Design of Blade for Horizontal-Shaft Ocean Current Generation Device

Chen liudong, Lin xiaxuan, Zhang feng

North China Electric Power University, No. 2, Beinong Road, Huilongguan Town, Changping District, Beijing

1151100104@ncepu.edu.cn

Abstract. Ocean current energy has become an important development direction of renewable energy and has broad application prospects. At present, most of the research on the energy of the current is on the improvement of the generator structure and the design of the blade, but the design of the blade is mostly the design of the wind turbine, which fails to meet the optimal condition of ocean currents. This paper aims at the development and utilization of ocean current energy, compares the application environment of wind turbines and ocean currents, and designs a blade suitable for ocean current energy generation devices. Through CFD simulation and PROFILI selection of blade airfoiled, the curve of the Lift-to-drag ratio with the angle of attack is obtained, and other parameters of the blade are obtained by solving the Wilson method through MATLAB. Finally, the 3D modeming is carried out by SolidWorks.

1. introduction

In the composition of China's energy structure, thermal power occupies 70%. In the composition of China's energy structure, thermal power occupies 70%, while the exploitation and combustion of fossil fuel destroy the environment. Therefore, it is particularly important to develop and utilize the renewable energy, such as wind, solar energy and ocean energy. 70% of the earth's surface is covered by the ocean, and the ocean energy can be covered by a wide range of oceans, in which only the current can be subdivided into various types, including the tidal energy generated by tidal movements and the rise, fall of the waves in the ocean, the temperature difference energy formed by the sea bottom temperature and ocean currents due to the movement of fixed currents in the deep ocean [12]

There are many advantages of the ocean current energy: a huge amount in the total ocean water; it belongs to the clean energy; compared to the other marine energy, such as a certain period of tidal energy and no periodic wave energy, the ocean current is stable and easy to control and the factors that affect the change can be monitored and predicted.

The utilization of ocean current energy refers to the conversion of ocean currents into electrical energy or other available forms by means of certain methods and equipment. IN the field of current power generation, the research on the blade of the current energy generating unit is mainly concentrated on the other energy in the ocean at home and abroad, and the research of the flow ocean energy related blade design is absent. For example, in document [13], the generation efficiency of a current turbine is analyzed from the point of view of hydrodynamics. In literature [14], the effect of tide on blade speed is analyzed by experiments

In this paper, the blade of the horizontal axis current generating unit has been designed. According to the characteristics of the current, the basic theory of blade design is combined to explore the difference between the application environment of the wind turbine and the current generator, to optimize the structure of the blade airfoil reasonably so that it can capture more energy and improve the utilization rate of the current.

2. Basic theory of blade design for horizontal axis current generator

2.1. Bates's limit

The Bates limit is the basic theory about the efficiency of wind energy utilization, which shows that the fluid is a continuous, incompressible fluid for an "ideal wind wheel" wind function that accepts all the kinetic energy of the fluid passing through the wind wheel, and the fluid is a continuous, incompressible fluid. In this case, the efficiency of the wind energy conversion to kinetic energy has a limit value of 59%. And when the axial induction factor A was taken at 1/3, it was obtained

Because the Bates limit is derived from fluid continuity equation, it is suitable for any flow field, so it is also suitable for horizontal axis ocean current power generation device [6].

The energy capture coefficient Cp is defined to indicate the percentage of other energy conversion to kinetic energy. For the general high-speed wind turbine, the Cp value is about 0.4 in the actual situation, and the low speed wind turbine is about 0.3. Considering that the resistance of the impeller in the water is greater than the air, and combined with the actual operating conditions of the general turbine, the speed of the impeller is similar to the low speed fan, which is generally 100~200r/min, so we choose the water energy capture coefficient as Cp=0.3[1]

2.2. Leaf momentum theory

The leaf is divided into several segments in its direction of development, and each micro segment is called Ye Su. By dividing leaf element, the three-dimensional leaf model can be divided into two-dimensional leaf element model. By analysing the stress of each leaf element, the force and moment on the turbine can be obtained. The Stressed are as follows:

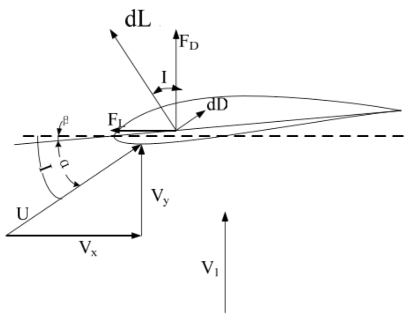


Figure 1 Leaf force analysis chart

According to the theory of wing shape dynamics：

$$dF = \frac{1}{2}\rho c U^2 C_l dr \quad (1)$$

$$dD = \frac{1}{2}\rho c U^2 C_d dr \quad (2)$$

In the formula， is Water flow density，c is Leaf momentum length， is resistance coefficient, is Lift coefficient.

Relative lobar inflow angle of water flow：

$$I = a\tan\frac{(1-a)V_1}{(1+b)\Omega r} \quad (3)$$

In the formula，a is axial inducer，At the limit of Bates's limit is 1/3.

The torque on the leaf momentum at the radius r：

$$dM = \frac{1}{2} B\rho c U^2 C_x r dr \tag{4}$$

The axial force acting on the leaf momentum at the radius r：

$$dT = \frac{1}{2} B\rho c U^2 C_y dr \tag{5}$$

In the formula， C_y is axial force coefficient， C_x is tangential force coefficient.

The leaf momentum theory provides a reference formula for calculating the inflow angle, the string length and the angle of attack. It provides a gradual method for the force analysis of the blade, and then the three-dimensional model is transformed into two-dimensional analysis, and the corresponding calculation formula is derived

2.3. *Energy capture optimization theory*

he fundamental purpose of blade design is to make the energy captured by the blade as large as possible at the same flow rate. The Wilson model is one of the most widely used models of blade design at home and abroad. The inducible factor A, B, and the Bates limit and the leaf prime momentum theory are used to deduce the characteristic parameters of the leaf momentum at the radius r, so that the energy capture coefficient Cp of the blade is as large as possible

Because the resistance has little effect on the axial induction factor A and circumferential inducer B, the Wilson method does not consider the influence of resistance when designing the blade profile

The formula of inflow angle is simplified as follows:

$$\tan I = \frac{(1-a)}{(1+b)} \frac{1}{\lambda} \tag{6}$$

In the formula， λ is local sharp speed ratio, its value is equal to $\lambda_0 \times \mu$ 。In the formula μ is ratio coefficient, the position r represents the value of the radius R of the impeller. λ_0 is leaf tip speed ratio, Its calculation formula is：

$$\lambda_0 = \frac{\omega R}{V_1} \tag{7}$$

In the formula， V_1 is flow velocity， according to the investigation of the tidal current resources of the coastal area of China by the State Oceanic Administration, the trend of most of the regions in our country is within the range of 0.6m/s - 1.0m/s. Because of the special design of the pipe structure in this paper, 1.2m/s is selected at this flow rate

The energy capture coefficient C_p :

$$C_p = \frac{8}{\lambda_0^2} \int_0^{\lambda_0} b(1-a) F \lambda^3 d\lambda \tag{8}$$

The chord length of each leaf：

$$\frac{BcC_l \cos I}{r} = \frac{8\pi a}{1-a} \sin^2 I \tag{9}$$

In the formula，B is Number of leaves， C_l is lift coefficient，r is leaf position，a is axial inducer, Select as the maximum energy 1/3.

Blade twist angle β 、angle of attack α 、inflow angle I satisfaction between:(The angle of attack is determined according to the rise resistance ratio)

$$\beta = I - \alpha \tag{10}$$

According to the formula given by the Wilson method, the important parameters such as blade twist angle, chord length and inflow angle can be solved, and then the optimal design of blades can be realized

3. The design examples and simulation of horizontal axis ocean current generator's blade

This paper focuses on the hydrodynamic design of the blade and assumes that the blade can withstand the tangential and axial forces of the water flow without deformation. For the ocean current power generation device, when it is determined that the fluid medium is seawater, in order to increase the lift-drag ratio of the blade so as to obtain greater energy, firstly it is necessary to select a reasonable airfoil structure [5]; after determining the airfoil, calculating its twist angle, incoming attack angle, and leaf length according to the Wilson method.

In the design of this paper, the power of the current generator is set to 10KW, and the general flow rate of the current is 0.5m/s. By setting the water guide mechanism below, the flow velocity of the water can be 3m/s, the seawater density can be 1025kg/m3, and the power coefficient Cp can be taken as 0.3, the drive chain and generator efficiency is taken as 0.83, and the impeller speed is chosen as 167r/min.

3.1. Determination of basic parameters

3.1.1. Reynolds numbers:

$$\mathrm{Re} = \frac{Vr}{\gamma} \tag{11}$$

According to the above formula, the Reynolds number is related to the chord length factor, so it varies with different leaf elements. According to the calculation, the Reynolds number is generally taken as 2×10^{6} [8].

3.1.2. Impeller diameter:

Calculate based on the above setting data：

$$D = \left(\frac{8P_n}{\eta\rho V_1^3\pi}\right)^{\frac{1}{2}} = \left(\frac{8*10000}{0.83*1025*3^3*\pi}\right)^{\frac{1}{2}} = 1.05m \tag{12}$$

3.1.3. Tip speed ratio:

$$\lambda_0 = \frac{\omega R}{V_1} \tag{13}$$

Experiments show that for high-speed wind turbines, generally 5 to 7 can be selected for λ_0 to obtain higher C_p values, and for low-speed wind turbines, the λ_0 values are often 3 to 5. Because of the requirements of actual operating conditions in seawater, the operating speed is in the category of low-speed fans. Calculated by entering the λ_0 data = 3.1, basically consistent with the previous analysis.

3.1.4. Blade numbers:

The number of blades is selected according to the tip speed ratio. The reference [1] pointed out that the impeller with six blades can have higher blade stability under the flow velocity often found in the seabed current. However, based on the Cl/Cd curve generated by the profile software, it can be concluded that the impeller Cp of the three blades is higher than the impeller Cp of the six blades, so that a higher efficiency can be obtained. Therefore, the number of blades used in this paper is designed to be B=3.

3.2. The selection of vane airfoil and determination of attack angle and lift-drag ratio

In this paper, we refer to the wind turbine blade design theory on the vane design and improve it by combining the difference between influent and air medium. Considering the main difference between gas and fluid is the difference in density (the air density is about 1.022, and the density of seawater is

1025) and the viscosity of water is about one-tenth of that of air. This results in a major difference in the two media in that the Reynolds number of the airfoil is different.

Use fluent software to investigate the lift-to-drag ratio of the same airfoil in different media. The NACA 63-412 airfoil was numerically solved in fluent, and its lift coefficient and drag coefficient at power angle of -8~15 degrees were calculated. The data was fitted by origin software and the lift resistance curve was plotted as follows:

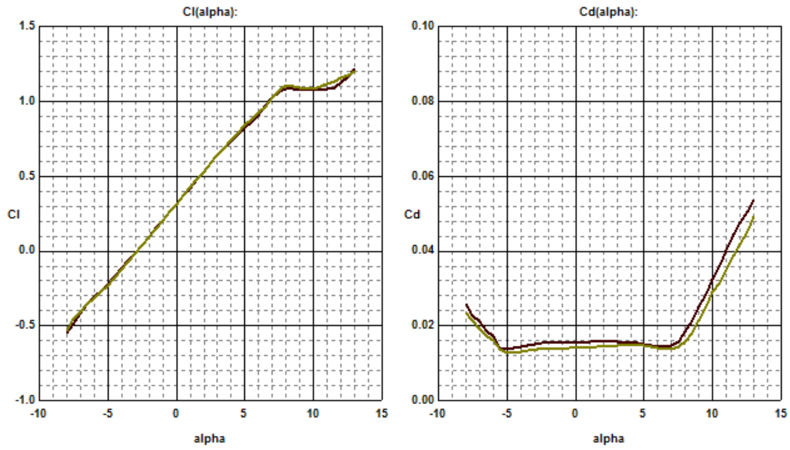


Figure 2 The change of the lift-resistance curve of NACA 63-412 with attack angle

The brown line is the lift-resistance characteristic in water and the black is air. It can be seen that the lift coefficient is basically the same, and they all enter the stall state when the power angle is 7 degrees, which achieves its maximum, and the drag coefficient is in the water, which is smaller than in the water. The NACA 63-412 aerofoil has a greater lift-to-drag ratio than water in air, so it is believed that the performance of this airfoiled is not affected by different air or water media, and its performance in water is slightly better in the air. Taking into account the actual conditions, the wind speed is about 10 times the speed of the water, and the viscosity coefficient of water is about one-tenth of that of air, resulting in a similar Reynolds number. Therefore, such results are practical. This demonstrates the possibility of applying the vane aerofoil of wind turbine to tidal current generators.

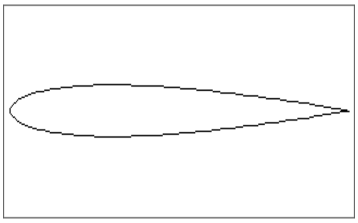
The reason why the airfoiled design has become the focus of the power plant design is that the geometric shape of the aerofoil has a great influence on its hydrodynamic performance. According to the reference [3], the parameters that affect the airfoiled performance are: aerofoil camber, airfoiled thickness, Reynolds number, aerofoil surface pressure distribution.

Analysing the pressure of the aerofoil surface is of great significance for analysing the dynamic performance of the airfoiled and avoiding the cavitation of the blade. According to the pressure distribution curve, the trend of the airfoiled lift coefficient and the drag coefficient with the change of the attack angle can be analysed. The NACA 63-412 aerofoil pressure distribution coefficient curve is plotted by PROFILI software, as shown in Figure 3:

Figure 3 Distribution of pressure coefficient with position r in the case of an attack angle of 7°

The figure of the pressure distribution curve is the distribution of the pressure coefficient under the condition that the intercepted attack angle is 7°. The green curve shows the pressure distribution of the upper part and the blue curve shows the pressure distribution of the lower part. The figure shows that the lower part of the pressure is greater than the upper part, which explains the reasons for lift: lift is due to the pressure difference between the upper and lower surfaces, so as the pressure difference increases, the lift coefficient will gradually increase; and the resistance is determined by the frictional resistance that within the range of attack angle of 0°-12°, the coefficient of drag does not change much, and the coefficient of lift rapidly increases, resulting in an increase in the ratio of lift to drag.

The NACA 0012 [4] and NACA 63-412 commonly used in wind turbines are compared and verified as follows,



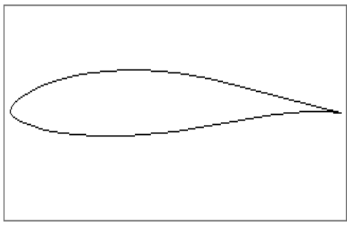


Figure 4 NACA 63-412 Airfoil Figure (left) NACA 0012 Airfoil Figure (right)

The resulting lift coefficient and drag coefficient curve are shown in the figure below:

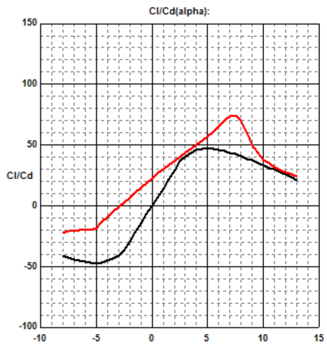


Figure 5 Variation of the lift-drag ratio of NACA 63-412 and NACA-0012 with attack angle

The red curve is the lift-resistance coefficient curve of the NACA 63-412 airfoil, and the black line is the lift-drag coefficient curve of the NACA 0012 airfoil. It can be seen from the figure that the lift-to-drag ratio of the NACA 63-412 airfoil is approximately 70, which is obviously better than the 0012 series (lift-drag ratio is about 50), so the NACA 63-412 airfoil is a more sensible choice.

According to the above figure, the maximum lift-to-drag ratio is about 70 for the NACA 63-412 airfoil at a power angle of 7°.

3.3. Determination of other blade parameters

After determining the airfoil, the hydrodynamic design of the blade requires the design of factors such as chord length and twist angle. The airfoil of the blade is a two-dimensional figure. After the factors such as chord length and twist angle are added, the entire three-dimensional blade can be constructed by stacking.

The remaining parameters of the blade were designed by the Wilson method. Using MATLAB to solve the parameters of the axial induction factor a, the circumferential induction factor b, the chord length c, the inflow angle I, and the torsion angle of the blade.

The solution to the axial and circumferential induction factors a and b is essentially a multivariate nonlinear programming problem whose objective function is:

$$\frac{dC_p}{d\lambda} = \frac{8}{\lambda_0^2} b(1-a)\lambda^2 \quad (14)$$

The constraints are:

$$b(1+b)\lambda^2 = a(1-a) \tag{15}$$

By iteratively solving a and b, the FMINCON function in MATLAB can be easily solved [15]. After a and b are solved, the inflow angle is solved by the above formula (6), and the formula (9) is used to solve the length of string, formula (10) solving the twist angle and list the result of the solution in the following table:

Table 1 Using the Wilson method to solve the blade parameters

Position r（m）	Axial inducing factor a	Circumferential inducing factor b	Inflow angle I	Chord length c（m）	Torsional angle β
0.3	0.298346	0.542757	36.43102	0.327041	29.43102
0.6	0.316987	0.183013	27.6365	0.336715	20.6365
0.9	0.324456	0.089419	21.40528	0.285962	14.40528
1.2	0.327896	0.052354	17.17629	0.238217	10.17629
1.35	0.328929	0.041850	15.57934	0.21838	8.57934
1.5	0.329700	0.034191	14.23402	0.201076	7.234024
1.65	0.330289	0.028440	13.0895	0.185988	6.089495

Based on the above data, the blade shape and torsion angle were obtained to complete the blade hydrodynamic design.

In practical operating conditions, taking into account that most of the power obtained by the impeller from the water flow comes from the tip of the leaf, that is, a little part of the blade, and the root of the blade mainly plays the role of connecting the wheel and supporting the blade with a less greater effect to the output of the prime mover. Therefore, the length and thickness of the chord length of the root should be increased, and the thickness of the airfoiled part of the blade tip should be reduced [1]. According to the analysis, this paper selects the NACA 63-412 airfoiled for the blade tip and the NACA 63—018 aerofoil for the root [2].

In order to show the changing trend of leaf, according to the calculated chord length data, the interpolated leaf elements were drawn by PROFILI software. The number of selected leaf elements was 10, and the figure showed the floor plan of each leaf element was from leaf root to leaf tip. According to the interpolation leaf map, the three-dimensional model of the leaf is established by the lofting and fitting function of SolidWorks as shown in the figure:

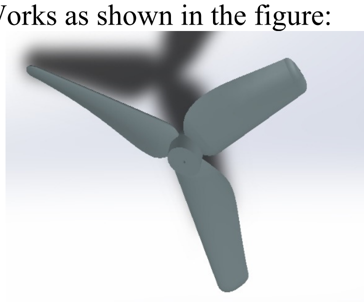


Figure 6 3D model of blade

4. Conclusions

This paper compares the application environment of ocean current generators and wind turbines and corrects the parameters of the relevant blade design theory in wind turbines and obtains the blade design theory suitable for marine environment. It is selected through CFD simulation and lift-resistance ratio curves. The applicable airfoil of different parts of the blade was solved by the Wilson method and the three-dimensional model was constructed by interpolation in SolidWorks. And we apply it to the actual design conditions to construct a physical model of the blade suitable for ocean current power generation, which can be directly applied to processing and production.

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