Influence of volute section form on hydraulic performance and pressure fluctuation in double suction centrifugal pump

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Abstract. Double suction centrifugal pump has characteristics of large flow rate and high head. It is widely used in agricultural irrigation and water delivery and other projects. As the flow components, volute has a great influence on the hydraulic performance in double suction centrifugal pump. Based on the original circular section volute of the double suction centrifugal pump, the trapezoidal section volute and the horseshoe-shaped section volute were designed. By analyzing the influence of three different volutes on hydraulic performance and pressure fluctuation, it was obtained that the circular section volute had higher head in the low flow rate condition, and efficiency of the three were similar. In the design condition, the circular section volute had the highest efficiency, and head of the three were similar. The decline of the efficiency in the circular section volute was the smallest in large flow rate condition, and the head of the three were similar. Thus, the hydraulic performance of the circular section volute was better. For the pressure fluctuation in the design condition, the pressure fluctuation in the volute is mainly affected by the impeller rotation. The pressure fluctuation in the circular section volute was the biggest, especially at the tongue. The horseshoe-shaped section volute was the second. The pressure fluctuation in the volute of the trapezoidal section was the smallest. Therefore, the trapezoidal section volute is helpful to reduce the pressure fluctuation in the volute. The results of this research provide reference for designing double suction volute of centrifugal pump in engineering.

1. Introduction
As an important form of pump, double suction centrifugal pump has characteristics of large flow rate and high head. It is widely used in petroleum, chemical, water conservancy and other fields. The volute and the impeller in double suction pump have rotor-stator interaction during the operation. As the flow components, volute has a great influence on the hydraulic performance in double suction centrifugal pump.

Xu analyzed geometry of eight profiles of flow duct, and established a mathematic model of geometry dimensions of profiles of flow duct in spiral casing of centrifugal pumps. It improved pump efficiency and provided theoretical basis for designing eight profiles of flow duct in spiral casing of pump. In order to optimize the structure, Fang carried out a 3-dimensional viscous numerical simulation of the complex turbulent flow field in the inducer components. With the visual analysis of the flow field, it is shown that the hydraulic performance of the spiral casing with the circle cross-section is superior to the one with rectangle cross-section on two aspects. Guo carried out numerical simulations of flow in a low specific speed single stage centrifugal pump with three different volutes.
The numerical results show that the differences in the performance of different volutes are quite small. In addition, the hydraulic losses in the pump with three different volutes are dissimilar with the flow variation.

Through the above research, the volute section form of single suction centrifugal pump has been studied deeply. The influence of the volute section form on the hydraulic performance and pressure fluctuation of single suction centrifugal pump has been obtained. But for double suction centrifugal pumps, the impellers are in the form of back to back, and the flow of the impeller outlet is more complicated than that of the single suction centrifugal pump[8-9]. But the relative research of volute section form of double suction centrifugal pump is relatively less. In this study, numerical simulation method is used to study the influence of the shape of different volute sections on hydraulic performance and pressure fluctuation. Based on the original circular section volute of the double suction centrifugal pump, the trapezoidal section volute and the horseshoe-shaped section volute were designed.

2. Computational model and mesh generation

2.1. Computational model
In order to study influence of volute section form on hydraulic performance and pressure fluctuation in double suction centrifugal pump, this study selected a good double suction centrifugal pump hydraulic model as the basic research object. The specific parameters are shown in table 1.

| Table 1. Basic parameters of double suction centrifugal pump model |
|---------------------------------------------------------------|
| Flow $Q_d$(m$^3$/h) | 800 | Shroud diameter of impeller inlet $D_{1s}$(mm) | 200 |
| Head $H_d$(m) | 1490 | Hub diameter of impeller inlet $D_{1h}$(mm) | 87 |
| Rotating speed $n$(r/min) | 25 | Diameter of impeller outlet $D_2$(mm) | 310 |
| Specific speed $n_s$ | 162 | Outlet width of single impeller $b_2$(mm) | 38 |
| Blade number $Z$ | 7 |

The original design of double suction centrifugal pump volute was circular section. As shown in figure 1, it was changed into horseshoe-shaped section and trapezoidal section. Mainly followed the principles: (1) Keep the base circle area unchanged; that is $D_{3c}=D_{1h}=D_{3c}$. (2) Keep the outlet width of the volute unchanged; that is $b_3=b_{3h}=b_{3c}$. (3) Keep the area of each section unchanged. According to the above principles, three kinds of volute models with different cross sections were established. was taken as an example, the whole flow passage calculation domain with the circular section volute was shown in figure 2.

![Figure 1. Section form of volute](image)
2.2. Mesh generation

In this study, the commercial software ICEM CFD was used to discretize the domain. Tetrahedral elements were used in all the components of the double suction centrifugal pump. A mesh independence check was conducted to ensure the simulation accuracy. Taking the circular section volute as an example, as shown in figure 3, the grid node was gradually increased to check the change of the head value. A grid scheme with both computational accuracy and computational time was selected. At the same time, based on the requirement of the wall function in the turbulence model, the number of mesh layers and the height of the grid near the wall were controlled to ensure that the $y^+$ was distributed within the range of 30–350, so that the mesh can effectively predict the flow near the wall. In this study, the number of mesh nodes used in each model were shown in table 2.

| Suction | Impeller | Circular section volute | Trapezoidal section volute | Horseshoe-shaped section volute |
|---------|----------|-------------------------|----------------------------|--------------------------------|
| 2264    | 9930     | 1867594                 | 1829593                    | 1831733                        |
| 959     | 45       |                          |                            |                                |

3. Simulation methods and settings

3.1. Simulation methods

In this study, the commercial software ANSYS CFX was used in numerical simulation. The SST (Shear Stress Transport) $k-\omega$ turbulence model was used to conduct steady and transient calculation. The $k$ function and $\omega$ function in SST $k-\omega$ turbulence model were $^{[12]}$. 
\[
\frac{\partial (\rho k)}{\partial t} + \frac{\partial (\rho u_i k)}{\partial x_i} = P - \rho \frac{k^{3/2}}{l_{k-\omega}} + \frac{\partial}{\partial x_j} \left[ \left( \mu + \sigma \mu_t \right) \frac{\partial k}{\partial x_j} \right] \\
\frac{\partial (\rho \omega)}{\partial t} + \frac{\partial (\rho u_i \omega)}{\partial x_i} = C_\omega P - \beta \rho \omega^2 + \frac{\partial}{\partial x_j} \left[ \left( \mu_t + \sigma \mu_t \right) \frac{\partial \omega}{\partial x_j} \right] + 2 \left( 1 - F_1 \right) \frac{\rho \sigma \omega}{\omega} \frac{\partial k}{\partial x_i} \frac{\partial \omega}{\partial x_i}
\]

where \( \rho \) is the density, \( P \) is the production term, \( \mu \) is the dynamic viscosity, \( \mu_t \) is the turbulent eddy viscosity, \( \sigma \) are the model constants, \( C_\omega \) is the coefficient of the production term, \( F_1 \) is the mixture function. In the term \( \rho \frac{k^{3/2}}{l_{k-\omega}} \), the turbulence scale \( l_{k-\omega} \) is expressed as:

\[
l_{k-\omega} = k^{1/2} \beta_k \omega
\]

### 3.2. Simulation settings

The multiple reference frame (MRF) was used for numerical simulation in this study. The impeller of the double suction centrifugal pump was arranged in a rotating domain. The rotating speed of the rotating domain was the same with the impeller rotating speed. The suction and the volute were set to the static domain. The reference pressure was 1 Atm. The boundary condition was set as the mass flow inlet. The outlet boundary condition was given static pressure with 0 Pa. All the solid walls were set as no-slip wall boundaries. The transient simulations began from the steady state result and continued for 10 impeller revolutions with 180 time-steps per revolution to monitor the head and pressure variations. As shown in figure 4, the pressure fluctuation monitoring points were set in the volute.

![Figure 4. Position of monitoring points](image-url)

### 4. Result analysis

#### 4.1. Influence of volute section form on hydraulic performance

In this study, the numerical simulation of double suction centrifugal pumps with three different volute sections was carried out to analyze the influence of the volute section form on the hydraulic performance. Figure 5 shows the comparison of discharge-head curves in different volute sections. Figure 6 shows the comparison of discharge-efficiency curves in different volute sections.
Figure 5. Comparison of discharge-head curves in different volute sections

Figure 6. Comparison of discharge-efficiency curves in different volute sections

As shown in Figure 5, in the design condition, the horseshoe-shaped section volute has the highest head. The head of the trapezoidal section volute is the second, and the circular section volute has the lowest head. But the three have reached the design requirements. With the flow rate decreasing, the head of circular section volute is higher than the other two volutes. In the 0.4Q small flow rate condition, the head of circular section volute is 6.32% higher than that of trapezoidal section volute and horseshoe-shaped section volute, and the hump can be effectively avoided. As can be seen from Figure 6, in the 0.6Q and 0.8Q small flow rate condition, the efficiency of the horseshoe-shaped section volute is higher than that of the trapezoidal section volute and the circular section volute. In the design condition, the circular section volute has higher efficiency. With the flow rate increasing, the efficiency of trapezoidal section volute and horseshoe-shaped section volute decreases obviously, and the efficiency of circular section volute decreases less. Therefore, for the double suction centrifugal pump of the specific speed, the performance of the circular section volute is better, and the horseshoe-shaped section volute is second, and the trapezoidal section volute is the worst.

4.2. Influence of volute section form on pressure fluctuation

In order to analyze the influence of the volute section form on the pressure fluctuation, the pressure values at each monitoring point obtained after numerical simulation were nondimensionalized. The pressure was nondimensionalized as the pressure coefficient, $C_p$: 

\[ C_p = \frac{P - P_0}{\frac{1}{2} ho u^2} \]
\[ C_p = \frac{P - P_{ref}}{\frac{1}{2} \rho \nu_{ref}^2} \]  

(4)

where \( P \) is the pressure of each monitoring point, \( P_{ref} \) is the reference pressure, that is suction inlet pressure, \( \nu_{ref} \) is the reference velocity, that is suction inlet velocity. Figure 7-9 showed the time domain and frequency domain diagrams of pressure fluctuation in three different section volute in design condition. The location of the monitoring points was given in figure 4.
Figure 9. Pressure fluctuation of horseshoe-shaped section volute

As can be seen from figure 7, the pressure at P1 point in the circular section volute fluctuates greatly, and the amplitude of the pressure fluctuation is the maximum. The pressure of P2, P3, P4 and P5 near the outside of the volute are higher than that of the P6, P7, P8 and P9 points near the outlet of the impeller at the same section. But the pressure fluctuation and pressure fluctuation amplitude of P2, P3, P4 and P5 points are smaller than those of P6, P7, P8 and P9. On the whole, the main frequency of each monitoring point is related to the rotating frequency. It illustrates that the flow in the volute is affected by the periodic rotation of the impeller.

As can be seen from figure 8, the pressure of each monitoring point in the trapezoidal section volute has little change. The pressure of P2, P3, P4 and P5 near the outside of the volute are higher than that of the P6, P7, P8 and P9 points near the outlet of the impeller at the same section. But the amplitude of pressure fluctuation is more average.

As can be seen from figure 9, the pressure fluctuation at the P1 point at the tongue of the horseshoe-shaped section volute is relatively large, and the amplitude of the pressure fluctuation is higher than that of other monitoring points. The pressure of P2, P3, P4 and P5 near the outside of the volute are higher than that of the P6, P7, P8 and P9 points near the outlet of the impeller at the same section.

Based on the above analysis, it can be seen that the pressure fluctuations in the three volutes are different in the design condition. The pressure fluctuation in the circular section volute is the maximum, and the amplitude of pressure fluctuation is higher, especially at the tongue. The pressure fluctuation in the horseshoe-shaped section volute is the second, and the amplitude of the pressure fluctuation in the trapezoidal section volute is the minimum.

5. Conclusion

In this study, the transient simulation was carried out for a double suction centrifugal pump model with the specific speed of 162. The influence of circular section volute, trapezoidal section volute and horseshoe-shaped section volute on hydraulic performance and pressure fluctuation of double suction centrifugal pump were compared and analyzed. It is concluded that in the small flow rate condition, the circular section volute has higher head and the three efficiency is similar. In the design condition, the efficiency of the circular section volute is the highest and the three head is similar. In the large flow rate condition, the head of the three is similar, and the efficiency of circular section volute decreases less. Therefore, the hydraulic performance of the circular section volute is better. In the design condition, the pressure fluctuation in the volute is mainly affected by the impeller rotation. Among them, the pressure fluctuation in the circular section volute is the maximum, especially the amplitude of the pressure fluctuation at the tongue is the biggest. The horseshoe-shaped section volute is the second. The pressure fluctuation in the trapezoidal section volute is the minimum, and the
amplitude of the pressure fluctuation is smaller. Therefore, the trapezoidal section volute is helpful to reduce the pressure pulsation in the volute.

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