The influence of the vane geometry on the hydraulic losses at the inlet of the impeller of a centrifugal pump has been investigated in this work. The edge of each vane has been projected into the eye, at different lengths, and the pump characteristics (flow rate, total head, speed of rotation, and energy input) were measured in each case. Then the overall efficiency of the pump was calculated using the collected data. The tests were carried out in a closed cycle test rig. A significant increase of the efficiency of the pump can be obtained by projecting the vanes into the impeller eye. Also, the total head of the pump increases depending on the length of the projection and the speed of rotation.

**Key words**: centrifugal pump, vane, pump efficiency.

**NOTATION**

\[ A, B, C \] Constants  
\[ \hat{c} \] Velocity vector, m/s  
\[ c_{u1} \] Tangential component of the velocity at the inlet of the impeller, m/s  
\[ c_{u2} \] Tangential component of the velocity at the outlet of the impeller, m/s  
\[ H \] Total head, m  
\[ m \] Mass flow rate, kg/s  
\[ Q \] Flow rate, m³/s  
\[ n \] Speed of rotation, rpm  
\[ r \] Radius, m  
\[ r_1 \] Radius of impeller eye, m  
\[ r_2 \] Radius of impeller, m  
\[ M \] Moment of torque, Nm²  
\[ t \] Time, s  
\[ \hat{T} \] Momentum at the axis of revolution, Nm²  
\[ W \] Work, J  
\[ Y \] Specific work of fluid, J/kg  
\[ \theta \] Angle, deg  
\[ \rho \] Density, kg/m³

**INTRODUCTION**

The basic equation describing the fluid flow through the impeller of a centrifugal pump, based on the principle of angular momentum, is:

\[
\frac{dM}{dt} = \frac{d}{dt} \int \rho (r \hat{c}) dr = \Sigma M
\]  

(1)
Applying the Equation (1) to the ideal fluid flow into the impeller, the Euler’s equation can be derived:

\[ \Delta W = m \left( r_2 c_{a2} - r_1 c_{a1} \right) \]  

(2)

An increase of the work \( \Delta W \) can be achieved by decreasing the factor \( r_2 c_{a2} \). For a certain impeller, the decrease of this factor depends on the magnitude the velocity \( c_{a1} \), which can be decreased by altering the flow patterns in the vicinity of the vane edge at the inlet (fig. 1).

Equation (2) expresses the work produced by an ideal impeller, which depends on the flow rate \( Q \) and on the total head \( H \):

\[ \Delta W = f(Q, H) \]  

(3)

The total head is a function of the design parameters of the impeller, as well as of the fluid flow rate and the speed of rotation [Bohl, 1980]:

\[ H = An^2 + BnQ + CQ^2 \]  

(4)

The Maximum head for certain values of the flow rate and speed of rotation can be achieved by the appropriate combination of the design parameters, which are related to the constants \( A, B, \) and \( C \). The values of the constants \( A, B, \) and \( C \), for a real impeller depend on the number of the vanes, the flow patterns in the eye around the edges of the vanes, the shape of the edges of the vanes at the entrance to the impeller, the pressure difference in the front and back walls of the vane, and the total hydraulic losses due to the friction, turbulence, and whirls of the fluid [Lazarkiewicz, 1956; Kavassik, 1967].

Fig. 1. Fluid flow entering at an angle \( \theta \) in the inlet of the impeller: \( r_1 \) is the radius of the impeller; \( c \) is the absolute velocity of the fluid; \( c_{a1} \) is the tangential velocity component.

The angle \( \theta \), at which the fluid flow enters the passages between the vanes, is essential to obtain the maximum efficiency of the impeller (fig. 1). For a non-tangential entrance, a high value of \( c_{a1} \) is obtained, resulting to lower efficiency. Furthermore, if the entrance angle \( \theta \) increases to more than a certain value, a deflection of the fluid flow pattern occurs, having as a result a turbulent flow due to the deformation of the boundary layer at the area of the stagnation point. The result of this kind of deflection of the flow pattern is the increase of the hydraulic losses and thus the decrease of the efficiency of the impeller. Also, the stability of the pump characteristics is influenced. For maximum efficiency, the stagnation point must lie on the middle line of the vane edge. There are indications that the overall fluid rotation, which appears in the impeller at under-flow conditions, is a result of the fluid flow deformation in the area around the vane edge at the inlet. These undesirable conditions might be avoided by projecting the vanes into the eye (fig. 2).

The pressure difference on both sides of the vane diversifies the velocities at the convex and concave sides of the vane. The area of maximum velocity minimizes the static pressure and thus causes a danger of creating cavitation conditions. The characteristics of the fluid flow depend on the shape of these passages. For vanes of short length, a danger of separation and discontinuity of the fluid flow occurs. For vanes of long length the hydraulic losses should increase. The appropriate design of the vane length contributes to maximize the efficiency of the impeller [Akritidis, 1988; Stepanoff, 1959].

Fig. 2. Improved fluid flow patterns at the inlet of the impeller: \( r_1 \) is the radius of the impeller; \( c \) is the absolute velocity of the fluid; \( c_{a1} \) is the tangential velocity component.

**MATERIALS AND METHODS**

The effect of the projection of the vane edges into the eye of an impeller on the pump characteristics, as well as on the overall efficiency of the pump, was measured in an experimental test rig. The measurements comply with the British Standards [BSI, 1966a].

A radial flow impeller of semi-closed type, settled in a volute casing, was used to carry out the experiments. The pump characteristics are shown in Fig. 3.

Fig. 3. Characteristic curves of the pump at various speeds of rotation: \( \times \) 300/min; \( * \) 500/min; \( \Delta \) 700/min; \( O \) 900/min; \( \square \) 1100/min; \( O \), 1200/min; ---, pump efficiency.

Sl. 3. Karakteristične krive pumpe pri različitim brzinama obrtanja: \( \times \) - 300 o/min; \( * \) - 500 o/min; \( \Delta \) - 700 o/min; \( O \) - 900 o/min; \( -1100 \) o/min; \( O \) - 1200 o/min; --- efikasnost pumpe
Projection of the vanes

According to the Equation (4) the total head, and consequently the efficiency of a pump, depends on parameters related to the geometry of the impeller and the construction of the case. These parameters are: the angle of the vanes at the inlet of the fluid flow, the number of the vanes, the size of the vanes, as well as the volute casing design. In order to study the possibility of increasing the efficiency of a pump, with certain designed impeller, a semi-closed impeller has been used. The specifications of the impeller were: eye diameter 100 mm, outside diameter 200 mm, vane height 15 mm, thickness of the vane 0.3 mm, number of vanes 8, angle curvature at the inlet 70° and at the outlet 65°, and radius of curvature of the central line 82.5 mm.

The vanes of the impeller were projected into the eye by 5, 10, 15 and 20 mm. The elongation of the vanes was made by re-casting the impeller, adding to each vane a length of 20 mm of the same thickness. A set of measurements was run using this impeller. Then, a portion of 5 mm was removed from each vane and a new set of the measurements was made. This procedure was repeated by removing a further portion of 5 mm in each case. In this way, five impellers with eye diameters 80, 85, 90, 95 and 100 mm were tested.

Test rig

The test rig is of closed cycle type, including a fluid flow circuit of Polyvinyl Chloride (PVC) pipes. The axis of the impeller is positioned vertically and it is coupled to an electromagnetic dynamometer. The speed of rotation ranges from 300 rpm to 1200 rpm. The pump of the test rig was designed for a maximum efficiency of 0.73 at a speed of rotation 1000 rpm. The discharge rate was regulated by a throttle-valve and it was measured by a fluid flow meter of venturi type [BSI, 1966b]. The total head was measured through a differential manometer of mercury type, using taps according to British Standards Specifications No 599 [BSI, 1966a].

The error of the measurements was estimated to range between 1% and 6%.

RESULTS AND DISCUSSION.

For each set of tests, the head and the torque for different mass flow rates, ranging from 1 to 8.1 kg/s, were measured at speeds of rotation 800 rpm and 1000 rpm. The results of the measurements were plotted against the length of the vane projection at the point of the maximum value of the efficiency. The total head, as a function of the length of the vane, is presented in fig. 4.

The projection of the vanes caused a significant increase of the total head. An increase of 21.5% was obtained for an elongation of 10-mm at nominal conditions. Elongation of greater than 10 mm seems not to affect the total head significantly, if the pump operates at nominal conditions. Also, an increase of the total head obtained at each length of elongation at 800 rpm. A significant increase (17.2%) was obtained for an elongation of 20 mm at 800 rpm.

Fig 4 The total head vs. the length of the vane projection at maximum efficiency for two different speeds of rotation.

Sl. 4. Ukupni napor u zavisnosti od dužine lopatice određenog profila pri maksimalnoj efikasnosti za dve različite brzine obrataja

In order to examine the change of the total head at constant flow rate, the function of the total head versus the length of the vane projection at 8 kg/s is presented in fig. 5, for a speed of rotation 1000 rpm. This figure shows that the hand increases as the elongation of the vane increases. At a certain flow rate, an increase of 12% was obtained for an elongation of 20 mm.

The change of the flow rate at maximum efficiency of operation, as a function of the length of the projection of the vanes, is presented in fig. 6. There is no any noticeable change of the flow rate in relation to the length of the vane projection. The higher value corresponding to the original diameter of the eye is attributed to the marginal conditions of the measurements.

Fig 6. Flow rate vs. the length of the vane projection at maximum efficiency.

Sl. 6. Protok pumpe u zavisnosti od dužine krila pri maksimalnoj efikasnosti

Figure 7 shows the power input as a function of the length of the vane projection, at maximum efficiency of operation. Although a significant increase of the total head obtained, whereas the flow rate remained almost constant, there is no any notice-
able change of the energy consumption in the same range of measurements. The maximum increase of the power consumption was 4%.

Figure 7 shows the power input as a function of the length of the vane projection, at maximum efficiency of operation. Although a significant increase of the total head was obtained, whereas the flow rate remained almost constant, there is not any noticeable change of the energy consumption in the same range of measurements. The maximum increase of the power consumption was 4%.

The experimental measurements showed that the total head of the pump was improved as the vane edges projected into the eye without a noticeable increase of the power consumption. The magnitudes of the changes depend on the length of the projection, as well as on the speed of rotation. Obviously, the improvement of the total head can be attributed to the decrease of the hydraulic losses due to the projection of the edges of the vanes, as it is indicated in fig. 2. This leads to the conclusion that the overall efficiency must increase accordingly. Indeed, a significant increase of the overall efficiency was obtained, as it is shown in the fig. 8. The longer the projection, the greater is the overall efficiency of the pump.

Since the impeller, under test, was designed for a speed of rotation of 1000 rpm, (nominal speed of rotation) its efficiency at 800 rpm was less than at 1000 rpm. The tests showed an increase of the efficiency of 4% at 800 rpm and of 3% at 1000 rpm. The aforementioned results indicate that an impeller with projected vanes should contribute to the improvement of the pump characteristics if the pump works away from the design point.

CONCLUSIONS

A significant increase of the overall efficiency of a pump can be obtained by projecting the edges of the vanes into the eye of the impeller. Also, the total head of the pump increases depending on the length of the projection and on the speed of rotation. The flow rate and the power consumption seems not to be influenced by the projection of the vanes.

Better pump characteristics would be expected by projecting the vanes into the eye of the impeller, if the pump operates away from the design point.

REFERENCES


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