Study on the influence of tip clearance of tidal tubular turbine on pressure pulsation of draft tube

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Abstract. With the development of clean and renewable energy, especially tidal energy, people pay more and more attention to the performance optimization of tubular turbine. Tip clearance of a tubular turbine affects the flow field at the draft tube inlet, and then affects the overall performance of the turbine. In this paper, a full-passage model is established for a bulb tubular turbine. When the tip clearance is 2mm, the variation of pressure pulsation in the different sections of draft tube and the wall surface in different working conditions are monitored. And the effect of tip clearance on the pressure pulsation in the diffusion section is analyzed. The results show that the pressure pulsation is significantly enhanced near the inlet wall of draft tube under the effect of clearance leakage flow. The main frequency amplitude of pressure pulsation on the draft tube wall decreases along the flow direction, indicating that the effect of tip clearance leakage flow on the draft tube wall decreases gradually. The amplitude of pressure pulsation under deviation condition is much larger than the optimal condition, indicating that the effect of clearance leakage vortex on the wall of diffusion section is stronger under the deviation condition. The research results provide reference for the draft tube design of the tubular turbine and the safe and stable operation of the unit.

1.Introduction

With people's attention to sustainable development, the development and utilization of renewable energy is increasingly concerned. As a kind of sustainable energy, tidal energy has the advantages of large reserves, clean and pollution-free. According to investigation and estimation, the tidal power resources of the Chinese mainland are $1.1 \times 10^8 kW$, and the annual electricity generation capacity can reach $2.75 \times 10^{11} kW \cdot H$. The development and optimization of tidal power generation device is of great significance to save fossil energy and reduce environmental pollution. Tubular turbine, as an important hydropower device using tidal energy, has good practicability and efficiency under the condition of less than 28m head and high discharge. However, with the wide application of tubular turbine, it is found that there is a gap leakage between the top of runner blade and the inner wall of runner, which will cause vibration, noise and cavitation of turbine, which has a significant hidden danger to the safe and stable operation of turbine.

At present, most of the studies focus on the influence of tip clearance on flow field inside the runner, while there are few studies on the influence of tip clearance on flow field inside draft tube. Min Z et al...
al. found that the draft tube vortex band of the tubular turbine will cause the increase of wall pressure pulsation under high flow rate. Duquesne et al. measured the pressure pulsation on the draft tube wall and found that the reduction of turbine efficiency is closely related to the flow separation in the draft tube. Meanwhile, the diffusion section plays an important role in the kinetic energy recovery of the draft tube. Buron et al. measured flow field and pressure recovery coefficient of bulb tubular turbine in draft tube diffusion section by TR-PIV technology. Qian Z et al. analyzed the influence of vortex bands in draft tube on pressure pulsation of bulb tubular turbine under different flow rates. Yang J et al. adopted LES model to study pressure pulsation caused by vortex band of Francis turbine draft tube. Wang L et al. predicted the cavitation in turbine runner and draft tube and compared the experimental results. Xia L et al. studied the evolution law of vortex bands in draft tube during transition of bulb tubular turbine. Xu H et al. demonstrated and analyzed the relationship between gap cavitation and pressure pulsation at high speed frequency by combining theory with experiment.

The above results indicate that the flow field at the draft tube inlet of a tubular turbine is not only affected by the wake of the blade and the vortex generated by the runner, but also by the tip clearance leakage. In this paper, a bulb tubular turbine is taken as the research object. Testing points are arranged at equal spacing on different sections and walls of the diffusion section to monitor pressure pulsation in draft tube under optimum and offset conditions with blade-top clearance of 2mm. The effect of blade-top clearance of the runner on pressure pulsation in draft tube diffusion section is analyzed so as to design draft tube of the tubular turbine and ensure safe and stable operation of the unit. Provide reference.

2. Calculation model and numerical calculation method

In this paper, a bulb tubular turbine is selected to establish the geometric model of the full flow channel. See Table 1 for main parameters of turbine. Figure 1 shows the main structure of a tubular turbine. The diameter of the model runner is $D_1=0.38m$. The gap width between the top of the blade and the runner chamber is represented by 2 mm in this paper.

| project                     | numerical value |
|-----------------------------|-----------------|
| Guide vane number           | $Z_g = 16$      |
| Number of runner blades     | $Z_b=3$         |
| wheel diameter              | $D_1=0.38m$     |
| Guide blade opening range   | $0^\circ$ to $80^\circ$ |
| Blade opening range         | $-15^\circ$ to $20^\circ$ |

The main flow through components of the bulb-type tubular turbine are all divided by hexahedral structured grid, but the grid between runner and draft tube needs to be dense. In addition, the grid at the tip clearance is densified. The related schematic diagram is shown in Figure 1.
For turbine, the boundary condition is set as mass flow inlet and outlet static pressure is 1 atm. The runner is in the rotating area and the rotating angular speed is determined by the unit speed. The wall and blade are set to be no-slip wall. The turbulence model is selected as the SS-CC model. The interface between guide vane and runner, runner and draft tube is selected as static and dynamic interface in numerical calculation and the interface between inlet section and guide vane is static and static interface. The calculation is simulated by an unsteady value. The calculated time step is the corresponding time interval of 3 degree rotation of the runner and the convergence standard is RMS 10^-4. Information on operating points of tubular turbine is shown in Table 2.

| Table 2. Simulation conditions of tubular turbine |
|-----------------------------------------------|
| Operating point | Optimum operating condition | Offset operating condition |
| Guide blade opening (°) | 62 | 74 |
| Q_{11}(m^3/s) | Q^{*11}=2.17 | 1.41Q^{*11} |
| N_{11}(rpm) | N^{*11}=199.86 | 1.48N^{*11} |

3. Analysis of pressure pulsation in draft tube

Figure 2 is the layout diagram of the draft tube monitoring points. The monitoring points at the inlet, middle and outlet of the axial section of the diffusion section are arranged with equal spacing along the radial direction, which are A1 ~ A6, B1 ~ B6 and C1 ~ C6 respectively. Four monitoring points D1 ~ D4 are arranged at equal intervals on the wall of the diffusion section.

Figure 3 shows the pressure pulsation frequency domain of the first set of monitoring points along the axis in the diffusion section. It can be seen from the diagram that the frequency domain of pressure pulsation at each monitoring point is symmetrically distributed with respect to the principal axis, and the principal frequency of pressure pulsation under the optimum operating condition is 3 times of the shaft frequency. Due to the influence of draft tube eddy band, the pressure pulsation amplitude at A3 and A4 monitoring points is large. The pressure pulsation amplitude at A2 and A5 monitoring points decreases significantly, indicating that the effect of vortex bands has been weakened. The pressure pulsation amplitude at A1 and A6 monitoring points increases significantly, even exceeds the pressure pulsation amplitude at the middle position, which indicates that the clearance leakage vortexes have a great influence on the pressure pulsation. The amplitude change of pressure ripple at inlet under partial condition is similar to that under optimum condition, the main difference is that the main frequency of pressure ripple at A3 and A4 monitoring points is 0.5 times of shaft frequency under partial condition.
Figure 3. Frequency domain diagram of pressure pulsation in draft tube diffusion section under different conditions at the first group of monitoring points.

Figure 4 shows the frequency domain diagram of pressure pulsation at the second and third monitoring points along the axis in the diffusion section. In the second group of monitoring points, the pressure pulsation amplitude at the optimum condition is reduced, but the main frequency of pressure pulsation at B4 and B5 monitoring points under partial condition is basically the same as that at the first group. In the third group of monitoring points, the amplitude of pressure pulsation under the optimum operating condition is not obvious, and the pressure pulsation under the offset condition is much reduced. For the last two groups of monitoring points, pressure pulsations are mainly concentrated at B3 and B4 monitoring points in the middle position, indicating that the pressure pulsation amplitude near the wall has basically disappeared, and the clearance leakage vortices have little effect on the flow near the wall at this position.
From the above three sets of pressure pulsation analysis along the axial direction of the diffusion section, it is found that the amplitude of pressure pulsation gradually decreases along the axial direction from the inlet. The clearance leakage vortices have a significant influence on pressure pulsation near the wall at the draft tube inlet, but have a small influence on the middle and rear of the draft tube diffusion section. The pressure pulsation in the middle position is mainly related to the eddy band of draft tube. Under different operating conditions, the shape and frequency of the eddy band are different.

Figure 5 shows the frequency domain diagram of pressure pulsation at the monitoring point of draft tube wall. Except for the difference of pressure pulsation amplitude, the main frequency of pressure pulsation is 3 times of shaft frequency, and gradually decreases along the axis. It shows that the effect of tip clearance leakage flow of runner on wall surface is weakening along the axial direction.

Figure 5. Frequency domain diagram of pressure pulsations on the wall of the draft section

In Figure 6, the main frequency amplitudes of pressure pulsations under two operating conditions are compared. The amplitude of pressure pulsation under partial conditions is much larger at each monitoring point than under optimal conditions. It is shown that the influence of clearance leakage vortices on the wall of diffusion section under offset condition is stronger than that under optimum condition.

Figure 6. Amplitude of wall pressure pulsation in draft tube diffusion section

4. Conclusion
In this paper, the influence of tip clearance on pressure pulsation inside draft tube is analyzed, especially the inlet of draft tube diffusion section, which plays an important role in kinetic energy recovery of draft tube. The main conclusions are as follows:
(1) The influence of tip clearance leakage flow on pressure pulsation in draft tube diffusion section is studied. At the inlet of the draft tube near the wall, the pressure pulsation is significantly enhanced under the effect of clearance leakage flow.

(2) By monitoring the pressure pulsation on the wall of draft tube diffusion section, it is found that the main frequency amplitude of pressure pulsation on the wall decreases continuously along the flow direction, which indicates that the effect of tip clearance leakage flow on the wall of draft tube is gradually weakened.

(3) By comparing the main frequency amplitude of pressure pulsation under two conditions, it is found that the amplitude of pressure pulsation under deviation condition is much larger than that under optimal condition, which indicates that the influence of clearance leakage vortices on the wall of diffusion section is stronger under offset condition.

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