

Study of the influence of the design of a centrifugal wheel on the pressure characteristics of a multistage pump

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Abstract. The article presents the results of an experimental study of the influence of the number of blades on the pressure-energy characteristics of a multistage centrifugal pump. A vertical submersible multistage centrifugal pump was tested, in which impellers with a different number of blades (6, 7 and 8 blades) were varied. The wheels were manufactured using the latest rapid prototyping technology through SLA printing on high strength polymer resin. The operating speed of the pump was varied at 1450, 2050 and 2850 revolutions per minute (rpm). The effect of different numbers of impeller blades on the performance of a centrifugal pump was investigated on three parameters: pump head (H), hydraulic power and efficiency (η). As a result of the experiments, the dominant influence of the speed on the performance of the centrifugal pump was revealed. It was also found that all pump performance characteristics are generally sensitive to changes in rotational speed, and not to changes in the number of blades. As a result of the research, it was revealed that the flow rate during pump operation plays a key role in head, power and efficiency indicators. The conducted research allowed to conclude that the number of blades does not have a significant impact on the performance of a centrifugal pump.

Key words: centrifugal pump, experiment, stereolithography (SLA), power, pressure, efficiency.

1 Introduction

The development of mineral deposits in the mining industry is often accompanied by pumping out large volumes of liquid media. It is a known fact that when pumping large volumes of liquid from wells, submersible centrifugal pumps are the most economical and less laborious in their maintenance compared to other types of pumps. Innovation is needed to improve the performance of a centrifugal pump in order to save energy. Several literature sources note that the performance of a centrifugal pump depends on some design parameters, i.e. impeller, guide vane, which affect the characteristics of the fluid flow inside the machine.

Various researchers have made significant contributions to the study of flow mechanisms within centrifugal impellers. In [1], the results of studies on determining the effect of the number of blades on the kinematics of the flow in the centrifugal impeller of a single-stage pump are presented. It is shown that wheels with the number of blades 5 and 9 have a higher flow friction inside the channels, and the most optimal is a wheel with 7 blades. In [2], the mutual influence of the number of wheel blades 5, 6, 7 and the number of diffuser blades 8, 9, 10 was considered. As a result of studies based on numerical modeling, it was found that the housing 7 + 8 has a minimum wheel oscillation,

which in turn will affect the efficiency and strength of the shaft as a whole.

The approach of choosing a wheel by strength parameters was used in [3], but it was based only on changes in the speed of rotation of the rotor shaft, but not on the effect of flow pulsation and the strength of the centrifugal wheel, which depends on the choice of the number of blades. The authors of [4] presented the results of studying the effect of natural vibration frequencies of a centrifugal wheel on the shaft strength caused by the difference in the number of wheel blades and diffuser. The work [5] was devoted to calculating the strength of disks and blades based on the use of a modified method of successive approximations in shifted Chebyshev polynomials.

In all these works, insufficient attention was paid to studying the influence of the number of blades on the pressure-energy characteristics of the pump. All this suggests that it is advisable to conduct experimental studies to determine the optimal number of blades that satisfy the maximum energy efficiency of the pump.

2 Research methods

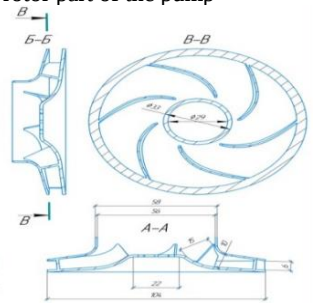
The investigated physical design is a multistage centrifugal pump, which includes 4 impellers and 4 guide vanes. Based on automated calculations in the PUMP module, refined models of impellers were built

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with parameters $\beta_1 = 28^\circ$, $\beta_2 = 30^\circ$, blade sweep angle $\theta = 70^\circ$, number of blades 6,7,8. The number of blades was varied to determine the effect of their number on the pressure and energy characteristics of the pump stages. To study the effect of the number of vanes on the performance of a centrifugal pump, Rapid prototyping technology was used. Rapid prototyping is the latest technology, using its designer can quickly physically reproduce a computer model of any complexity [6,7]. When creating a prototype centrifugal wheel close to the real model, the main factor was the choice of 3D printing technology in terms of roughness. When choosing the SLA technology that works with a liquid photopolymer (stereolithography), the data of the author [8] were taken into account. In accordance with the manufacturing technology and the requirements for parts of the centrifugal submersible pump stage, an absolute roughness of up to 0.3 mm is permissible for the internal surfaces of structural elements. Figure 2 shows samples of tested wheels printed with SLA technology. Figure 1 shows the design of a multistage pump.



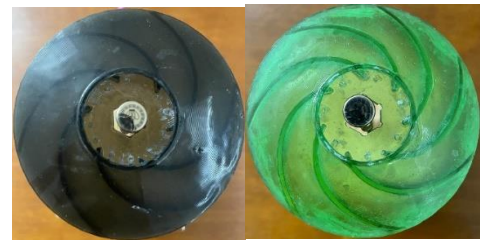
a) rotor part of the pump



b) drawing of the impeller

Fig. 1. Pump design (Photographer: G. Abilezova).

The study of three wheels was carried out at three different rotational speeds in the range from 1450 to 2850 rpm. One impeller model after another was tested to study its performance. The flow of the centrifugal pump was measured by a flow meter, the error of which is $\pm 0.3\%$ of the measured value. The model pump head was obtained using a manometer with an accuracy of $\pm 0.1\%$ of the measured value. An experimental test setup as shown in Figure 3 allows accurate measurement of mass flow.



wheels with a) 6 blades b) 7 blades

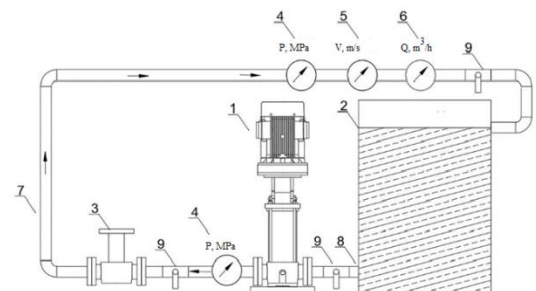


c) wheel with 8 blades

Fig. 2. Models of pump wheels printed with SLA technology (Photographer: G. Abilezova).

3 Measurement technology and data processing

In the laboratory of Kazakh National Research University named after K.I. Satbayev, the installation of the stand was assembled, which is shown in Figure 3 and Figure 4.



- Legend:
1. vertical multistage centrifugal pump STR 15-4
 2. cylindrical tank with a volume of 2 m³
 3. supply device (stop valves-ball valve)
 4. water pressure sensor
 5. flow rate sensor
 6. water flow sensor - water meter
 7. water injection pipeline
 8. water suction pipe
 9. valve

Fig. 3. Test stand for pumping equipment.



Fig. 4. Test stand photo (Photographer: G. Abilezova).

The measurement data is transferred to a computer via built-in adapters in the measuring instruments and

processed in the EXCEL application. The experiments were focused on the study of three operating parameters of the pump: pump head (H), hydraulic power (hydraulic) and efficiency (η), with different numbers of vanes and pump operation. In centrifugal pumps, all these parameters are usually defined by equations 1) to 3).

$$H = \frac{P}{\gamma} = \frac{P_d - P_s}{\rho \cdot g} \quad (1)$$

where

P_d - discharge pressure at the pump outlet (N/m^2)

P_s - suction pressure at the pump intel (N/m^2)

ρ - liquid density (kg/m^3)

g - gravity and $\gamma = pg$

The hydraulic power of the pump is determined by the formula:

$$P_{гид} = \rho \cdot g \cdot H \cdot Q \quad (2)$$

where Q is the pump flow (m^3/s)

Accordingly, the pump efficiency is defined as:

$$\eta = \frac{P_{hid}}{P_{sh}} \quad (3)$$

where

P_{sh} - is the power transmitted to the pump shaft (W).

4 Results

Figure 5 shows the relationship between the head and the performance of a centrifugal pump with a different number of blades and at three different rotation speeds, i.e. 1450, 2050 and 2850 rpm.

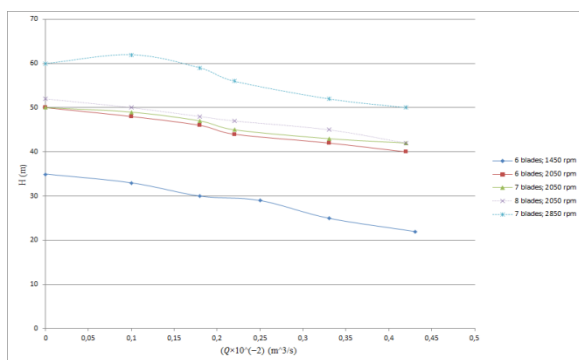


Fig. 5. Experimental graph of the dependence of pressure and pump flow.

Figure 6 shows the power versus performance of a centrifugal pump at various flow rates at three different rotational speeds as explained earlier.

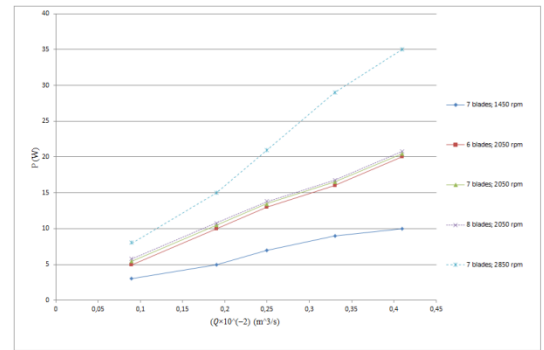


Fig. 6. Pump power.

On the experimental graph, a linear dependence of the pump power on the flow is obvious, which is consistent with the theoretical description of this dependence.

Figure 7 shows the efficiency of a centrifugal pump at various flow rates at three different rotation speeds.

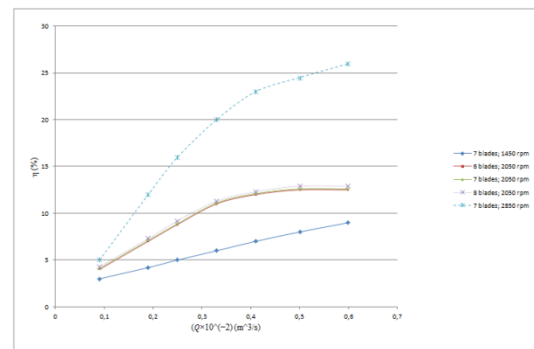


Fig. 7. Pump efficiency diagram.

In the diagram in Figure 6, there is an obvious gap in efficiency values at different levels of shaft speeds, which cannot be said about the influence of the number of blades.

5 The discussion of the results

The use of a seven-vane impeller increases the small clearance of the pressure pump compared to a six or eight vane impeller. From the point of view of the trend, this conclusion is confirmed by the experimental and numerical study carried out in [9]. RPM has been found to have a significant effect on increasing pump power. Pump power is rapidly increased by switching the speed from low (1450 rpm) to high (2850 rpm). The power of the seven-vane centrifugal pump can be increased up to 35 W at 2850 rpm. From the point of view, when using the number of vanes, the pump power increases slightly with a larger number of vanes.

In the present study, the efficiency of a seven-vane centrifugal pump can be increased to 24.99% for a speed of 2850 rpm. On the contrary, the efficiency decreases significantly when moving to a speed of 1450 rpm. This is in good agreement with studies [10,11]. As for the change in the number of blades, there is no significant difference when working with a lower flow rate. This

means that the efficiency of a centrifugal pump is not sensitive to changes in the number of blades.

6 Conclusion

In the present study, the influence of the rotation speed and the number of blades on the internal flow and performance of a centrifugal pump was experimentally investigated. It can be concluded that the performance of a centrifugal pump is generally more sensitive to changes in rotational speed than to changes in the number of vanes. The flow rate during pump operation plays an important role in the performance of a centrifugal pump. The use of an impeller with a different number of blades does not significantly affect its performance.

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