Numerical analysis of axial-flow pump with different bell mouths

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Abstract. Based on the FVM(Finite Volume Method), standard turbulent model used to close the RANS(Reynolds Average Navier-Stokes Equations) equations and scalable wall function was adopt to treat the flow near wall, the flow pattern in the bell mouth of a certain axial-flow pump was simulated. The analyze results show that there were some vortexes and spiral flow in the bell mouth if we used traditional bell mouth which was also used in mixed-flow pump. By optimized the structure of the bell mouth, the simulated results showed that the flow pattern in the bell mouth was better than traditional bell mouth, there was no vortexes and spiral flow in the bell mouth, and the performance of the pump was also better than before. Based on the numerical simulation, the new structure of the bell mouth was proposed to be used practical engineering.

1. Introduction

The bell mouth is an important part of the axial-flow pump; it’s installed in the suction side before the impeller chamber. The bell mouth is used to guide the water and makes it flow smoothly and evenly into the inlet of the impeller. So the structure of the bell mouth has great influence on flow pattern at the inlet section of the impeller chamber, and thereby affecting the pump performance. With the development of the computational fluid dynamics (CFD), CFD technology has been used to study the condensate pump phenomena. Feng carried out numerical simulation of the cavitation occurred in the first stage impeller of the condensate pump. He get the cavitation occurring position and analyzed the volume fraction of the liquid and gas within the impeller. Because the physical model is so simple that it can not simulate the actual working conditions of the first stage impeller, further study is need to validate his simulation.

Many researchers were intent upon the design of the bell mouth and its flow condition. Lu Linguang optimized the hydraulic design of axial-flow pump intakes based on the analyzed of the bell mouths designed by main pump manufactures in China. Qiu Baoyun analyzed the influence of each factor on blade inlet flow of a large vertical axial-flow pump and its influence on pump performance. Liu Donggui designed a new bell mouth and applied in engineering project according to the inlet flow characteristic of the axial-flow pump.

Base on the engineering project requirements, the CFD technology was used to predict the pump performance and simulate the flow field in different bell mouths. With the analyze results, the optimum design of bell mouth was selected and applied in engineering projects.
2. Structure design
The traditional structure of bell mouth is signal arc with flat bottom (B1). Its structure is simple and the hydraulic performance is good, but there is always some vortex flow in it. Base on the structure of B1, 2 new bell mouths (B2, B3) were designed to optimize the flow. The 3 bell mouths are showed in the Figure 1.

![Figure 1. The structure of 3 bell mouths](image)

(a) B3  (b) B1  (c) B2

B1: Traditional design bell mouth; B2: A groove is added compared with B1; B3: 4 plates are added in the groove of B2;

The 3 bell mouths are install in a same axial-flow pump with DN1600 discharge nozzle, the design flow rate is 8.5m$^3$/s, head 6.5m.

3. Numerical analysis and performance prediction
Based on the CFD technology, numerical calculation was done to simulate the flow within the designed axial-flow pump using commercial software CFX 12.1. In the simulations, the pump model was simplified; the outlet regions were extended. The pump Calculation domain is showed in the Figure 2. Tetrahedral mesh scheme was adopted to mesh the three parts respectively. During the meshing process, the grids were refined in the domain where the geometry changes sharply. The flow field of the bell mouths ware analyzed according to the simulated results. Figure 3 shows the section plans of bell mouth, the green plan is the cross section near the impeller chamber and the purple plan is the axial section. These two plan were used to analyzed the flow velocity and streamline in the bell mouths.

The numerical calculations are carried out with a multiple frame of reference approach; the impeller flow field is solved in a rotating frame and the bell mouth and the diffuser in a fixed one. The grid for these two frames of reference ware generated separately. Frozen-rotor model was used to treat the rotating impeller and the static inlet region and stage model was used to treat the rotating impeller and the static guide vanes.

The boundary conditions were specified as follows: Inlet boundary: total pressure (stable) was specified at the inlet of the bell mouth and the relative pressure is set to 0 Pa (relative to the atmospheric atmosphere). Solid walls: For the surfaces of the blade, hub, diffuser, relative velocity components were set as zero. Also, wall function was applied. Outlet boundary: A constant mass-flow rate was specified at the outlet of the calculation domain for each computation. Various mass-flow rates were specified so as to predict the pump performance. When the convergence criterion was reached, the numerical calculation was finished and the flow within the mixed flow pump was obtained.
In performance numerical prediction, it must to study the mesh sensitivity. Table 1 is the mesh densities used in numerical prediction. The results of mesh sensitivity studies are showed in figure 4. From the figure, it can be found that the good compromise between the results accuracy and the resource requirements is the mesh density 14.9E+07. As seen, increasing the mesh density beyond 14.9E+07 does not result in a noticeable head increase.

**Table 1.** Mesh densities used in numerical prediction

| Mesh Number | 1     | 2     | 3     | 4     | 5     |
|-------------|-------|-------|-------|-------|-------|
| Mesh Density| 5.30E+06 | 9.60E+06 | 1.28E+07 | 1.49E+07 | 1.67E+07 |

**Figure 4.** Grid sensitivity test

Figure 5 shows the streamline within the pump at the flow rate of Q/Q_{opt}=1.0. It can be found that the velocity in the bell mouth of B1 is higher than B2 and B3, and the flow in the outlet of B1 uneven. Such uneven flow and high velocity inlet flow may affect the pump performance. So the flow condition in the B3 is the best compared with B2 and B1 from the streamline in the pump.

To compare the different flow conditions in different bell mouths, the streamline, velocity vector and pressure contour at the cross section and axial section plan were analyzed at the flow Q/Q_{opt}=1.0. Figure 6 shows the streamline within the bell mouths and figure 6 shows the streamline at the axial section. It can be found that the streamline in B1 is like spiral line, this will make the inlet flow of the impeller worse. And the streamlines in B2 and B3 are almost straight lines, so the water can flow axially into the impeller. In the figure 7, it can also be found that there are some vortexes in the groove of B2, but such vortexes are disappeared in B3. This means that the 4 plates in the groove of B3 destroyed the vortexes.
The streamline within the pumps

(a) B1
(b) B2
(c) B3

Figure 5.

The streamline within the bell mouths

(a) B1
(b) B2
(c) B3

Figure 6.

The streamline at the axial section of bell mouths

(a) B1
(b) B2
(c) B3

Figure 7.

The streamline at the cross section of bell mouths

(a) B1
(b) B2
(c) B3

Figure 8.

Figure 8 shows the streamline at the cross section of bell mouths. It can be found that the streamline of B1 is also like spiral shape, but the spiral disappeared in B2 and B3.

Figure 9 shows the velocity vector at the cross section of bell mouths. It can be found that the velocity vector of B1 is not parallel to the rotational axis and the velocity is high. The velocity vectors of B2 and B3 are almost parallel to the rotational axis, and the velocity of B3 is slower than B2.

Figure 10 shows the pressure contour at the cross section, it can be found that the pressure in B1 is uneven, and B2 and B3 are better.

Based on the numerical calculation, the pump performance was predicted. The pump head was calculated based on the total pressure difference at the suction of the bell mouth and the discharge flange of the pump. The shaft power was calculated according to the rotational speed and the hydraulic moment acting on the impeller. The pump performance was shown in table 2 and figure 11.
It can be found that the head of B1 and B2 does not meet the design point, and the B3 meets the design point.

![Velocity vector at cross section of bell mouths](image)

**Figure 9.** The velocity vector at the cross section of bell mouths

![Pressure contour at cross section of bell mouths](image)

**Figure 10.** The pressure contour at the cross section of bell mouths

| Parameter | Value |
|-----------|-------|
| Q/Q_{opt} | 0.5   | 0.6  | 0.7  | 0.8  | 0.9  | 1.0  | 1.1  | 1.2  |
| H_{B1}(m) | 7.89  | 7.60 | 8.76 | 8.13 | 6.95 | 5.50 | 3.57 | 1.30 |
| H_{B2}(m) | 8.27  | 7.78 | 9.23 | 8.60 | 7.46 | 6.07 | 4.21 | 2.08 |
| H_{B3}(m) | 10.33 | 8.97 | 10.09| 9.20 | 8.11 | 6.75 | 4.70 | 2.41 |

**Table 2.** The pump performance

![Pump performance](image)

**Figure 11.** The pump performance

4. Conclusions
Based on the traditional design, two new structures of bell mouths were designed and its performance was predicted using CFD simulation. According to the numerical simulation, it was found that the stream line in traditional bell mouth is like spiral line and its velocity vector is not parallel. This makes the inlet flow of the impeller uneven, and affects the pump performance. The new designed bell mouth B3 improves the flow condition in the bell mouth, makes the spiral streamline and vortexes disappear, so that the water flows smoothly and evenly into the impeller. And the pump performance is also improved to meet the design point. So the new design bell mouth B3 is chose and used in practical project.

References
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