Design and Analysis of Horizontal Axial Flow Motor Shroud

Shiming Wang, Yu Shen*
Engineering College of Shanghai Ocean University, Shanghai 201306, china

*Corresponding author e-mail: 1280376974@qq.com

Abstract. The wind turbine diffuser can increase the wind energy utilization coefficient of the wind turbine, and the addition of the shroud to the horizontal axis wind turbine also plays a role of accelerating the flow of the condensate. First, the structure of the shroud was designed and then modeled in gambit. The fluent software was used to establish the mathematical model for simulation. The length of the shroud and the opening angle of the shroud are analyzed to determine the best shape of the shroud. Then compared the efficiency with or without the shroud, through the simulation and the experiment of the water tank, it is confirmed that the horizontal axis of the shroud can improve the hydrodynamic performance.

1. Preface
In today's society, energy is in short supply. The development and utilization of renewable energy are receiving increasing attention. All countries in the world are making great efforts to develop renewable energy. China has more than 18,000 km of coastline and the ocean is rich in natural resources [1]. However, the existing marine power generation installations in our country have such problems as low power generation, short power generation time, large generator set size and high development cost [2]. The isep team from Argentina proposed a method of installing a shroud on a vertical turbine [3]. This method increases the flow rate of the water near the rotor and reduces the size of the rotating shaft at the same output power, so that the transmission Reduce the size, and thus reduce costs.

Based on the project of renewable energy resources of Shanghai Ocean University, the horizontal turbine used to capture ocean energy has completed the sea trial. The horizontal turbine-driven power generation device has reached 300W rated power, and how to improve the horizontal Turbine capture efficiency, the generator power from the original 300W up to 1kW, without changing the size of the turbine is a problem to be solved.

In response to the above problems, based on the previous studies on the installation of shrouds on straight-axis straight-blade turbines and blade-type turbines, this paper proposes that the shrouds be installed with the same size to improve the output efficiency. The simulation results show that, the installation of the water turbine shroud method is a better solution to the above problems.

2. Shroud principle
2.1. Shroud working principle
Under the opening angle of the opening, the deflector will form a low-pressure zone at the tail, and the low-pressure zone will generate a suction effect on the fluid to allow more fluid to flow into the
enclosure and increase the fluid velocity in the enclosure. The main parameters shown in Figure 1, including the expansion of the scaffold flare opening angle and length, to the flow rate. The addition of a shroud outside the turbine equates to an increase in the velocity of the flow around the turbine, that is, an increase of the turbine's energy efficiency.

Transverse turbine installation of shrouds, turbine shaft output power of the formula [6] can be abbreviated as:

$$ P = \frac{1}{2} \rho A v_1^3 C_p $$

In the formula: $\rho$, the fluid density; $C_p$, power factor; $A$, Ying Ying area; $v_1$, the flow rate. For a given turbine, assuming $C_p$ is a constant value, if the fluid velocity $v_1$ is increased, the resulting shaft power will increase by a third power. Therefore, in the direction of the incoming flow of the original horizontal-axis turbine, a shroud is added to increase the flow rate of the convergent flow so as to improve the energy-efficiency of the horizontal-axis hydraulic turbine.

2.2. Shroud design

The shroud is designed as an octagonal flaring shape for machining and horizontal turbine installation. The flaring shape mainly includes circular, linear, hyperbolic and elliptic surfaces. According to the literature [7], the circular flared dome has better overall hydrodynamic performance. Therefore, it is determined that the shape of the flaring is circular, as shown in Fig. 2 for the model physical structure.

The flaring section of the shroud is tangent to the middle section, and the middle section is also octagonal. The horizontal axis turbine is inside the middle section. The installation of the shroud turbine system simplified into two-dimensional plane model, shown in Figure 3, the turbine diameter is $D$. 

![Fig.1 Shroud plan](image1)

![Fig.2 Shroud model](image2)
3. Modeling and grid division

3.1. Shroud modeling

In Gambit, a two-dimensional plane model is created and meshed. Because of its axisymmetric structure, one side of the symmetry axis is analysed. The catchment has a width of 3 H and a length of 8 H. The center of the shroud is 3 H to the left and the center to the right is 5 H [5]. H is the maximum inscribed circle diameter of the flared section, which can be determined by the trigonometric calculation of the opening angle and the length shown in FIG. 1. Taking into account the boundary layer effect of the wall, the boundary layer of the deflector wall is refined to ensure the calculation accuracy of the flow field around the deflector. The minimum grid volume [10] is (1.65473e + 001) m³ and the maximum grid volume is (1.223042e + 003) m³. The volume is the two-dimensional area of the river basin multiplied by the height and the height taken as 1. As shown in Figure 4 (a) for the entire grid, while Figure 4 (b) is a partial enlargement of the grid, the simulation entrance is speed entrance, the speed is 1.5m / s, the exit is the pressure exit pressure-out, the wall of the shroud adopts the wall boundary, and the upper and lower sides adopt the symmetry boundary symmetry. To model and calculate the shroud separately, the grid is relatively small, not only improving the working efficiency, but also ensuring the accuracy of calculating the size parameters of the shroud.
3.2. The installation of the shroud before and after the turbine system modeling

After numerical simulation and calculation of the shroud, the horizontal axis turbine is placed in the middle section of this size shroud, and the efficiency of hydro turbine before and after the shroud is compared. In Gambit software, the flow field of turbine with no shroud is divided into grids. As shown in Fig. 4, (a) and (b) are the grids of the turbine system and the enlarged part of the grid of the turbine system. As shown in Figure 5, (a) and (b) are grids of the rear-wheel system with additional shrouds, as well as the rear-wheel system drainage system partially enlarged grid.

4. Calculation and Performance Analysis of Shroud Parameters

4.1. Shroud length influence law

Using the grid established in Fig. 4, the influence of the three different shroud flaring lengths (1000mm, 1250mm and 1500mm) on the flow field was analyzed, and the water flow velocity at different positions from the center point was calculated as shown in Fig.6.
It can be seen from Fig. 6 that for any of three different flared length shrouds, assuming an angle, as the length increases, the velocity curve moves upward as a whole, and the flow velocity at different positions from the central point gradually increases. So the bigger the better, but in order to coordinate the structure of the whole machine, take the shroud length of 1500mm.

4.2. Deflector opening angle affect the law
After calculation, the velocity profiles with opening angles of 10°, 14°, 18°, 22°, 26° and 30° are obtained as shown in FIG. 7:

As can be seen from the velocity profile of each opening angle, as the opening angle increases, the internal speed gradually increases, but when the opening angle is greater than 26°, the speed change is not obvious. In order to further analyze the water of the shroud Dynamic performance, where two fluid parameters are introduced.

When the fluid moves through different sections, the Reynolds number and pressure change:

\[ K_{Re} = \frac{R_e}{R_{e,\text{min}}} \]  \hspace{1cm} (2)

\[ K_p = \frac{P}{P_{\text{min}}} \]  \hspace{1cm} (3)

In the formula: \( K_{Re} \), Reynolds number ratio, which \( R_e \) is the Reynolds number [9], \( R_e = \frac{4v_1R}{\nu} \); \( v_1 \), the flow rate of the incoming flow; \( R \), the hydraulic radius of the flow cross section; \( \nu \), the kinematic viscosity of the liquid.

\( K_p \), the pressure ratio; \( P \), the maximum cross-section pressure of the shroud; \( P_{\text{min}} \), the shroud minimum cross-section pressure. Reynolds number changes and pressure ratio changes can reflect two different cross-section flow changes and pressure changes. The large Reynolds number ratio indicates
that the flow rate changes greatly. The more fluid enters the shroud, the faster the flow rate. The higher the pressure ratio value, the lower the pressure in the middle section will be when the inlet pressure is the same. The more significant pumping effect. According to the selection of different angles calculated the changes of these two ratios, as shown in Figure 8.

![Figure 8: Reynolds number and pressure ratio](image)

**Fig.8 Reynolds number and pressure ratio**

It can be seen from Fig. 8 that Reynolds number ratio and pressure ratio are both the maximum at 26°. It can be seen that the hydrodynamic performance of the draft dome is good when the opening angle is 26°. Therefore, the opening angle is 26°.

4.3. Turbine efficiency before and after retrofitting shroud

Using the grid established in Fig. 4 and Fig. 5, the torque coefficients of the turbine before and after the addition of the shroud are calculated by using the Fluent software, and then the torque coefficients are calculated by the torque coefficient expression before and after the turbine is installed in the three number of revolutions (75 r / min, 110 r / min, 150 r / min) under the water turbine torque. Calculated using the formula [8],

\[
C_p = \frac{\text{Turbine output power}}{\text{The total energy of flow}} = \frac{T_o}{0.5 \nu (V - D b)}
\]

obtained under different speeds, the installation of diversion shroud before and after the turbine's energy efficiency, as shown in Figure 5-9.

![Figure 9: The water turbine energy efficiency before and after the installation of shroud](image)

**Fig.9 The water turbine energy efficiency before and after the installation of shroud**

It can be seen from Fig. 9 that after the shroud is installed on the outside of the turbine, the turbine's energy-using efficiency obviously increases and the kinetic energy of its transformation becomes larger, so that the power generation efficiency will be higher.
5. Sink experiment
In order to verify the simulation results, a test was carried out in the sink of East China Sea centre of standard & metrology (technology), SOA. The field experiment diagram is shown in Fig. 10.

![Field test chart](image1)

**Fig.10** Field test chart

First of all, the choice of size parameters of the shroud was tested. The length of the shroud of the shroud was 1500mm, while the opening angle of the shroud was 18°, 22°, 26° and 30°. The water flow was measured through the shroud. After the speed changes, the model deflector installed in the sink trailer, set the trailer speed of 1.5m/s, installed in the middle section of the flow meter measured flow velocity, and use the formula (2) Reynolds number ratio changes, shown in Figure 11.

![Open angle changes of Reynolds number ratio change rule](image2)

**Fig.11** Open angle changes of Reynolds number ratio change rule

As can be seen from Figure 11, after the tank test, the measured data are calculated by the formula, and the variation law of the Reynolds number ratio is basically the same as the simulation result. It is more appropriate to determine the opening angle of the shroud to be 26°.

Then, the energy efficiency of the turbine before and after the addition of the shroud is tested and studied. The draft shroud with the length of 1500mm and the opening angle of 26° is installed, and the turbine is installed in the turbine. The turbines are respectively operated at three revolutions Sink experiment, measured by the torque sensor torque, as shown in Figure 12:
The average of the turbine torques for the next three revolutions is taken and the data obtained is shown in Table 1:

| Number of revolutions /r/min | No shroud turbine torque /N·M | Turbine turbine torque /N·M |
|------------------------------|-------------------------------|-----------------------------|
| 75                           | 31                            | 98                          |
| 110                          | 78                            | 178                         |
| 150                          | 103                           | 181                         |

The resulting torque into the formula to calculate \( C_p = \frac{T_{out\, \text{power}}}{The\, \text{total\, \text{energy\, \text{of\, \text{flow}}}}} = \frac{T_{so}}{0.5 \rho \omega^2 D_b} \), get the shroud installed before and after the turbine efficiency situation, as shown in Figure 13.

It can be seen from Fig. 13 that the efficiency of hydro-turbine with retrofit shrouds is significantly higher than that without shrouds. Compared with the simulation results in Figure 9, the experimental results are basically consistent with the simulation results.

6. Conclusion
In this chapter, the basic aerofoil horizontal axis turbine is equipped with a shroud. The structure of the shroud is octagonal and the shape of the line is circular. The main parameters of the shroud and the
energy efficiency are numerically simulated. Test simulation results, we can draw the following conclusions:

1. Calculate the proposed parameter size according to the wattage to be generated by horizontal axis hydroelectric power generation. First calculate and determine the length of shroud is 1500mm.

2. Taking the angle of opening angle in increments from 10° to 30°, the comparison of the introduced variables and the experimental results of the water tank shows that the mechanical performance of the guide is relatively good when the opening angle is 26°.

3. The calculation of the CFD software and the experiment of the tank have shown that the hydro turbine with the improved shroud is more efficient and the simulation results are in good agreement with the experimental results. The main parameters of the shroud with improved energy efficiency are also obtained. It provides a reference for the research of horizontal axis turbine power generation.

References

[1] Wang S, Yuan P, Li D, et al. An overview of ocean renewable energy in China [J]. Renewable & Sustainable Energy Reviews, 2011, 15(1): 91-111.

[2] Li D, Wang S, Yuan P. An overview of development of tidal current in China: Energy resource, conversion technology and opportunities [J]. Renewable & Sustainable Energy Reviews, 2010, 14(9): 2896-2905.

[3] Reyes Caorsi W, Tortajada G, Varela G. Predictores de arritmias ventriculares en el infarto agudo de miocardio [J]. Sociedad Uruguaya de Cardiologia, 2014, 29(1): 122-127.

[4] Binyamin Sasson, David Greenblatt, Effect of Leading-Edge Slot Blowing on a Vertical Axis Wind Turbine. AIAA JOURNAL Vol. 49, No. 9, September 2011

[5] Zhang Jianyu.H numerical simulation of vertical axis wind turbine and leaf type optimization [D]. Huazhong University of Science and Technology, 2011

[6] He Dexin. Wind Engineering and Industrial Aerodynamics [M]. Beijing: National Defense Industry Press, 2006

[7] WANG Shu-Jie, XU Shi-Qiang, et al. Study on hydrodynamic characteristics of deflector of axial flow tidal current energy generation device [J] Vol.35 No.6, June 2014: 1098-1103

[8] Li Wei, Lin Yonggang et al .. Horizontal axis propeller-type sea current energy generation technology research [C]. China renewable energy Proceedings of the First Symposium of Ocean Energy Professional Committee, 2008: 81-90

[9] Li Wenchao.Research on maximum power capture technology of horizontal axis tidal current turbine [D].China Ocean University,2011

[10] Wang Jianwen, Sun Ke et al .Numerical simulation of flow field in a wind turbine diffusion amplifier [J]. Energy Technology, Vol.25.No. 5, October 2004: 185 ~ 190