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Influences of Guide Vanes Airfoil on Hydraulic Turbine Runner Performance

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Abstract

The 4 different kinds of guide vanes airfoil turbines are used as objects, and under the same dimensions of the turbine wheel (high-pressure side diameter, low-pressure side diameter, and blade width of inlet, outlet placement angle and number of blades) and the same design, numerical simulations were performed for turbines by using software FLUENT 6.3. The experiment shows that the blade pressure surface and suction surface pressure is low when the hydraulic turbine installations were added standard positive curvature of the guide vane and modified positive curvature of guide vane. Therefore, the efficiency of energy recovery is low. However, the pressure of negative curvature guide vane and symmetric guide vane added on hydraulic turbine installations is larger than that of former ones, and it is conducive to working of runner. With the decreasing of guide vane opening, increasing of inlet angle, flow state gets significantly worse and obvious reflux and horizontal flow appeared in blade pressure surface. At the same time, the vortex was formed in Leaf Road, Leading to the loss of energy.

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Keywords: hydraulic turbine; guide vane airfoil; runner; performance; numerical simulation;

1. Introduction

Hydraulic turbine is an energy recovery device-specific the rotating runner of which is driven by high-pressure fluid, and the fluid pressure is converted to the mechanical energy. In this structure, the internal space of the Hydraulic turbine is separated into two parts, a high-pressure chamber Sandy Bay and low-pressure chamber by Runner and Shell Sandy Bay. The runner is driven by pressure of the High-pressure

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fluid when the latter flows through it. So that the runner gains kinetic energy, the hydraulic turbine spindle transfers the energy into the motor or other motive by beyond the clutch, in order to achieve excess energy recycle[1]. Figure 1.

![Diagram of the hydraulic turbine energy recovery system](image1)

The current design of Hydraulic turbine is not perfect, then this study is aimed to shorten product design cycles, to reduce the design costs and to improve the efficiency of energy recovery by adding different guide vanes airfoil to explore that influences of them on hydraulic turbine runner performance. Choosing the appropriate hydraulic turbine guide vanes has important reference value to structural optimization and performance prediction of hydraulic turbine in future.

2. Research Program

In order to explore that influence of the structure of the hydraulic impact on turbine hydraulic performance, after research and analysis, the standard vane positive curvature (program I), a variant of the guide vane positive curvature (program II), negative curvature guide vane (program III) and symmetrical guide vanes (program IV) was added on the components of water of the hydraulic turbine to study its performance. The airfoil section shown in Figure 2. In view of the shape of the airfoil vane influence on flows, in this study, the airfoil thickness and guide vane head was specially designed, using the traditional thick head is not conducive to flow around the guide vane flow, there is serious loss of energy at guide vanes head, therefore, the head trimming and airfoil thinning of the guide vanes are used as objects in program II, III IV to lower the flow velocity in the guide vanes back of the head and reduce the hydraulic losses of over-current components and improve the flow state within the runner, and then to find concrete solutions to optimize structure of hydraulic turbine.

![Airfoil section](image2)

2.1. The basic parameters and mode of dual channel hydraulic turbine model

In this research, solid modeling were performed for study object turbines by using software pro/E, and then to divide adaptable unstructured grid using GAMBIT, input it to FLUENT6.3 software to conduct
numerical simulations for internal flow of energy recovery hydraulic turbine. Among of them, as shown in Figure 3, the 3-D model of runner and the 3-D model overall hydraulic turbines shapes.

Tab. 1. Performance parameters of turbine runners

| Parameter       | Design Flow Q/ m³/h | Design head H/m | Speed n/r/min | The number of guide vanes z₀/a | Vane height h/mm | Vane circle diameter D₀/mm | Nominal wheel straight D₀/mm | Rotor blades z₀/a |
|-----------------|---------------------|-----------------|---------------|-------------------------------|-----------------|-----------------------------|------------------------|-----------------|
| Value           | 600                 | 70              | 2980          | 16                            | 44              | 215                         | 180                    | 16              |

Fig. 3. the 3-D model of runner and the 3-D model overall hydraulic turbines shape

2.2. Numerical Simulation

Equations are used in our study, including the continuity equation, Reynolds time-averaged Navier-Stokes equations (RANS) [2]. The standard k-ε model is used as Turbulence model. In order to realize coupled solvers of the pressure field and velocity field, we use the SIMPLEC algorithm.

Inlet conditions: speed inlet conditions was adopted, Assuming velocity distribution uniform of inlet, the Specific numbers depend on the flow and the area ratio of inlet [3].

3. Results and Analysis

In order to explore that influence of the guide vanes airfoil on hydraulic turbine performance, we conduct numerical analysis to hydraulic turbine that was added standard Positive curvature guide vanes (program I ), negative curvature of the guide vane (program III) and the symmetrical guide vanes (solution IV).

3.1. Optimal conditions (pressure unit: Pa; speed unit: m / s)

In the optimal operating point, we can know that overall pressure is gradually reduced from the blade pressure side to the suction side through analyzing rotor blade surface pressure distribution of design program. there are same direction between the force formed by the pressure that is pressure side and suction side with rotation, Pressure also showed a regular downward trend from inlet to outlet on the same surface of the vane, which complete comply with the acting principle of the hydraulic turbine. In the programs, the pressure is basically parallel to the inlet and outlet water contour of blade, and Isobar in vane pressure side perpendicular to the direction flow line.

The area is small in blade suction surface of low pressure area, and it basically distribute on the vicinity of vane water's edge [4]. We can know from the fig. 4 of velocity vector, the velocity distribution is very uniform on pressure side and suction surface, Hydraulic turbine runner relative velocity of the
flow of inlet and vane bones and tangent direction, Runner outlet flow is normal, uniform fluid flow from the edge of blade inlet to the outlet side, there is no obvious phenomenon is separation flow, back flow, secondary flow, the overall flow line is smooth.

Figure 4. runner flow characteristics in optimal conditions Ⅰ～Ⅳ regional program (pressure distribution and velocity vector)

3.2. High flow conditions (pressure unit: Pa; speed unit: m/s)

In the large flow operating point, there is a high-pressure area at the pressure side diaphragm in the program Ⅰ，Ⅱ，Ⅲ, program Ⅱ have the largest area of high pressure, causing the blade suction surface of the inlet pressure is higher than the corresponding pressure surface pressure, which is not conducive to energy conversion, while in the program Ⅲ, the Pressure distribution is still uniform on the pressure side; The suction side pressure distribution are relatively uniform, the overall situation is better. The velocity distribution is basically uniform and good on pressure surface in the programs, and flow lines is smooth. but there is less lateral flow and no other second flow phenomena, such as flow separation and secondary flow back. as head vanes smaller inflow of negative angle of water flow on the blade suction surface has a negative impact, so the separation blade pressure surface, especially at the clapboard, the speed distribution appear varying degrees disorder, increasing the hydro loss.

3.3. Low flow conditions (pressure unit: Pa; speed unit: m/s)

In low Flow conditions point, pressure of the blade pressure side is Uniform reduce from the blade into the face to the water's edge the water's edge in every Design program, contour smooth transition, no
significant mutations, compared with the optimal conditions of pressure and large flow more evenly distributed, but the part negative pressure zone appeared at the edge of the surface water in the pressure; its negative pressure at suction side of the waterfront area is increasing significantly In the program I, II, III, Severe cases, it will cause to cavitation damage at the Blade water's edge, affect the normal operation of hydraulic turbine, and in the program IV, Its the negative pressure area relatively small at the suction side of water's edge.

Overall, the pressure is small in the blade pressure surface and suction surface the program I, II, so the energy recovery efficiency is low; however, the pressure is higher than the previous two programs in the program II, III, it is conducive to working of runner. With the decrease of guide vane opening, increasing of inlet angle, flow state gets significantly worse, the phenomena that obvious reflux and horizontal flow appeared in blade pressure surface. At the same time, the vortex was formed in Leaf Road, Leading to the loss of energy.

Fig. 6. wheel low flow conditions I ~ IV regional program flow characteristics (pressure distribution and velocity vector)

3.3. Performance curve of runner under the different airfoil

Runner efficiency can be calculated according to the following two methods: According to the definition of the head can Calculate actual head

\[ H = \frac{P_1 - P_0}{\rho g} + z_1 - z_2 \]

(1)

Hydraulic efficiency of the hydraulic turbine

\[ \eta_b = \frac{M \omega}{q \cdot \rho g H} \]

(2)

Taking into account the volume loss and mechanical losses, the efficiency of hydraulic turbine

\[ \eta = 0.995 \eta_b \]

(3)

Or using equation ( 4) to calculate

\[ \eta = \frac{P_{out}}{P_{in}} = \frac{M \omega}{\Delta P \cdot Q} \]

(4)

Where: to read the relevant parameters, Report function in Fluent software can is used, obtained combined M of the runner torque around the axis and flow Q of hydraulic turbine runner. Calculate guide
vane rate of efficiency at different flow in every design program [5], establish the relationship between flow and efficiency shown in Figure 7.

Fig.7. Performance curve of turbine runners

Through Comparing and analyzing the pressure distribution, velocity distribution, streamline distribution which are main acting parts runner flow region and the relationship between flow and efficiency in every program, taking into account the practical application of hydraulic turbine, which runs most of the time in the design flow and small flow operating point, almost impossible to have a large flow operating point, so the program Ⅲ used in the study design is more suitable for engineering applications.

4. Conclusion

The flow of optimal operating point for the design program is basically the design flow, meeting the design requirements, the maximum efficiency of the hydraulic turbine is 83.88% at \( H = 70 \text{m}, Q = 0.165 \text{m}^3/\text{s} \) in the program Ⅳ.

The blade pressure surface and suction surface pressure is low when the hydraulic turbine installations was added standard positive curvature of the guide vane and modified positive curvature of guide vane. Therefore, the efficiency of energy recovery is low. However, the pressure of negative curvature guide vane and symmetric guide vane added on hydraulic turbine installations is larger than that of former ones, and it is conducive to working of runner, With the decrease of guide vane opening, increasing of inlet angle, flow state gets significantly worse, the phenomena that obvious reflux and horizontal flow appeared in blade pressure surface. At the same time, the vortex was formed in leaf road, leading to the loss of energy.

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