Diagnostic tests of vertical pumps modernized pump stations

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Abstract. The article discusses the methods of maintenance and technical diagnostics of large vertical pumping units of modernized pumping stations of the largest cascades of the Amu-Bukhara and Karshi channels to ensure reliability during their operation, assesses the qualitative and quantitative changes in their modes. The operation of large pumping stations poses a number of problems that cannot be solved without experimental studies. The aim of the research is the problem of comprehensive diagnostics of pumping units and the development of new export-oriented diagnostic devices. The use of new designs of pumping power and diagnostic equipment involves the use of mathematical modeling of control of the operating modes of machine channels, which gives significant savings. Methods of accounting for cavitation – hydroabrasive wear of the blades are based on the study of the movement of the hydroabrasive flow along the radius of the impeller. Recommended elimination of pump operating modes with a maximum wear rate of their parts.

1. Introduction

Ways to improve the efficiency of irrigated agriculture largely depend on reducing operating costs for irrigation. In Uzbekistan, up to 50% of the irrigated area is the area with machine-generated water. To ensure reliability in the operation of pumping stations (PS), the authors consider new maintenance methods and technical diagnostics of pumping units (PU) during the modernization of pumping stations. The development of new energy-saving operating modes of the PS-1 of the Karshi main channel (KMCh) provides for the improvement of the PS mode, which gives significant savings due to the elimination of energy overruns due to adverse operating modes of the PS [1, 2]. The scientists of Uzbekistan were engaged in the issues of modernizing irrigation pumps, among which the works of the authors, Jurabekov A.I., Mamajonov M., Muhammadiev M.M., Rustamov Sh.R., Pulatov T.R. [3, 4]. Famous Spanish, American, and Polish scientists, including G. Urbikain and L. Lopez de Lacalle, Sarteg R., Karassik I.J. studied the wear of pumps depending on various materials and their operating modes [5–11]. However, an analysis of the study of issues of hydroabrasive and cavitation-abrasive wear of hydraulic machine elements according to literature shows a lack of work on their combined influence. The aim of the work is to increase the working life of the pumps while eliminating abrasive-cavitation erosion. The practical significance of the developed design measures is to create wear-resistant pump elements and diagnostic methods for monitoring rational modes.

2. Methods

When determining the vibration of operating in various modes and conditions, methods have been developed for creating computer calculation programs that reflect their technical condition by
analyzing vibration spectrum and vibration acceleration spectrum diagrams on the chamber and pump motor of pumping units.

3. Results and Discussion
In practice, there are numerous cases of prolonged operation of the pumps with greatly increased compared to the design hydraulic losses due to mechanical damage to the pump units due to cavitation-abrasive wear [12–17].

In figure 1 shows the dynamics of the wear of the blades at the entrance zone in three sections along the radius. The pattern of wear in all sections is curved in all three arcs. A more intense increase in wear was recorded on arcs located closer to the tops of the blades, which is explained by the following above reasons.

![Figure 1. Dynamics of wear of the middle zone of the impeller blades](image)

The form of wear of the impeller is determined by the following factors: when the hydroabrasive flow moves along the radius of the impeller, the particles move with the highest kinetic energy. In the study, it is necessary to take into account the main criteria:

\[
\frac{\varrho^2 \rho}{H} \text{ is a complex criterion; } \frac{D \varrho}{\nu} \text{ is Reynoldca criterion; } \frac{\varrho^2}{Dq} \text{ is Froude criterion; } \frac{D}{G} \text{ are simplex criterion; } \frac{1}{E} \text{ is Oberle criterion.}
\]

However, the regularity of the influence of all criteria in a generalized form is not yet known. Therefore, many researchers find solutions to waterjet wear in special cases. It is possible to use the following relationship to evaluate waterjet wear:

\[
\Delta G = kmS \varrho^3 t,
\]

here \( k \) is a coefficient depending on the properties of abrasive particles (hardness, size, shape, specific gravity of grains of sand), the wear resistance of the material of the part, and the flow around the part. and sediment transport;

\( m \) is the mass of grains of sand in the stream;

\( \varrho \) is the average flow rate, m/s;

\( t \) is the exposure time, s;

\( S \) is the concentration of grains of sand in the stream;
This formula shows that the abrasive wear of a stationary part, flowing around a weighing flow, is directly proportional to the concentration in the stream of grains of sand, a cube of the flow rate, the time of exposure to the part and the mass of each grain of sand.

When determining wear, the equation does not give exact results since many factors depending on the properties of the material and abrasive particles are given by one coefficient $k$.

Monitoring of the state of PU according to the results of measuring vibration on non-rotating parts is carried out as a normalized parameter of the general vibration level and the rms vibration displacement in the working frequency band 2...1000 Hz is established during the stationary operation of the pump. From the point of view of vibrational strength in aggregates, the most dangerous are oscillations of a periodic nature, which are the result of mechanical, electromagnetic, and hydraulic processes with clearly expressed discrete components. Such dangerous vibrations are mainly strong diagnostic signals (that is, they stand out well against the background of vibrational interference).

In the pump, vibrations of a hydraulic nature manifest themselves at a blade frequency proportional to the number of impeller blades (IB). For the new pump 300 VO-37/26 C there are 6 of them and the blade frequency is equal to:

$$f = 6 \times f_0 = 25\text{Hz}$$

The pump OPV11 - 260 has 4 blades and the blade frequency is equal to:

$$f = 4 \times f_0 = 16.67\text{ Hz}$$

The straightening apparatus at the exit from the RK excites oscillations with a frequency proportional to the number of its blades:

$$f = f_0 \times 12 = 50\text{Hz}$$

The causes of vibrational activity of a vertical PU are, by origin, divided into mechanical, hydraulic, and electrical, including the main nodes [16]. The reason for the heterogeneity of the flow is the asymmetric flow around the rotating blades during the formation of whirlpool zones [17, 18]. The heterogeneity of the flow leads to the appearance on the impeller chamber of vibration at the blade frequency $f_l$ and its higher harmonics. For worn spherical chambers in the absence of technological capabilities of turning, a combination of the above reasons prevails.

On vertical units in which the electromagnetic and hydrodynamic radial forces are ideally balanced, the clearances in the plain bearings increase in cases where there are other defects, such as imbalance or misalignment of the shafts. These defects cause vibration, which should lead to shaft deformation around the circumference of the bearing. That is, there is an external force that in certain phases of rotation will press the shaft against the bearing shell, or unload the bearing at least for a fraction of the time, causing a violation of the “oil wedge”.

The wear rate of bearings depends on the size of the additional defect and increases in the presence of abrasive in the lubricant.

Monitoring of such diagnostic parameters as the size of the clearance in the pump guide bearings, the overall vibration level, the insulation resistance of the windings, the transient resistance of the electrical contacts (especially the frontal connections) and the purity of the process water are not carried out, which often leads to accidents and failures. Currently, work is underway to create diagnostic systems for monitoring such diagnostic parameters.

In the practice of operating the OP10-260 pumps (which are the head samples of the largest pumps), there were no such precedents, therefore, the task of creating a diagnostic system was divided into the 1st and 2nd stages similarly [19].

The first stage involves monitoring a limited number of diagnostic parameters during operation, changes in which, according to statistics, caused the greatest number of failures. Other diagnostic parameters also affect the technical resource and the service life of the units. Their control is provided by the second stage of the diagnostic system.
Besides, the second stage of the technical diagnostic system provides for automatic shutdown of the unit in case of unacceptable deviations of the diagnosed parameter, while the first stage of the system provides in the same cases only the issuance of an alarm signal to the control panel.

To prevent accidents of units associated with excessive wear of bearings; ensuring the operation of bearings to the limit state, it is necessary to control the wear of bearing shells.

The definition of the technical condition of a nuclear power plant was usually determined by periodically or discretely monitoring the dimensions of its moving mates and the working body (diameters of the rubbing pairs, sizes of the blades, and their geometry).

The maximum vibration amplitude of 17.9 m s\(^{-2}\) at a frequency of 989.8 Hz in the vertical direction, which may be associated with increased mechanical vibration of the RC at low frequencies, was recorded on the IB chamber of the second new pump (PU № 3) (fig. 2).
PU the No 3.

PU the No 4.

PU the No 5.
A similar picture was observed during the examination of PS-1 in 2012, when at PU № 4, with a range of movement at the reverse and blade frequencies of 32 ... 42 micron, the value of the peak vibration acceleration was 22.1 m/s².

On the IB chamber of pumps, the main source of increased vibration is the hydrodynamic imbalance and flow inhomogeneity in the IB. The nature of these two defects is the same - uneven clearance between the blades and the chamber, differences in the pitch and angle between the blades, in length and thickness, or during their uneven wear and tear, and the vibration manifestation is different.

The increase in vibration at the blade frequency and its higher harmonics indicates the unevenness of the velocity field and pressure in the flow between the impeller blades.

Hydrodynamic imbalance, as the asymmetry of the forces acting on the wheel blades, leads to an increase in vibration at the reverse frequency and the first three harmonics, depending on the form of symmetry breaking.

Since all the blades are welded on the PS-1 KMC impellers, it is not possible to correct the influence of a certain unevenness of the angle of inclination of the blades on the hydrodynamic imbalance of the wheels and the flow in them. The hydraulic imbalance is also present on two of the three new 300VO-37 /26C pumps, where both the blades are new and the chambers are cylindrical.

At the extreme PU № 1, the maximum swing exceeds 32 ... 41 microns, and there at PU №6, the swing rises to 42 ... 53 microns, which indicates the unfavorable water supply conditions of the extreme pumps.

4. Conclusions

1. Depreciation of individual elements of the main hydromechanical equipment of the NS leads to a deterioration of the pump operation mode, reduction of their efficiency, and significant losses. In the case of pumps, the reasons for the increase in vibration may be the incorrect arrangement of HA
relative to the water level in the downstream basin, associated with the peculiarities of their operation in transient conditions, other defects, such as imbalance or misalignment of shafts.

2. A methodology has been proposed for accounting for hydroabrasive wear of the blades and impeller elements of an axial pump, taking into account the forms of wear of the impeller when the hydroabrasive flow moves along the radius of the impeller, the hydrodynamic parameters of the pump, the properties of the wear material and the characteristics of the suspension flow.

3. The operating modes of the pumps with the maximum intensity of wear of their parts are established. At the extreme PU № 1,6, the maximum range exceeds 42 ... 53 microns, which indicates the unfavorable water supply conditions of the extreme pumps. The increase in vibration at the blade frequency and its higher harmonics indicates the unevenness of the velocity field and pressure in the flow between the impeller blades.

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