Vane pumps with cavitation-abrasive wear of their parts

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Abstract. The article presents the results of the tests on cavitation-abrasive wear of pumps, depending on their operation modes. And also, in the work, the issues of the appearance of cavitation in hydro abrasive flows, which can lead to rather complex phenomena, which presents difficulties for understanding the essence of the process, are considered. To date, the wear of the working bodies of centrifugal and axial pumps, depending on the mode of their operation, has not been sufficiently studied and a methodology for choosing operating modes that takes into account the wear of their parts has not been developed. Also, the work presents the results of comprehensive laboratory and field studies to research the wear rate of the elements of the flowing part of centrifugal and axial pumps. An alternating pulsating load leads to an increase in the force of interaction of the hydro abrasive flow with the surface of the chamber and increases its wear by 10%, and also reduces the productivity of the pump unit to 9%. It is recommended that the operating modes and the geometric height of the suction of the pumps be selected based on cavitation characteristics constructed from erosion tests.

1. Introduction
Numerous pumping stations have been created in Uzbekistan for the irrigation of agriculture, which serve for supplying to high-located irrigation areas. The operating experience of pumping stations has shown that many of them operate with a supply significantly lower than by design. The main reasons for this are the wear of the elements of the flow part of the pumps, many of which are vanes. Therefore, the study of the causes of wear of the structural elements of vane pumps is an urgent task in the operation of pumping stations. The study of the causes of the origin of wear, influencing factors, its intensity, and direction was conducted by many scientific researchers [1, 2, 3]. It should be noted that due to the complexity of the multi-factor process of wear of the pump blades, it has not been sufficiently studied. In this case, after the wear of the blades, their hydrodynamic characteristic changes, this affects the operating mode of the pumping stations. Based on the foregoing, the choice of optimal operating modes of pumps, taking into account changes in the hydrological characteristics of the water source and the hydrodynamic parameters of the pump station units with a minimum wear rate of their parts, is defined as the main goal of this work [4, 5].
2. Methods
A method for researching this work is the analysis of the operation of pumping units of pumping stations in various modes, operating under different conditions and different values of the angles of blade installation, and the development of a method for choosing the optimal operating mode of pumping stations.

3. Results and Discussion
The obtained experimental data showed that the intensity of hydro abrasive and cavitation-abrasive wear of parts of the flow part of centrifugal and axial pumps are directly dependent on the operating mode. For a centrifugal pump, the dependence of the intensity of hydro abrasive wear of the impeller blades on the operating mode (figure 1) shows that within the characteristic working range there is a zone of less hazardous modes. The exit of the working point from this zone leads to a sharp increase in the intensity of watered wear. For example, when supplying a 3K-6 pump, $Q=0.55Q_{opt}$, corresponding to the lower boundary of the working zone limitation of the characteristic recommended by the manufacturer, the amount of wear attributed to pump supply $\Delta G/Q$ is two times higher than when supplying $Q=(0.9...1.1)Q_{opt}$. At high feeds, for example, at $Q=1.25Q_{opt}$, corresponding to the upper boundary of the recommended working zone of the characteristic, the amount of wear per unit of water supply $\Delta G/Q$ increases slightly by 8-10%. Given the small increase in specific wear values per water supply unit $\Delta G/Q$, centrifugal pump operating modes with a supply of $Q\geq Q_{opt}$ should be recommended.

A comparison of the specific wear values per water supply unit $\Delta G/Q$ for different operating modes of the axial pump 05 – 35 shows that the modes with a supply of $Q\geq Q_{opt}$ in the working area of the characteristics are also optimal for the minimum specific wear.

The zones of minimum wear of the blades of the impeller of the axial pump correspond to the zone of maximum efficiency of the pump at all angles of installation of the blades of the impeller. Deviation of the pump supply by 15-20% from the maximum efficiency zone in one direction or another leads to an increase in the wear rate by 40-80%, which is especially noticeable at large angles of installation of the impeller blades ($\varphi=\pm20^\circ$). It should be noted that the choice of the type of pump or its operating modes, taking into account the wear of parts, is a task that requires a technical and economic comparison of options in each case.

Based on a generalization of the results of laboratory bench tests, a universal characteristic of the relative cavitation-abrasive wear of a 3K–6 centrifugal pump was compiled (figure 2, a). As can be seen from the figure, the lowest cavitation-abrasive wear rate corresponds to the zone where the value of the cavitation reserve is greater than its permissible value $\Delta h>\Delta h_{dop}$ ($\Delta h_{dop}$ – is the allowable cavitation reserve accepted by the energy method).

When choosing an acceptable cavitation margin in the practice of designing pumping units, use the expression [2, 3, 4, 5, 6, 7, 8]:

$$\Delta h_{dop} = k \cdot \Delta h_{cr}$$  \hspace{1cm} (1)

here $\Delta h_{cr}$ – critical cavitation reserve, taken from the cavitation characteristics of the pump for a 2% decrease in pressure or flow, $K$ – is the safety factor.

To determine the values of the safety factor $K$, there are no recommendations in the corresponding instructions for the design of PS [9, 10, 11, 12, 13]. Therefore, in design practice, the values of $K$ are taken approximately within 1.1…1.5. An unreasonable choice of $K$ values leads, as shown by the operating experience of pumps, to unforeseen intensive wear of their working parts.

The studies carried out allowed us to clarify the value of the safety factor $K$ taking into account the wear of pump parts. Using the data presented in (figure 2, a), the dependencies are compiled $\Delta h=f(Q)$ for a centrifugal pump 3K-6 for various working conditions (figure 2, b). The data
obtained show that in centrifugal pumps, to reduce cavitation-abrasive wear of parts, one should increase the value of cavitation stock by 5...30%, depending on the mode of its operation.

Figure 3 shows the universal characteristics of the relative cavitation-abrasive wear of the impeller of the pump 05-35 at $\varphi=+20$ and $\varphi=0^\circ$, obtained also by summarizing the results of experimental studies. The lowest intensity of cavitation-abrasive wear on the field $Q-\Delta h$ takes place at feeds close to optimal near the first critical mode $\Delta h_1$ according to cavitation characteristic.

In the axial pumps of high speed, on the cavitation characteristics obtained by the energy method, there are no distinct breakdown points, but there is a gradual decrease in pressure and efficiency with a decrease in the cavitation reserve. Under these conditions, it is more difficult to determine the operating modes of pumps with partially developed cavitation, which do not noticeably affect the external parameters of the machine, but at the same time cause intense wear of the elements of their flow part.

The dashed-dotted lines in figure 3 a and 3 b show the allowable cavitation margin in terms of the minimum wear rate (lines I-I and II-II). The results obtained suggest that for this axial pump model OP5-35 at a speed of 960 rpm, the safety factor should be taken $K=1.05...1.1$ for blade angle $\varphi=+20$ in modes $Q<Q_{opt}<Q$. For blade angle $\varphi=0^\circ$ when working in modes $Q>0.93Q_{opt}$ should be taken $K=1.05...1.1$ and in operating modes $Q>0.93Q_{opt}$. At negative angles of installation of the blades $\varphi$ recommended $K=1.5$.

Location of line I-I and II-II (figure 3 a, and 3 b) on the field $Q-\Delta h$ for various pumps may vary depending on their speed. However, the results of this work allow us to establish general provisions on the selection of an acceptable cavitation margin or an acceptable suction height for the minimum wear rate. The nature of the dependence of the intensity of cavitation-abrasive wear $J$ on the cavitation stock $\Delta h$, estimated experimentally, it is not possible to establish at least the simplest theoretical dependence due to the complexity of the influencing factors.

For a reasonable choice of pump operating modes, it is necessary to carry out an appropriate analysis of their specific operating conditions at the design stage and the pump station operating period.

The operational experience of centrifugal and axial pumps on irrigation systems shows that their efficiency is mainly determined by the hydro abrasive wear of the working surfaces of the blades and of the sealing elements of the impellers [14, 15, 16]. An analysis of the degree of wear of the working surface of the impeller blades of the pumps, as well as the end edge of the blades of the axial pumps, shows that the local concentration of solid particles in the flow plays the main role here $p_{m1}$, since this value due to the separation of solid particles in the field of centrifugal forces will be significantly higher than the average concentration of solid particles in the stream.

Based on the analysis of the main similarity criteria related to the movement of solid particles in the field of centrifugal forces and pump tests, formulas (2) and (3) were obtained to determine the local concentration of solid particles $p_{m1}$ and $p_{m2}$ in impellers of centrifugal and axial pumps:

$$p_{m1} = \frac{p}{1-0.9\cdot u\left(\frac{d\cdot S}{D}\right)/V_m}$$

$$p_{m2} = \frac{p}{1-2.36\cdot u\left(\frac{d\cdot S}{D}\right)/V_m}$$

Here $p$ - average mass concentration; $u$ - peripheral speed; $V_m$ - axial component of absolute speed; $d$ and $D$ - respectively the diameter of the solid particles and the impeller of the pump; $S$ - simplex of Archimedes.

When operating the pumps, it is difficult to regulate all the values included in formulas (2) and (3), except for $V_m$. By increasing the flow $Q$, it is possible to reduce the value of $p_m$ and accordingly, the
wear of the impellers of the pumps. Here we consider a specific example of choosing the optimal for reducing wear parts, operating modes of the axial pump OP5-110, taking into account changes in the water level, and the amount of sediment in the water source (figure 4).

It is possible to reduce the PS value during floods when a large amount of sediment enters the pumping station and the water level in the water sources rises sharply. During this period, due to a decrease in the geodetic height of the lift, the working point A moves to point B, and the calculated actual cavitation reserve increases $\Delta h_p$.

The estimated actual cavitation reserve $\Delta h_p$ is determined by the formula:

$$\Delta h_p = H_a - h_{p,j} - H_s - h_{ws}$$

(4)

Here: $H_a$ – Atmosphere pressure, m; $h_{p,j}$ – saturated vapor pressure, m; $H_s$ – geodetic suction height, which is determined by the difference in the marks of the axis of the pump and the level of the downstream, m (figure 4, b); $h_{ws}$ – pressure loss in the suction pipe, m (figure 4, g).

The principle of choosing the optimal operating mode of the pump is that in size $\Delta h_p$ look for a working point C and D on the characteristic of the pump (figure 4), observing the condition $\Delta h_p \leq \Delta h_{dop}$ ($\Delta h_{dop}$ – allowable cavitation margin corresponding to the point C and D [19].

With subsequent fluctuations in the water level in the source, the selection of the pump operating modes according to the proposed calculation and graphical method is repeated. Saving the total supply of the pumping station when changing the operating modes of the units is possible by changing their number.

Centrifugal pumps have solid impellers, and their universal characteristics are given for different impeller diameters $D$. Therefore, the selection of centrifugal pump operating modes, taking into account the decrease in local sediment concentration, is carried out by the same method, but only at the design stage PS. In this case, the pump operation modes for different impeller diameters $D$ are compared for various possible changes in the water levels of the lower and upper heads, since an increase in the impeller diameter $D$ also reduces the local concentration of PM deposits on the surfaces of the blades [formula (2)].

In conclusion, we can draw the following conclusion that, in order to reduce local sediment concentrations and wear rate, in the design stage of pumping stations, pumps with a larger diameter $D$ of the impellers, with a lower speed $n_o$ and select the modes with the highest feed $Q$ [18,19,20].

4. Conclusions

1. The operating modes of pumps with a minimum rate of wear of their parts have been experimentally established. Rational from the point of view of reducing hydro abrasive wear parts of centrifugal and axial pumps are the feed modes $Q \geq Q_{opt}$.

2. A method is proposed for choosing the optimal operating conditions for the pumps, taking into account changes in the hydrological characteristics of the water source and the hydrodynamic parameters of the pump, which ensures a decrease in the wear rate due to a decrease in the local concentration of sediment on the surfaces of the parts.

3. Based on the obtained universal characteristics of cavitation-abrasive wear, it is recommended to take the safety factor when determining the allowable cavitation stock depending on the operating mode for a centrifugal pump from 1.15 to 1.7 and for an axial pump from 1.05 ... 1.1 to 1.5.

4. The nature of the dependencies of the intensity of the joint cavitation-abrasive wear of the pumps, evaluated experimentally, does not allow us to establish even the simplest theoretical dependence due to the complexity of the influencing factors. However, the characteristics obtained make it possible to develop a new direction in the study of the mechanism of cavitation-abrasive wear.
Figure 1. The dependence of the wear rate of the impeller blades on the operating mode of the centrifugal pump.

Figure 2. Universal characteristic of relative cavitation-abrasive wear (a) dependence of cavitation reserve on the operation mode of a centrifugal pump (b): 1 and 2 obtained by the energy method; 3 and 4 – obtained taking into account the minimum intensity of cavitation-abrasive wear.
Figure 3. Universal characteristics of relative cavitation the abrasive wear of the axial pump 0-35 at the angle of installation of the blades + 2° (a) and 0° (b).

Figure 4. Graphs for selecting the mode of operation of the axial pump: a - water supply; b and c - fluctuations in water levels in the lower and upper pools; g - dependence pressure losses from water supply; d - universal characteristic axial OP5-110 pump at n = 485 min⁻¹.

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