

Theoretical models and dependences for calculating intensity of hydroabrasive wear of pump working parts

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Abstract. The paper presents the results of a theoretical and experimental study of the wear intensity of the elements of the flow part of centrifugal and axial pumps. Theoretical formulas recommended by various authors, obtained for models with flat samples based on energy theory, do not consider the features of hydraulic machines. Considering the movement of a solid particle in the interblade channels of the impellers of centrifugal and axial pumps, we chose design schemes that correspond to hydraulic and physical wear processes. The analysis shows that the action of centrifugal and inertial forces in the interblade channel of the impellers of centrifugal and axial pumps results in the separation and redistribution of solid particles in the flow. As a result, in centrifugal pumps at the end of the blade and axial pumps at the end gap of the impeller, the local concentration of solid particles increases compared to the average. The paper also provides dependencies for calculating the intensity of hydroabrasive wear of pump working parts.

1 Introduction

Considering the flow turbulence and the streamlined surfaces' roughness, it should be assumed that the particles transported by the flow in the pump impeller move along complex trajectories [1-3]. Therefore, determining the nature and direction of movement of a solid particle in the channels of the impeller, even in an approximate form, is extremely difficult. It should be noted that the difference in the density of solid particles ρ_t and liquid flow ρ_o leads to the approach of particles to the blade's surface and their separation along the radius due to the emergence of centrifugal and inertial forces during the rotation of the impeller. The destruction of pump parts occurs due to numerous, continuous collisions of solid particles transported by the flow with a streamlined surface, as evidenced by the structure of the wear surfaces of pump parts.

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A solid particle located in the interblade channel of an axial pump is affected by various forces: centrifugal, inertial, drag, gravity, pressure gradient, etc. The direction of these forces in the spatial coordinate system x, y, z is schematically shown in fig.1. The particle will move in the direction of the resultant force F and will come into contact with the surface of the blade at an angle α . At the same time, some particles, moving in the same direction, fall into the gap between the blade and the impeller chamber, which increases the local concentration of solid particles. Assuming in the first approximation, $\angle \alpha = \angle \alpha_1 = \angle \alpha_2$ (fig. 1, b) we note that the collision of the particle with the end surface occurs with an angle $(90 - \alpha)$ [4-7].

Considering also that the relative velocities of the suspension-carrying flow in the inter-blade channel and the slot gap are different, it can be reasonably argued that the wear of the end part occurs according to a different pattern than for the rest of the blade surface [8-13].

In the interblade channel of the impeller of a centrifugal pump, the suspended particle is affected by the same forces similar to an axial pump. Still, their direction and location should be considered not as in a spatial inertial coordinate system x, y, z . Still, but a planar coordinate system x, y (fig. 2). The particle will move in the direction of the resultant force F and come into contact with the blade's surface with an angle α . However, the interaction angle α for centrifugal pumps is much smaller than for axial pumps since, in this case, the hydrodynamic F_1 and centrifugal F_2 forces lie in the same plane, and they are directed to the outer circumference of the impeller, and the angle between these forces will always be less than 90° [14-17].

The analysis of the considered schemes in figure 1 and figure 2 shows that from the impact of centrifugal and inertial forces in the interblade channel of the impeller of the axial and centrifugal pumps, separation and redistribution of solid particles in the flow occur. As a result, in centrifugal pumps at the tip of the blade and axial pumps in the end gap of the impeller, the local concentration of solid particles increases compared to the average, which should be considered when determining the wear rate of these elements [18-24].

2 Method

An analytical method for determining the wear of metals, a method for balancing the energy of hydraulic machines, and generally accepted methods for laboratory and full-scale testing of pumps and their water intake chambers.

3 Results and Discussion

Considering also that the relative velocities of the suspension flow and the local concentration of solid particles in the interblade channel and structural gaps are different, it can be argued with the sufficient reason that the wear of the details of the structural gaps occurs according to a different pattern than the surfaces of the impeller blades of pumps.

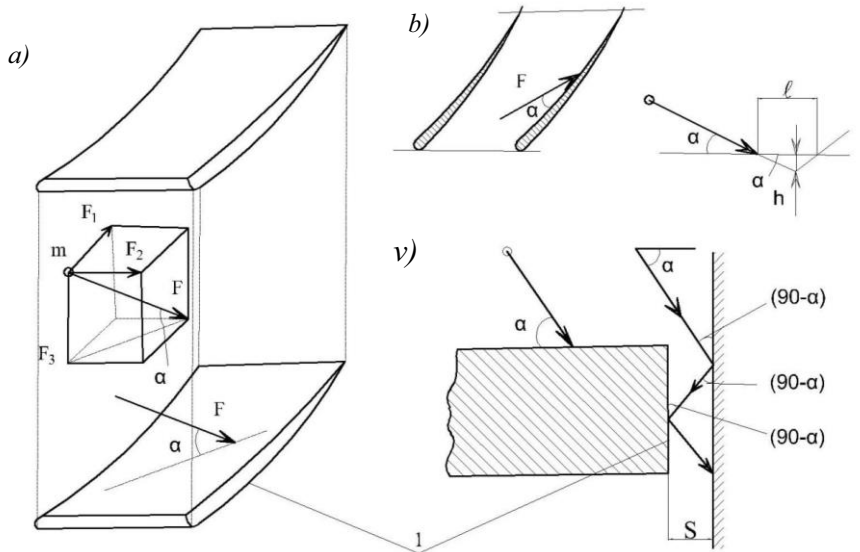


Fig. 1. Scheme of impact of a solid particle with the surface (a and b) and the end part (v) of the blade of the axial pump impeller: 1 is end of the blade; 2 is chamber impeller

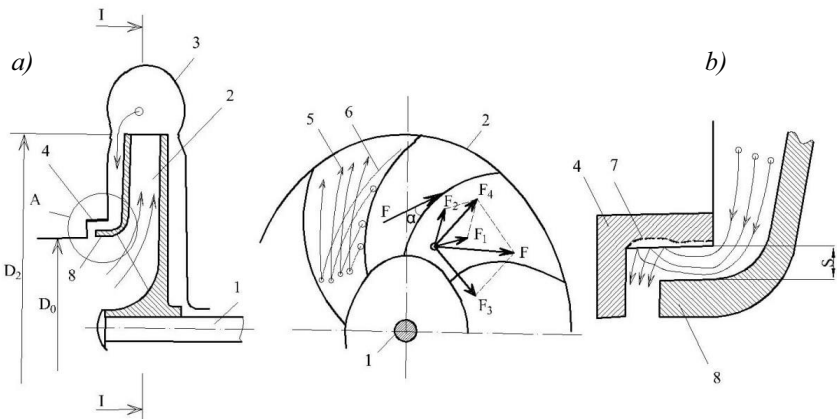


Fig. 2. Scheme of the movement of solid particles in the interblade channel (a) and the sealing gap (b) of the impeller of a centrifugal pump: 1 is shaft, 2 is impeller, 3 is retractor, 4 is seal rings, 5 is liquid flow path, 6 is solids path, 7 is wear line of the sealing ring surface, 8 is impeller front disc seal area.

In our opinion, in centrifugal and axial pumps, the intensity of wear on the surface of the blades and the surface of the details of the design gaps of the impellers should be considered as a result of several separate processes:

a) wear over the entire surface of the blade ΔG_n , which occurs when the main flow flows around the blade;

b) an increase in the gap due to wear of the end part of the blade ΔG_t and the chamber ΔG_k of the impeller of the axial pump, which occurs when some volume of the

most saturated with solid particles volume of the suspension-carrying flow leaks through the end gap;

c) an increase in the sealing gap due to wear of the sealing ring $G\Delta_y$ and disk G_d of the impeller of a centrifugal pump, which occurs when part of the flow leaks through the sealing gap.

Then the totals wear of the impeller blade of the axial pump:

$$\Delta G = \Delta G_n + \Delta G_t \quad (1)$$

In addition, the total increase in clearance due to wear:

- for axial pump

$$\Delta S = \Delta S_t + \Delta S_k \quad (2)$$

- for centrifugal pump

$$\Delta S = \Delta S_y + \Delta S_d \quad (3)$$

here ΔS_t and ΔS_k are, respectively, the wear thickness of the surfaces of the butt end of the blade and the chamber of the impeller of the axial pump; ΔS_y and ΔS_d are, respectively, the wear thickness of the surfaces of the sealing ring and the disk of the impeller of a centrifugal pump.

The considered mechanism and scheme of the interaction of a solid particle with the surface of the parts show that other things being equal (i.e., when the operating modes of the pump, the mechanical properties of the hydroabrasive flow and solid particles, as well as the properties of the wear material) are constantly maintained, the wear rate individual parts of the pump differ from each other and is determined by the following functional relationship:

$$\Delta G = f(P_m, W, \alpha, D) \quad (4)$$

here P_m is local concentration of solid suspended particles; W is the local relative velocity of solid particles; α is angle of interaction of solid particles with the surface of the part; D is the characteristic size of the part.

The proposed model most fully corresponds to the actual wear processes that were observed during the full-scale examination of centrifugal and axial pumps.

The wear of the working parts of the pump when flowing around it with a hydroabrasive flow occurs due to cutting metal microchips by abrasive particles and knocking out individual micro volumes of material. The papers [7, 8] present a theory for assessing the wear of solids based on the fatigue nature of this phenomenon. At the same time, it is indicated that when the material is pushed aside, the separation of metal particles is possible due to low-cycle fatigue.

Using the main provisions given in [4-6], we will carry out a theoretical analysis of the mechanism of hydroabrasive wear, taking into account the following conditions:

- a) the fluid flow has a steady cavitation-free regime;
- b) all sediment particles are homogeneous and are suspended in the flow;
- c) the saturation of the flow with sediments is relatively small so that it does not change the nature and properties of the flow;
- g) the wear blade material has constant physical and mechanical properties and a homogeneous structure;

d) in the considered time interval, there is no spalling or breaking of large parts of the wear part, i.e., the process is considered with a constant mechanism of hydroabrasive wear in time.

Under the conditions described above, the pump parts will be subjected to hydroabrasive wear, the intensity of which is determined mainly by the parameters of the hydroabrasive flow, the properties of the wear material, and the design features of the streamlined surfaces. As a result of introducing a solid particle into the material of the blade, the worn surface will have depressions in the form of holes. The dimensions of the holes for the same metal depend on the impact velocity of the abrasive particle V , the angle of attack α , and the size and hardness of the abrasive particle. The amount of wear can theoretically be expressed as:

$$\Delta G = \Delta G' N \quad (5)$$

here, ΔG is weight loss of the blade material from the impact of N particles during time T ; $\Delta G'$ is mass loss from the impact of one particle; N is the number of particles involved in the wear of the blade.

First, let us consider the wear mechanism of the vane of an axial pump along the surface and its end part. Based on the previously selected theoretical model (1), the mass loss over the surface and end of the blade will be equal to:

$$\Delta G_n = \Delta G'_n \cdot N \quad (6)$$

$$\Delta G_t = \Delta G'_t N' \quad (7)$$

here N and N' are, respectively, the number of particles involved in the wear of the surface and the end of the blade during the time T .

To determine the wear value of the impact of one particle, there is [67] the following equation:

$$\Delta G' = \frac{0.0885k\rho_m\rho^{\frac{5}{n+2}}d^3V^{\frac{10}{n+2}}(\sin\alpha)^{\frac{8-n}{n+2}}\cos\alpha}{\Phi^{\frac{5}{n+2}}} \quad (8)$$

where n is the Meyer constant characterizing the properties of the wear material; K is coefficient of proportionality; ρ_m is metal density; ρ is solid particle density; d is the particle diameter; V is velocity m of the particle; α is angle of impact of a solid particle with the surface; Φ is the constant characterizing the hardness of the metal is determined by the expression [12]:

$$\Phi = 0.98 (NM)_{dyn} + 352.5 M.n/m^2 \quad (9)$$

Here $(NM)_{dyn}$ is the Meyer dynamic hardness of the metal.

Taking into account that the solid particle collides with the blade surface with an angle α , and with the end part with an angle $(90 - \alpha)$ (fig. 1), based on equation (8), we can write:

$$\Delta G'_n = \frac{0.0885k\rho_m\rho^{\frac{5}{n+2}}d^3V^{\frac{10}{n+2}}(\sin\alpha)^{\frac{8-n}{n+2}}\cos\alpha}{\Phi^{\frac{5}{n+2}}} \quad (10)$$

$$\Delta G_T' = \frac{0.0885k\rho_m \rho^{\frac{5}{n+2}} d^3 V_1^{\frac{10}{n+2}} (\cos\alpha)^{\frac{8-n}{n+2}} \sin\alpha}{\Phi^{\frac{5}{n+2}}} \quad (11)$$

here, V and V_1 are, respectively, the speed of particles in the interblade channel and the end gap of the impeller.

The number of particles involved in wear over the entire surface of the blade:

$$N = \psi N_o \quad (12)$$

and end part

$$N' = \psi' N'_o \quad (13)$$

here N_o and N'_o are, respectively, the total number of particles passing through the interblade space and the end clearance of the impeller.

Using the method of dimensions, it was shown in [5, 8] that the number of particles that come into contact with the surface with a characteristic size D or S is proportional to the ratio d/D or d/S . Based on this position:

$$\psi = K_y \frac{d}{D} \text{ and } \psi' = K_y \frac{d}{S} \quad (14)$$

here K_y is coefficient of proportionality; D is impeller diameter; S is value of the end clearance of the impeller (fig. 1 and 3).

In addition, it is necessary to introduce a correction into expression (12) for unaccounted for factors that occur during the flow around the blade under various operating modes of the pump - λ .

4 Conclusions

1. Based on the analysis of worn parts of pumps in natural conditions, a mechanism was chosen, and a theoretical model of wear of the main parts of the flow part of centrifugal and axial pumps.
2. Analytical formulas are derived for determining the magnitude of pump parts' hydroabrasive wear, considering the characteristics of the suspended flow, the properties of the wear material, and the operating modes of the pumps.
3. The conducted studies of centrifugal and axial pumps made it possible to identify their operating mode with a minimum intensity of parts wear.

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