

Improving impeller and water flow section of vane pumps

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Abstract. As a result of the research, it was found that the blades of the working impellers of the pumps are eroded at the inlet and outlet. Based on software studies, the points of erosion caused by cavitation and sand particles at the entrance of the impeller and the points of operation of the impeller under heavy load have been determined. The operating points under heavy load are compared with working impellers in nature. After comparison with software developments, it is determined that they are compatible with working impellers in natural conditions. The following impeller model is recommended to reduce cavitation and erosion processes in the impeller (Figures. 6, 10). The recommended impeller is shown in the inlet of the impeller to free water entry, prevent water shortage, and reduce the level of cavitation. (Figures 6, 10, 11). The ingress of water into the impeller is freed, the continuous movement of water is restored, and the methods of preventing the processes of decay and holes formed in the impeller are given. Recommended methods of significantly reducing the level of wear in the input and output parts of the impeller are given.

1 Introduction

The Republic of Uzbekistan has 4.3 million irrigated areas; 1,683 pumping stations and devices provide water for 53% of cultivated areas. In addition, more than 8,047 small pumping stations and devices are used to supply water to another 25% of agricultural land where water consumer associations and farms operate. Out of the 11.0 billion kWh of electricity consumed on average per year in agriculture, 8.2 billion kWh is consumed by pumping stations, or 75% of the annual budget for the operation of the water management complex, is spent on the operation of state pumping stations. During the conducted research, it became known that there are different types of impellers, and it was determined that there are open, closed, and semi-open impellers. Also, the blade of the impellers can be made straight, bent back and forth. Little information is given in the literature about three-dimensional centrifugal pump impellers. When viewed from a meridional view of such a wheel, the blades are three-dimensionally deflected from the axial (axial) direction to the

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radial direction. We know only two experimental works reporting experimental work on three-dimensional impellers. Troskolanski and Lennemann made a very clear comparison of the flow behavior in three-dimensional impellers[1,2]. Only the flow close to the impeller outlet was studied, as it was observed that vane deflection in the initial part of the impeller, i.e., the passing probe system, was more ineffective. The scientists of our republic have also studied the working life of pumps, methods of erosion, flow dynamics in the pump, materials from which the pumps are made, the effect of the increase in the flow rate in the pumps on the pressure, and the effect of the particles mixed in the flow on the erosion rate[3]. The fact that the pumps are used in very difficult conditions, the presence of various types of particles in the water hurts the operation mode of the pump and pumping devices has been determined by our scientists as a result of research [5]. The research determined that the increase in the percentage of erosion with the increase in the hours of operation of the pumps is due to the effect of various types of supersolid substances in the water [4]. Sh. Rustamov also researched the flow part of the pump and, proposed anti-cavitation measures, improved the cavitation characteristics due to the elimination of the cavitation center at the pump entrance, which increased the reliability and durability of the pump [6,7,8]. The impellers of large pumps were brought to the repair shops, the flow parts were scientifically studied, and the material properties were improved and repaired [9,23]. Many types of vane pumps are produced by the industry, including general purpose pumps and special pumps. Pumps for general use are designed for pumping clean water (small amounts of impurities are allowed, but not aggressive, the water temperature does not exceed 70-100°C). They are serially produced with the following indicators: supply from 1.5 to 5000 l/s, pressure from 5 to 700 to 800 m, and power from 0.5 to 1500 kW. These pumps include cantilever, two-stage, vertical, diagonal, and multi-stage. The second is pumps used to generate pressure above 100-120m. Special pumps designed for pumping liquids containing a large number of abrasive particles (hydraulic mixtures with solid additives: soil, sand, ash, crushed ore) may differ depending on the type of liquid they carry — soil pumps; for elevating manure and other contaminated liquids – used liquid manure pumps[23]; for elevating chemically active liquids - acid pumps, etc. Special pumps include pumps designed for extracting water from wells or mines — well pumps and submersible electric pumps. Special pumps can also be classified as pumps whose performance goes beyond the limits indicated for general use: pumps of large irrigation facilities, pumped storage power plants, or circulation systems of large thermal power plants. These pumps, designed to supply water to steam boilers, must provide very high pressure - up to 2000 - 3500 m and work in water with a temperature of up to 160°C and higher. Condensate pumps designed to discharge condensate must operate under high vacuum conditions with water temperatures up to 120°C [10, 11].

2 Materials and Methods

To comprehensively assess the effectiveness of irrigation pumps, the cases of pump failure resulting from mechanical impact when changing the hydraulic properties of the water intake facility are analyzed. Based on software drawings, the continuous movement of the flow in the pump was analyzed. Field studies and diagnostic results showed the need for a connection between theoretical and experimental studies [12, 13]. Based on surveys and research conducted in the production company, it was determined that the influence of reading forces on the working parts of the pumps was determined. Experiments were conducted by changing the number and shape of the working vanes of the pump device to study the process of cavitation erosion. Based on statistical processing of the received data, the initial version of the pump was prepared according to the optimal parameters, and the results of the experiments showed that the cavitation reduction could be reduced and the

impellers of the pumps could be used without damage for a long time. [14,15]. Because turbidity destroys all its parts when it passes through the pump together with water, the characteristics of the pumps change, and water consumption and efficiency decrease.

The sediments passing through the "Narpay" pumping station have a very negative effect on the pump's impeller (Fig 5). We can see from the obtained laboratory tests in the pressure pipeline of the disassembled pump unit sediments passing through it is mainly 46.60% and 48.60% of the sediments between 0.5-0.25mm and 0.25-0.05mm were found to cause erosion. These data were obtained based on a laboratory test in May 2022. The second sample was taken from the 4th water intake chamber of "Narpay" PS and underwent laboratory analyzing. According to the results, 31.82% of sediments was 0.1-0.05mm, and 54.53% was 0.05-0.01 mm. According to the operational staff, in June, July, and August of the growing season, the amount of turbidity in the water exceeds the norm, and the process of deterioration in the pumps begins to increase significantly. As a result of the analysis, it became clear that the aggregates of the "Narpay" pumping station are mainly caused by turbidity in size range of 0.5-0.01 mm.

Table 1. The results of laboratory determinations of the physical properties of sediments (Narpay pumping station 22.05.2022)

№	Name and number of developments	Granulometric composition in %						
		1.0 - 0.5 mm	0.5-0.25 mm	0.25-0.10 mm	0.1-0.05 mm	0.05-0.01 mm	0.01-0.005 mm	0.005-0.002 mm
1	Turbidity sediments in the pressure pipeline of the disassembled pump unit	2.40	46.60	48.60	2.40			
2	Sandy water taken from the chamber of "Narpay" PS's pump number of 4	1.60	3.60	3.00	31.82	54.53	5.45	

3 Results and Discussion

The meridional movement of the water in the impeller must be converted to radial movement by ensuring that the flow enters the escape pump device without hydraulic resistance when the water is lifted up. To ensure such complex behavior, the choice of the shape and size of the impeller blades should be taken into account during the design period. To find a solution to the problem, as in the two-dimensional case, the basic concepts of surface continuity, curvature, and change of curvature were taken into account. One-dimensional and three-dimensional software calculation methods were used to construct these blade forms (Fig. 6,7-10). As a result of the studies, it is clear that the main approach is to control the vane angle β of the impeller, and the analysis of the characteristics of the impeller by changing β is presented.

In the course of the studies, the article introduces a simple one-dimensional technique for estimating the pressure generated in the pump. Blade entry and exit angles, radii, and traverse widths are easily determined using a one-dimensional design. This is based on Euler's work equation (1) and one of the various displacement corrections shown below:

$$W_x = \Delta UV_\theta \quad (1)$$

The analysis uses the output velocity triangle, as shown in (Figure 1). The speed in the triangle was shown as follows:

$$V_{\theta} = U - \frac{V_m}{\tan\beta} - V_s \quad (2)$$

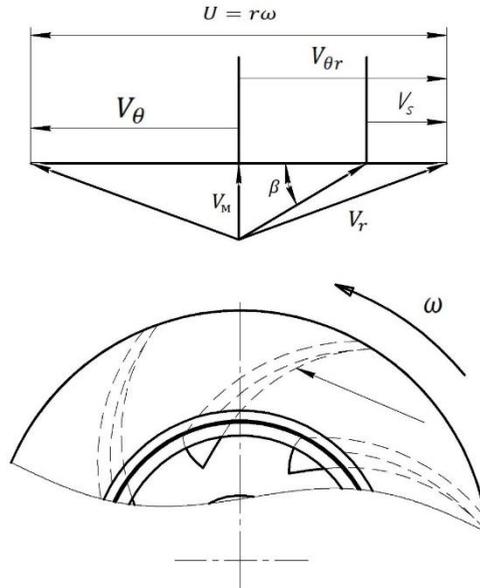


Fig. 1. One-dimensional theory of inlet and outlet velocity triangles in a backforward curved impeller

In the above expression, the absolute rotational speed of the liquid at the exit from the impeller is given by the meridional speed V_m , the angle of the outlet vane β (the outlet vane speed U and the sliding speed V_s).

The meridional velocity can be estimated using the flow continuity principle using the value of V_m :

$$V_m = \frac{Q}{A} \text{ and } A = 2\pi Rq - zqb \quad (3)$$

The meridional velocity can be estimated using the flow continuity principle using the value of V_m ; Research has shown that one of the biggest challenges in designing centrifugal pump impellers is determining the impeller shape. Concepts of hair shape can be approached in different ways. Simple concepts of smoothness, curvature, change in curvature, film thickness, and entry and exit angles dominated these studies. Some very simple pumps have been observed to use circular arc vanes that satisfy the smoothness and curvature requirements. But they are known to be used only for cheap, low efficiency coefficient, and low power pumps [16,17]. The advantages of the turning angles of the impellers have been found in research, mainly because of the use of three types of impeller blades:

- backforward curved, i.e., turned opposite the flow direction (Figs. 2b and 4b.)
- straight, i.e., radial vane (Fig. 4a)
- forward curved, that is, turned in the direction of the flow (Fig. 2a.)

We know that maximum pressure is developed in centrifugal pumps

$$H = \frac{V_{w2} \cdot U_2}{g}$$

Generated from the output angular velocity,

$$\tan\beta_2 = \frac{V_{f2}}{u_2 - V_{w2}} \qquad V_{w2} = u_2 - V_{f2} \operatorname{ctg}\beta_2$$

But consumption is generated from speed as follows

$$V_{f2} = \frac{Q}{\pi D_2 B_2}; \qquad (Q = \pi D_2 B_2 V_{f2})$$

Here: D_2 and B_2 are the diameters of the impeller and the width of the outlet

$$V_{w2} = u_2 - \left(\frac{Q}{\pi D_2 B_2}\right) \operatorname{ctg}\beta_2$$

If u_2, D_2, B_2 are constant, the pressure H depends on the angle of the exit vane and the output flow Q .

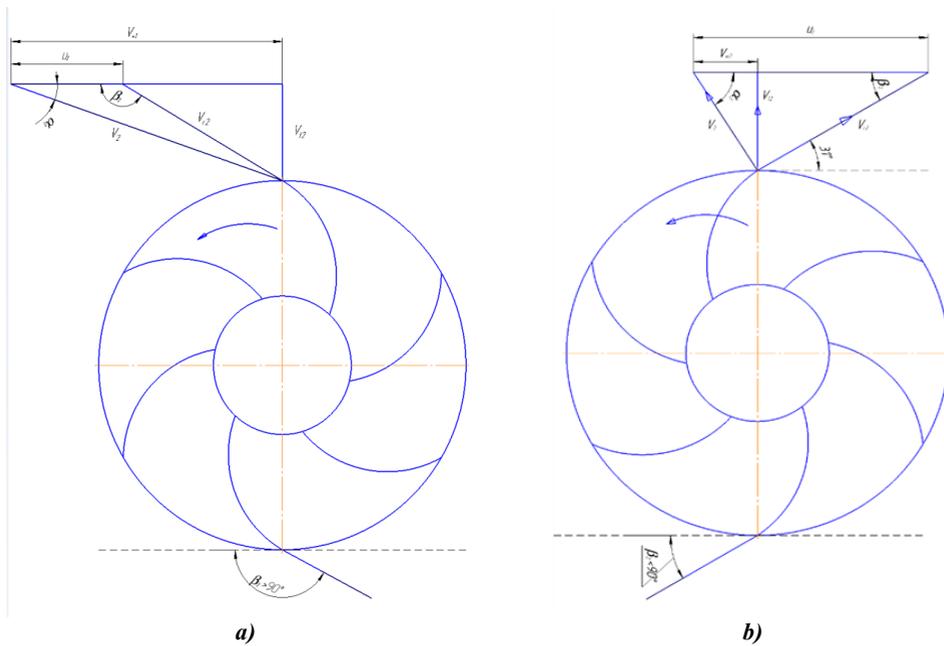


Fig. 2. Impeller speed triangles: *a* is bent forward, i.e., turned in the direction of flow; *b* is a back-bent, i.e., an impeller blade turned against the flow direction

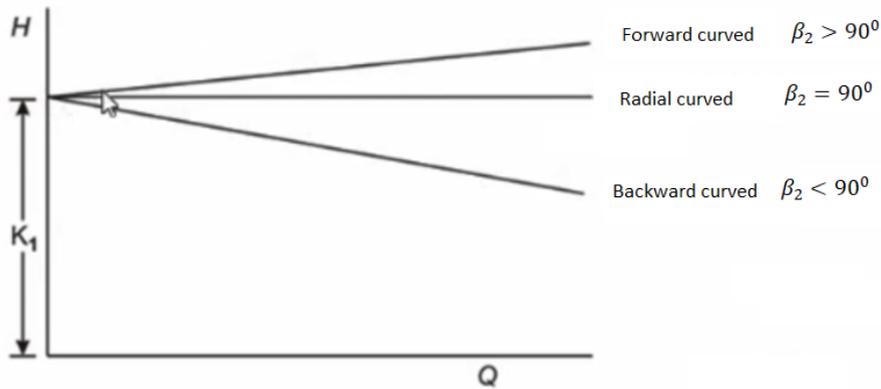


Fig. 3. From the graph, we can see that there are lines with different bending angles

If C_{tg} is negative, the pressure rises at the outlet if it is bent forward, i.e., turned in the direction of rotation of the vane (Fig. 2a). It creates the high pressure (V_{w2} maximum) that is, the absolute speed at the exit (V_2).

This is not the method we want, where the pressure is high and can cause large losses due to the formation of air bubbles and flow eddies inside the pump. In converting kinetic energy into pressure energy, cavitation phenomenon and vibration processes occur inside the pump, causing large losses. Due to the low coefficient of useful work, at present, blades of impellers bent in the direction of rotation are not used. Blades facing forward, that is, in the direction of flow, are not used [18,19].

$$H = \frac{u_2}{g} \left[u_2 - \left(\frac{Q}{\pi D_2 B_2} \right) ctg \beta_2 \right]$$

Radial impeller vanes are straight, that is, vanes with $ctg \beta_2 = 0$ equal to $\beta_2 = 90^\circ$, so the outlet pressure remains constant. This type of blade is easy to manufacture and relatively light in weight. The impeller and casing have equal energy generation and operate at high pressure levels and efficiently (Fig. 4a).

These data were obtained based on a laboratory test in May 2022. The second sample was taken from the 4th water intake chamber of "Narpay" PS and underwent laboratory analyzing. According to the results, 31.82% of sediments was 0.1-0.05mm, and 54.53% was 0.05-0.01mm. According to the operational staff, in June, July, and August of the growing season, the amount of turbidity in the water exceeds the norm, and the process of deterioration in the pumps begins to increase significantly. As a result of the analysis, it became clear that the aggregates of the "Narpay" pumping station are mainly caused by turbidity in size range of 0.5-0.01 mm (Table 1).

To overcome the distortions in Figure 6, the imperfections in the impeller were studied. As a result of studies, it was found that there is an obstacle to the required water at the inlet of the impeller; that is, the required water does not reach the flow part. After that, a new view of the impeller was prepared based on software calculations. In this case, the entrance parts of the impeller blades located in odd places were cut by 12%, and the water dynamics were restored (Figures 6, 10).

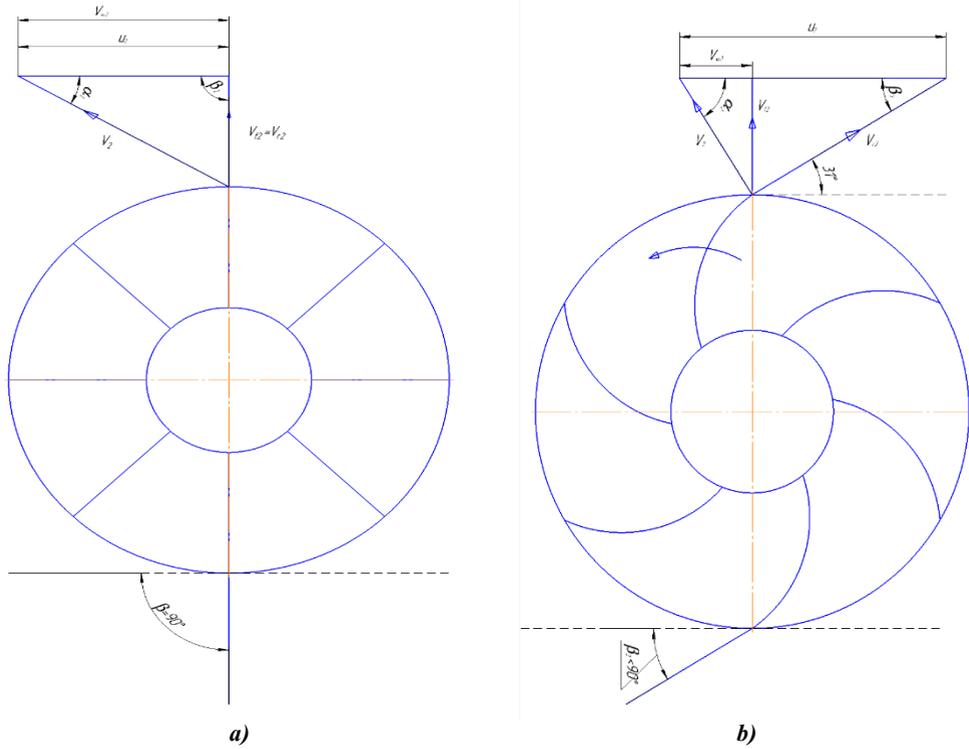


Fig. 4. Diagram of the speed at the exit of the blades of the impeller: *a* is radial blades, i.e., impeller blades are straight; *b* is back-bent, i.e., blades bent against the flow direction



Fig. 5. Cavitation perforation of *D*-type pump impellers at the pump station

As a result, the pump's cavitation phenomenon, vibration, and noisy operation have been significantly reduced. Water consumption increased, and pump capacity decreased by 4%. In the back-bent blades, i.e., the blades are bent against the direction of flow, the angle

is $\beta_2 < 90^\circ$ small, $\text{ctg}\beta_2$ positive, and therefore the pressure decreases at the outlet, V_{w2} is minimized

$$H = \frac{u_2}{g} \left[u_2 - \left(\frac{Q}{\pi D_2 B_2} \right) \text{ctg}\beta_2 \right]$$

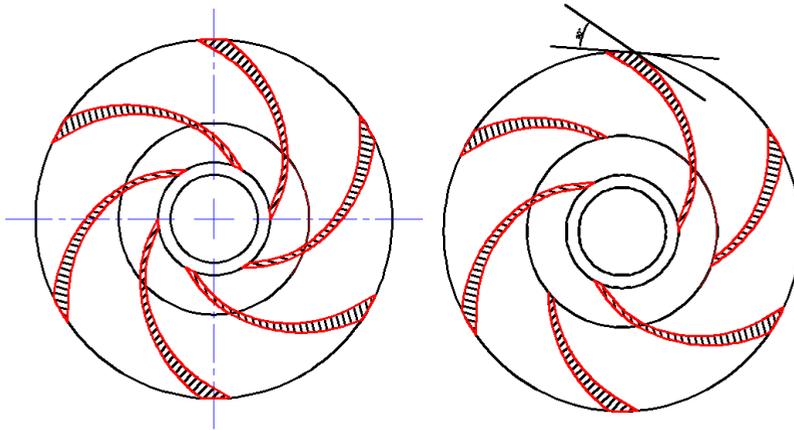


Fig. 6. Uncut and cut views of the impeller

It was found that if U_2 is reduced, then the pump starts to give low pressure, and the speed increases. That is, as U_2 decreases, angle β_2 begins to increase. In this process, the transformation of liquid from potential energy to kinetic energy is observed. As we decrease the angle β_2 , it was observed that the pressure on the impeller, that is, the potential energy, increases. When we increase the angle β_2 , it was found that the energy of speed, i.e., effort, increases. When looking at the best efficiency point of the useful work coefficient, it was found that the reciprocating blades are the best and operate for a long time without breakdowns. Because the potential energy is high in the back-bent vanes, the cavitation phenomenon does not occur during pump operation, and the possibility of long-term pump operation without breakdowns increases. Also, the corner on the back vanes β_2 approximate efficiency coefficient was found to be superior in performance intervals up about 20° to 30° . To conclude this discussion of two-dimensional centrifugal impellers, the conclusions are repeated. These conclusions apply to two-dimensional constant-width engines with log spiral or radial blades. The fluid is assumed to be incompressible, lossless, and follows the fins. A backward-bent vane has a large radial vane force, which radial vane impellers do not have. Eckardt [20], Young [21], and Fischer and Thoma [22] reported water separations in backward inclined impellers. In Eckardt's work, at the outlet of the impeller $\beta = 60^\circ$. He found good evidence of arousal. However, he says that he used the reverse shift on the impeller, which started much further from the entrance. By the time the liquid reached the reverse part of the impeller, the real drive had already formed. Nevertheless, the excitation is smaller, and the edges are less pronounced than those shown in his previous work for an impeller of a similar radius. In contrast, Adler and Levy showed $\beta = 61^\circ$ at the outlet of the attached flow in the impeller.

Two other authors who reported splits on backward-inclined impellers both used two-dimensional designs with high pitch vanes [19] at $\beta = 22^\circ$ and [21] at $\beta = 28^\circ$. These angles keep the pump impellers in the appropriate range (about 15° to 30° . Young's work [20] describes a technique involving photography of particles introduced into the flow. These particles are neutrally dense; that is, they have a density similar to the liquid in which they are immersed. During the design process, the results showed a boundary layer at the outlet

of the impeller and a thick suction part surface. This boundary layer had a thickness of approximately 15% of the outlet distance between the fins or 10% of the fin edge. It was not buoyant because it did not have an extended region of reduced relative velocity. In addition, the Reynolds number of Young's impeller was relatively low (1×10^5), which was expected to be favorable for thicker boundary layers.

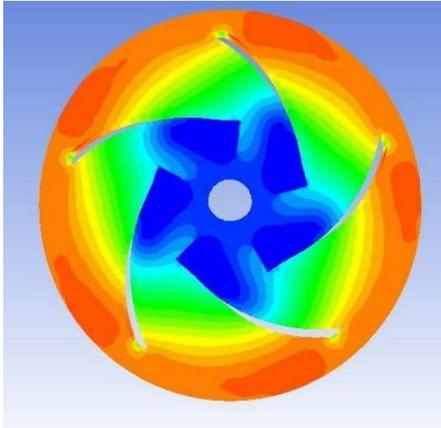


Fig. 7. High pressure points in the exit zone of the impeller

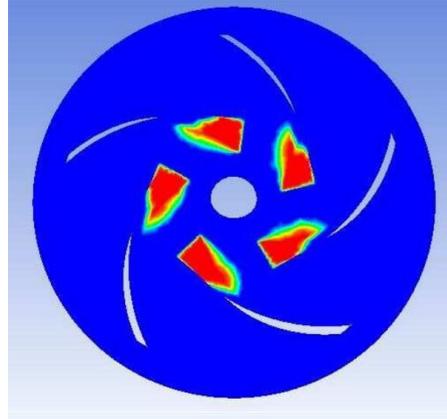


Fig. 8. High pressure points at the inlet to the impeller

When impellers were analyzed based on field observations and software calculations, it was found that under the main load, erosion occurs in the inlet and outlet parts of the working parts. Based on software calculations, the parts working under heavy load were determined, and it was determined that the load depends on the input and output angular velocities (Figures 7,8). To reduce these loads, the option of cutting the impeller and designing the inlet and outlet angles to match the pump flow part was recommended (Figures 9, 10, 11).

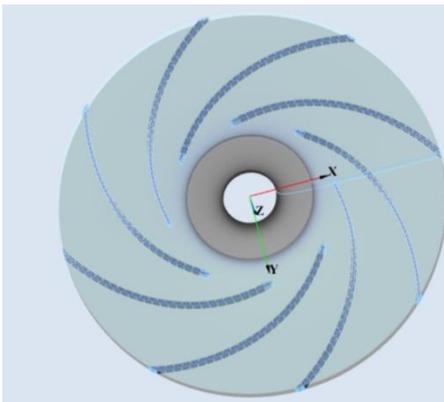


Fig. 9. 8-blade impeller drawn by software

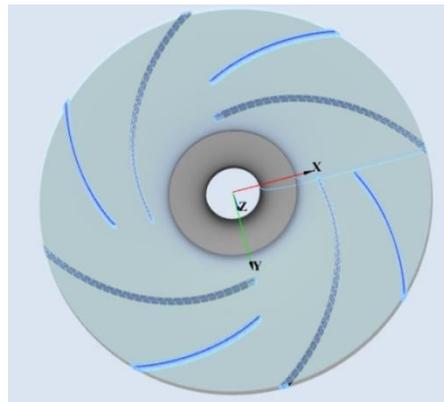


Fig. 10. As a result of my software research, the version of the 8-bladed impeller blades with the water inlet cut in the odd places

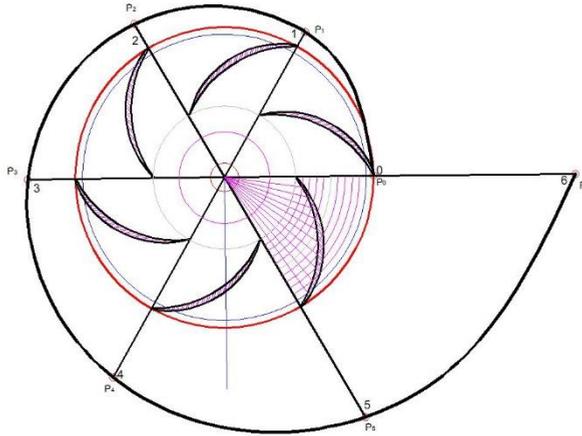


Fig. 11. Redesign of the pump flow part in proportion to the impeller

Based on direct field research and questionnaires, analytical studies, systematic analysis, and measurement work carried out in repair shops of impellers of pumps, it became clear that the causes of high pressure in the inlet part of the impeller are the non-dynamic centrifugal force in the impeller, i.e., the violation of water continuity in the flow part, which causes these problems. It was found that the reasons for the exit were not considered in the design of the impeller and shell. To eliminate this disproportion, the pump impeller was redrawn to match the flow part (Fig. 11). In this case, the main focus was on adjusting the pump vanes to the diameter of the impeller, and the number of vanes was selected based on the diameter of the vane, a cylindrical vane was created, and the pump was designed by dividing each vane into a separate section in the flow part. As a result, flow continuity in the pump was ensured, and efficiency coefficient was increased by 7% (Fig. 11). based on my analysis, it was clear that back-bent blades, i.e., blades turned against the direction of flow, are preferred because of the highest efficiency coefficient potential energy and the formation of cavitation is much lower. In earlier designed pumps, it was found that the flow section did not match the number of blades when divided into sections. As a result, a water shortage occurred, a cavitation phenomenon was observed, and the pumps worked with malfunctions (Fig. 5).

4 Conclusions

1. As a result of the research, it was found that the impellers of the pumps are eroded at the entrance and exit of the blades.
2. As a result of the analysis, it became clear that the aggregates of the "Narpay" pumping station are mainly caused by turbidity in size range of 0.5-0.01 mm.
3. Based on software studies, the wear of the impeller due to cavitation and sand particles at the entrance and the operating points of the impeller under heavy load were determined.
4. The determined heavy-duty operating points were compared with the operating impellers in nature.
5. After comparing the results with the software developments, it was determined that they correspond to impellers in natural conditions.
6. To reduce cavitation and erosion processes in the impeller, the following models of the impeller and pump flow part were recommended (Figs. 6, 10, 11).

7. Through the recommended impeller, water ingress at the inlet of the impeller is freed, and water shortage is prevented; the cavitation level is reduced by 7% (Fig. 6).
8. Water access to the impeller is freed, and continuous water movement occurs.
9. The wear at the inlet and outlet of the recommended impeller is significantly reduced.

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