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Influence of Axial Clearance on Water-Jet Axial Flow Pump

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Abstract. Three dimensional Reynolds averaged N-S equation and S-A turbulent model were adopted to simulate the flow field and hydraulic performance of the waterjet axial flow pump with the different impeller axial clearance. The numerical research results show that with the increase of axial clearance size, total pressure and static pressure rise at first and then decreases, torque and shaft power remain basically unchanged, the efficiency decreases gradually, the suction surface separation zone of stator expanded under the design condition. When the axial clearance is 30mm, the pump hydraulic performance and flow field are the best, and stator load distribution is the most uniform. When the axial clearance is 40-50mm the load of the lower part of stator leading edge is reduced greatly, which is not conducive to maintain static blade strength and maintain the stator rectifying action.

Keywords. Waterjet axial flow pump, axial clearance, hydraulic performance

1. Introduction

Appropriate axial clearance can not only improve the hydraulic performance of the axial-flow pump, but also optimize the internal flow field of the axial-flow pump and improve the anti-cavitation performance of the pump [1-3]. At present, the numerical simulation method is widely used to study the axial clearance flow phenomenon between the rotor and stator of turbomachinery. Among them, Wan [4] used variable axial clearance to study the compressor with straight and curved stator blades, and achieved good results. Zhang [5] calculated the three-dimensional flow and total performance of axial flow fan stage with different axial clearance, and he thought that the size of axial clearance has a great influence on the performance of fan stage. Zhang [6] carried out numerical calculation on small axial flow fan and concluded that the axial clearance is reduced in a certain range, the total pressure efficiency is improved, which is conducive to improving the performance of the fan. Han [7] and others have carried out the research on the influence of axial clearance on the hydraulic characteristics of counter-rotating water-jet pump. Through numerical simulation, it is found that the increase of axial clearance of counter-rotating impeller can improve the low pressure area of the first stage impeller, but it is not conducive to the secondary

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impeller to recover the fluid energy of the first stage impeller. However, the research on the effect of axial clearance on the performance and flow field of water jet axial-flow pump is still less [8-9].

In this paper, based on the existing research results, the influence of axial clearance on the flow field and hydraulic performance of water-jet axial-flow pump is studied in order to obtain the influence law of axial clearance on the flow field and performance of water jet axial-flow pump, and provide some guidance for the optimization design of water jet axial-flow pump.

2. Calculation Model and Numerical Method

2.1. Physical Model

The impeller diameter of the model is 300 mm with 5 blades. The ratio of hub to cover is 0.45. There are 9 stators. NACA airfoil is selected as the blade airfoil and the rated speed of impeller is 1450 r/min. The tip clearance is 0.3mm. The pump stage model is shown in figure 1.

2.2. Computational Domain and Boundary Conditions

The calculation domain of the axial-flow pump stage is shown in figure 2. In order to ensure the uniformity of the inflow, the axial length of the cylinder passage in front of the rotor is about 3 times of that of the rotor blade. The axial length of the cylinder passage behind the stator is about 2 times of the axial length of the stator to ensure sufficient flow.

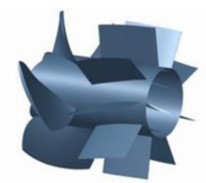


Figure 1. Three dimensional model of pump.

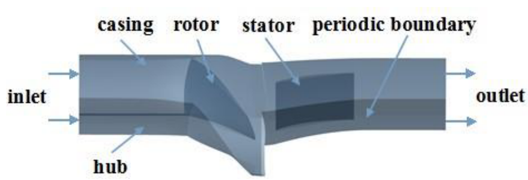
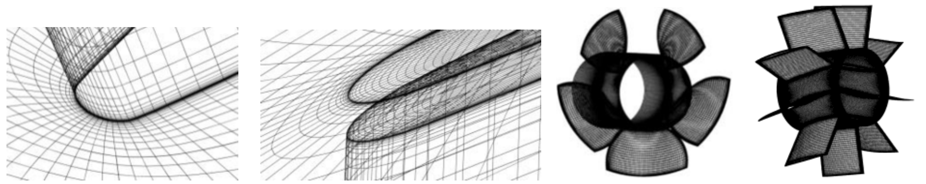


Figure 2. Calculation domain of pump stage.

In the process of numerical simulation, the boundary conditions to be dealt with are inlet, outlet, periodic and wall boundary conditions. For the inlet boundary, the total inlet pressure is 106000pa, the total inlet temperature is 293k, and the inflow direction is axial uniform. For the outlet boundary, only a given flow rate is needed, and the specific value is determined according to the working conditions. Considering the periodicity and speed of the flow, only the single channel region of the pump stage is calculated, and the rotating periodic boundary condition is used. The adiabatic non slip boundary condition is adopted for the solid wall.

2.3. Computational Grid and Numerical Method

The calculation domain grid is divided by autogrid 5 module of NUMECA. In order to control the quality of mesh generation, the computational domain is divided into two parts: rotor domain and stator domain. The O-H grid is used in the rotor and stator regions, and the O-grid is used near the blade for refinement. The tip clearance of rotor blade adopts butterfly grid, as shown in figure 3. The total number of grids in the rotor blade area is about 780000, and that in the stator blade area is about 680000. The results show that y+ of all the wall surfaces is less than 10, which meets the requirements of turbulence model [10].



(a) O-H grid near blade root (b) Tip clearance grid (c) Grid of the rotor (d) Grid of the stator

Figure 3. Computing grid.

3. Grid Independence Verification

In order to accurately reflect the change of hydraulic performance of axial-flow pump without too many grids, the models with grids of 1.26 million, 1.46 million, 1.66 million and 1.86 million are selected for grid verification when the flow rates are 440kg/s and 484kg/s respectively. The calculation results are shown in figures 4 and 5. It can be seen from the two figures that when the number of grids exceeds 1.46 million, the continuous increase of the number of grids has little effect on the hydraulic performance of the pump, and the excessive number of grids will cause periodic fluctuations in the convergence curve. This is also the reason why 1.46 million grids are selected in this paper.

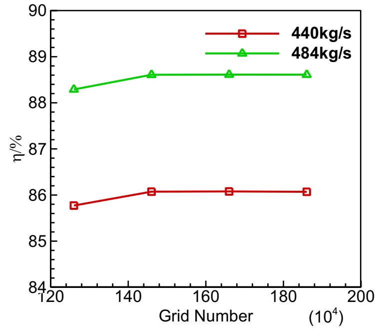


Figure 4. Efficiency vs grid number.

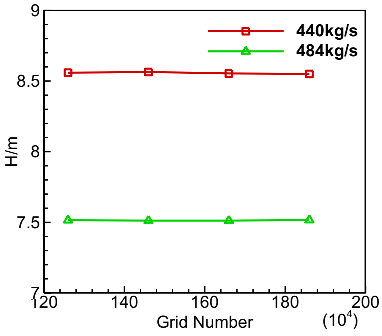


Figure 5. Head vs grid number.

4. Calculation Results

Theaxial clearance size of 20mm, 30mm, 40mm, 50mm and the flow rate of 440 kg/s, 460 kg/s, 484 kg/s, 500 kg/s, 520 kg/s were selected for numerical calculation, and the performance parameters of the water-jet axial flow pump were analyzed.

4.1. Effect of Axial Clearance on Performance of Axial Flow Pump

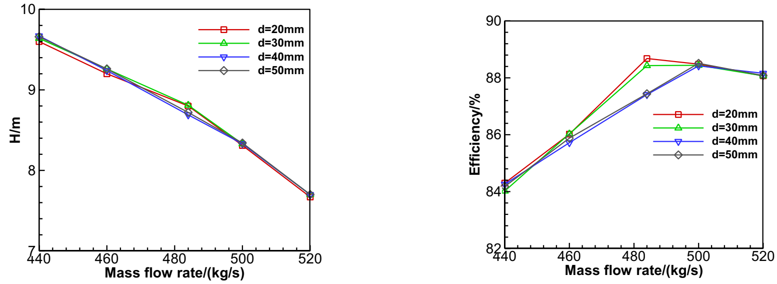
In order to study the influence of axial clearance on the hydraulic performance of the pump under the design condition (the flow rate is 484kg/s), the changes of the performance parameters of the pump under different axial clearances under the design condition are firstly analyzed, as shown in table 1.

Table 1. Parameter of pump with various axial gaps.

Clearance width (mm)	Rate of flow (kg/s)	Total pressure change (Pa)	Static pressure change (Pa)	Torque (N·m)	Shaft power (w)	Efficiency (%)
20	484	86452	82095	310.46	47141	88.675
30	484	86556	82386	311.68	47327	88.427
40	484	85348	80292	311.07	47234	87.408
50	484	85588	80507	311.4	47283	87.44

It can be seen from table 1 that under the design condition, with the increase of axial clearance the pressure rise first increase and then decrease, the torque and shaft power basically remain unchanged, but the efficiency gradually decreases. If the axial clearance increases from 20 mm to 50 mm in table 1, the total pressure efficiency decreases by 1.235%. When the axial clearance increases, the effect of the optimal clearance on the angular separation of the suction surface of the rotor is the smallest, and the flow disturbance in the blade is also the lowest, so as to improve the static pressure and total pressure of the outlet. This can be verified in the following flow field analysis.

For the variable condition, it can be seen from figure 6 that with the increase of flow rate, the pump head decreases gradually and is not affected by the axial clearance. The efficiency first increases and then decreases with the increase of flow rate, and decreases rapidly with the increase of axial clearance near the design condition. But when the axial clearance is 20 mm and 30 mm, the efficiency is higher and the difference is not big, indicating that the best axial clearance is between 20-30 mm.



(a) Head vs mass flow rate (b) Efficiency vs mass flow rate

Figure 6. variation curve of pump hydraulic performance with flow rate.

4.2. Flow Field Analysis of Impeller under Design Condition

4.2.1. Disturbance of Axial Clearance to Outlet of Rotor

In order to study the disturbance of axial clearance change on outlet of rotor, the circumferential velocity difference and axial velocity difference with blade height distribution of outlet of rotor and inlet of stator under design condition with axial clearance change are analyzed, as shown in figures 7 and 8.

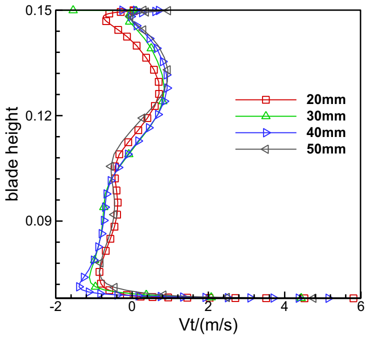


Figure 7. Distribution curve of circumferential velocity difference with blade height.

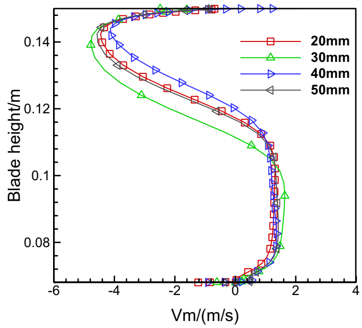


Figure 8. Distribution curve of axial velocity difference with blade height.

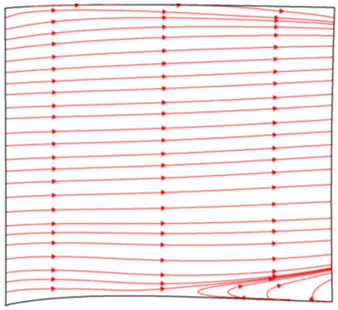
It can be seen from figures 7 and 8 that with the increase of the axial clearance, the circumferential velocity difference of the fluid behind the outlet of rotor increases positively in the upper part of the blade and negatively in the lower part of the blade. The axial velocity difference is relatively small with the increase of axial clearance, even unchanged in the lower half of the blade. Therefore, the axial clearance increases, and the range of the circumferential velocity difference increases more than that of the axial velocity difference. Furthermore, the deviation between the inlet angle of stator calculated from the average flow velocity of impeller outlet and the actual inlet angle increases, which leads to the decrease of pump efficiency.

4.2.2. Effect of Axial Clearance on Separation of Stator Blade Corner Zone

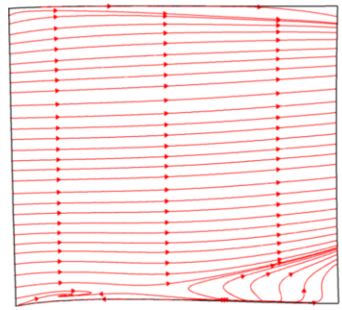
The limit streamline of suction surface of stator blade under design condition are analyzed, as shown in figure 9 (the left side of the blade is the leading edge of the blade). It can be seen from figure 9 that with the increase of the axial clearance, the angular separation of the stator expands continuously. When the axial clearance is 40mm, the separation helix appears on the suction surface of the stator, which not only causes large flow loss, but also causes cavitation more easily. Therefore, the choice of axial clearance is not easy to be too large, it should be between 20-30mm.

4.2.3. Effect of Axial Clearance on Load Distribution of Stator Blade

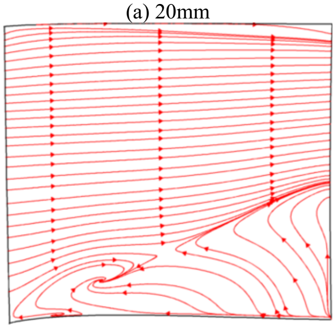
Figure 10 shows the load distribution of stator with different sections under design condition. It can be seen from figure 10 that the load distribution of the stator is similar when the axial clearance is 50% and 90% of the blade height. With the increase of chord length, the load on the stator decreases gradually, and the load distribution is relatively uniform. The blade load at 10% blade height is greatly affected by the axial clearance. The blade load distribution is uniform when the axial clearance is 20 mm and 30 mm, but the blade leading edge load decreases rapidly when the axial clearance is 40 mm and 50 mm. The reason is that the separation zone of the suction surface (as shown in figure 9) of the stator expands to the leading edge of the blade, which causes great disturbance to the flow near the suction surface. This is not conducive to maintaining the strength of the stator and the rectification effect of the stator.



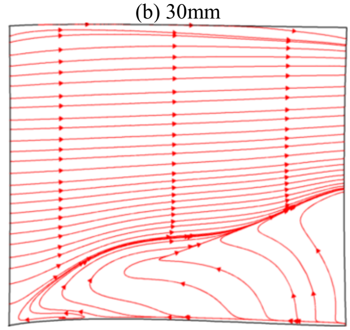
(a) 20mm



(b) 30mm

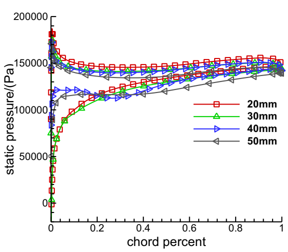


(c) 40mm

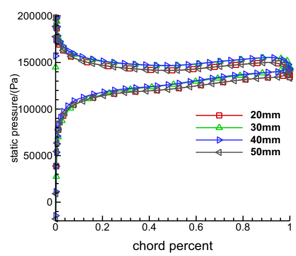


(d) 50mm

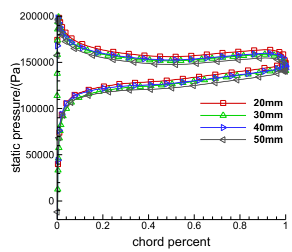
Figure 9. Limit streamline of suction surface of stator blade under design condition.



(a) 10% of blade height



(b) 50% of blade height



(c) 90% of blade height

Figure 10. Stator load distribution under design condition.

5. Conclusion

(1) Under the design condition, when the gap width is 30mm, the hydraulic performance and flow field distribution of the pump are the best, and the static blade load distribution is the most uniform.

(2) With the increase of the axial clearance, the angular separation region of the stator expands. When the axial clearance is 40mm, the separation helix appears on the suction surface of the stator, which not only causes large flow loss, but also causes cavitation more easily.

(3) The axial clearance has a great influence on the load of the lower leading edge of the stator. When the axial clearance is 20-30mm, the load distribution of the stator blade is uniform. When the axial clearance is 40-50mm, the load of the leading edge of

the stator blade decreases more. This is not conducive to maintaining the strength of the stator and the rectification effect of the stator.

Acknowledgments

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