Method for determining optimal overhaul service of centrifugal and axial pumps

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Abstract. The efficiency of pump operation mainly depends on the maximum permissible wear of the parts of their flow path. One of the factors determining the need for repair and restoration of centrifugal and axial pumps is the wear of parts that form the sealing and slotted gaps of the impellers. With an increase in the design clearances of the impellers, the leakage of liquid increases proportionally, and this worsens the energy performance of the pumps and, accordingly, leads to an increase in operating costs. At certain clearance values, the costs reach such a value that the pump operation becomes impractical. Therefore, when assessing the pump's performance, it is important to establish the wear limits of its parts. About a machine part, the limit state is a state in which its further operation is impossible due to an unrecoverable decrease in operating efficiency below the permissible level or the need for repair.

1 Introduction

Concerning vane pumps used in irrigation systems, the task of establishing allowable wear is mainly technical and economic. Taking into account the leading role of the size of the sealing and end gaps of the impellers of centrifugal and axial pumps with a decrease in energy performance, we have proposed a method for determining their optimal overhaul life based on a technical and economic comparison of options for reduced costs [1-6].
The equation expresses the given costs associated with the maintenance and operation of pumps:

$$K_{np} = K_i + C_i\, T \rightarrow \min \qquad (1)$$

where, K_i is the costs associated with restoring the pump performance over time T; T is duration of operation of the pump, T = 1 year; C_i is costs associated with fluid leakage through sealing and slotted gaps of pump impellers
The annual cost to restore pump performance

$$K_i = K_1 i \tag{2}$$

where i is the number of repairs; K_1 is the cost of one repair.
If during the year the pumping unit will be operated t_e hours, then:

$$i = \frac{t_e}{t_i} \quad and \quad K_i = K_1 \cdot \frac{t_e}{t_i} \tag{3}$$

where t_i is the duration of the pump operation up to a certain amount of wear of the parts that form the gaps of the impellers.

After appropriate processing of the experimental relations q=f (S) and q = f (t), obtained for a centrifugal pump 200 D-90 and an axial pump 05-35, for determining the total amount of leakage through the gap during time t, based on the compiled computer program, the following equations are obtained:

- for centrifugal pump:

$$\sum_{i=1}^{n} q_i t_i = \int_0^{t_1} 2.14 \cdot 10^{-2} dt + \int_0^{t_1} 3.96 \cdot 10^{-5} t \cdot dt - \int_0^{t_1} 6.6 \cdot 10^{-9} t^2 \cdot dt \tag{4}$$

- for axial pump:

$$\sum_{i=1}^{n} q_i t_i = \int_0^{t_1} 1.17 \cdot 10^{-2} dt + \int_0^{t_1} 2.11 \cdot 10^{-5} t \cdot dt - \int_0^{t_1} 3.69 \cdot 10^{-9} t^2 \cdot dt \tag{5}$$

According to the above formula (4), the reduced costs of CPR were determined by calculations through the computer programs. The extreme values of the curves Kpr=f (t) will correspond to the effective duration of the operation of the pumps and the maximum allowable values of the radial clearances of the impellers. When operating for six months during a year, the optimal overhaul life of a 200D-90 centrifugal pump t_o=810 h, the maximum allowable clearance S=1.9 mm, and for the PG-35MA axial pump t_o =1725 h and S=2.2 mm. This means that for the effective use of pumps for six months, it will be necessary to repair their parts at least 3-4 times [7-12].

2 Research method

An analytical method for determining the wear of metals, a method for applying a polymer coating to metal surfaces, and generally accepted methods for laboratory and full-scale testing of centrifugal and axial pumps.

Results of research and discussion

The operating costs associated with the increase in sealing and slotted gaps of pump impellers are expressed as the energy spent on fluid leakage through these gaps in the following form:

$$C_i = e \cdot E_i = e \frac{9.81 \cdot H \cdot q_{av} \cdot t_i}{\eta_n \eta_{dv} \eta_{av} / \eta_0} \tag{6}$$

where e is cost of 1 kw/h of electricity; q_{av} is average gap leakage over time $\Delta t = t_{i+1} - t_i$; η_p

and η_{dv} are pump and motor efficiency; η_{av} is average volumetric efficiency of the pump for each certain period of time (ti+1 - ti.= Δt); η_0 is initial volumetric efficiency of the pump.

The volumetric efficiency of the pump and its average values are determined by the expressions

$$\eta_0 = \frac{Q_t - q}{Q_t} \text{ and } \eta_{av} = \frac{Q_t - q_{av}}{Q_t} \tag{7}$$

where Q_t is the theoretical flow of the pump; q is fluid leakage through the gap at a certain duration of operation t.

The formula determines the theoretical feed:

$$Q_t = Q + q \tag{8}$$

where Q is the initial actual flow of the pump.

Fluid leakage through gaps:

- for centrifugal pump:

$$q = 2\pi D_y \cdot S \cdot \mu \cdot \sqrt{2g \cdot \Delta H} \tag{9}$$

- for axial pump:

$$q = Z \cdot L \cdot S \cdot W_m \tag{10}$$

where L and Z are the length and number of blades, respectively.

Average leakage:

$$q_{av} = \frac{q_i + q_{i+1}}{2} \tag{11}$$

When calculating C by formula (6), the value $\sum q_i t_i$ should be set. To do this, based on the results of a study of a centrifugal 200D - 90 pump and a 05–35 axial pump, the dependencies $q=f(s)$ and $q=f(t)$ were constructed (Fig. 1 and 2). After appropriate processing of the results, based on the compiled computer program, the following equations are established:

- for centrifugal pump:

$$q = 2.14 \cdot 10^{-2} + 3.96 \cdot 10^{-5} \cdot t - 6.6 \cdot 10^{-9} \cdot t^2 \tag{12}$$

- for axial pump:

$$q = 1.17 \cdot 10^{-2} + 2.11 \cdot 10^{-5} \cdot t - 3.69 \cdot 10^{-9} \cdot t^2 \tag{13}$$

To determine the total amount of leakage through the gap during time t, equations (12) and (13) must be integrated within the range from 0 to t1, i.e.:

$$\sum_{i=1}^{n} q_i t_i = \int_0^{t_1} 2.14 \cdot 10^{-2} \, dt + \int_0^{t_1} 3.96 \cdot 10^{-5} t \cdot dt - \int_0^{t_1} 6.6 \cdot 10^{-9} t^2 \cdot dt \tag{14}$$

$$\sum_{i=1}^{n} q_i t_i = \int_0^{t_1} 1.17\cdot 10^{-2}\, dt + \int_0^{t_1} 2.11\cdot 10^{-5} t\cdot dt - \int_0^{t_1} 3.69\cdot 10^{-9} t^2 \cdot dt \qquad (15)$$

The final cost can be summarized as follows:

$$K_{av} = K_1 \frac{t_e}{t_i} + 9.81\cdot e\cdot H \frac{\sum_{i=1}^{n} q_i t_i}{\eta_n \cdot \eta_{dv} \cdot \eta_{av} / \eta_0} \qquad (16)$$

The numerical values of t, $\Sigma q_i t_i$, C, K and K_{pr} are determined, respectively, by formulas (14), (15), (6), and (16). Considering that these calculations require labor-intensive computations, computer programs have been used.

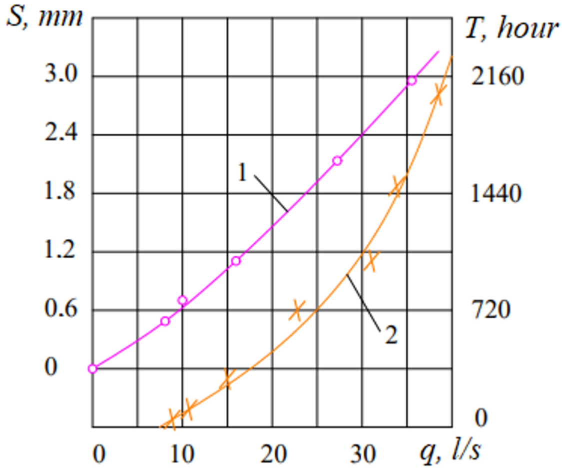

Fig. 1. Depending on the increase in leakage from the size of the sealing gap of the impeller (1) and the duration of operation (2) of the centrifugal pump

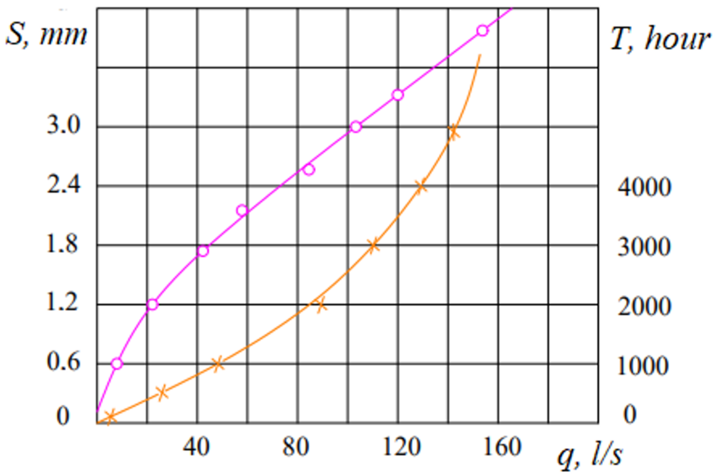

Fig. 2. Dependences of the increase in leakage on the size of the end clearance of the impeller (1) and the duration of operation (2) of the axial pump

Initial data for determining the optimal overhaul life of a centrifugal pump 200D-90: n_0=1480 rpm; Q_t=0,2 m^3/c; P_t =90 m, D_2=0,5 m; D_y=0.23 m; L=0.03 m; η_n=0.81; η_{dv} =0.95; t_e=5880 h; K_1=43 rub; e=0.02 rub; arrays t_1=0, t_2=360 h; t_3=720 h; t_4=1080 h; t_5=1800 h; $S_1=0.5\cdot10^{-3}$m; $S_2=1.2\cdot10^{-3}$m; $S_3=1.8\cdot10^{-3}$m; $S_4=2.4\cdot10^{-3}$m; $S_5=3\cdot10^{-3}$m; μ_1=0.524; μ_2=0.583; μ_3=0629; μ_4=0.661; μ_5=0676.

Initial data for determining the optimal overhaul life of the PG-35MA axial pump PG-35MA: Q_t=0.36 m^3/c; H=7 m; D=0.35 m; n=1200 об/min; Z=4; L=0.245m; β=24^0; η_n=0.7; η_{dv}=0.92; t_e=5880 h; K_1=51.3руб; e=0.02 руб; t_1=0; t_2=800 h; t_3=1600 h; t_4=2400 h; t_5=3200 h; t_6=4000 h; t_7=4800 h; $S_1=0.5\cdot10^{-3}$m; $S_2=1.25\cdot10^{-3}$m; $S_3=1.91\cdot10^{-3}$m; $S_4=2.53\cdot10^{-3}$m; $S_5=3.05\cdot10^{-3}$m; $S_6=3.54\cdot10^{-3}$m; $S_7=3.92\cdot10^{-3}$m; μ_1=0.83; μ_2=0.845; μ_3=0.865; μ_4=0.895; μ_5=0.92; μ_6=0.98.

According to the above initial data, using special computer programs, calculations were made, and, based on the calculation results, graphs were drawn up, presented in Figures 3 and 4. values of radial clearances of impellers. The extreme values of the curves $K_{пр} = f_1$ (t) + f_2 (t) will correspond to the effective duration of the operation of the pumps and the maximum allowable values of the radial clearances of the impellers [13-16].

When operating for six months (from 1.05 to 1.11) a year, the optimal overhaul life of a 200D-90 centrifugal pump is t_0=810 h, and the maximum allowable clearance is S=1.9 mm, and for the PG-35MA axial pump is t_0=1725 h and S=2.2 m. This means that for the effective use of pumps with a duration of operation of six months during the year, it is necessary to carry out current repairs of their parts at least 3-4 times. Since it is impractical to carry out repairs during the irrigation season, to increase the overhaul life of pumps, recommendations should be developed on the choice of their operating modes, improving structural elements, the use of wear-resistant materials for the manufacture of parts and modern methods for their restoration [17-22].

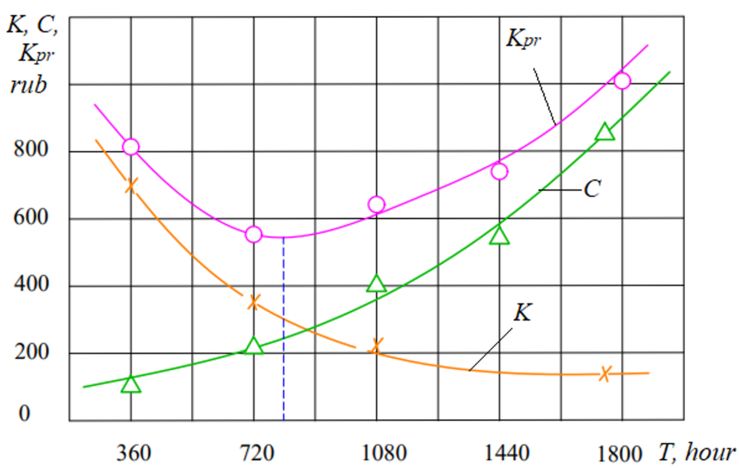

Fig. 3. Schedule for determining the optimal overhaul life of a centrifugal pump

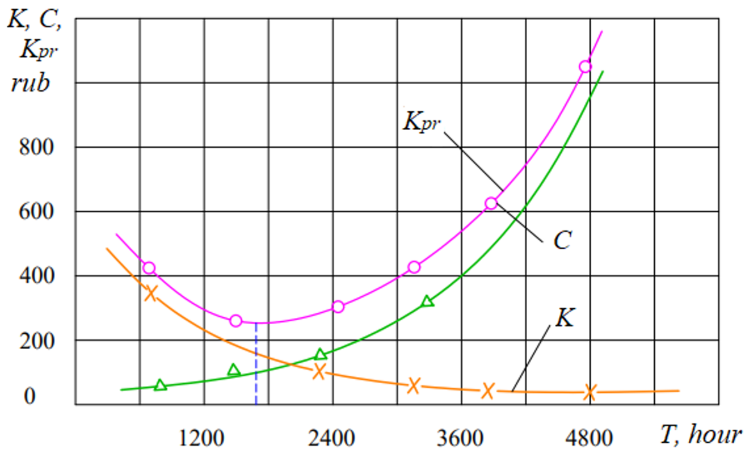

Fig. 4. Schedule for determining the optimal overhaul life of an axial pump

3 Conclusions

1. The proposed methods' calculations are compared with the data obtained due to measurements of pump parts of various standard sizes in operating conditions. The quantitative and qualitative correspondence of the calculation results with field data convinces us of the reliability of the hypothesis about the physical picture of the impact, which is the basis of the analytical wear equations.

2. Based on the methodology for calculating the wear intensity of pump parts, a method is proposed for determining their optimal overhaul life based on a technical and economic comparison of options at reduced costs. Calculations show that when operating for six months during a year, the optimal overhaul life of a 200D-90 centrifugal pump is 810 hours, and for a PG-35MA axial pump - 1725 hours. Therefore, it is required to develop various measures to increase the overhaul life of pumps.

3. The overhaul life of pumps can be increased by applying recommendations for choosing their operating modes, improving structural elements, using wear-resistant materials to manufacture parts, and using modern methods for their restoration.

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