Numerical Simulation and Research of the Axial Flow Fish-friendly Turbine in Plateau Area

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Abstract: Based on the design methods of fish friendly hydraulic turbines at home and abroad and traditional hydraulic turbines, this paper designs an axial flow fish friendly hydraulic turbine in plateau area by using Unigraphics NX. The steady-state simulation of the turbine is carried out by fluent, and the energy characteristics of the three blade runner are analyzed. Through the transient computation, the pressure fluctuation characteristics in the leafless area of the turbine with guide vane opening of 18.2 ° and 14.2 ° are studied, and the fish passing characteristics are analyzed. Compared with the evaluation criteria of fish friendly water turbine, the variation rate of pressure obtained is less than 550.3kpa/s, which meets the design criteria of fish friendly water turbine and basically meets the demand of fish passing down the dam.

Key words: Plateau area, Fish-friendly, Axial flow turbine, pressure pulsation, design criteria

1. Introduction

At present, both at home and abroad are making great efforts to study fish friendly water turbines that can generate electricity efficiently and help fish go down safely[1-4]. The design and research of fish friendly water turbine by researchers mainly start from the following ideas: ① Determine the design and evaluation criteria, including: determine the fish passing target survival rate, and determine the target efficiency of the turbine;② Preliminary calculation of the overall dimensions of the turbine and three-dimensional geometric modeling;③ Using CFD technology to simulate the flow field of hydraulic turbine, according to the calculation results, the hydraulic turbine is optimized, so that the above-mentioned mechanical, pressure, shear force, cavitation and other factors can meet the requirements of the survival rate of the target fish body, and also meet the efficiency target of the hydraulic turbine[5-8].

In order to complete the fish friendly design of water turbine, AHTS team established two teams, ARL/NREC and Voith, to evaluate the mortality and cause of death of fish flowing through water turbine, and put forward new ideas in the direction of water turbine design. The ARL/NREC team proposed a new type of turbine that almost broke the traditional cognition. They started from the single channel commercial spiral runner design. Because the runner can be used to transport fish safely, the team took the runner as the design basis, optimized and improved the new runner repeatedly through two-dimensional design and three-dimensional CFD analysis. The Voith team

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is to optimize the design of the existing turbines, and put forward improvement plans for the rotor turbine and the Francis turbine respectively. Through the three-dimensional CFD simulation analysis of the flow pattern change in the channel and the performance of the fish passing characteristics of the turbine, the improvement and optimization are carried out strictly in accordance with the fish friendly turbine standard[9,10].

The altitude of plateau area is high. When fish pass through the turbine, the possible damage caused by hydraulic factors is also greatly different from that in low altitude areas. In this paper, the CFD model of fish friendly hydraulic turbine is established by using fluent and other related CFD software, and the numerical simulation of the fish passing characteristics of the axial flow fish friendly hydraulic turbine in the plateau area is carried out. Find out the best efficiency point of fish friendly turbine by analyzing the operation characteristics of fish friendly turbines, choosing two different working conditions to analyze the internal flow pattern change of fish friendly turbine and its impact on fish. And the differences between working conditions are compared, so as to obtain a relatively reasonable and comprehensive fish passing characteristics of fish friendly turbine.

2. Model establishment and boundary conditions

2.1 Turbulence model

In turbulence numerical simulation, standard k-ε model, RNG k-ε model and realizable k-ε model are widely used in engineering and research. In RNG k-ε model, the viscosity term is modified, and the influence of small-scale is expressed by viscosity term and large-scale motion, so the small-scale motion system is omitted from the control equation.

Compared with standard k-ε model, RNG k-ε model modifies the dynamic viscosity of turbulence, so that the swirling flow is included in the average flow calculation and a term reflecting the time average strain rate of the main flow is added to the ε equation. Therefore, RNG k-ε model can be better applied to flow calculation with high strain rate and sharp change of streamline, and better simulation results can be obtained. In this paper, RNG k-ε model is selected as the turbulence model.

2.2 Geometric model and mesh generation

The three-dimensional blade modeling in this design does not consider the problem of blade airfoil temporarily, and this paper adopts three blades with equal thickness. The three-dimensional shape of the blade is controlled by helix. Three logarithmic helices are selected as the guide line of the three-dimensional runner blade, and the three logarithmic helices correspond to the intersection of the blade, hub and shroud, and adjust the runner blade according to the triangle angle of inlet and outlet speed obtained above. The initial three-dimensional model of fish friendly
turbine runner established by Unigraphics NX is shown in Figure 1.

![3D model of fish friendly turbine]

Considering the calculation capacity of the workstation and the subsequent calculation settings, this grid division divides the turbine model into four parts: spiral casing area, guide vane area, runner area and draft tube area, and makes unstructured grid division with stronger grid adaptability for the four parts of the model watershed. After grid independence verification, the components of the model after grid division are shown in Figure 2.

![Grid diagram of each part of turbine]

**2.3 Boundary condition setting**

The boundary condition of pressure inlet and pressure outlet is adopted, and the influence of external atmospheric pressure is not considered. The working head of hydraulic turbine is converted into the pressure inlet, and the static pressure of outlet is set as 0. During the steady-state operation of the turbine, the runner part rotates at a constant speed of \( n = 70 \text{r/min} \). MRF model is used for steady-state calculation and sliding grid model is used for transient calculation, other parts adopt the default wall boundary conditions.

Since this calculation is for the axial-flow units in the plateau area, the physical properties of the water are set according to table 2-1.

| Temperature(°C) | density(kg/m³) | Dynamic viscosity(kg/m/s) | Coefficient of thermal conductivity(W/m) |
|----------------|---------------|---------------------------|----------------------------------------|

![Table 2-1 comparison of water physical properties in Linzhi Area]
**2.4 Solution condition setting**

In order to obtain faster calculation speed and save calculation time, the first-order upwind scheme is adopted in calculation. In the numerical solution, SIMPLEC algorithm is used to couple the velocity and pressure in the turbulent flow field; setting 0.0001 as the residual to ensure the accuracy of calculation; monitoring the residual, total outlet pressure and torque change, when the monitoring parameters tend to be stable or show periodic fluctuations, the calculation can be considered as convergence.

**3. Analysis of calculation results of fish-friendly turbine in plateau area**

**3.1 Energy characteristics of fish friendly turbine**

In this paper, the optimized turbine model is a new turbine model which combines the design of traditional turbine and fish friendly turbine, so its operation characteristics have not been known. In order to find the optimal efficiency point of the new type of fish friendly turbine, this study mainly tests the operation characteristics of the turbine from two aspects of head and opening, and obtains the law of the efficiency of the turbine changing with head and opening through numerical calculation.

![Variation curve of turbine efficiency with water head](image)

**Fig. 3 Variation curve of turbine efficiency with water head**

The design head of the water turbine is 25.6m. With the change of the head, the efficiency of the water turbine will change. The water heads of 20.6m, 23.1m, 25.6m, 28.1m and 30.6m are respectively taken for calculation, and the variation curve of the efficiency of fish friendly turbine with the effective head of the turbine under the guide vane opening of 18.2° is shown in Figure 3. When the head is 25.6m, the efficiency of the turbine is the highest. When the head increases or decreases, the efficiency of the runner decreases. It is preliminarily concluded that the optimal efficiency head of the fish friendly turbine is 25.6m. The movable guide vane of hydraulic turbine
controls the output of hydraulic turbine mainly by controlling the flow of hydraulic turbine, and its opening will affect the efficiency of hydraulic turbine to a certain extent. In order to find the optimal opening point of hydraulic turbine, under the optimal head of 25.6m, the steady-state numerical simulation is carried out at 18.2°, 16.2°, 14.2°, 12.2° and 22.2° near the design opening of 20.2° respectively, The calculated total efficiency of the turbine is shown in Figure 4, but the optimal opening of the turbine deviates from the design opening, and the turbine reaches the highest efficiency at 18.2°.

![Fig. 4 Variation curve of turbine efficiency with guide vane opening](image)

3.2 Pressure fluctuation characteristics in leafless area of fish friendly turbine

In order to analyze the influence of pressure and pressure change rate on fish passing through the turbine, the flow field of the turbine is calculated and analyzed. Select turbine operation condition 1 with guide vane opening of 18.2° and turbine operation condition 2 with guide vane opening of 14.2° as shown in Figure 4, to monitor the pressure fluctuation in the center of the leafless area and the center of the draft tube, and figure 5 shows the positions of the leafless area monitoring point (V6) and the draft tube monitoring point (D8).

![Fig. 5 Leafless area monitoring point (V6) and draft tube monitoring point (D8)](image)

Carry out transient simulation for condition 1 and 2 respectively for 8s, and monitor the...
pressure change of measuring points V6 and D8. The results are shown in Fig. 6 and Fig. 7. The amplitude of the pressure fluctuation in the leafless area of condition 1 is higher than that in condition 2, and the rate of pressure change with time is kept below 550kpa/s, basically in line with the criteria of fish friendly turbine. The pressure fluctuation in the draft tube area is relatively disordered, but the overall change amplitude is less than 10kpa. In the 8s simulation process, the pressure fluctuation in the leafless area and draft tube of condition 1 is relatively stable, and that in the leafless area and draft tube of condition 2 is relatively unstable. The results show that the operation condition of condition 1 is better than that of condition 2.

Fig. 6 Comparison of pressure fluctuation in leafless area
4. Conclusion

This paper designs an axial-flow fish friendly turbine in plateau area based on the traditional axial-flow turbine. Through the steady-state calculation, the energy characteristics of the three blade runner are analyzed. At the same time, through transient calculation, the influence of pressure change on fish passing characteristics is analyzed. The results are as follows:

(1) The guide vane opening of 18.2° is the optimal efficiency point of the turbine, with a water head of 25.6m. Under this condition, the steady-state calculation efficiency of the turbine is 83.99%, and the average efficiency in the transient calculation is 89.53%.

(2) Under the optimal condition 1 (guide vane opening 18.2°) and the condition 2 (guide vane opening 14.2°) which deviates from the optimal condition, the change rate of pressure with time is kept below 550kpa / s, basically in line with the criteria of fish friendly turbine.

(3) Compared with condition 1, the pressure fluctuation of leafless area and draft tube in condition 2 is not stable. The results show that the operation condition of condition 1 is better than that of condition 2.

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