IOP Conference Series: Materials Science and Engineering

PAPER • OPEN ACCESS

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To cite this article: Oleg Glovatsky *et al* 2021 *IOP Conf. Ser.: Mater. Sci. Eng.* **1030** 012115

Estimation of the forecast of pump ready rate for reclamation systems

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Abstract. The aim of the authors' research is to improve the hydraulic conditions for supplying the flow to the impeller and to reduce the cavitation wear of the pump working bodies. This goal is achieved by the fact that the device for supplying liquid at the inlet to the pump contains guide elements in the form of flat plates mounted on the axis of the suction pipe. With further modernization, the pumped liquid was stabilized after the impeller, with the elimination of vortex flows along the entire flow path of the pump due to new elements in the pump chamber. The problem is solved by the design of a straightening blade with a free cross-sectional area of the wall channel less than the inner channel. The research methods include the conduct of field and laboratory studies using modern technical means of observation. Long-term experimental work carried out at large pumping stations investigates interconnected systems of connecting structures and pumps. The stability function is determined as a result of taking into account a number of factors: the external environment, technological properties of systems and operational requirements. The change in the critical, from the point of view of the emergence of cavitation, the value of the pump supply from different densities of the pumped liquids was established as a result of bench tests. In the experiments, the cavitation erosion of the growth was compared with analogs in the average 90-100 times. The ratio of the performance of the surface tension force to the density for mercury and water at a temperature of 15° C turned out to be equal to 91. As a result of the development of a new design together with Joint-Stock Company SUVMASH and the method of calculating the working parts of the pump with a minimum wear rate of the pump with a minimum wear rate of 5%.

1. Introduction

In modern conditions of improving the infrastructure of agriculture and water management, associated with the use of machine water lifting, the issues of construction and operation of pumping stations are of particular importance.

The operating conditions of pumps in the Republic of Uzbekistan, as well as in other southern regions, are very difficult. This is a high content of mechanical impurities - up to 6-15 g/l, a wide range from high ambient temperatures - 35-40° C to low -20 - 25° C. At the stations, the situation is aggravated by insufficient equipment of world-class automation equipment. Therefore, the authors of the article propose new estimates of the forecast of the availability factor of amelioration systems modernized on the basis of the latest inventions.

Within the framework of the general scheme for forecasting operational parameters, it is necessary to apply the simulation model of the pumping unit developed by the authors with the parameters of the water supply devices and the flow path of the pumps, which minimizes the cavitation-abrasive wear. In the changed economic situation, which led to a reduction in financing for repair work, it is necessary to take a new approach to the maintenance of pumping station equipment. The most rational service system is service based on the actual state and readiness for work [1, 2].

Currently, there are three main methods for resistance to cavitation erosion - hydrodynamic (natural) cavitation, hydrojet (shock) impact on the sample and ultrasonic (vibration) cavitation. A significant number of works have been published, in which researchers try to assess the quantitative ratio of losses from corrosion and mechanical factors in the total volume of cavitation wear and the problem of stability of pumping stations [3, 4].

Determination of the intensity of the total cavitation-abrasive wear at various ratios of each of the destructive processes separately is relevant. Both of these problems remain unresolved to date. The main reason for this situation is the lack of experimental data and difficulties in identifying the role of each of these processes in the destruction of parts of hydraulic machines [5, 6].

The aim of the authors' research is to increase the volumetric efficiency, improve the hydraulic conditions for supplying the flow to the pump impeller and reduce cavitation wear.

2. Methods

The methodological foundations of the research being carried out are based on a systematic approach, since the research topic is a complex physical phenomenon arising under a complex of factors during pump operation. Research methods include generalization and scientific analysis of available stock and published materials, laboratory and bench research using modern observation tools.

3. Results and Discussion

The pump is a complex system that operates in real time with the transition from one state to another. In each state, all its characteristics depend on the operating time [7, 8]. The phenomenon of cavitation has a negative effect on the operation of pumps, it manifests itself in a deterioration in performance [9,10]. As a result of this phenomenon, it becomes impossible to use the full potential of the pumping system. The operation of pumps in cavitation mode leads to accelerated wear of parts (Figure 1).

Figure 1. Wear of the impeller of the pumping station Amubukhara 2.

Based on the analysis of numerous theoretical studies, it can be concluded that the intensity of cavitation erosion should increase with an increase in the density and surface tension of the liquid and decrease with an increase in viscosity. The correctness of this conclusion is confirmed by the results of interesting experiments in which mercury was used as a working fluid. As it was found, cavitation erosion in this case increased in comparison with water by an average of 90-100 times. It is extremely tempting that the ratio of the products τp (surface tension multiplied by density) for mercury and water 15° C is 91 [11, 12].However, in a number of other experiments, in which liquids of various origins were used as the working medium, it was not possible to establish any relationship between the physical properties of the liquid and the intensity of cavitation erosion.

The presence of suspended sediment in the flow leads to a change in the physicochemical properties of the liquid. A stream saturated with such particles is a homogeneous liquid with a density p1 and a viscosity μ1 that exceeds the viscosity of pure water [13, 14]. The change in the critical, from the point of view of cavitation, the value of the pump flow on the density of the pumped water was established as a result of bench tests by the authors (Figure 2).

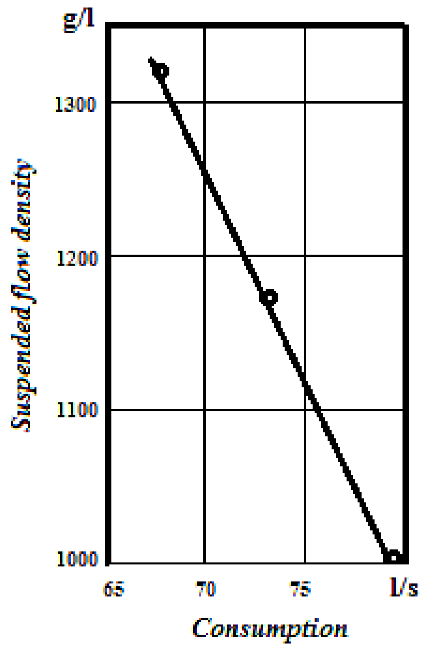

Figure 2. Changing the critical, from the point of view of the occurrence of cavitation, the value of the flow rate of the pump from the density of the pumped water

Long-term scientific and experimental work carried out at large pumping stations confirm that in order to assess the reliability of hydromechanical equipment of an irrigation system, it is necessary to study them as interconnected systems of connecting structures of pumping stations and pumps [15 – 19].

The stability function is determined as a result of taking into account a number of factors: the external environment, technological properties of systems and operational requirements.

When studying systems, the obtained indicators of objects are compared with the stability indicators required by technical conditions.

$$P_{set} \geq P_{req} \tag{1}$$

where P_{set} - the calculated value of the lower bound of the estimation of the probability of no-failure operation;

P_{req} - the required value of the probability of failure-free operation.

When condition (1) is not met, the stability requirement is considered unfulfilled, and it is necessary to carry out revisions to ensure that the relation is satisfied.

When assessing parametric stability, the stability condition is written:

$$U \geq E \tag{2}$$

where U - the potential ability of the structure to withstand external influences throughout the entire period of operation;

E - external influence.

Inequality (2) can express the condition of stability of an object in the limiting state (stability, deformability of pump units).

Function E can express both external influences and deformations arising from them. In the general case, all calculations that ensure reliable operation can be reduced to equality

$$Y_1 - Y_2 \geq 0 \tag{3}$$

where Y_1 - the sum of internal factors characterizing the limit of permissible deformation;

Y_2 - the sum of external factors characterizing the acting loads at their most disadvantageous combination.

Then stability is determined by the probability of values greater than zero

$$P = P(v \geq 0) \tag{4}$$

When the relation Y = f (x_1, x_2, ..., x_n) and the distribution law of random variables xi are known, then the moments of distribution of random variables are set according to the stability indicator P.

One of the most important reliability characteristics is the availability factor [18 – 28]. Therefore, when performing production tasks, a significant place is taken by the issues of a thorough analysis of the transition of the system from one state to another and the dynamics of changes in the pump availability factor for each of its states.

Suppose the pump is in states during the execution of the task and the period of time it has been in each state $t_i = t_{K_i} - t_{H_i}$. Here t_{H_i} and t_{K_i} are the times of the beginning and end of being in the i_m state.

It can be noted that the assessment of the state of the pump depends on the length of time spent in each state and the dynamics of change in the availability factor at each time interval [t_{H_i} , t_{K_i}].

The cumulative time for normal pump operation can be determined as follows:

$$T = \sum_{i=1}^{n} t_{M_1} + \sum_{i=1}^{n} (t_{K_i} - t_{H_i}). \tag{5}$$

The following differential equation can be used to estimate the pump availability at each time interval:

$$\pi_i(t) + (\lambda_i + \mu_i)\pi_i(t) = \mu_i. \tag{6}$$

Here $\pi_i(t)$ is the pump availability factor on the interval [t_{H_i} , t_{K_i}]; λ_i ; and μ_i - the rates of failure and recovery in a given interval.

The general solution of the differential equation (6) has the form

$$\pi_i(t) = \frac{\mu_i}{\lambda_i + \mu_i} + Ce^{-(\lambda_i + \mu_i)t_i}. \tag{7}$$

Here $t_i \in [t_{H_i}, t_{K_i}]$.

The following initial conditions can be used to find the value for each state:

$$t_i = t_{H_i}, \pi_i(t_i) = \pi_i(t_{H_i}), (i = 1,2,..., n). \tag{8}$$

Now, using the initial conditions, from the general solution (6) we obtain

$$\pi_i(t_{H_i}) = \frac{\mu_i}{\lambda_i + \mu_i} + Ce^{-(\lambda_i+\mu_i)t_{H_i}}.$$

From here

$$C = \frac{\pi_i(t_{H_i})(\lambda_i + \mu_i) - \mu_i}{\lambda_i + \mu_i} e^{(\lambda_i+\mu_i)t_{H_i}} \tag{9}$$

Substituting (8) into (6), we obtain particular solutions of differential equations in the following form:

$$\pi_i(t) = \frac{\mu_i}{\lambda_i + \mu_i} + \frac{\pi_i(t_{H_i})(\lambda_i + \mu_i) - \mu_i}{\lambda_i + \mu_i} e^{(\lambda_i+\mu_i)(t_{H_i}-t_i)}. \tag{10}$$

It is clear here that $t_{H_i} - t_i \le 0$, therefore, at $t_i \to t_{K_i}$, the value $\pi_i(t_i)$ decreases.

When examining pump availability, the following two cases occur:

1) the pump availability $\pi_i(t_i)$ is equal to the availability at the end of the previous time interval, i.e. $\pi_i(t_i) = \pi_{i-1}(t_{K_{i-1}})$;

2) the pump availability $\pi_i(t_i)$ is not equal to the availability at the end of the previous time interval, i.e. $\pi_i(t_i) = \pi_{i-1}(t_{K_{i-1}}) + \alpha_i$, where α_i are the jumps in the availability factors during the transition from one state to another. In this case, if, taking into account the proposed methodology, it will be possible to reduce the absolute value α_i to zero, then the research can be continued as in the first case, otherwise additional research is required to study α_i.

Consider the algorithms for the first case. In this case, instead of initial conditions (5), it is sufficient to use only one initial condition set for the first time interval:

$$t_i = t_{H_i}, \pi_i(t_i) = \pi_i(t_{H_i}).$$

For the remaining time intervals $\pi_i(t_{K_i})$, it can be determined from the initial conditions $t_i = t_{H_i}, \pi_i(t_i) = \pi_{i-1}(t_{H_{i-1}}), (i = 2,..., n).$, taking into account that $\pi_{y_{i+1}}(t_{H_{i+1}}) = \pi_i(t_{K_i}).$ Let us take into account that the coefficients of the operational availability of the pump for each time interval $\pi_i(t_{K_i})$ can be obtained by a calculation method sequentially in increasing numbers of time intervals. This algorithm greatly facilitates the process of clarifying the pump availability for the entire period of operation.

Similarly to this technique, it is possible to carry out a multi-stage examination of the condition of the pump according to other characteristics with high requirements for its cavitation qualities and conditions of water supply. It is especially important to increase the efficiency of the pump in control modes. For this, a rigid movable diaphragm is installed in the spiral bend near its lateral surface in a number of structures, repeating the shape of the lateral surface of the spiral bend and connected with a regulating mechanism for its movement along the pump axis by an amount c to change the width of the wheel flow path.

This is unreliable and expensive to operate, since the movement of the disk and the diaphragm must be carried out by synchronously operating hydraulic power cylinders, and the movement is transmitted to the disk by a rod passing inside the hollow shaft of the impeller. If the device additionally contains a profiled regulating needle connected by means of a bypass channel equipped with a hydraulic reducer with a pressure pipe and taking an additional part of the water, this leads to a low volumetric efficiency of the pump.

Poor hydraulic conditions for the flow supply, the exchange of momentum between the layers and zones of the transit flow and eddies causes an increase in energy losses and a redistribution of flow velocities across sections. It is necessary to emphasize the significant difference between the considered problem of creating a laminar parallel jet flow at the pump inlet from the free expansion of a turbulent jet.

In the same directions, one should look for ways to mitigate the negative impact of cavitation and hydroabrasive erosion on the pump resource. The main operational cause of cavitation is the operation of pumps with unfavorable hydraulic conditions for water supply. The presence of non-stationary vortex areas is characteristic. Cavitation in the pump occurs when the pump operating modes differ from the nominal, especially when the influence of vortex formation is enhanced; fluctuations of velocities and pulsations of flow pressure.

The aim of the authors' research is to increase the volumetric efficiency, improve the hydraulic conditions for supplying the flow to the pump impeller and reduce cavitation wear. This goal is achieved by the fact that the device for supplying liquid at the pump inlet additionally contains guide elements in the form of flat plates installed in the area of the throttle washer on the axis of the suction pipe, and the cavity is made closed with an elastic outer surface.

The drawing schematically shows the proposed device (Figure 3).

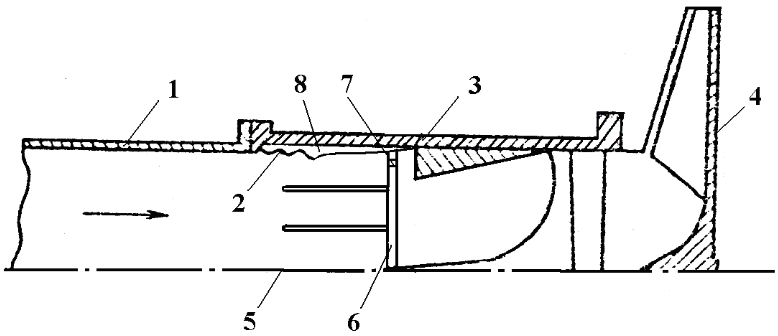

Figure 3. Device for supplying liquid at the pump inlet

The device for supplying liquid at the inlet to the pump contains a suction pipe 1 with an elastic element 2 on the inner surface of the suction nozzle 3 in front of the impeller 4. In the middle part 5 of the suction nozzle 3 there is a throttle washer 6 with discharge holes 7, forming with the inner surface of the nozzle 3 and with an elastic element 2, a cavity 8 and guide elements fixed on it in the form of flat plates 9 parallel to the axis of the suction nozzle 3.

The device for supplying liquid at the pump inlet operates as follows. In cavity 8, the pressure is set corresponding to the nominal flow rate of the liquid through the pump. This pressure is created due to the vertical component of the hydrodynamic external pressure of the fluid on the elastic element 2.

With an increase in the liquid flow rate, the pressure drop across the throttle washer 6 increases and the elastic element 2 is stretched with a decrease in the flow rate and, accordingly, the pressure due to the elastic outer surface, and the guide elements in the form of flat plates 9 contribute to the direction of flow, while the flow area of the throttle washer 6 decreases in this way Thus, leaving a constant value of the liquid flow rate at the inlet in front of the impeller 4.

When the operating mode and flow rate of the pump change in cavity 8, the pressure is set corresponding to the new flow rate, while the volume of cavity 8 and, accordingly, the configuration of the elastic outer surface changes and moves in the suction nozzle 3, taking a position corresponding to the new flow rate. Discharge holes 7, located symmetrically on the orifice plate 6, additionally stabilize the flow and reduce the inlet resistance.

The action of the guiding elements is determined by the high-speed head, calculated by the average speed and small in value due to the discharge holes 7. The use of the utility model makes it possible to increase the volumetric efficiency of the pump by eliminating the vortex zones in the suction nozzle 3, thus reducing the energy consumption for its operation, improving the hydraulic conditions of the flow supply to the pump impeller and to reduce the possibility of cavitation wear due to the deviation of the streamlines from their normal trajectory as a result of flow separation or compression.

The disadvantages of a number of pumps are the need for an autonomous source of liquid under pressure to create an auxiliary flow and the fact that the cavitation center is eliminated only at the inlet to the impeller in the zone of pipes that are installed tangentially to the side surface of the suction pipe, allowing the development of cavitation throughout the flow path of the pump.

The task of further modernization is to stabilize the shockless outlet of the pumped liquid after the impeller, with the elimination of vortex flows along the entire flow path of the pump due to new elements in the pump chamber.

The problem is solved by the fact that the chamber is equipped with a straightening vane forming a channel with a free cross-sectional area of the wall channel less than the internal channel. Figure 4 shows the proposed cross-section of a pump with a modified free area of the wall duct.

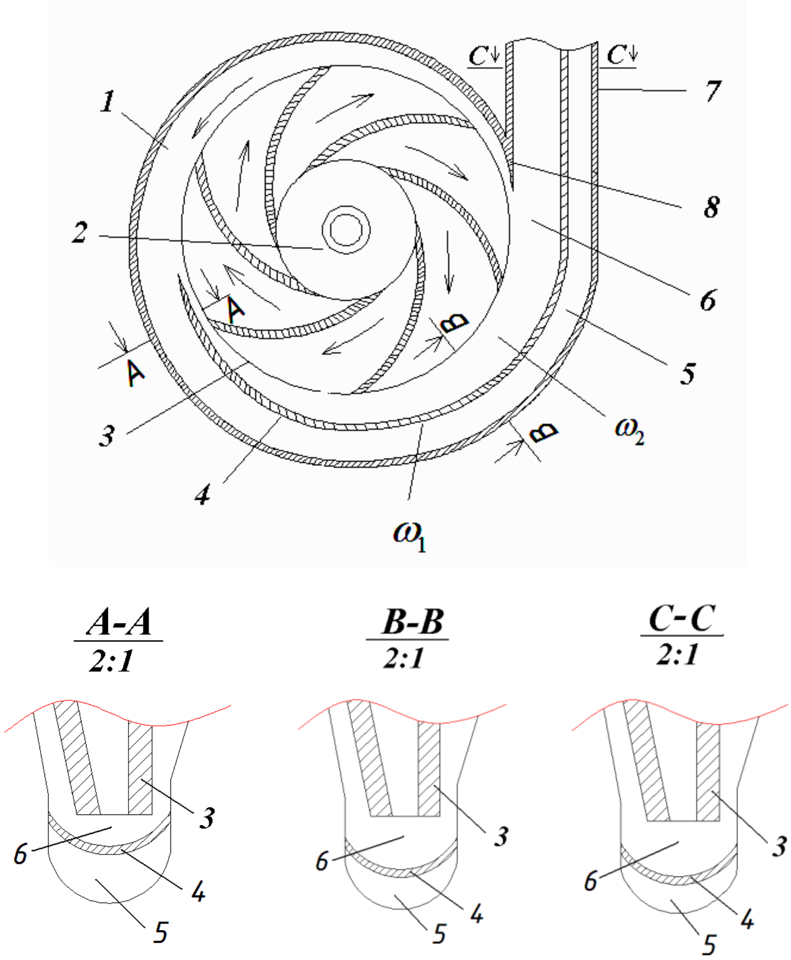

Figure 4. Pump with a modified free area of the wall channel.

The arrows in the drawing show the direction of flow when the pump is running. The change in the chamber cavity (decrease in channel 5 and increase in channel 6) in the direction of flow is shown.

Shaft 2 is installed in the pump chamber 1, on which the impeller 3 is mounted. Chamber 1 is equipped with a straightening vane 4, made in the form of a curved stationary plate, forming channels 5 and 6 with an outlet to the discharge pipe of the pump 7, through which a flow goes from the impeller 3 of the pumped liquid. The free area of the channel 5 ω1 is less than the area of the free area of the channel 6 ω2. By increasing the flow rate at the walls of channel 5, vortex backflows are eliminated along the entire flow path of the pump.

The pressure under which the flow is supplied from the impeller 3 can be kept constant, which ensures the stability of the pumped liquid supply.

The uniformity of distribution and the increase in the value of the velocities in the near-wall part of the chamber 1 has the most favorable effect on the operation of the pump.

The beginning of the blade 4 is located on the opposite side of the chamber 1 at the junction of the chamber 1 with the discharge pipe of the pump 7 at level 8 to maintain the balance of the flow and the working elements of the flow path (balancing conditions).

The pump works as follows. When the impeller 3 rotates, the liquid enters the spiral chamber 1, through the straightening blade 4, eliminating the difference in velocities at the impeller and the walls of the chamber 1 due to the different lengths of the flow streams. At the same time, the flow of the pumped liquid after the impeller is stabilized with the elimination of vortex flows near the walls of the chamber 1. The location of the straightening vane allows converting the vortex velocities into static pressure and directs the flow parallel to the axis of the spiral chamber 1, eliminating the separation of the flow from the guide walls.

The separation of the flow from the guide walls in the pump chamber with a decrease in the value of 15–30% can lead to an increase in head losses and turbulent eddies, which has an adverse effect on other modes.

A decrease in the amount of pumped liquid in the wall channel equalizes the flow rate due to the different length of its passage in chamber 1. Elimination of vortex flows throughout the entire flow path of the pump eliminates the possibility of cavitation phenomena.

Computational and theoretical studies of flow parameters at boundary points were carried out using an improved method for calculating the instantaneous regime of unsteady water movement for a certain selected moment in time. Methods for the development of new technological modes of flow with the variation characteristics of pumping units and pumping station supply channels are generalized [9, 13].

Further recommendations on the use of mathematical models of water movement in the "canal - pumping station" system are used in the main characteristics of movement in the section under consideration, taking into account the hydrometric characteristics. As a result of the development of a new design together with the Joint Stock Company SUVMASH and a method for calculating the minimum wear of working parts of a centrifugal pump, an increase in the efficiency of the pump by 5% was achieved [24, 25].

4. Conclusions

- Long-term scientific and experimental work carried out at large pumping stations confirms that in order to assess the reliability of hydromechanical equipment of an irrigation system, it is necessary to study them as interconnected systems. This direction predetermines the correct assessment of the forecast of the availability factor of the pumps of reclamation systems.
- Taking into account that the system research method is an effective way of assessing and ensuring the reliable operation of the pumps of the irrigation system, based on the purpose of the work, a system has been developed that makes it possible to determine and eliminate the causes leading to pump failure due to cavitation-abrasive wear.
- The results of the analytical survey show that the scientific problem of inquiry and the process of cavitation in the pump has not been studied in full. In this regard, it was necessary to carry out cavitation tests to obtain experienced emergency cavitational characteristics. The results of the tests carried out show that the content of the use in the pumped water has a significant effect on the operating mode of the pump and that it is the most important for the pump.
- The aim of the authors' research is also to increase the volumetric efficiency, improve the hydraulic conditions for supplying the flow to the pump impeller and reduce cavitation wear. As a result of the data obtained, it became obvious that the cavitation characteristics of the

pump began to improve as a result of the development of new pump designs. A number of devices proposed by the authors for supplying liquid at the inlet to the pump additionally contains guide elements in the form of flat plates mounted on the axis of the suction pipe.

- The task of further modernization is to stabilize the shockless outlet of the pumped liquid after the impeller, with the elimination of vortex flows along the entire flow path of the pump due to new elements in the pump chamber. The problem is solved by the fact that the chamber is equipped with a straightening blade forming a channel with a free cross-sectional area of the wall channel less than the internal channel.

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