ACMME 2017 IOP Publishing
IOP Conf. Series: Materials Science and Engineering **207** (2017) 012085 doi:10.1088/1757-899X/207/1/012085

Numerical simulation of VAWT on the effects of rotation cylinder

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Abstract. Based on Finite Element Analysis Method, studying on Vertical Axis Wind Turbine (VAWT) which is added rotating cylinder in front of its air foils, especially focusing on the analysis of NACA6 series air foils about variation of lift to drag ratio. Choosing the most suitable blades with rotary cylinder added on leading edge. Analysis indicates that the front rotating cylinders on the VAWT is benefit to lift rise and drag fall. The most suitable air foil whose design lift coefficient is 0.8, the blades relative thickness is 20%, and the optimistic tip speed ratio is about 7.

1. Introduction

Due to the energy crisis and the rising costs of oil products, wind turbines were recognized and developed for its potential in power generation. Compared to wind-oriented horizontal axis turbine, as is shown in Figure 1, vertical axis turbines are affected less by wind direction and have no yaw systems. VAWTs have advantages in its quieter system and lower cost. What's more, Figure 2 shows that VAWTs makes it possible for Integration between wind power and constructions. In the near future, there will be more and more wind energy environmental protection buildings which combine wind energy with construction design.

Figure 1. Vertical axis wind turbine.

Figure 2. Integration of turbine and constructions.

In 1852, a physicist of German, Magnus [1], pointed out that the fluid exerts a force in vertical directions on the surface of rotating object. One and a half centuries later, Kozlov and Bychkov [2] applied Magnus effect to the development of new type of wind turbines, and it has been proved very effective. Thereafter, the University of British Columbia V.J.Modi [3] did research on a two-dimensional flat plate, airfoils, rectangular prism, even truck model with rotating cylinder added. They put forward the moving surface boundary layer control technology, and conducted a lot of experiments. The results show that the moving surface can increase the lift coefficient of airfoils. As a result of the relatively success of NACA6 series airfoils in laminar flow, this paper mainly focus on the numerical analysis of it.

2. Establishment of numerical model and parameter setting

To perform the VAWT simulations, we adopt the sliding mesh method. The flow field is calculated with an ideal incompressible gas, which is assumed valid for the present application because the Mach number is low. The sliding mesh method governing equations are posed as follows:

$$\frac{d}{d_t}\int_V \rho\phi dV + \int_{\partial V} \rho\phi(\vec{u} - \vec{u_g}).dA = \int_{\partial V} \Gamma\nabla\phi dA + \int_V s_\phi dV \tag{1}$$

Where is the density and $\vec{u}$ is velocity of fluid flow respectively, $\bar{u}_g$is the velocity of moving grid, Γ is diffusion coefficient, $s_\phi$and is the source. After the first order backward difference, the equation of time derivative term (1) can be described as (2):

$$\frac{d}{d_t}\int_V \rho\phi dV = \frac{(\rho\phi V)^{n+1} - (\rho\phi V)^n}{\Delta t} \tag{2}$$

Where n and n+1 expressed in the formula are respectively the current time and the next layer of time. In the calculations, the multi-block structure grid shown in Figure 3 was used. The grids around the airfoil nose is O grid and its trailing edge are topologically C grid. Due to rotation of cylinder, the grid quality near leading edge should be high.

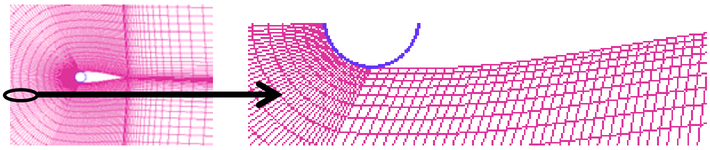


Figure 3. Computational grid of the leading edge rotating air foil and its magnification.

All the calculations were made for the Reynolds number Re = $RU_\infty/\nu = 5\times10^5$, where U∞ is the incident flow velocity and ν is the kinematic air viscosity, U = 10 m/s, and different design lift coefficient and relative thickness of the airfoils are distributed in table 1:

Table 1. Main parameters of new air foil.

parameters	values
gap value(mm)	0.003
chord(mm)	1000
lowest pressure points to the leading edge	30%*chord[4]
different design lift coefficient	0, 0.2, 0.4, 0.6, 0.8
relative thickness	12%, 14%, 16%, 18%, 20%

3. Numerical simulation analysis

The meaning of the curves in Figure 4 and Figure 5 are as follows: C indicates that the leading edge of airfoils with rotating cylinder added, the first number is the relative distance of minimum pressure point to the leading edge, the second number is the design lift coefficient, and the third number is the relative thickness. It can be seen in Figure 4 that the values of lift coefficient C_L are related to relative curvature. When the air flow over the surface of airfoils, the velocity upside of the airfoil is faster because of higher value of airfoil bending angle. But it is easy to result in the phenomenon of stall. For example, as we choose minimum pressure point whose relative distance to leading edge is 30% and lift coefficient is 0.4, the lift coefficient of new airfoil, leading edge rotation airfoil, is totally improved. The reason is that traditional airfoils are restricted by stall. However, leading edge rotation airfoils can solve this problem as the result of the existence of Magnus effect and be able to delay the stall. As shown in Figure 5, when relative curvature becomes larger, the lift to drag before 20 degree of attack angle increases more obvious. Nevertheless, after 20 degree of attack angle, lift to drag ratio C_L/C_D are less influenced, and the curves appear the phenomenon of cross. According to study on the lift and lift to drag ratio, the design lift coefficient 0.8 and the relative thickness 20% is superior. In contrast with the traditional airfoils, Leading edge rotating airfoils remarkably delay the phenomenon of stall.

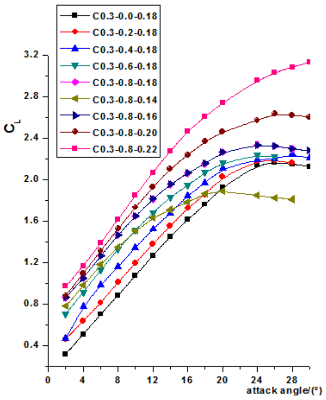


Figure 4. CL of different angles of attack.

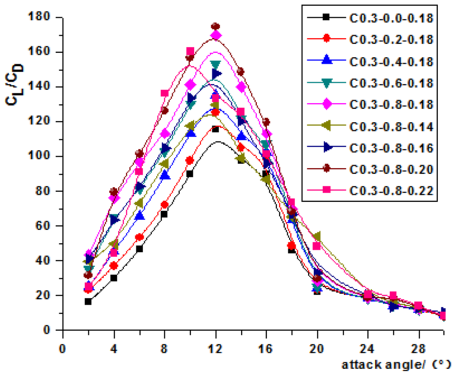


Figure5. CL/CD of Different angles of attack.

4. Construction of leading edge rotating VAWT model

4.1. Calculation method and parameter setting:

Leading edge rotating VAWT model consists of three blades. It includes two forms of rotational motion, the revolution of airfoils around the column and the rotation of cylinder. For double sliding grid calculation, the flow field is also calculated with an ideal incompressible gas. Moreover, k-e RNG turbulence model which mixes with the activation energy equation and the two order upwind difference discrete scheme based on pressure implicit SIMPLE algorithm are used.

Figure6 shows us that the grid is so organized that the cell dimensions increase with distance from the center. The wind wheel radius is 600mm, the shape of the wing chord length 140mm, blade combination installation angle of 2 degree [5]. The external boundary of the computation grid is a rectangle with a size of 15m*10m.The multi-block structure grid is a little complex for VAWT model. So it must take a lot of time. The inlet velocity is 10m/s, the rotation speed ratio of the cylinder is 4.

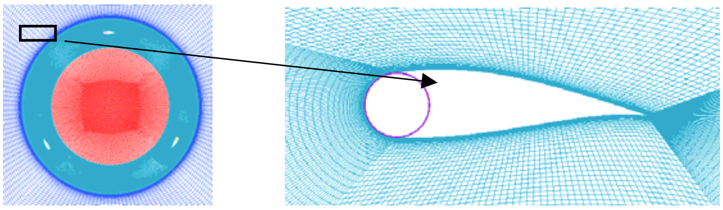
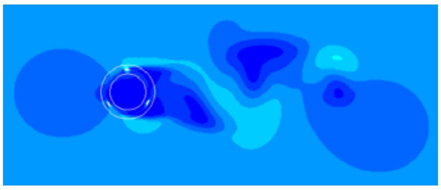


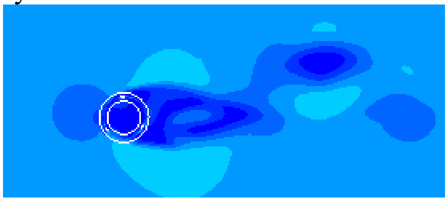
Figure6. Computational grid of vertical axis wind turbine model.

4.2. Results analysis

The Figure7 indicates the presence of vortex tubes that are created due to massive flow separation, and that quickly disintegrate and turn into further downstream. In addition to the wind turbines own energy consumption, the more obvious of vortex phenomenon, the greater consumption of whole VAWT. It's apparently to see Figure 7(b) which is the Leading edge rotation airfoil VAWT is better than Figure 7(a) that is the traditional VAWT because of rotation cylinder about vortex. Compared with traditional airfoils, rotating cylinder of new airfoils can adjust the directions of wind flow, so the downstream wake phenomenon of new VAWT has been significantly improved, and the vorticity produced from wind turbine farther.



(a)Velocity contour of traditional air foil VAWT at t=2s



(b) Velocity contour of Leading edge rotation air foil VAWT at t=2s

Figure7. Velocity contour of VAWT model.

The torque which changes cyclically with time is shown in figure8. The negative value is the torque that drives the wind turbine to rotate and the positive torque is just the opposite, which will prevent vertical axis wind turbine model from rotating. In the whole, the wind turbine rotation torque is positive. It is just we want to see.

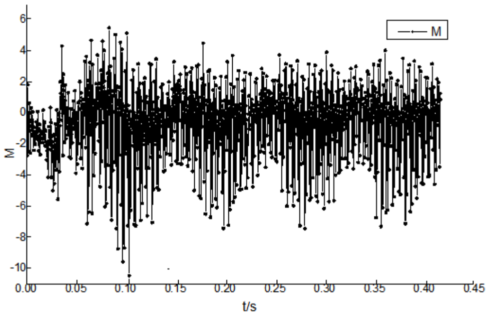


Figure8. Cp with tip speed ratio.

Figure9 shows that the maximum Cp is at the tip speed ratio (TSP) 7.1. When the speed is up to 140rad/s, the maximum power is 260w, as is shown in figure10. That is to say, when we give the speed of wind velocity is more than about 160rad/s, it will sharply decrease, and the rotating cylinder affect weaker on its improvement.

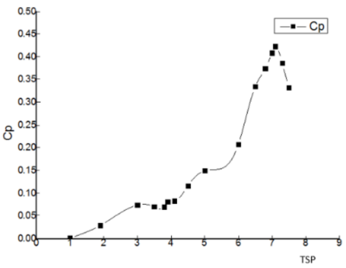


Figure9. Cp with tip speed ratio.

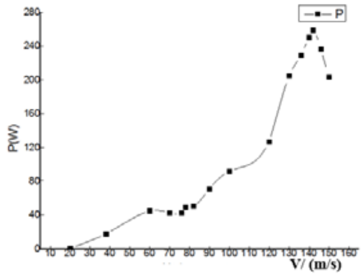


Figure.10 Power with the rotating speed.

5. Conclusions

The program shows that the leading-edge rotating cylinder is a successful device in increasing the sectional lift coefficient and lift-to-drag ratio at low angles of attack, hence reducing the need for higher angles of attack. Also, with high-speed rotation of the cylinder, the stall has been delayed. The increase in the lift coefficient and the delay in the stall angle of attack were about 10 degrees. The most suitable airfoil whose design lift coefficient is 0.8and the relative thickness is 20%, and the optimistic tip speed ratio is about 7. Selection methods of optimal airfoils and the calculation of the two-dimensional VAWT model provide a good reference for the construction of the three-dimensional model and other numerical analysis.

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