Research on energy conversion mechanism of a screw centrifugal pump under the water

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Abstract. In order to research screw centrifugal pump impeller power capability and energy conversion mechanism, we used Navier-Stokes equation and standard $k$-$\varepsilon$ equation turbulence model on the basis of the Euler equations to carry out screw centrifugal pump internal flow numerical simulation. This was explored by simulating specific design conditions; the medium is water, variation of speed and pressure of flow filed under the action of the impeller, and the screw centrifugal impeller shroud line and wheel line segment take monitoring sites. The monitoring points are between dynamic head and static head change to analyze the energy conversion capability along the impeller corners of screw centrifugal pump. The results show that the energy of fluid of the screw centrifugal pump is provided by spiral segment, the spiral segment in front of the impeller has played a multi-level role, it has significant reference value to research the energy conversion mechanism of screw centrifugal pump under solid-liquid two phase.

1. Introduction

The screw centrifugal pump is a new type of miscellaneous quality pump. It is an integration of screw pump and centrifugal pump. The unique structure of its impeller can give full play to the advantages of both [1,2]. The screw centrifugal pump offers advantages of non-clogging performance, good suction ability, adjustment performance and cavitation performance in comparison with other impurity pumps. In addition to this, it also has other merits like non-overload, high efficiency performance and wide range of high efficiency [3]. Because of the unique structure impeller of screw centrifugal pump, it makes the internal flow an obvious mixed spiral motion. So its efficiency is still has a lot of room for improvement compared to general centrifugal pump. And the screw centrifugal pump belongs to the typical solid-liquid two phase flow pump, as a kind of energy conversion machinery, under a logical structure design, what individuals care about is the problem of energy efficiency. The present research state mostly stay in qualitative analysis stage instead of quantitative analysis.

This paper will play an important role in the further analysis of solid-liquid two phase impeller’s work in screw centrifugal pump, via the analysis of energy conversion mechanism when the medium is pure water. It also can provide a brand new thinking of design method and theory for this kind of impurity pump.

2. Theoretical foundation and establishment of the model

2.1. Theoretical foundation

From the perspective of energy conversion, impeller are used to convert the mechanical energy into the energy of fluid in a pump, impeller transfer moment to fluid when it rotating with fluid, so the
motion state of the fluid changed, the Euler equation of fluid machinery can describe this kind of energy change [4-6].

The expression of Euler equation is

\[ H_{th} = \frac{v_2^2 - v_1^2}{2g} + \frac{u_2^2 - u_1^2}{2g} + \frac{w_2^2 - w_1^2}{2g} \]  

When \( H_{th} \) is the theoretic head, \( v \) is the absolute velocity, \( u \) is the blade speed and \( w \) is the relative velocity. The subscript 1 and 2 refer to the inlet and outlet of blade.

Therefore, the energy what fluid gained can be divided into two parts, the dynamic head and the static head, the dynamic head is the kinetic energy rise when fluid passed through impeller, it will be transferred into static head in volute casing. The sum of the second term and third term is the static energy rise when passed through impeller called static head. This equation offers theoretical support for work numerical simulation at different parts of impeller.

2.2. Experiment scheme definition

Measure different points on impeller to analysis its working capacity, in order to get even monitoring points which can clearly reflect the change of flow field at different parts of impeller, put points on the crossing of shroud and hub when impeller axial projection rotates every 36°. Symbols PIN1 and PIN23, PIN24 and PIN46, PIN47 and PIN68, PIN69 and PIN90 respectively stand for the start and end points on the shroud and hub lines.

![Figure 1. The monitoring points along the impeller shroud and hub](image)

3. Modeling and numerical method

3.1. Modeling and meshing

The type 150×100LN-32 centrifugal pump is used as the model pump. The performance parameters: flow \( Q = 165m^3/h \), head \( H = 32m \), rotate speed \( n=1480r/min \), shaft power \( P=23.2kw \). The whole model is shown in Figure 2.

![Figure 2. The screw centrifugal pump impeller model and the whole features grid](image)

The calculation region is divided into unstructured tetrahedral mesh. There are 89403 grid nodes and 507886 cells in the entire flow channel. The independent inspection of the grid is also established.

3.2. Numerical method

The channel of screw centrifugal pump are consist of impeller and volute casing, using the rotational coordinate fixed on the surface of impeller as the relative coordinate, the flow in impeller are regarded to steady, the whole internal flow field is assumed to three-dimensional, incompressible, and steady turbulent [7]. Use velocity entrance condition at inlet and outflow boundary condition at outlet, at the same time, use non-slip boundary condition on the whole solid wall, and use standard
To save compute time under a high accuracy condition, use first order upstream scheme on convection term and center difference scheme on dissipation term, set the convergence precision as $10^{-5}$, introduce the SIMPLE method to iterate the pressure-velocity [10-12].

4. Performance test and verification

4.1. Testing system establishment

The experiment method of pump is used to test the performance of pump when transporting different fluid or at different work condition directly. It is the directly, effectively, and reliably research method of pump so far. Because of the construction of open test bed is simple and convenient, this test bed use open cycle and horizontal layout shown in figure 3.

![Figure 3. The opened-architecture testing platform of screw centrifugal pump](image)

1-motor 2-torque and speed meter 3-pump 4-import manometer 5-water seal valve 6-outlet pressure gauge 7-turbine flow meter 8-gate valve 9-pool.

4.2. Characteristic curve plotting

Test the performance of 150×100LN-32 screw centrifugal pump on test bed, measure the pressure, flow rate, torque and rotate speed at inlet and outlet, plot the characteristic curve shown in figure 4.

![Figure 4. Characteristic curve of screw centrifugal pump](image)
As can be seen from Figure 4, $H_t$ is greatly affected by $Q_t$. It is reflected on the characteristic curve is like a steep drop of a straight line. Corresponding to the smaller flow rate change, the head should have a greater change. So, the pump of this characteristic curve is very suitable for sewage treatment occasions.

As can be seen from the efficiency-flow curve, the optimal condition of 150X100LN-32 screw centrifugal pump is beside the point of $Q=180\text{m}^3/\text{h}$. It is a tendency to the working condition of large flow rate. The maximum efficiency of the pump is 63%. It is close to the design efficiency of 65%. In the flow rate range from $Q = 115\text{m}^3/\text{h}$ to $Q= 240\text{m}^3/\text{h}$, the pump efficiency is higher than 50%. Compared with the general water pump, the screw centrifugal pump shows a low overall efficiency. This is because that the screw centrifugal pump is designed for pumping two-phase flow. In pumping solid-liquid two-phase flow, the efficiency of the screw centrifugal pump is higher than other sewage pumps. With a large range, the shaft power curve of the experimental pump is close to a straight line and rise slightly. When the flow rate reaches $Q= 230\text{m}^3/\text{h}$, the shaft power begin to fall. So, the motor will not overload if we selected the pump’s motor according to the shaft power value of the maximum power point.

5. The numerical simulation results

5.1. The results of numerical simulation in the water medium

Pressure and velocity in the screw centrifugal pump is available when transport pure water at design condition shown in figure 5.

It can be seen from figure 5 that the pressure distribution at work side, back side and the cross-section of volute are uniform, the pressure gradient spiral rise from hub to shroud. Pressure level is also rises from inlet to outlet of blade, it is in accordance with the work principle of screw centrifugal pump. The pressure of work side is apparently higher than back side and the pressure gradient keep a same trend at the same angle. It forms a difference which can make fluid propulsion from screw section to centrifugal section. The velocity on impeller changes evenly and spiral rise from hub to shroud, it also has impact phenomenon at casing tongue.

5.2. The change curve of some parameters about the wrap angle under the design condition

From numerical simulation calculations, we can conclude the changing of radius, pressure and
velocity along the flange under the design condition when the medium is clear water in Figure 6.

Figure 6. The curve of each parameter along the wrap angle

Some following points can be seen by analysis each parameter changes in Figure 7. (1) The radius of the blade increases and then decreases with wrap angle increasing, which accords with the actual change from spiral type in entrance region to centrifugal type in exit section. This implies that the impeller of screw centrifugal pump completed the transient process from the spiral segment to the centrifugal section at the radius of the largest, and convected velocity is determined by the radius so that the variation trends of convected velocity and radius are consistent. (2) Relative velocity is gradually reduced with wrap angle ranging from 0° to 300°, but gradually increased after 300°. It can be judged that doing work of the impeller of a screw centrifugal pump is mainly provided by the spiral segment of the impeller. (3) Absolute velocity increases and then decreases with wrap angle increasing, and inflection point appears in the vicinity of wrap angle 580°. (4) Analyzing from the pressure, regardless of the static pressure or total pressure, whose whole developing trend is increasing, which accords with the working principle of a pump. The spiral segment does work to the fluid so that the pressure of the fluid increases. The radial pressure of impeller increases because the inertia of fluid motion makes the fluid have a motion trend of the edge of the impeller when the fluid is effected by centrifugal force of the impeller at centrifugal segment.

In the vicinity of the spiral segment inlet and the conversion process of geometric from spiral segment to centrifugal segment, the pressure appears a drastic change, and the latter is particularly evident. The transformation of axial velocity and radial velocity in the transition from spiral segment to centrifugal segment easily lead to reflux, vortex and so on, and there’s pressure down, and after the role of the centrifugal section, the transformation of kinetic energy to pressure energy is completed, and the working process for the fluid of screw centrifugal pump is achieved.

5.3. Analysis of energy conversion of the impeller analysis

We can make variation curves about wrap angle of dynamic pressure and static pressure with the Euler equations of equation (1) by numerical simulation of the flow field inside the screw centrifugal pump.

5.3.1. Performance abilities of each segment of flange line on working face along the wrap angle.

The dynamic pressure and static pressure are both increased on the whole on working face of the flange with wrap angle increasing, in the case of spiral segment whose wrap angle is probably in the range of 0°~600°, and the output of static pressure is much higher than the dynamic pressure. In another word, the increasing amount of static pressure is higher than the dynamic pressure for a
screw centrifugal pump, because the energy is transferred by lift forces in the helical section which has the ability of spiral propulsion.

The static pressure and dynamic pressure both appear a drastic drop in the transition, whose wrap angle is about 600°, from spiral segment to centrifugal segment, because the radius just reaches its maximum and then decreases in the transition where the centrifugal force is the largest and the axial velocity is converted to the radial velocity, and the effect of the energy conversion is obviously decreased. Static pressure and dynamic pressure increase significantly after the sharp decline in the centrifugal segment thereafter, because it is different that the directions of the velocity of the fluid flowing out from the spiral segment and doing work in the centrifugal section, and the two fluids make an impact when mixed, which consumes part of the energy, while there has been a significant rally for the energy in the outlet. The reason for the increase is that the area of the channel is increased and the velocity of the fluid is reduced and part of kinetic energy is converted into pressure energy in the segment.

It can be seen that the increase in static pressure and dynamic pressure in the spiral segment is positive value in the working process of the impeller of a screw centrifugal pump, and it’s just the opposite in the centrifugal section. The static pressure reaches a maximum in maximum radius, which shows that the pressure of a screw centrifugal pump is mainly generated by spiral segment and the front portion of spiral section of the impeller plays a role in increase energy. It also verifies that doing work of an impeller is mainly provided by spiral section.

![Figure 7](image_url)

**Figure 7.** The curve of power capability that the face side of the shroud line along the corners

5.3.2. Performance abilities of each segment of flange line on working face along the wrap angle. The change of the energy in inlet section is distinct on the working and back of an impeller. The energy of the fluid is gradually increased due to the thrust of the impeller on the working face, on the contrary, the energy of the fluid is greatly reduced on the back, because on the back of inlet section, an area of low pressure is formed due to the rotation of the impeller and the volume change of the space behind the inlet on the back, and the working face is the major part of doing work of an impeller. The result indicated that it accords with the working principle of a pump.
5.3.3. Performance abilities of each segment of flange line on working face along the wrap angle.
The static pressure maintains substantially greater than zero in the other segments except the outlet segment where the increase of the static pressure is negative value on the working face of hub, while the dynamic pressure changes greatly in all segments. This shows that static pressure maintains a good growth and it is good enough to keep the transitivity of energy. The concussion of dynamic pressure is determined by the fluid field of the chamber of screw centrifugal pump. Due to the effects of the volute of the inlet section, the linking-up section from spiral segment to centrifugal segment and the outlet section, plus the influence of the large wrap angle of the impeller and radius change, the size and direction of the flow velocity of the flow field change with the impeller operation. Besides, the cavity is smaller than others at the hub where some phenomena, such as reflux, vortex, is produced, and the transmission effects of impeller energy is impacted. Because the overall improvement of the static pressure makes up for the loss of energy due to the change in the state of the movement, the demand for the pump head is well ensured.

5.3.4. Performance abilities of each segment of flange line on working face along the wrap angle. On the back of the hub, the same situation is that the static pressure maintains a good increase in the other segments except that the static pressure appears decrease in a smaller interval in the inlet of impeller and after the transition from spiral segment to centrifugal section, the increases in dynamic
pressure is still unstable. On the one hand, some flow disturbance appears at the hub because the angle between the blade and the hub is so small that it is difficult to meet the conditions of flow around. On the other hand, since the fluid enters the pump under the atmospheric pressure, the thrust which is generated by the blade at the inlet acting on the fluid is smaller, and the blades occupy some certain volume, an area of low pressure appears in the inlet. With the entry of the fluid and the increase of the work from the blade acting on the fluid, the pressure of the fluid on the working face is greater than the back, and a pressure difference is formed, and the fluid flows from the working face to the back. In other words, the fluid flows from the high pressure area to the low pressure area, and some phenomenon, such as reflux, vortex, is prone to appear, which impacts the play of the dynamic pressure in the transmission of impeller energy.

![Diagram](image)

**Figure 10.** The curve of work capacity that on the back side of the hub lines along corners

### 6. Conclusions

1) We can see that doing work of each impeller is mainly provided by the spiral section and the anterior part of the impeller, the spiral segment, play an important role in increase energy by analyzing the working process of the impeller of a screw centrifugal pump.

2) By the change trend of the relative velocity along the wrap angle, we can draw that it reduces the quality of the energy conversion of the impeller that the general change trend of relative velocity is gradually increased from the inlet to the outlet of screw centrifugal pump.

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