

A Visualization Experimental Study of Icing on Blade for VAWT by Wind Tunnel Test

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Abstract—Blade icing is problematic to the safe and efficient operate of wind turbine. It is important to prevent and remove ice from the blade surface. To invest the characteristics of blade surface icing of wind turbine, wind tunnel tests were carried out on the wind turbine blade with NACA0018 and NACA7715 airfoil. The tests were made in winter. The outside cold air was induced into the wind tunnel, and a water spray was set up before the output of the wind tunnel to supply the icing condition. A CCD video camera was used to record the ice accretion in 20 minutes. By image processing software the icing distributions of the two kinds of airfoils were obtained and analyzed. Furthermore, the icing area increasing rate was also discussed.

Keywords- wind turbine; blade; deicing

I. INTRODUCTION

The wind energy is one of the most used renewable energy in the world now. The power performance is not the most important point concerned by researchers benefiting from the long term study and development. The problems such as safety, noise, the effects from extreme weather to wind turbine have become the hot research fields. Generally, many wind farms were built up in cold regions, such as North Europe, North America. When the wind turbine works under the condition of wet and low temperature, icing will happen on the wind turbine, especially on blade which is the most important part to produce aerodynamics. The icing on blade changes the shape of blade airfoil and leads to a lot of serious problems. A dramatic decline of performance and safety of wind turbine will be caused. Therefore, the icing problems have received a lot of attention in the world. For example, Neil Bose researched icing on the small horizontal-axis wind turbine [1, 2]. Andrea G. Krai researched the phases of icing and ice adhesion force on wind

turbine blade by wind tunnel tests [3, 4]. The effect of temperature and droplet size variation on ice accretion of wind turbine blades was researched by Matthew C. Homola [5]. Olivier Parent proposed critical reviews about anti-icing and de-icing techniques for wind turbines in 2011 [6]. In addition, the authors also carried out some tests on wind tunnel and numerical simulations on the blade icing both for HAWT and VAWT [7,8].

Based on the past researches mentioned above, the icing problems on wind turbine have been more and more known to people. However, almost all the wind tunnel tests on blade icing just took photos at one time only and made analysis on icing characteristics of this time. The duration of icing was not recorded yet and no researches on the icing development have been carried out. Therefore, in this study, a CCD video camera was adopted and icing of 20 minutes were recorded. This makes the icing development visualization.

II. EXPERIMENTAL DETAILS

A. Test Blade Airfoil

The NACA0018 airfoil and NACA7715 airfoil were selected in this study. Based on the experimental condition, the chord of the blade was 0.22 meter, and the width of the blade is 0.1 meter.

B. Test System

Figure 1 shows the experimental system. The wind tunnel used in this study is a small scale open type one with the outlet of 0.4m×0.4m. The sensitivity of wind speed sensor is ±5%. To supply the icing condition, a water spray nozzle was set near the outlet of wind tunnel. The flow discharge was con-

trolled by a flow controller and measured by a flow meter. The average diameter of water droplet is 0.2mm. During the test, the cold air outside was sucked into the wind tunnel, and at the same time, the water was sprayed from the nozzle and mixed with the cold wind. The test blade is fixed at 0.3m downstream from the outlet. The wind speed used in this study was 6m/s. The flow discharge of water sprayed with wind which can be represented as the humidity of air was 0.5 L/min. The environmental temperature was -15 degree. A video CCD camera was used to record the ice accretion in 20 minutes. By using image processing software the icing photos were processed to be clearly visualization. The icing distributions on blade at every minute were obtained.

The test blade is in the water spray. Each test was carried out for 20 minutes. Then the test blade was photographed every minute. At last, data were recorded through computer. In this study, the humidity of air was 0.3L/min. The environmental temperature was -10 degree centigrade. The wind speed was 6m/s. The attack angle was 0 degree.

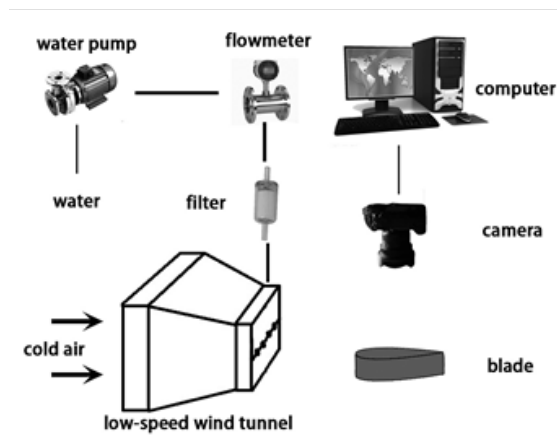


FIGURE I. EXPERIMENTAL SYSTEM.

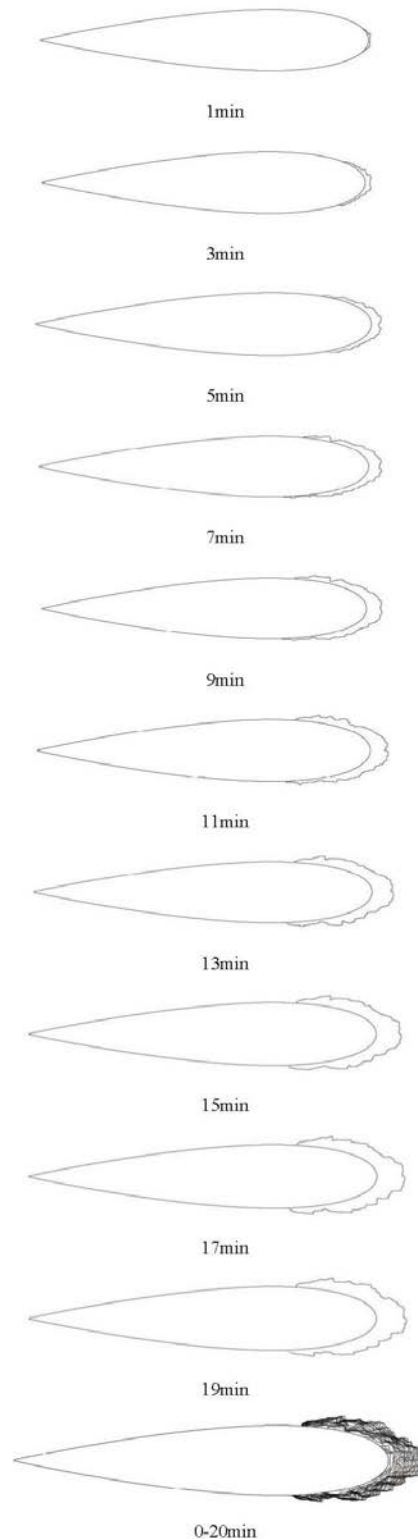
III. RESULTS AND DISCUSSION

A. Distribution of Icing on Blade Airfoil Surface

Figure 2 shows icing development at every minute on blade surface on NACA0018 airfoil and NACA7715 in 20 minutes.

According to Figure.2, icing occurs at the leading edge part of airfoil and development along the up and down side of airfoil surface. When the ice reaches to the point near the largest thickness, it does not develop along the chord direction. Therefore, the icing of NACA0018 airfoil almost remains at the front part of airfoil at the attack angle of 0 degree. The icing on NACA7715 airfoil is not similar to NACA0018. At beginning, the icing occurs both at the leading edge and trailing edge because the NACA7715 is an airfoil. The icing development is not balance on the upside and downside. The icing on upside is many than icing on downside. Similar with the results of NACA0018 airfoil, the icing distance from leading edge of blade to the point about the first third of the length of blade chord. The icing length from trailing edge is also about first third of blade chord.

Based on the test results, it can be concluded that the icing on blade surface mainly depend on the airfoil type. For the symmetry airfoil, the de-icing and anti-icing device should be installed in the leading edge part. For the asymmetric airfoil, they should be installed both in the leading edge part and trailing edge part.



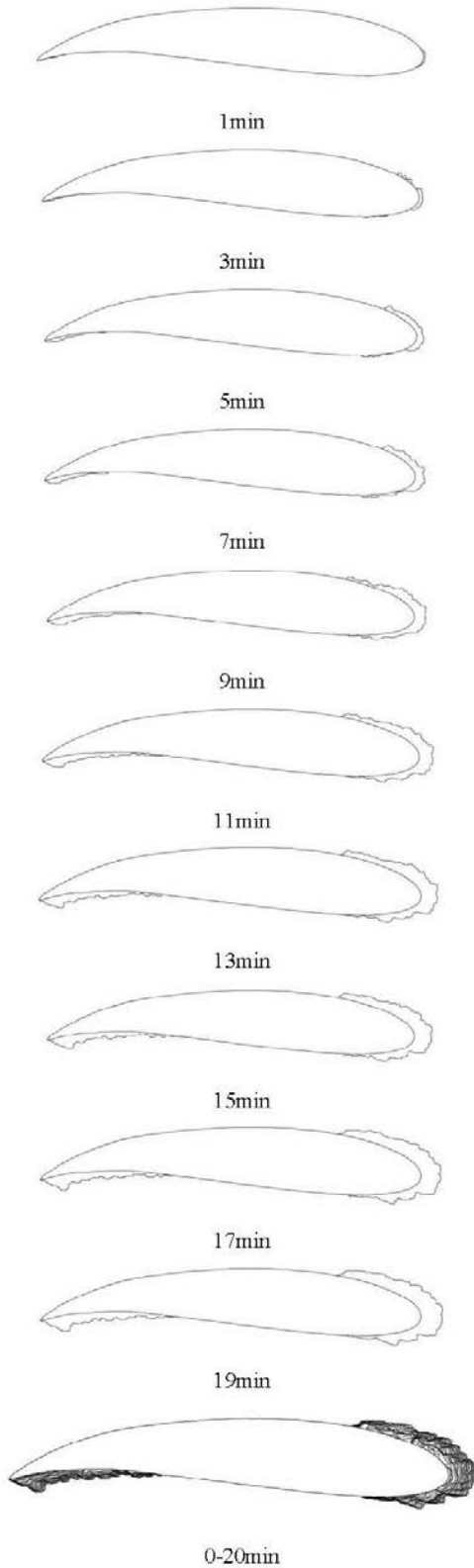


FIGURE II. ICING DISTRIBUTIONS ON NACA0018 AND NACA7715 AIRFOIL.

B. Icing Area

1) Total Icing Area Increasing Rate (TIAIR)

To clearly describe the icing rule on blade surface, icing area was analyzed. Figure 3 shows the definition of icing area at every minute. The icing area of blade surface at 1 minute is S_1 , the new increasing icing area from 1 minute to 2 minutes is S_2 . Finally, the new increasing icing area from 19 minutes to 20 minutes is S_{20} .

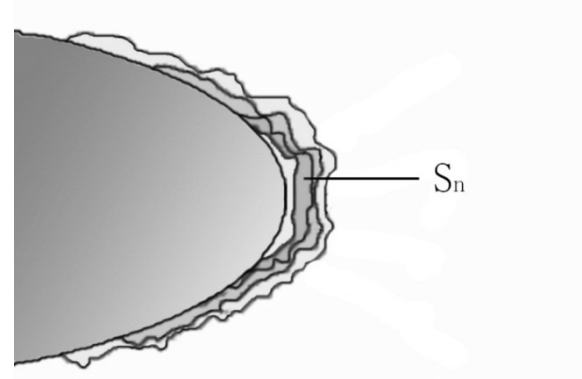


FIGURE III. DEFINITION OF ICING AREA.

Total icing area increasing rate (γ) was defined as shown in Table 1 where, S is the area of airfoil.

TABLE I. TOTAL ICING AREA INCREASING RATE.

T	Icing area rate	
1min	r_1	$S_1/S*100\%$
2min	r_2	$S_1+S_2/S*100\%$
.....
20min	r_{20}	$S_1+S_2+...+S_{20}/S*100\%$

Figure 4 shows the total icing area increasing rate for both the NACA0018 and NACA7715 airfoil. According the Figure4, the TIAIR shows a growth trend for both the two types of airfoil. During the 20 minute, the TIAIR of NACA0018 airfoil is 18.78% and NACA7715 airfoil is 20.62%. Between first minute and fifteenth minute, the TIAIR of NACA0018 airfoil is larger than that of NACA7715 airfoil. Between sixteenth minute and twentieth minutes, the TIAIR of NACA7715 airfoil is larger than that of NACA0018 airfoil.

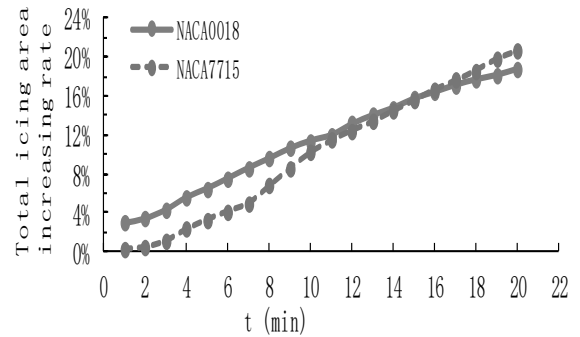


FIGURE IV. TOTAL ICING AREA INCREASING RATE.

2) Total Icing Area Increasing Rate (TIAIR)

Furthermore, the net icing area increasing rate (δ) during every one minute was defined shown in Table 2 like the definition of total icing area increasing rate.

TABLE II. NET ICING AREA INCREASING RATE.

T	Net icing area rate	
1min	δ_1	$S_1/S^*100\%$
2min	δ_2	$S_2/S^*100\%$
.....
20min	δ_{20}	$S_{20}/S^*100\%$

Figure 5 shows the net icing area increasing rate for both the NACA0018 and NACA7715 airfoil. According the Figure 5, the NIAIR shows a fluctuation trend on both two types of airfoil. NIAIR of NACA0018 airfoil is between 0.45% and 1.5%. NIAIR of NACA7715 airfoil is between 0.18% and 1.79%. In order to analyze NIAIR of two types of airfoil better, trend line is introduced. There is a gradually decrease on the NIAIR of NACA0018 airfoil. Nevertheless, the NIAIR of NACA7715 airfoil increases first and then decreases.

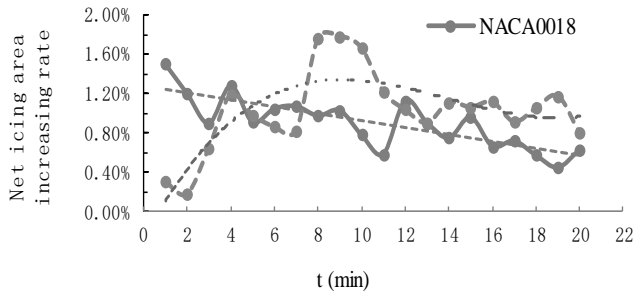


FIGURE V. NET ICING AREA RATE.

According to Figure.4 and Figure.5, it can be concluded that although the net icing area increasing rate is quite different between NACA0018 and NACA7715 airfoil during every minute, the total icing area increasing rate keeps the liner increasing speed.

IV. CONCLUSIONS

Under the conditions of this experiment, conclusions can be summed as below:

1) The icing development on both NACA0018 and NACA7715 airfoil were well recorded and the icing distributions were clearly visualization.

2) The icing on blade surface mainly depended on the airfoil type when the attack angle was fixed. For the symmetry airfoil, the icing distributions were mainly at the leading edge part of blade. For the asymmetric airfoil, the icing occurred at both the leading edge part and trailing edge part of blade. This can be a reference for installing of de-icing and anti-icing device on blade.

3) The total icing area increasing rate kept linearly increasing during the test time.

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