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An optimization methodology for wind lens profile using Computational Fluid Dynamics simulation

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ABSTRACT

An effective optimization method is presented for the shape design of the axis-symmetric wind lens aiming at velocity augmentation and drag force reduction. The profile of the wind lens is approximated by a polynomial function. Velocity and drag force are calculated by CFD (Computational Fluid Dynamics) method. The wind lens profile is optimized adopting GA (genetic algorithm). GA and CFD method are combined by the platform software modeFRONTIER for fully automatic process. By this method, an actual wind lens is researched. The optimized results show that the velocity inside the wind lens is increased and the drag force is decreased dramatically. The recommended inlet length of the wind lens is given through analyzing the optimized results. The effect of incoming boundary conditions on the optimized result is also discussed. The results indicate that the optimized wind lens has good performance under various incoming boundary conditions. It is suggested that the combination of CFD and GA is an effective method for wind lens profile design.

1. Introduction

With the increasing population and the economic development, the demand for energy is increasing notably. However, the limitation of fossil energy and the environmental problems caused by burning the fossil energy are becoming increasingly severe, which arouses the attraction to various types of renewable energies, such as solar energy, wind energy, biomass, etc. Among these types of renewable energies, wind energy is one of the most important ones.

In recent years, wind energy has been developed rapidly for it is environmental friendly and renewable. The statistical data shows that the global installed capacity of wind turbines has kept increasing in the past ten years. The annual installed capacity of the wind turbines for 2015 is 63 GW, which increases by 22% compared with the one for 2014 [1]. In the future, wind energy will play a more and more important role in China. It is claimed by the government that 17% of the electric power load will be supplied by wind energy in China by 2050 [2].

Wind energy is extracted by wind turbine and transformed into electricity. Previous study has found that the power output of the wind turbine is proportional to the third order of the wind speed [3]. Therefore, a slight augmentation of the wind speed can lead to notable increment of the power output. It was proved that a flanged diffuser adding around the rotor of the wind turbine, known as the wind lens [4], was able to increase the wind speed at the rotor significantly, and increase the power output of the wind turbine notably.

Experiments and numerical simulations were carried out to study the efficiency of the wind lens. Ohya et al. tested the power output of the wind turbine with wind lens and then compared it with bare wind turbine. The power output was found to be increased by 2 ~ 5 times after adding the wind lens to the wind turbine [4,5]. According to the wind tunnel and field experiments, Gilbert et al. found that the power output was increased by 4 times with diffuser device [6,7]. Abe and Ohya investigated the flow field around the diffuser pipe experimentally. The results indicated that the pressure at the exit of the diffuser was lower than that at the

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upstream, while the velocity at the entrance of the diffuser was higher than the incoming wind speed [5]. PIV image by Ohya showed that the air at the entrance was drawn into the wind lens because of the pressure difference, which increased the flow rate inside the wind lens. The effect of the flange was investigated by Abe. The experimental data demonstrated that the velocity inside the wind lens with the flange was remarkably larger than that without the flange [8]. Mansour proved that the curved inlet of the wind lens contributed to the velocity augmentation through CFD (Computational Fluid Dynamics) method [9]. Gaden simulated the flow field of the diffuser and investigated the correlation between the diffuser angle, area ratio of exit to entrance and the acceleration performance [10]. Matsushima found that the acceleration performance showed positive correlation with the length of the wind lens [11]. Kardous analyzed the height of the flange and proposed a recommended value [12]. Ohya researched several shapes of the wind lens such as straight line, arc and cycloid. The comparison of experimental data showed that arc and cycloid presented better performance [4]. The same conclusion can also be found in the study of Amer [13]. Based on the experimental results by Ohya, a wind lens with smaller dimension and higher output was proposed which was called compact wind lens, as can be seen in Fig. 1.

The investigations on wind lens design in recent survey are mainly based on several existing typical profiles. The wind lens profile is far from optimal. Besides, the existing studies mainly focus on the increase of power output, ignoring the drag force on the wind lens exerted by the moving air. The drag force usually increases as the wind speed, which results in more cost of the wind lens. Therefore, an effective optimization method for the shape design of the wind lens should be developed, both regarding to velocity increasing and wind load decreasing.

Fig. 1. A 200 kW wind turbine with compact wind lens (The photo is provided by Aviation Power Control Co., Ltd in China).

In this paper, an optimization method combining CFD calculation and multi-objective optimization algorithm is introduced for shape design of wind lens, aiming at improving the velocity inside the wind lens as well as reducing the drag force of the wind lens. The remaining parts of this paper are organized as follows. Section 2 deals with the statement of the problem. Section 3 introduces the optimization method. Based on the method, a real wind lens is optimized and the results are discussed in Section 4. The conclusions are given in Section 5.

2. Problem statement

The profile of the compact wind lens, which presents high efficiency and occupies small space, is shown in Fig. 2. The wind direction is from left to right. For normal operating condition, the axis of the wind lens is parallel to the wind direction. The profile of the wind lens is a continuous curve. The diameter of the cross section decreases at the entrance port and then increases along the wind direction. In the middle there is a narrowest cross section called the throat of the wind lens. On the profile, three points are defined, denoted as P_0, P_{e1} and P_{e2}. P_0 is located on the throat while P_{e1} and P_{e2} stand for the endpoints of the profile. Therefore, the whole profile is divided into two segments by P_0, including inlet segment from P_{e1} to P_0 and diffuser segment from P_0 to P_{e2}, as shown in Fig. 2.

2.1. Profile of the wind lens

In order to describe the profile mathematically, a coordinate system is set in Fig. 2. Supposing that the profile of the wind lens can be described by the following polynomial function

$$f(x) = \sum_{n=0}^{N} a_n x^n, \quad x_{e1} \le x \le x_{e2} \tag{1}$$

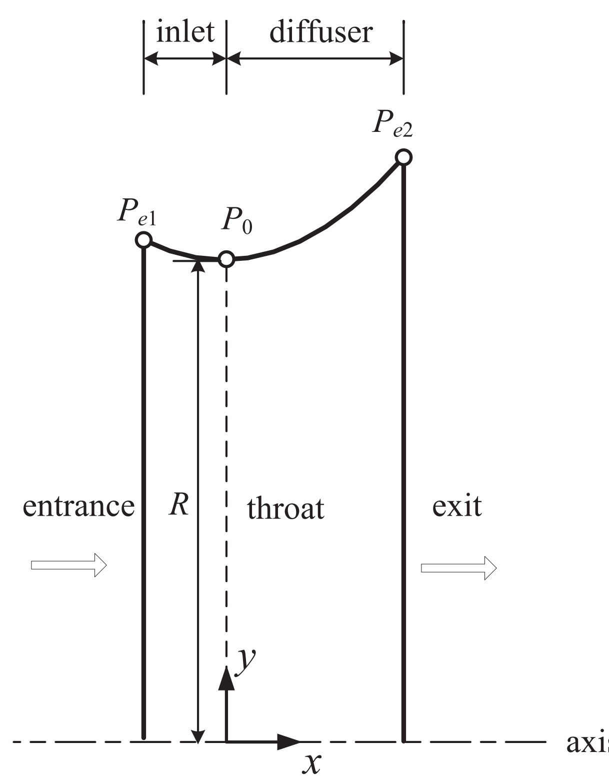

Fig. 2. One half profile of an axis-symmetric wind lens.