Analysis of Internal Flow in Boiler Water Circulating Pump

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Abstract. As one of the core components of supercritical power station, boiler water circulating pump is a kind of glandless pump in which motor and pump are integrated. The circulating medium in the pump is high temperature and high pressure water. Understanding the internal flow characteristics is helpful to improve the hydraulic design of the pump. The numerical simulation of pressure distribution and streamline in the pump body of boiler water circulating pump were carried out with software ANSYS-CFX under three working conditions (0.6 Q, 1.0 Q and 1.4 Q). The results show that: The pressure near the outer wall of pump body is larger, and gradually decreases to the interior. With the decreases of cross section radius, the number of vortices increases. The vortices gradually decrease with the increase of flow rate, and the flow becomes more and more uniform. The pressure increases from the inlet pipe to the outlet pipe under different flow rates. The inlet and outlet pressure difference is inversely proportional to the flow rate. Under the condition of small flow rate and large flow rate, there are many low pressure zones in the inlet side of the blade.

1. Introduction
Boiler water circulating pump is an important component which forces circulation in supercritical power stations. The medium in the boiler water circulating pump is high temperature and high pressure water. Most of the current analysis of boiler circulating pump mainly is concentrated on the study of system fault [1]-[3], while the analysis of internal flow is scarce [4]-[6]. Fan Yizhang analyzed the pressure fluctuation in boiler water circulating pump with different inner diameters, the optimum inner diameter volute was confirmed and the efficiency was raised [7]. It was pointed out in Hideo Ohashi’s paper that the fluid dynamic action between stator and rotor would cause partial pressure fluctuation, which would cause vibration of rotating machinery [8]. This paper analyzed the internal flow of a boiler water circulating pump under three working conditions (0.6 Q, 1.0 Q and 1.4 Q), and provide some theoretical guidance for the design and improvement of boiler water circulating pump.

2. Numerical Simulation
2.1. Calculation Model
The basic parameters of the boiler water circulating pump are: design flow $Q=965 \text{ m}^3/\text{h}$, head $H=133 \text{ m}$, rotate speed $n=2950 \text{ r/min}$, number of blades $Z=6$, impeller outlet diameter $D=346 \text{ mm}$, impeller outlet width $b=40 \text{ mm}$, temperature $T=360^\circ \text{C}$, pressure $P=36 \text{ MPa}$.

Figure 1 shows a schematic diagram of boiler water circulating pump. Modeling software Pro/Engineering is used to build 3D model of boiler water circulating pump.
In order to make the flow of inlet and outlet fully developed, the inlet and outlet sections were extended. The extension was three times as long as the diameter of the inlet and outlet.

2.2. Mesh Generation
The numerical simulation of the boiler water circulating pump is carried out by ANSYS. The method used is finite volume method. In order to analyze the condition of internal flow, the flow field mesh should be generated. Considering the convergence of grid and limitation of computer performance, hexahedral mesh was adopted. In addition, considering the complexity of the swirl near the wall and the effect of the blade, the mesh of each blade is encrypted. The quality of each part of the water body divided by software ANSYS-ICEM is above 0.35, and the y+ value of the boundary layer is above 200, which is in accordance with the calculation requirements of Computational Fluid Dynamics. The assembly mesh of boiler water circulating pump is shown in Figure 2.

The mesh is checked by the grid independence which is shown in Table 1. The total number of grids is selected as 2.9×10^6 through grid independent analysis.

| Mesh Number | Forecast Head/m | Forecast Efficiency/% |
|-------------|-----------------|-----------------------|
| 2.0×10^6    | 138.0           | 80.0                  |
2.3. Numerical Calculation Method and Boundary Condition

In the actual operation of the pump, the internal flow is incompressible turbulence. In order to solve the complex flow problem under different working conditions, the k-ε model, RNG k-ε model, SST model and so on are put forward, and these models are used to calculate the corresponding practical problems. In order to obtain accurate flow in the internal flow of boiler water circulating pump, the SST model, mixed by k-ω model and k-ε model, is applied in this paper. This model has a high accuracy for the swirl near the wall calculation. The basic control equations of SST are as follows:

\[
\frac{\partial (\rho k)}{\partial t} + \frac{\partial (\rho u_i k)}{\partial x_i} = \frac{\partial}{\partial x_i} \left[ \mu + \frac{\mu_t}{\sigma_k} \frac{\partial k}{\partial x_i} \right] + P_t - \beta \rho \omega \frac{\partial \omega}{\partial x_i}
\]

\[
\frac{\partial (\rho \omega)}{\partial t} + \frac{\partial (\rho u_i \omega)}{\partial x_i} = \frac{\partial}{\partial x_i} \left[ \mu + \frac{\mu_t}{\sigma_{\omega}} \frac{\partial \omega}{\partial x_i} \right] + D_\omega + \alpha \frac{\omega}{k} P_t - \beta \rho \omega \frac{\partial \omega}{\partial x_i}
\]

The constants in the equations above are defined as follows: \( \beta^{'}=0.09 \), \( \alpha=5/9 \), \( \beta=0.075 \), \( \sigma_k =2 \), \( \rho \) represents density, \( P_t \) represents the productivity of turbulence. Boundary conditions should be set up according to the actual situation in the calculation. The flow field of the impeller was set up as Rotating Domain, whose speed was 2950r/min, and the other flow fields are set up as Stationary Domain, and the connection between the motion and static domain was set up as Frozen-Rotor. The boundary condition of inlet should be set to pressure and the outlet should be set to mass flow. The residual convergence accuracy is set to \( 10^{-5} \).

3. Analysis of Calculation Results

3.1. Analysis of Overall Pressure Distribution

The circulating medium in the boiler water circulating pump is high temperature and high pressure water, so the pump body generally adopts a hemispherical shape. However, the hemispherical shape is not conducive to the flow and diffusion of the fluid. Understanding the overall pressure distribution of the water circulating pump is helpful to improve the hydraulic design of the pump. Figure 3 shows overall pressure distribution on cross section of shaft. The pressure increases from the inlet pipe to the outlet pipe under different flow rates. The inlet and outlet pressure difference is inversely proportional to the flow rate. Under the condition of small flow rate and large flow rate, there are many low pressure zones in the inlet side of the blade.

3.2. Analysis of Internal Flow in Pump Body

The internal flow of the pump body is analyzed by four cross sections, which is shown in Figure 4. A-A cross section is axial cross section, B-B cross section is the z=150mm plane, C-C cross section is the z=-50mm plane, and D-D cross section is z=-250mm plane near the pump inlet.
Figure 5. to Figure 8. show the pressure cloud diagram of four cross sections under three working conditions (0.6 Q, 1.0 Q and 1.4 Q). It can be seen from Figure 5, the internal pressure distribution of the pump is disordered, the pressure at the bottom of the pump close to the outer wall is greater, and there is a low pressure zone in the part of the outlet section. As can be seen from the pressure cloud diagrams of B - B, C - C and D - D cross section, the pressure near the outer wall is larger, and gradually decreases to the interior, some areas have low pressure or high pressure zone. The pressure distribution is more and more uniform with the decrease of Z value (away from the inlet of the pump). Compared with different working conditions of the same cross section, the pressure distribution under large flow rate is relatively uniform.
Streamlines of cross sections A-A, B-B, C-C, and D-D are shown in Figure 9 to Figure 12. According to Figure 9, on cross section A-A, there are a lot of backflow vortices at different flow rates, which are mainly concentrated in the pump body inner ring. For B-B, C-C, D-D cross sections, as the radius of cross section decreases, the number of vortices increases. Vortices on C-C cross section are mainly concentrated in inner circle, with low flow velocity and more stagnant water area. The vortices on D-D cross section are larger and more disordered. The vortices gradually decrease with the increase of flow, and the flow becomes more and more uniform.
4. Conclusion
The internal flow in the boiler water circulating pump were analyzed by numerical simulation. The results show that
1. The pressure near the outer wall of pump body is larger, and gradually decreases to the interior. Compared with different working conditions of the same cross section, the pressure distribution under large flow rate is relatively uniform.
2. As the radius of cross section decreases, the number of vortices increases. The vortices gradually decrease with the increase of flow, and the flow becomes more and more uniform.
3. The pressure increases from the inlet pipe to the outlet pipe under different flow rates. The inlet and outlet pressure difference is inversely proportional to the flow rate. Under the condition of small flow rate and large flow rate, there are many low pressure zones in the inlet side of the blade.

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