Suppression of secondary flows in a double suction centrifugal pump with different loading distributions

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Abstract. Secondary flow is one of the main reasons for low efficiency in double suction centrifugal pump. In a 3-D inverse design method, the pump blade could be designed by a specified loading distribution to control the flow field in pump. In order to study the influence of loading distribution on secondary flow of a double suction centrifugal pump, the external characteristics and the internal flow field of the pump with three kinds of loading distributions are analysed by using CFD approach. According to the simulation results, it is found that the form of fore-loading distribution at shroud and aft-loading distribution at hub could improve the optimal efficiency and broaden the high efficiency area of the pump. Furthermore, the secondary flow in impeller exit region and volute could be significantly suppressed if the slope of loading distribution curve of shroud is set to be -0.7.

1. Introduction

Double suction centrifugal pumps are widely used in water diversion, irrigation, drainage and water supply engineering. However, pump sometimes operates at partial design conditions and results in low efficiency. At this condition, the secondary flows including the backflow and vortex present in the pump chamber [1]. Therefore, it is a challenging issue to control the secondary flows inside a double suction centrifugal pump.

The 3-D inverse design method is a new design tool in which the blade loading distribution has to be specified [2]. The flow field in a pump could be controlled by specifying a suitable blade loading distribution, so it is necessary to study the influence of the blade loading distribution on suppression of secondary flows in a double suction centrifugal pump.

The blade loading distribution curve is a three-segment curve [3-4] consisting of a parabolic curve and a straight line section followed by another parabolic curve in the 3-D inverse design method. Zangeneh [5] designed a mixed-flow pump impeller by using the inverse design method with a small slope of the straight line, this kind of loading distribution improved the backflow and wake-jet of impeller exit. Ashihara [6] improved a centrifugal impeller by using aft-loading distribution at shroud and hub, the results showed that pump inlet suction performance was improved, but the backflow of impeller exit was obvious. Zangeneh [7] designed a centrifugal impeller by using two kinds of loading distribution, the first is fore-loading distribution at shroud and hub, and the second is fore-loading distribution at shroud + aft-loading distribution at hub. The results showed that the second loading distribution is better than former for both the backflow of impeller inlet and exit. To sum up, the form of aft-loading distribution at hub could helps to improve the suppression of secondary flows in pump, but the influence of loading distribution at shroud was not clear. Therefore, a CFD method is adapted.
to analyze the suppression of secondary flows in a double suction pump with three kinds of loading
distributions.

2. Numerical modeling and blade loading distributions

2.1. Investigation object
The main parameters of the pump are as follows: \( Q = 10800 \text{m}^3/\text{h} \), \( H = 32 \text{m} \), \( n = 490 \text{r/min} \), impeller inlet diameter \( D_0 = 690 \text{mm} \), impeller outlet diameter \( D_2 = 1100 \text{mm} \), the impeller blade number \( Z = 6 \). The computational domain of the pump includes suction chamber, impeller, volute and the extensions for inlet and outlet. The flow model is established as shown in figure 1. Unstructured tetrahedral cells with strong flexibility are used for the entire domain.

![Figure 1. The computational domain of double suction centrifugal pump](image)

2.2. Blade loading distribution
In order to study the influence of blade loading distribution on the suppression of secondary flows in
double-suction centrifugal pump, three kinds of loading distributions are used to design the impeller.
The loading distributions as shown in figure 2, case 1 is aft-loading distribution at shroud + aft-loading
distribution at hub; both case 2 and case 3 are fore-loading distribution at shroud + aft-loading
distribution at hub, but the slopes are different. The details for control parameters are listed in table 1.

![Figure 2. Specified blade loading distributions](image)

| Case       | Location | NC  | Slope | ND  |
|------------|----------|-----|-------|-----|
| Case 1     | Shroud   | 0.30| 2.00  | 0.75|

Table 1. The details for control parameters of loading distributions
2.3. Turbulence model and boundary condition
The RNG $k$-$\varepsilon$ turbulent model [8-10] is used to simulate the flow in the double suction centrifugal pump. The wall functions for the near wall, consistent with the non-slip wall condition are adopted. The boundary condition of inlet is determined by the velocity, and the outlet boundary condition is set to outflow.

2.4. Grid independence
The grid independence is checked to give a meaningful result. As shown in figure 3, the pump head increases with the number of grid from 1.5 million to 2.2 million, but the change is little when the grid number reaches to 2.2 million. It is believed that the grid number continues to increase over 2.2 million has little effect on the calculation result. Therefore, the computational domain grid number is controlled around 2.2 million in this paper.

2.5. Accuracy of the calculation method
The external characteristics of the pump are predicted by using the CFD method above. Compared with the experimental results, the errors for head and efficiency are less than 5%, as shown in figure 4. It indicates that the numerical method based on the RNG turbulence model could accurately predict the external characteristics of the pump.

![Figure 3. Grid independence checks](image)

![Figure 4. The external characteristics](image)

3. Results and discussions
3.1. Comparison of external characteristics
Figure 5 shows the external characteristic curves of the double-suction centrifugal pump designed by three loading contributions. It can be found that the heads and efficiencies given by the three loading contributions are almost the same at small flow rates, while the efficiency curve of case 3 has wider range of high efficiency. Case 3 gives more than 5% higher efficiency than case 1 and Case 1 do at $1.2Q_n$ flow rate. The efficiency of case 1 is lower than other cases at any flow rate. It proves that the form of fore-loading distribution at shroud + aft-loading distribution at hub is better than the aft-loading distribution at shroud + aft-loading distribution at hub in broadening the high efficiency zone.
3.2. Flow in impellers

It can be seen from figure 6, all the stream-lines are smooth near the inlet of impeller at all flow rates for all three cases. However, they become curving near the outlet of impeller at small flow rates for case 1 and case 2, while the stream-lines for case 3 is smooth at each point. The reason is that the case 1 has the form of aft-loading distribution at shroud + aft-loading distribution at hub, and this kind of loading distribution makes the pressure gradient larger. The loading distribution at shroud in case 2 has a steep slope. The pressure in outlet of impeller is low, and thus the working capacity is decreased. Case 3 improves the suppression of secondary flows by adopted the form of fore-loading distribution at shroud + aft-loading distribution at hub and a suitable value of the slope.

**Figure 5.** The external characteristics of three kinds of cases
3.3. Vortexes in volutes
From the streamlines in the volute section (figure 7), it can be seen that the vortexes appear in the volute at all flow rates for all the cases. It shows that the secondary flow in the impeller outlet will be transferred to the downstream and affect the flow in volute. According to the results, it is also found that the vortex is small for case 3, and the vortex of case 1 is large. It is demonstrated that the form of fore-loading distribution at shroud + aft-loading distribution at hub plays an important role for suppression of vortex in volute.

**Figure 6.** The streamlines in the impeller

**Figure 7.** The streamlines on the volute section
4. Conclusions
The external characteristics and the internal flow fields for a double suction centrifugal pump with three kinds of blade loading distributions are analyzed by using CFD approach. According to the simulation results, the fore-loading distribution at shroud and aft-loading distribution at hub could improve optimal efficiency and broaden the high efficiency zone of the pump. Furthermore, the secondary flows in impeller exit region and volute are suppressed when the form of fore-loading distribution at shroud + aft-loading distribution at hub and a suitable value of the slope are adopted. In the future, it still needs to explore more excellent loading distributions for optimization.

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