

Analysis on hydraulic characteristics of Kaplan water turbine with different spiral casing and stay vane

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Abstract. This paper introduces a water turbine which is used to recycle rich energy for hydraulic cooling towers. That cooling tower's head are from a few meters to more than ten meters, and mass flow is from 300t/h to 1300t/h. The water turbine has a small radius size, a long and narrow flow passage and higher velocity, so the hydraulic loss in spiral casing and stay vane is too high to decrease the hydraulic efficiency. To decrease hydraulic loss, three diversion components with different spiral casing and stay vanes are introduced. When the radial dimension of the spiral casing is same, the double-spiral casing with the same rectangle section, a spiral casing with same rectangle section and stay vane, and a common spiral casing according to the same circumferential velocity rules are designed. The simulation results show that the hydraulic efficiency of the water turbine for same rectangle section spiral casing and stay vane is highest, and that for constant circumferential velocity spiral casing is lowest in low mass flow zone. In the high mass flow zone, hydraulic efficiency for double-spiral casing with same rectangle section is highest, and that for same rectangle section spiral casing is lowest. The double spiral casing is better than that with constant circumferential velocity for this micro Kaplan turbine.

1. Introduction

The water cooling towers are widely used in area of electricity, oil, chemical, steel and pharmaceuticals. There is from 4 to 15 meter head rich hydraulic power at the re-circulation cooling water outlet in cooling tower^[1]. If that cooling water pours into micro water turbine connected by fan, the electric motor driving fan is canceled. China has one hundred and thirty million amount of water in traditional water cooling towers. If the water turbine is used to that traditional water cooling tower, It's amazing project to save energy.

The special turbine is installed in series connection of circulating cooling water system. The flow rate depends on cooling water rate beyond $0.06 \text{ m}^3/\text{s} \sim 1.3 \text{ m}^3/\text{s}$. The rotating speed hinges on fan speed beyond 100r/min~250r/min. The output is lower, so specific speed stays at 40m.kw ~60m.kw. Since the conversion energy is less, high hydraulic efficiency of water turbine is expected. At the same time, small working room in cooling power requires smaller size turbine, so Kaplan or Francis turbine can be chosen and Kaplan turbine a brighter application prospect^[2-4].

Such as water turbine applied in cooling tower, the hydraulic loss mainly focuses on diversion component and runner^[5-7], this paper chooses three different diversion components to match the same Kaplan turbine runner to discovery the hydraulic efficiency. In the view of a good application of CFD



about predicting hydraulic efficiency in hydraulic machinery field and this water turbine is a small size, CFD is used to simulate flow field of Kaplan turbine and analyze hydraulic characteristics.

2. Diversion components introduction

To study the hydraulic efficiency of Kaplan turbine with low head and special speed, three diversion components with same outer radial dimension are designed, seeing figure 1.

Figure 1 (a) shows that diversion components consist of spiral casing and stay vanes set in axial flow passage. The maximum radius of spiral casing is 1.22 times longer than that of runner. The section of spiral casing is a rectangle section with a same area. Under a certain axial height at spiral casing inlet, the horizontal size is wider to decrease flow speed and mass flow at front of spiral casing. Limiting to the axial stay vanes and keeping an appropriate circulation at front of spiral casing, that horizontal size is 0.75 times longer than runner radius's. To simplify the structure of stay vanes, the single airfoil section is chosen.

Figure 1 (b) shows that diversion component is a traditional spiral casing. The spiral casing section is rectangle with decreasing area to get a same circumferential velocity. The maximum radius of spiral casing is 1.22 times longer than runner radius, and the horizontal size of inlet is 0.61 times longer than runner radius's.

Figure 1 (c) shows that diversion component is double spiral casing with same section. Basing on the design of figure 1 (a), the stay vanes is cancel, the horizontal size at inlet is little more than that showing figure 1 (a).

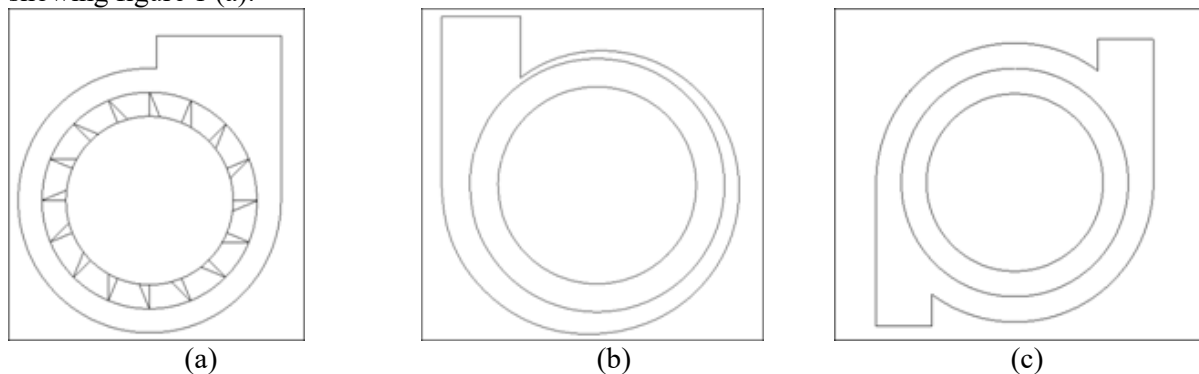


Figure 1. three diversion components

3. Numerical method

The runner diameter of Kaplan turbine is 0.45 meter and blade number is 24. The draft tube is a circular tube to connect sprayer to cool water. Three diversion components are shown in figure 1. This simulation geometry model includes diversion component, runner and draft tube passages dispersed by the non-structural mesh. The mesh number of diversion component, runner and draft tube is separately 2,000,000, 400,000 and 360,000.

The 3D-steady Navier-Stokes equations with standard k- ϵ turbulence closure models are applied to simulate Kaplan turbine flow field. Since the turbine has no guide vane, the rotating speed, output and head all are relative to mass flow, the inlet boundary condition is mass flow, and the outlet boundary condition is zero pressure. The rotating speed is 240 r/min. Five computing operating conditions are chosen that mass flow is separately 139, 169, 199 and 222.2 kg/s. The mass flow with 169kg/s is a designed one.

4. Simulation result

Through the steady flow simulation, the hydraulic characteristics of water turbine with above three diversion components can be concluded, and simulating flow field can be drawn, showing the following figure 2 to figure 7.

4.1. Result of diversion component with spiral casing and stay vanes

Through line *a* on figure 2, the hydraulic efficiency of Kaplan turbine reaches to 83% at small mass flow area, and decrease quickly on large mass flow area. The spiral casing hydraulic loss is about 4%, the stay vanes's is about 9%, and the runner's changes from 5.37% to 9.84% on operating conditions area, shown in figure 3. The hydraulic efficiency changes a lot on large mass flow area because runner hydraulic loss changes quickly, and is low because of high hydraulic loss of diversion component. The same rectangle section of spiral casing causes nonuniform circumferential velocity, circumferential velocity at front of spiral casing is high and circumferential velocity at tail of spiral casing is low, seeing figure 4. That nonuniform circumferential velocity and high velocity in spiral casing cause to a high hydraulic loss and a large angle of attack on runner blade inlet, so the hydraulic loss is lower than traditional water turbine.

4.2. Result of diversion component with traditional spiral casing

Line *b* on figure 2 is about water turbine with traditional spiral casing, the hydraulic efficiency is lower than line *a* on low mass flow area, and higher than that on high mass flow area. On low mass flow area, the difference of two hydraulic efficiency is 6%. From figure 5 and figure 6, the output and head of water turbine with traditional spiral casing is lower than that with same section spiral casing and stay vanes. So the water turbine with same section spiral casing and stay vanes is optional if the designed mass flow is small.

4.3. Result of diversion component with double spiral casing

The double spiral casing is designed to uniform circumferential velocity. To simplifying the structure of water turbine, no stay vane is designed, so hydraulic efficiency is highest among three diversion components on large mass flow area and similar to the water turbine with traditional spiral casing, seeing line *c* on figure 2.

The hydraulic loss of water turbine with double spiral casing is similar to that turbine with traditional spiral casing, and it is about 12% and changes little with the mass flow, seeing figure 7. The hydraulic loss of runner changes largely with mass flow.

If the transition flow passage between those three diversion components flow and runner is fluent, the hydraulic efficiency can rise about 2%.

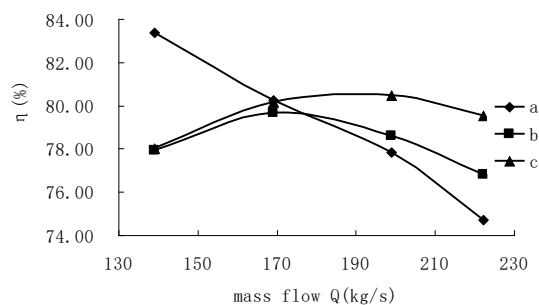


Figure 2. hydraulic efficiency vs. mass flow

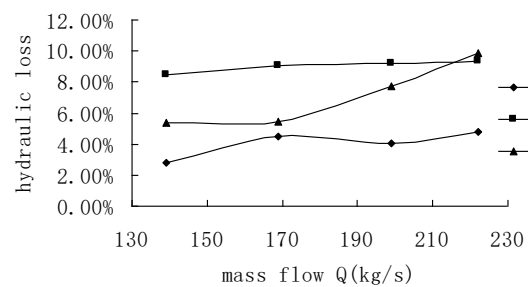
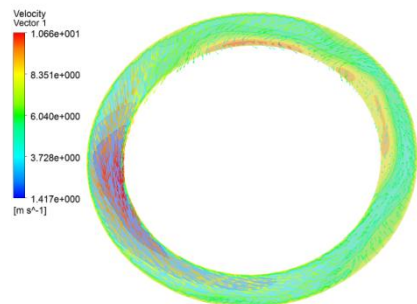


Figure 3. hydraulic loss

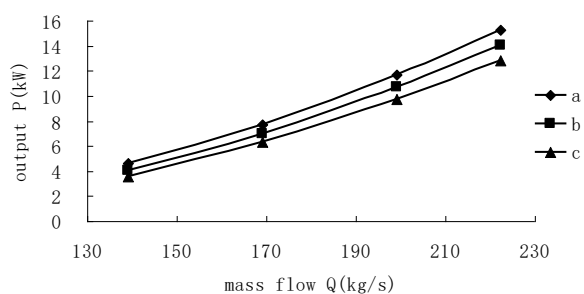
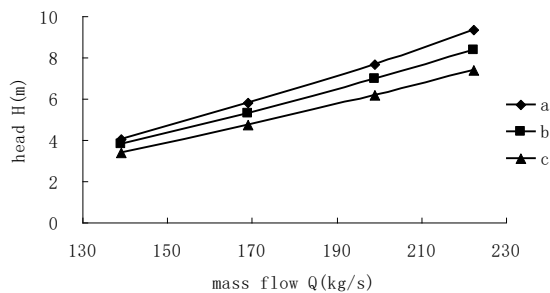
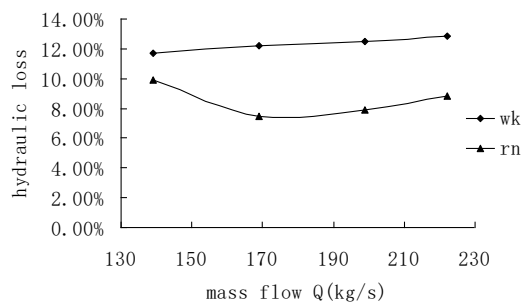


Figure 4. velocity on the stay vane inlet**Figure 5.** output vs. mass flow**Figure 6.** head vs. mass flow**Figure 7.** hydraulic loss

5. Conclusion

Through the simulation and analysis of three water turbines, some conclusions are drawn.

When the radial dimension is same, hydraulic efficiency of water turbine with same section spiral casing and stay vanes is highest on the low mass flow area, and the hydraulic efficiency of turbine with double spiral casing is highest on the high mass flow area. But the double spiral casing is simpler.

When the radial dimension is same, water turbine with double spiral casing is superior to that with traditional spiral casing, and structure of double spiral casing is simpler than that of traditional spiral casing.

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