Influence of cavitation-hydro abrasive wear and wear of vane hydraulic machines on the hydraulic resistance of the suction line of pumping units

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Influence of Cavitation-Hydro Abrasive Wear and Wear of Vane Hydraulic Machines on the Hydraulic Resistance of the Suction Line of Pumping Units

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Abstract. The paper considers the issues of the appearance of cavitation in hydroabrasive flows, which can lead to rather complex phenomena, which presents difficulties for understanding the essence of the process. Until now, the wear of the working bodies of blade hydraulic machines, depending on the mode of their operation, has not been sufficiently studied, and the method for selecting the operating modes of hydroelectric power plants (HPP) and pumping stations (PS) has not been developed, taking into account the cavitation-hydroabrasive wear of their parts. Also, the work presents the results of field and laboratory studies to study the intensity of wear of the elements of the flow path of blade hydraulic machines, taking into account the effect on the hydraulic resistance of the suction line of hydropower plants.

INTRODUCTION

One of the main reasons for the decrease in the operational parameters of vane hydraulic machines is the intensive wear of the blades and the sealing clearances of the impeller in a hydroabrasive environment. As the practice of operation shows, it has been little studied so far, the wear of the working bodies of blade hydraulic machines, depending on the mode of their operation, is little studied, and a method for selecting operating modes, taking into account the wear of their parts, has not been developed. Therefore, the identification of wear during various operating modes of pumping units is an urgent problem. In pumps and hydraulic turbines, due to a decrease in general or local pressure for some reason, cavitation phenomena may occur, which take place at most operated hydroelectric power plants (HPPs) and pumping stations (PS) [1-3]. It is well known that cavitation phenomena are accompanied by erosive effects on streamlined surfaces. In the presence of sediments in the flow, the intensity of joint cavitation-abrasive destruction of working parts of hydraulic machines increases sharply, which leads to their accelerated failure and requires significant material resources for repair and restoration work [4-7].

A detailed analysis of those or other factors influencing the onset of cavitation and other questions of an applied nature can be found in the works of R. Knepp [7], K.K. Shalnev [9], V.Y. Karelin [4], S.P. Kozyrev [11] and others. Therefore, without going into the details of the physical essence of the occurrence of cavitation, we will focus on the manifestation of cavitation and the mechanism of cavitation destruction in blade hydraulic machines.

Hydrodynamic cavitation in hydraulic machines can occur if the local pressure on the flow path elements becomes close to the pressure of the saturated vapor of the liquid at a given temperature. In addition, an additional decrease in pressure can occur in hydraulic machines, which causes the risk of cavitation due to the following reasons [5]: decrease in absolute pressure or increase in fluid temperature in the system; an increase in the geometric suction head or additional resistances of the suction lines; separation of flow in the boundary layer and deviation of streamlines from the normal trajectory; an increase in the local flow rate on individual machine elements; pressure pulsations in turbulent jets and the presence of secondary flows in the gaps; contamination and gas content of the stream, etc. Such a variety of reasons influencing the occurrence of cavitation in hydraulic machines lead to certain

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difficulties in the theoretical solution of the problem.

RESEARCH METHODOLOGY

Full-scale and laboratory studies were carried out to identify the causes of cavitation-hydroabrasive wear and wear of parts of blade hydraulic machines.

RESULTS AND DISCUSSION

In the practice of pumping, for a quantitative assessment of the development of cavitation, a special criterion is usually used - a cavitation reserve Δh, the minimum value of which sets the permissible suction lift H_s^{perm}. The existing theoretical methods do not make it possible to reliably establish Δh min, but only in special cases, when it comes to the shockless entry of the flow into the pump impeller, the determination of Δh_{min} is possible by calculation.

For example, Fig. 1 shows a universal characteristic of a large full-scale axial-flow pump OP10-185 with isolines of the beginning of slotted cavitation at $H_s = -5.0\ m$ and $H_s = -3.3\ m$, obtained from the results of the oscillogram of pressure pulsations on the walls of the impeller chamber. According to the technique proposed by V.Y. Karelin [4], the application of such lines to the characteristics of pumps can be of great practical use in predicting the wear of parts from crevice cavitation.

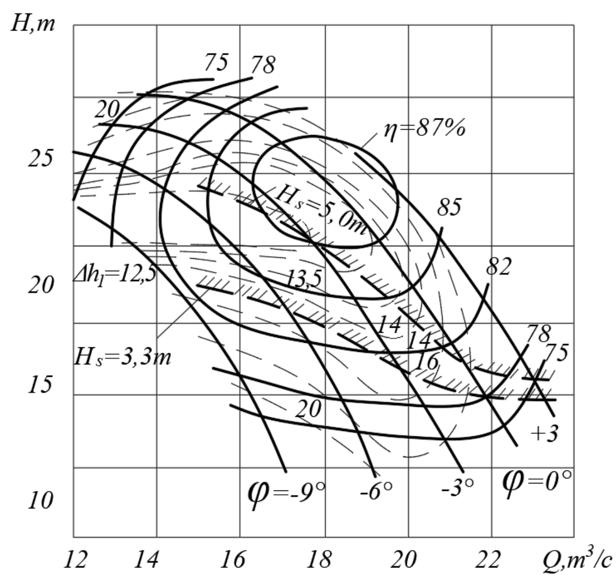

FIGURE 1. Universal characteristic of the OP10-185 pump with contours of the beginning of crevice cavitation

Methods for assessing the development of cavitation given in the literature are successfully used in scientific research work in a laboratory and natural conditions. Still, they have not yet been replaced by the energy method in the relevant regulatory documents and technical instructions due to insufficient knowledge of the problem.

The cavitation erosion equations, proposed in , do not reflect the analytical processes occurring in hydraulic machines. Therefore, their use for calculating cavitation erosion of parts of real machines is associated with certain difficulties.

Undoubtedly, a step forward is the one put forward by S.P. Kozyrev, the theory of the formation of not ordinary but high-speed cumulative jets during the collapse of cavitation cavities. These streams are identified by the author with the streams formed in the recesses of explosive shaped charges.

The proposed theory made it possible for S.P. Kozyrev to draw up equations to determine the average volume ΔW of the metal removed in N blows:

$$\frac{\Delta W}{d^3} = \frac{4 \cdot 10^3 K_z V_0^5 d \cdot N \rho^3}{(HM)_{dyn}^2 \eta_k} \tag{1}$$

where K_z is the coefficient; ρ is the fluid density; V_0 is the jet impact velocity; d is the liquid jet diameter; N is the number of beats; $(HM)_{dyn}$ is the dynamic metal hardness according to Meyer; η_k is the fluid viscosity.

The resulting equation, although it takes into account the main factors affecting cavitation erosion, is not very acceptable for practical calculations, due to the complexity of determining the parameters d, N and V_0.

To determine the intensity of cavitation erosion, a group of authors proposed the formula (2):

$$I = \frac{\Delta G_{sp}}{q \cdot V^6} \tag{2}$$

where, $\Delta G_{s.c.}$ is specific weight loss of the sample in g/h; q is the area of the cavitation zone in cm^2;

V is the flow velocity in the characteristic section in m/s.

Although the formula is simplified and convenient for use, the intensity of erosion I is expressed in a complex dimension, complicating the assessment of research results.

Based on numerous studies on the effect of flow rate on cavitation erosion, it is generally accepted that:

$$\Delta G = A_1 V^n \tag{3}$$

where ΔG is weight loss; A_1 is dimensional factor; V is flow rate; n is exponent.

Figure 2 shows the change in the speed index n, depending on the duration of the tests, obtained by SP Kozyrev [11]. The change in n from 10 to 2.5 in the considered period limit can be explained by the difference in the values of the velocity index obtained by several researchers [18, 19]. According to the experimentally obtained nonlinear character of the wear value, depending on the test duration, it was possible to distinguish between the period of latent wear ("incubation"), the period of intensive wear and the period of decrease in the wear rate, which correspond to different values of n [14].

The cavitation characteristics of vane hydraulic machines, obtained by the power method, do not explain the intensity of cavitation erosion of their parts. From this point of view, the most interesting is the experimental study of E.D. Lunatsi and D.A. Voitashevsky [9], carried out on a model of a large centrifugal pump. Establishing the intensity of cavitation erosion J using varnish coatings, the authors managed to plot the isolines of the function J on dimensionless coordinates in $\bar{q}$ and $\bar{p}$ (fig.3), where:

$$J = \phi_1\left(\bar{q}, \bar{p}\right) \tag{4}$$

the functional dependence of the erosion intensity on the geometric, kinematic and energy parameters of the pump:

$$\bar{q} = \frac{60Q}{n_0 D_1^3}; \qquad \bar{p} = \frac{\Delta P}{\rho\left(\frac{n_0 D_1}{60}\right)^2}; \tag{5}$$

where Q is water supply; n_0 is rotation frequency; D_1 is inlet wheel diameter; ρ is the density of the liquid; $\Delta P = P_{in} - P_{steam}$ excess of pressure at the pump inlet over the pressure of saturated vapors of the liquid.

As can be seen from fig. 3, the contours of the intensity of cavitation erosion in different modes have different outlines, which once again convinces the complexity of the relationship between erosion processes and the energy performance of the pump and the hydrodynamic characteristics of the flow.

The intensity of wear under the influence of a hydroabrasive mixture mainly depends on the mechanical properties of the material of the part, on the hydrodynamic parameters of the flow, on the mechanical properties and geometric shapes of abrasive particles, as well as on the physicochemical properties of the liquid.

The wear curve plotted in relative values according to Ilgaz data in Fig. 4 shows [17] that when the particle size is more than 0.2 mm, the size of the sand grains does not affect the increase in wear.

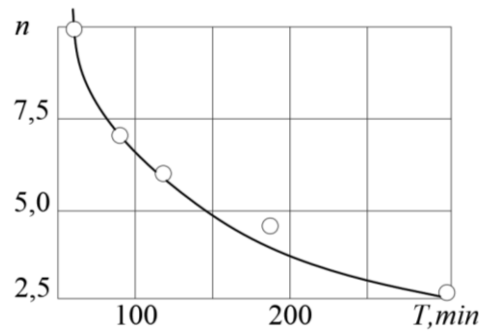

FIGURE 2. The change in the exponent of the speed from the duration cavitation test.

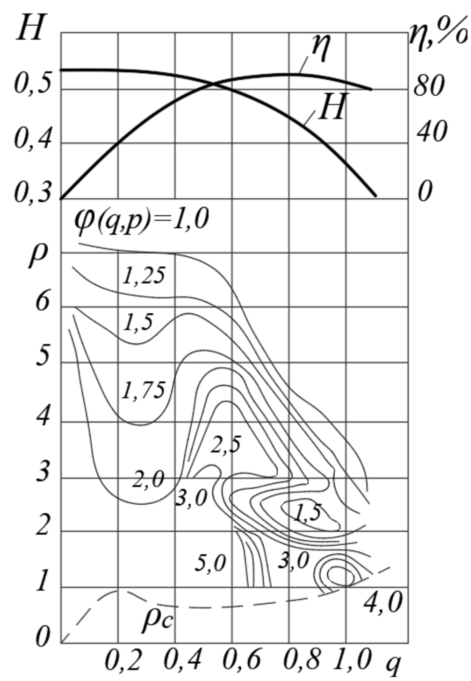

FIGURE 3. Relative cavitation-erosion characteristic model centrifugal pump

Using sharpened particles, V.B. Dulnev received another pattern, which is also plotted in Fig. 4. The same figure shows the curves plotted according to the data of R.I. Pylaeva and E.I. Pazyuk. According to the presented curves, it can be noted that if particles d> 0.2 mm have 100% abrasion capacity, then for d = 0.1 mm, the abrasion capacity is 70-80%, and for d = 0.07 mm, it is 65%. At a high hardness of abrasives (corundum with hardness (9), even microscopic particles (0.003–0.005 mm) used in micropowders are capable (albeit weakly) of abrading steel. As noted by M.M. Orakhelashvili, these data show that small particles also have a real danger to hydraulic machines. The discrepancy between the nature of the curves in Fig. 4 can be explained by the difference in the authors' research methods.

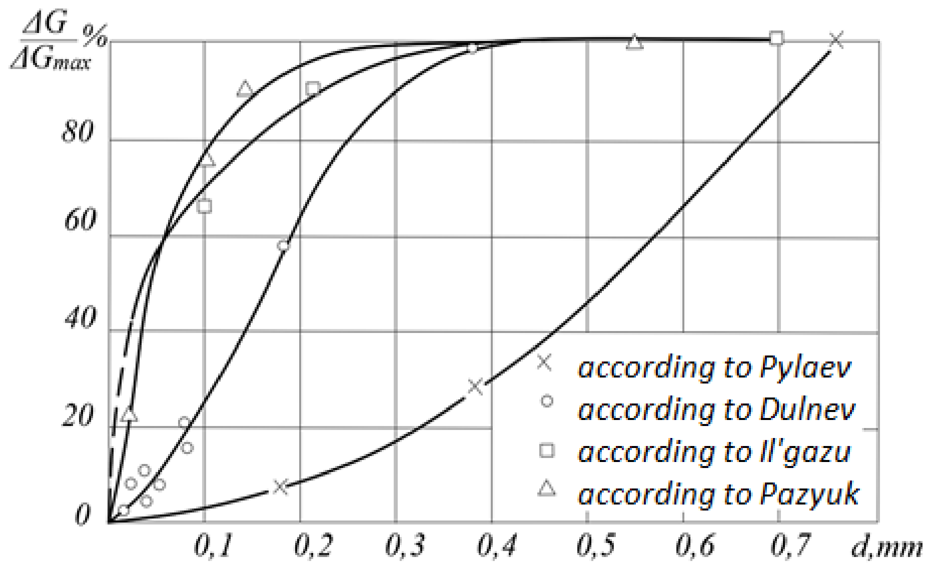

FIGURE 4. Change in the relative amount of wear depending on sand size.

The hardness of the sediment also has some relationship with its size. To explain this concept, a graph is drawn in Figure 5, showing the percentage of sediments with hardness greater than 5 (on the Mohs scale) for the respective fractions. When drawing up the schedule, the data given in the book by V.Y. Karelin for the Vakhsh irrigation canal were used. With a particle size d> 0.2 mm, the percentage of sediments with a hardness of ≥5 remains unchanged, as well as the amount of wear is in good agreement with the curves shown in Fig. 4.

According to the results of works [14, 16-27], it can be concluded that with the appearance of cavitation in a hydroabrasive flow, rather complex phenomena can occur, which presents difficulties for understanding the essence of the process. Depending on the operating conditions of hydraulic systems, the amount of joint wear can be in some cases less than purely hydroabrasive wear, and in other cases, less than purely cavitation wear. From this point of view, it is of particular interest to identify the operating modes of vane hydraulic machines with minimal cavitation-abrasive wear.

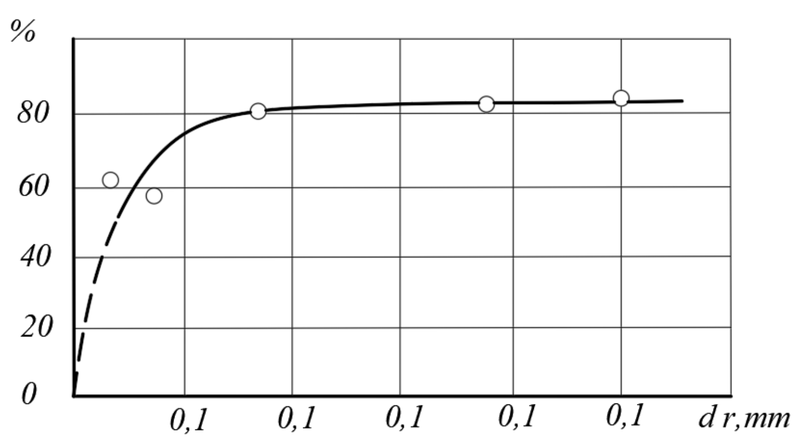

FIGURE 5. The percentage of particles of this fraction with hardness greater than 5 (according to Mohs)

The discrepancy between the results obtained by various researchers is apparently because the mechanism of joint action of cavitation and abrasive particles is different under different flow conditions and forms of cavitation. The issues of joint cavitation-abrasive wear have not been sufficiently studied. There are no generalizing criteria for assessing the amount of joint wear. When two types of wear, cavitation and hydroabrasive, are superimposed, the destruction process is complicated by the presence of a three-phase flow (liquid - vapor-gas cavity - solid particle).

Depending on the operating conditions of this hydraulic system, the intensity of the total destruction in comparison with the intensity of cavitation erosion or hydroabrasive wear can be different.

The dynamics of the increase in the end clearance of the impeller of an axial pump show that the impeller chamber's wear occurs more intensively than the ends of its blades. This is because a pulsating alternating load acts on the surface of the chamber due to the pressure difference on the working and rear surfaces of the blades.

Until now, the wear of the working bodies of centrifugal and axial pumps, depending on the mode of their operation, has not been studied enough, and a method for selecting operating modes, taking into account the wear of their parts, has not been developed. To resolve the issue, it is necessary to further study the mechanism of cavitation-abrasive wear on pumping units that most fully simulate the hydrodynamic processes of real blade hydraulic machines.

CONCLUSIONS

Assessment of the current state of knowledge of the issues of reducing the performance of blade hydraulic machines allows us to make the following conclusions:

1. One of the main reasons for the decrease in the performance of vane hydraulic machines is the presence of solid mechanical impurities in the pumped water. Solid particles, acting on the surface of the parts, lead to intensive hydroabrasive wear and increase the hydraulic resistance of the suction line of the pumps due to siltation of the front chamber and the water intake chamber of the PS.

2. In centrifugal pumps, the most intense wear occurs at the outlet sections of the impeller blades and its sealing elements. When pumping turbid water for 2000 hours, the sealing clearances of the impellers of type D pumps with heads of 75-80 m are 2.8-3.1 mm.

3. As a result of siltation of the water intake chambers, as well as an increase in the roughness of the surfaces of the parts and the size of the sealing gap of the impeller due to hydroabrasive wear, the efficiency of the D4000-95 pumps was 12-15% lower than the design one.

4. With an increase in the end clearance of the impeller of an axial pump from the effect of a slotted cavitation-abrasive flow, the pressure value and the local concentration of solid particles in the flow play the leading role. The increase in the clearance due to wear depends on the head in the 1.2-1.5 degrees.

5. The relationship between the intensity of cavitation erosion and the operating modes of a hydraulic machine is extremely complex. At the same time, there are modes with minimal wear that can be detected experimentally.

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