Study on the influence of the number of guide vane blades on the flow characteristics of axial flow pump

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Abstract. Axial flow pump is widely used in energy, agriculture, urban water supply and drainage, water conservancy engineering, ships and other fields. As one of the important flow passage parts of axial flow pump, guide vane can be used to smooth the rotation of fluid after passing through the impeller, change it into axial motion, and change the kinetic energy of rotation into pressure energy. In this paper, the hydraulic performance and pressure pulsation of axial flow pump with three different guide vane numbers are analyzed by numerical simulation. Under rated flow and large flow conditions, increasing the number of guide vanes is more conducive to suppress the pressure pulsation.

1. Introduction
Axial flow pump is a kind of fluid machinery commonly used in the industrial field, which is widely used in agriculture, urban water supply and drainage, water conservancy engineering, ships and other fields. The impeller of the axial flow pump is generally equipped with 2-7 blades, which rotate in the cylindrical pump shell. The upper end of the impeller is equipped with fixed guide vanes, which are used to eliminate the rotating motion of the fluid after passing through the impeller, and then guide the fluid into axial motion, and convert the kinetic energy of the rotating motion into pressure energy. As one of the important flow passage parts of axial flow pump, guide vane has been widely studied in recent years. It was found in reference [1] that the change of the relative position of guide vane and impeller, guide vane and elbow will affect the flow characteristics, and the analysis shows that the pump performance can be optimized by reducing the elbow angle or adjusting the guide vane arrangement. In reference [2] and reference [3], the influence of the placement Angle of guide vane inlet and outlet on flow performance was respectively studied. Through numerical analysis, the recommended range of the placement Angle of guide vane inlet and outlet was obtained. In reference [4], the author chose a mixed oil and gas pump as the research object, and performed numerical calculations on the unsteady flow field with different guide vane blade numbers and different gas content. Through comparative analysis, the working parameters that can make the mixed gas pump operate more stably were given. In reference [5], in view of the turbine blade surface cavitation will happen this problem, 3-D modelling of hydraulic turbine is established, then the whole flow field numerical simulation, respectively on the blade surface under different guide vane opening pressure, air bubble size distribution analysis, the results of the study provides reference for the safe and stable operation of the turbine.

In this paper, by means of numerical simulation, the hydraulic performance and pressure pulsation of axial flow pump are analysed under three different guide vane numbers, which provides support for the optimization design of axial flow pump guide vane.
2. Parameters of axial flow pump and fluid calculation domain
The rated speed of axial flow pump selected in this paper is 1470r/min, the design flow is 1000 m$^3$/h, and the lift is 5.8m. The impeller is designed as 4 blades, the hub diameter is 150 mm, the flange diameter is 300mm, the axial flow pump has the rear guide vane, the diameter of the guide vane hub is 130mm, the flange diameter is 150 mm, and the axial spacing between the impeller and the guide vane is 30mm.

In order to study the influence of the number of vanes on the flow characteristics of the axial flow pump, there are three schemes for the guide vane design. The blade types of the three schemes are unchanged, and the number of blades is 5, 7 and 9 respectively.

The axial-flow pump operates in a closed test-bed, so according to the actual situation, the calculation domain includes the inlet extension section, inlet elbow, impeller area, guide vane area, outlet elbow, outlet extension section and so on. The impeller area is a rotating area, and the others are non rotating areas. The tip clearance of the impeller area is ignored in the modelling process. Figure 2 shows the grid diagram of the longitudinal section of the calculation domain, the impeller surface and the guide vane surface. All grids in the calculation domain are structured grids. Local grid densification is carried out on the blade surface and the pipe wall, and the total number of grids is about 3 million.

3. Influence of number of guide vane blades on hydraulic performance of axial flow pump

3.1 Fluid simulation calculation Settings
RNG K-ε is selected to calculate the hydraulic performance of axial flow pump, and the reason is that the turbulence model can better deal with the flow state of high strain and large curvature of streamline, which is suitable for the simulation of strong rotating flow in pump. The first-order upwind scheme is used to discretize the convection term of the governing equation to obtain a higher convergence rate, and the SIMPLEC algorithm is used to couple the pressure and velocity.
Taking the rated flow $Q_s$ as the abscissa and the head and hydraulic efficiency as the ordinate, the calculation formula of head and efficiency is as follows:

$$\text{Head} = \frac{P - P_i}{\rho g}, P = p + \frac{1}{2} \rho V_z^2$$

$$\text{Efficiency} = \frac{\text{Head} \times Q}{M \times \omega}$$

(1)

In the above formula, the subscripts I and e represent the inlet and outlet monitoring surfaces respectively, the subscripts $Z$ represent the axial velocity of the pipeline, and the subscripts $Q$, $m$ and $Z$ represent the axial velocity of the pipeline $\omega$. The distribution is axial flow pump flow, impeller torque and rotation angular velocity.

3.2 Hydraulic performance calculation

The hydraulic performance curve of the axial flow pump is shown in Figure 3 (the guide vane is 7 blades). It can be seen from the figure that the pump head and efficiency calculated under the rated flow are 6.11m and 81% respectively. The design head of the axial-flow pump is 5.8m, the expected working efficiency is not less than 80%, the error between the numerical simulation value and the design value is not more than 2%, and the error is within the acceptable range. The reason may be that the mechanical loss and uneven inlet flow are not considered in the numerical simulation.

![Fig. 3. Hydraulic performance curve of axial flow pump](image-url)

Figure 4 shows the streamline diagram of axial flow pump under three different flow conditions, which are 0.6, 1.0 and 1.3 times of rated flow respectively. The left side is the streamline distribution on the longitudinal section, and the right side is the streamline diagram on different sections perpendicular to the axis of rotation. From the streamline distribution on the longitudinal section, it can be seen that the flow in the guide vane region is affected by the existence of 90 degree outlet elbow, and the flow separation occurs near the axis in the guide vane region near the outside, and the influence range and degree of elbow on the flow field increase with the decrease of flow rate. In addition, there is an obvious transverse flow from the outside to the inside of the elbow in each section, which will produce a greater transverse force on the shaft.

Moreover, due to the existence of a 90 degree bend at the inlet, the flow into the impeller presents a non-uniform state along the circumferential direction. Under the condition of small flow, there is flow separation at the inlet of the impeller. From the streamline distribution of each cross section, the change of flow rate will cause the change of the size and range of the passage vortex. The passage vortex is smaller at the rated flow rate and appears on the suction side; At high flow rate, the passage vortex is close to the pressure surface; Under the condition of small flow, the range of passage vortex is the largest.
3.3 Influence of number of guide vane blades on hydraulic performance of axial flow pump

In Fig. 5 and Fig. 6, the variation trend of the head and efficiency of the axial flow pump with different number of guide vanes is shown respectively.

Fig. 4. Streamline distribution under different flow rates

Fig. 5. Influence of blade number on axial flow pump head
It can be seen from the figure that the change of the number of guide vanes has little effect on the head and efficiency of the axial flow pump. Relatively speaking, the head of the axial flow pump with 9 guide vanes decreases slightly, and the efficiency of the axial flow pump with 5 guide vanes decreases at the rated operating point.

4. Influence of blade number of guide vane on pressure pulsation

4.1 Unsteady pressure pulsation monitoring point

Figure 7 shows the location of monitoring points in unsteady flow field calculation. Four monitoring points are set at the three sections of impeller inlet (ylin), impeller outlet (ylout) and guide vane outlet (vout) along the radial direction. The radius of the monitoring points are 80mm, 100mm, 120mm and 140mm respectively, and the corresponding monitoring points are 0, 1, 2 and 3 respectively.

![Fig. 7. Schematic diagram of monitoring point location](image)

The pressure pulsation coefficient is expressed by $C_p$ as follows. Where $p$ is the instantaneous pressure at the monitoring point and $p_{avg}$ is the time average pressure at the monitoring point. $\rho$ and $\omega$ are fluid density and angular velocity of impeller rotation. $R$ is the impeller radius.

$$C_p = \frac{p - p_{avg}}{0.5\rho\omega^2R^2}$$ (2)
4.2 Influence of blade number of guide vane on pressure pulsation

It can be seen from Figure 8 that the pressure pulsation frequency under different flow rates and different number of guide vanes is blade passing frequency and its high order harmonics. As the number of guide vanes changes from 5 to 9, the peak value of pressure pulsation coefficient on blade frequency is shown in Table 1. Under rated flow and high flow conditions, the pressure pulsation coefficient decreases with the increase of the number of guide vanes, especially when the number of guide vanes increases from 7 to 9. However, when the axial flow pump is running in the condition of small flow, the pressure pulsation caused by the 7-blade guide vane is the largest.

Fig. 8. Pressure pulsation distribution at No.3 measuring point of impeller inlet under different blade numbers
Table 1. Pressure pulsation coefficient at blade passing frequency.

| Calculation condition | 5 blades | 7 blades | 9 blades |
|-----------------------|----------|----------|----------|
| Q/Qs=0.6              | 0.159    | 0.168    | 0.152    |
| Q/Qs=1.0              | 0.098    | 0.096    | 0.086    |
| Q/Qs=1.3              | 0.087    | 0.086    | 0.080    |

It is shown in Figure 9 and Figure 10 respectively that the distribution of pressure pulsation at No. 0 monitoring point of impeller outlet section and guide vane outlet section. It can be seen from the figures that the decrease of axial flow pump flow will lead to the increase of pressure pulsation. From the inlet to the outlet of the impeller and then to the outlet of the guide vane, the pulsating energy of the blade passage frequency gradually decreases, and the pressure pulsation with lower frequency appears. There is no obvious pressure pulsation of the blade passage frequency in the spectrum at the outlet of the guide vane, which shows that the guide vane can play a better role in smoothing the flow field.
Fig. 10. Pressure distribution at No.0 monitoring point of guide vane outlet section

5. Conclusion
In this paper, a vertical axial flow pump is taken as the research object. Through numerical simulation, the hydraulic performance and pressure pulsation of axial flow pump with different number of guide vanes are calculated and analyzed, and the following conclusions are obtained.

(1) The number of guide vanes has little effect on the hydraulic performance of axial flow pump, but the guide vane with 7 blades has the best comprehensive performance under rated conditions.
(2) The existence of the guide vane has a significant smoothing effect on the flow in the pump, especially on the blade passing frequency. Under rated flow and large flow conditions, increasing the number of guide vanes can effectively suppress the pressure pulsation.

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