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AIRFOIL PROFILE OPTIMIZATION OF AN AIR SUCTION EQUIPMENT WITH AN AIR DUCT

by

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On the basis of boundary layer with the airfoil profile, this research attempts to investigate the effect of the angle of spread of the winged air suction equipment on the efficiency of operation. The application of Fluent with the split-middle method under the identical operation mode is expected to optimize the spread angle. The investigated airfoil profile is NACA6413, of which the restrictions on the critical angle of spread suggested in literature will be overcome through the interactions between the internal and external flow fields. As a result, the air speed might increase. The wind tunnel test employed in this research offers the solid evidences to support this hypothesis. The test demonstrates that when the angle of spread is larger than 12°, the effect of accelerating the air flow is still observable. Following the optimization, the air suction effect of the equipment would be optimal when its angle of spread reached 30°.

Key words: *numerical simulation, fluent, optimized analysis, wind driven generator*

Introduction

Winds flowing in the nature are generally unsteady. As for the draught fans, the priority of the designers goes to guarantee that the wind energy resources can be maximally captured and transformed into other types of resources. The air suction equipment with an air duct is rounded, with the climbing force of the impeller initially shrinking and expanding later in the radial direction. The reaction force is inevitably generated when the airstream is changing. Compared to the free stream draught fans, in the case of the air suction equipment with an air duct, the flowing stream will be stressed inside the air duct, leading to the compression of air flow in the unit time and the maximization of the power on the unit wind-sweeping fan [1-3]. According to this rationale, the section of the air suction equipment has been designed into the NACA airfoil profile in pursuit of the maximal regional wind speed. The study suggested that in case the length remains unchangeable, with the change of the angle of spread, the flow velocity will be increased along with the acceleration of the wind speed. When the angle of spread reached 12°, the flow velocity was maximal [4, 5]. This research fully utilizes the features of air duct to increase the pressure difference between the internal and external flow field in pursuit of the acceleration of the speed.

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Rationale of the air suction equipment

The function of air suction equipment is designed to accelerate the regional wind speed. In general, the blowing wind in motion has to comply with the principle of momentum conservation and mass conservation [6, 7]. In case of facing the obstacles, the winds will keep the balance through accelerating around the obstacles. Thus, it is necessary to consider the component of the radial speed in course of design.
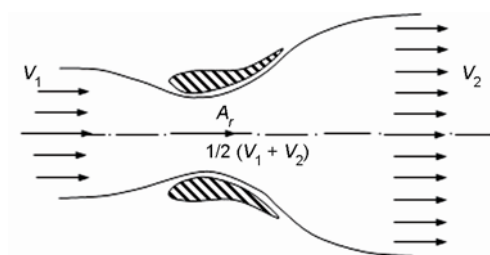

Figure 1. The change of the speed of the wind driven generator and its radial force

Figure 1 clearly demonstrates the influence of aerodynamic force on the streamline after the installation of air duct.

The climbing force of the airfoil profile (on the perimeter of wind wheel) on unit wind wheel is calculated by:

$$A_r = \rho w \Gamma \qquad (1)$$

In eq. (1), Γ is the Ring value, and ρ – the air density. The incoming flow speed of the airfoil profile, marked as w, is calculated as:

$$w = \frac{1}{4}\left(3 + \frac{v_1}{v_2}\right) + B_2 \frac{2\Gamma}{D} \qquad (2)$$

where w is generated in course of the airflow of an ideal air suction equipment with an air duct.

The induced speed increase generated in the wind wheel under the optimal power is:

$$v_r = \frac{12}{5} B_1 \frac{A_r}{\rho v_1 D} \qquad (3)$$

where D refers to the diameter of wind wheel, while b is the length of section of the airfoil profile of the air duct. The B_2 in eq. (2) and the B_1 in eq. (3) are the change range of the vortex of the section of airflow along the wind direction. They can be calculated by eqs. (4) and (5). The ratio without any speed increase is applicable to all the mentioned equations.

$$B_1 = \frac{1}{\pi}\left[\ln\left(2\frac{D}{b}\right) + \frac{3}{4}\right] \qquad (4)$$

$$B_2 = \frac{1}{4\pi}\left[\ln\left(16\frac{D}{b}\right) - \frac{4}{5}\right] \qquad (5)$$

The establishment of model and the division of gridding

The pro/E would be employed to set the established angle of the air suction equipment as 29°. Models would be created for every 0.1° by which the established angle was lifted up until the wind speed reached the maximal. In real situation, the air was flowing through the air suction equipment in a regular way. Namely, the wind speed remains minimal in the place nearby the wall. The closer the place nears the central position, the faster the wind speed will be. In order to simulate the real situation, this research established the external calculation domain for the air suction equipment. The size of external calculation domain is set not to affect the calculation result. Furthermore, ICEM CFD was employed to divide these ten models into the hexahedral gridding with method of O-shaped gridding division method. The quality of the gridding

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was required to be above 0.2 while the parts of gridding nearby the air suction equipment must be denser. In an attempt to test that whether the variation of the gridding has the effect in the analytic result, the gridding was divided in a rougher way, which would be further divided in a sophisticated manner after the test. A comparison between the analytic results from these two kinds of gridding would be subsequently conducted. In case that these two division methods did not affect the result, the gridding divided in a more sophisticated way would be preferred.

Configuration of the boundary conditions and the selection of calculation model

In course of the Fluent analysis, the model could be confirmed through the Reynolds number. The formula is $Re = \rho UL/\mu$, where ρ is the density of the fluid, U – the wind speed of the incoming flow, L – the characteristic length, and μ – the viscosity coefficient of the fluid. As the result suggested, the Reynolds number was larger than 10^5. The calculation model was chosen to be the standard k-ε model, while the standard wall was preferred. Simple algorithm is chosen. Each relaxation factor in the solver initially was in the default setting but would be gradually modified during the calculation in pursuit of the stability. As the influence of secondary flow was not being considered in this research, the steady state was more suitable to be employed in the solution procedure. In general, the situation where the air is slightly compressed can be considered as the one where the air is the incompressible fluid. Thus, the inlet velocity was set as the inlet boundary while the pressure outlet was identified as the outlet boundary. The non-slipping condition was applicable to the wall, while the roughness of the wall depended on the materials being used.

Results and discussion

The cloud pictures suggested that the boundary layers were detached to each other while the wind speed was being increased. Figures 2 and 3 indicated that under the identical angles of spread, the wind speed of the air suction equipment with the airfoil profile section increased faster than that of the one with arc-shaped section due to the huge disparity between the pressures of the external and internal flow fields. In fig. 4, due to the fact that the angle of spread was changed, the detachment of the boundary layers became more conspicuous along with the enlargement of the angles. The wind speed reached maximal when the laryngeal of the suspended hood approached the wall. The wind speed started decreasing when the
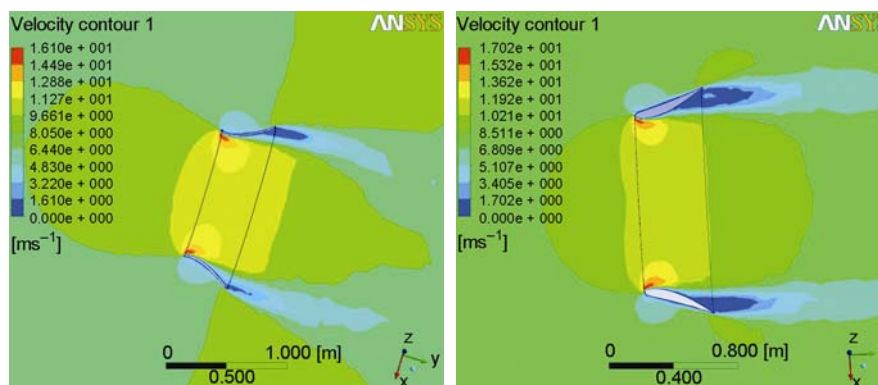

Figure 2. Arc-shaped section and the wind speed of airfoil profile section

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suspended hood moved away from the wall. Due to the overlay effect of the velocity field, the wind started accelerating before approaching the exhaust inlet and appeared in shape of hemisphere. The wind speed was recorded as an S-shaped curved line in the air suction equipment. The split-middle method was employed to optimize the angles of spread of the airfoil profile. When the angle reached 30°, the wind speed increased significantly with the maximal speed up to 18 m/s.
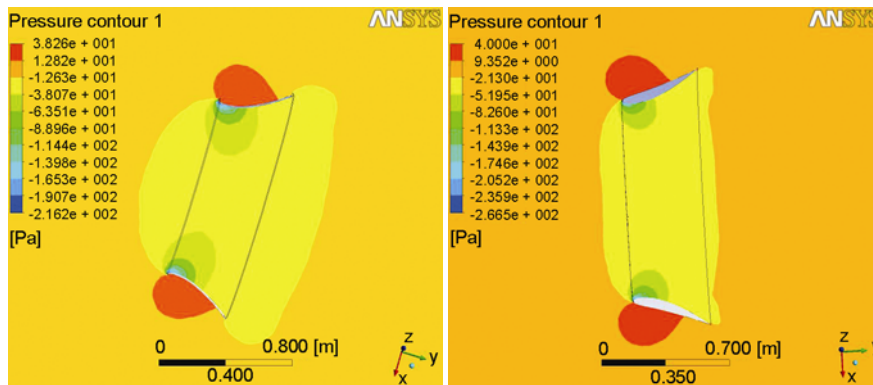
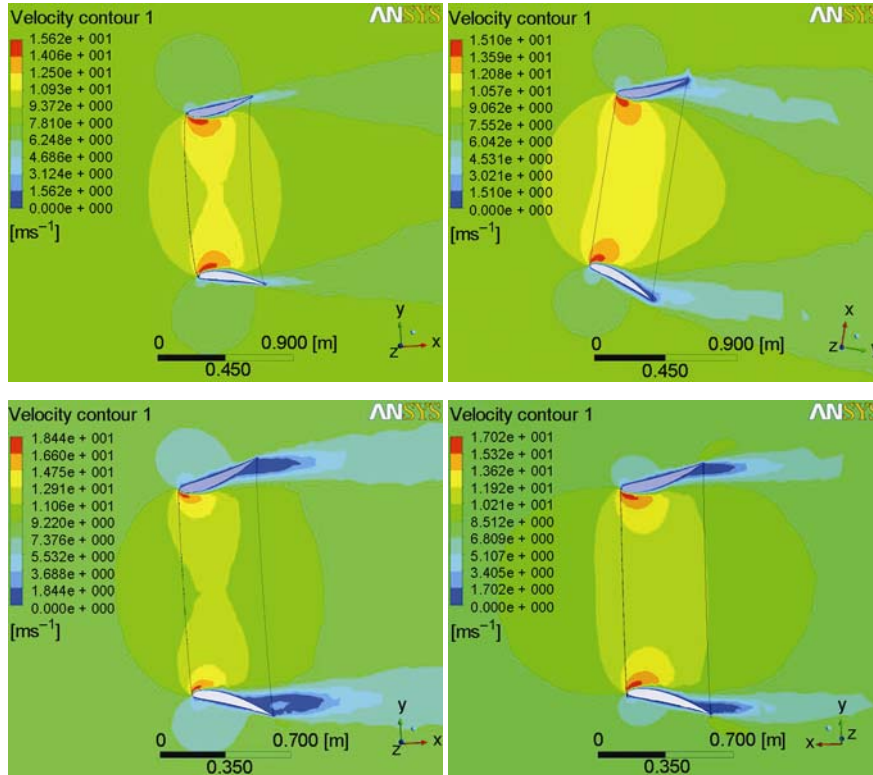**Figure 3. Arc-shaped section and pressure on the airfoil profile section**

Figure 4. The angles of spread are 20°, 25°, 27.5°, and 30°, respectively

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Installation experiment for the air suction equipment

The air suction equipment was installed in a draught fan with 12 blades for simulation. Test data are given in tab. 1.

Table 1. Tested data

| 12 blades with hood 300 W						
Rotated speed	Angular velocity	Electricity current	Power	Electricity torque	Voltage	Wind speed
406.6	30.39819	0.2	7.8	0.256594	28.4	6.8
399	29.83	0.8	24.1	0.807911	27.1	7.5
405	30.27857	1.3	33.4	1.10309	27.6	9
418.3	31.2729	1.8	51.8	1.656386	27.6	10.2
442.1	33.05224	2.7	79.7	2.411334	28.2	11.3
448	33.49333	2.8	93	2.776672	27.7	11.8
466	34.83905	3.9	118.3	3.395615	28.1	12.5
474.6	35.482	5	136.1	3.835748	27.8	13.5
497	37.15667	6.2	180.5	4.857809	28.2	15.8
521	38.95095	8.2	230	5.904862	27.8	17.6
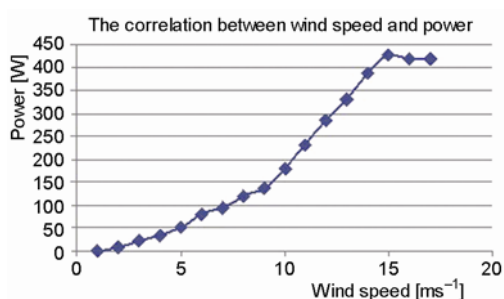
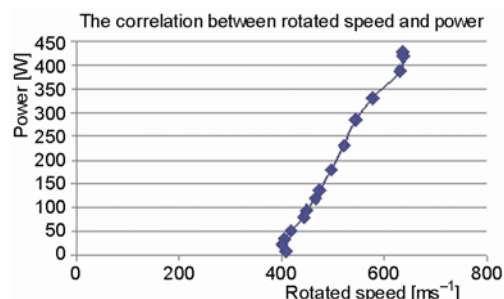
Figure 5. Wind speed and power

Figure 6. Rotated speed and power

As suggested by figs. 5 and 6, the wind speed and power in fig. 5 were gradiently increased. When approaching to 15 m/s, the power of the draught fan stopped increasing along with the enlargement of the wind speed. In fig. 6, the rotated speed formed a linear relationship with the power. The experiment result indicated that the draught fan with the air suction equipment worked steadily. The speed was significantly improved.

Conclusions

- Under the identical operation modes, a comparison between the simulation of the air suction equipment with the airfoil profile section and arc-shaped section suggested that the former one was superior.
- The split-middle method was employed to optimize the angle of spread for the airfoil profile. This research contended that when the angle of spread reached 30°, the wind speed

would be improved most significantly, as supported by the simulated wind speed and pressure cloud picture.
- Under the identical wind speeds, the larger the angle of spread was (but smaller than 30°), the more conspicuous the boundary layers were.
- The wind tunnel test suggested that the optimized air suction equipment with air duct worked effectively with the experiment result hitting the expectation.

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