\ m3/s;\ 3.H = 18.0\ m;\ 4.\ Hs = -4.1\ m;\ 5.V_{av} = 7.8\ m/s.$

Fig. 2. Plots of absolute flow rates in the water intake PS-1 KMCh.

The efficiency of the developed new flow supply methods predetermines their wide application.

4 Conclusions

1. One of the reasons leading to a decrease in reliability and an increase in the number of failures of pumping stations may be the wear of elements and components of the equipment. This can lead to the appearance of an increasing level of pump vibration, a decrease in pressure characteristics, a general technical condition of the system, and low operating life of pumps.

2. Vibration of pump units is caused by causes of mechanical, electrical, and hydrodynamic origin. The least studied and predictable vibration of hydrodynamic origin occurs when pumps operate under severe conditions.

3. One of the reasons for the vibration of centrifugal pumps is cavitation, which occurs due to the pressure drop in the fluid flow below the saturation (boiling) pressure; it occurs in areas with high fluid velocities, in particular, as a result of insufficient backwater at the pump intake.

3. The presence of increased flow turbulence or hydraulic vortex funnels at the inlets of the water intake, caused by an uneven field of velocities, the flow on the approach, can significantly affect the operation of the pumps, increasing their vibration and changing the supply.

4. Installation of new flow-forming elements of the water intake does not increase pressure losses. However, the head loss increases in other modes of operation of the pump, caused by the need to change the head. Their accounting method is the use of methods for analyzing operational information on operational and economic characteristics coming from the PS and analyzed according to the forms developed in the laboratory of pumping stations and hydropower of RIIIVP.

5. Modernization of water intakes complies with modern norms for designing PS and calculating water supply structures. These methods were approved when considering the advanced principles of operation of pumps on irrigation systems by specialists the training to improve the skills of NS specialists, taking into account the requirements for stability and safety of workers in the regional conditions of the Republic of Uzbekistan.

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