Research of Drag Reduction Effect of The Wind Turbine with Drag Reduction of Convex Hull

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Keywords: drag reduction of convex hull, the wind turbine, streamlined convex hull.

Abstract. According to the drag reduction mechanism of the wind turbine blade on the non-smooth surface, that is, the streamlined convex hull surface, the blade is modified for drag reduction. The drag reduction of the blade is carried out in this paper, and the mechanism of the convex hull drag reduction is also analyzed. In this paper, the convex hull is arranged according to the structure of the wind turbine blade, and the wind turbine model is established. After CFD numerical simulation, the average drag coefficient of the smooth surface is 0.875 and the average drag coefficient of the non-smooth surface is 0.693. The drag reduction rate of the convex hull surface is 20.8% on the wind turbine.

Introduction

The drag reduction of non-smooth surfaces was a hot spot in the drag reduction of shape. Among them, the convex hull has become a research hotspot because of its special structure and complexity. Studying the drag reduction of convex hull on the plate was the basic. At present, due to the easy control of the slab in the turbulent region and the simple experimental model, many scholars have studied the reduction of convex hull on the plate.

Domestic and foreign scholars have used numerical simulation and theoretical analysis ware to compare the drag reduction ability of the convex and smooth surfaces. The effects of drag reduction on the flow velocity and arrangement of convex hull were studied. The most important thing is to make a very detailed analysis on the drag reduction mechanism of the convex hull on flat-plate. Later, the study of the mechanism of drag reduction was applied to the bodies of revolution and some simple models. Such as a simple car body model, hull model. The results showed that the non-smooth convex hull surface has good drag reduction effect.

Advantages of convex hull surface

Whether it is experimental or numerical simulation, the drag reduction of non-smooth surfaces has achieved certain results. However, many scholars have focused on pits, grooves, and rib structures on the selection of non-smooth surfaces of wind turbine blades, which are less used in wind turbine blades. However, the convex hull structure has advantages that cannot be ignored:

1) The blade structure will not be damaged

The original smooth wind turbine blades are destroyed to form non-smooth surfaces such as pits and grooves, but the stress structure of the wind turbine blades is destroyed by such non-smooth surfaces, which causes the wind turbine to be more easily damaged.

Since the convex shell and the blade are not combined, the stress structure damage of the blade is not serious. This is an important advantage of the convex hulls.

2) Convenience of convex hull structure

First of all, the arrangement of the convex hull can be changed: the arrangement of the convex hulls can be adjusted according to the working conditions, so that it is more suitable for different wind turbine blades. Secondly, the installation and destruction of the convex shell structure is convenient: it is convenient to replace the new convex hull after the convex hull is worn or damaged.
Establishment of physical model

Numerical simulation method. The large eddy simulation resolves large-scale of the flow field solution, which allowing better fidelity than alternative approaches such as RANS methods. It also models the smallest scale of the solution, which makes the computing cost of the practical engineering systems with complex geometry or flow configurations attainable using supercomputers. This study used the LES method. By filtering the vortex smaller than a certain scale from the partial differential equations, only vortices greater than that scale were involved, the smaller vortices were solved from the additional equations.

Establishment of physical model. (1)Convex hull model. After a lot of experiments, the convex hull structure can reduce drag. Therefore, the turbine blade convex hull structure has great research potential. This paper uses the streamlined convex hull which is different from a general point structure and makes it more suitable for aerodynamics and drag reduction requirements. The convex hull model is shown in Fig. 1. The convex hull is 10 mm long and 6 mm high and the whole is a streamlined structure.

![Convex hull model](image)

Fig 1: Convex hull model

(2)The arrangement of the convex hull on the blades of the wind turbine. The horizontal axis wind turbine was used by this simulation with three blades. Therefore, based on the concentric circles of the blades, the arrangement of the convex hull is staggered on the blades. When the impeller revolving, the turbulent perturbation is the least at the blade root, and the turbulent perturbation is the most disturbed at the leaf sheath. Therefore, the arrangement of the convex hull is increasing tendency along the blade orientation.

![Convex hull in blade](image)
![Wind turbine model](image)

Fig 2: the distribution of convex hull in the blade  
Fig 3: the wind turbine model

As shown in Fig. 2 and Fig. 3, the convex hulls of the blades are arranged in 20 layers, and no convex hulls are arranged at the roots of the blades. The outermost convex hulls are 5mm apart, and the innermost convex hulls are 20mm apart. The outer tangential line of the convex hull points to the center of the circle.

CFD numerical simulation

Establishment of mathematical model. The wind turbine simulation based on the rated conditions that the rated power is 300W, the rated wind speed is 10m/s, and the rated speed is 750rpm. STAR CCM+ fluid simulation software and LES method is adopted by this paper.
In order to obtain the drag reduction efficiency of the convex hull in the wind turbine blade, this paper compares the wind turbine of smooth-blades with the wind turbine of convex-blades. The length of the wind turbine blade is $R=0.7m$.

The domain size upstream the wind turbine is 1 times of impeller diameter and the domain size downstream is 10 times larger than the diameter of the impeller, which is large enough to eliminate the influence of boundary. The grids around the cylinder and in the wake are refined. The grid of the domain is shown in Fig.4.

This paper uses a cylindrical domain. The entrance of the calculation domain is the speed inlet, and the flow velocity can be determined to be 10 m/s according to the rated working condition of the wind turbine; The outlet is a pressure outlet. The number of meshes are about 4.5 million.

**Analysis of simulation result.** The wind wheels are the most important working components of wind turbines, which directly affects the efficiency of wind turbines. The law of the drag coefficient from models with different blades of wind turbine is discussed.

It can be seen from Fig. 6 that the maximum wind speed is about 45 m/s at the blade root in the velocity cloud picture, and the wind speed decreases along the blade spanwise. The result show that the impeller mainly uses wind energy at the middle and the bottom ends of the blade. It can be concluded from the velocity cloud picture that the area with lower wind energy utilization accounts
for 1/3 of the blade span length in the wind wheel. When the impeller rotates, the vorticity is most about 400 at the blade tip in the vorticity picture of wind turbine. The area accounts for 2/3 of the blade spanwise length that a large amount of vortex is generated with severe edge detachment and the area is increase along the blade.

Therefore, the arrangement of the convex hulls avoid the root region, and the upper portion of the middle portion of the blade starts to be arranged and the density of arrangement is gradually increased.

![Fig 7: the vortex picture of the non-smooth impeller in the wind turbine](image)

When the blade is rotating with convex hull, the area with large vorticity has obvious change with large vorticity in the vortex picture. First, the vortex increases significantly, with a maximum of about 2000. Second, the region of large vorticity does not increase along the blade, but the vorticity changes uniformly in the 2/3 region of the blade. The results show that the boundary layer separation point is moved backwards in the non-smooth impeller.

The distribution of the drag coefficient of the non-smooth impeller and the smooth impeller in the time domain is shown in Fig. 8. The drag coefficient of the smooth impeller is $C_{d_s}$ and the drag coefficient of non-smooth impeller with the convex hull is $C_{d_f}$. The equation of drag reduction rate becomes as follow:

$$h = \frac{C_{d_s} - C_{d_f}}{C_{d_s}} \times 100\%$$

![Fig 8: drag coefficient of different wind wheels](image)

The drag coefficients of the two types of wind turbines are relatively stable within the range of Fig. 8. Therefore, the average data of the two wind turbines is taken as the average drag coefficient value of the two wind turbines. The data of 13-14s is averaged as the average drag coefficient value of the two wind wheels. The results are shown in Table 1. For this wind turbine, the drag coefficients rate of the convex-hull impeller is 20.8%.

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<th>$C_{p_{g}}$</th>
<th>$C_{p_{f}}$</th>
<th>h (%)</th>
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<td>0.875</td>
<td>0.693</td>
<td>20.8%</td>
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Conclusions

In this paper, the convex shell method is used to study the drag reduction effect of wind turbines. Firstly, the convex hull adopts a streamlined structure, which is more in line with pneumatic requirements. According to the research on the wind turbine of the smooth wind wheel, the arrangement way of convex hull is determined: avoiding the root of the blade, and the density of the arrangement gradually increases from the middle of the blade. Secondly, the drag coefficients of the two types of wind wheels are compared. The results show that the drag reduction rate of the convex hull wind wheel is 20.8%. It is proved that the convex hull structure can reduce the drag coefficients of the wind turbine.

Acknowledgements

This work was financially supported by Research on the aerodynamic load of high-speed train pantograph under crosswind(2018LH01011); Study on the aerodynamic characteristics about high-speed train pantograph under cross wind (NJZY17105) and Analysis and research on aerodynamic characteristics of pantograph for high speed Train under strong cross wind(ZD201706).

References


