Wind tunnel test on a straight wing vertical-axis wind turbine with attachment on blade surface

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Abstract

Recently, many straight wing vertical-axis wind turbines (SW-VAWT) are installed in community, urban areas and high mountain areas as an independent power supply or community power. However, when the SW-VAWT is used in cold regions, the icing will affect its performance or even make the power system down. To research the icing effects on the SW-VAWT, the condition of icing on the leading edge of blade surface were simulated by a kind of attachment - clay in this study, and the effects of attachment on the performance of SW-VAWT were measured by wind tunnel tests. According to the test results, the rotational performance and power performance reduced for the existence of attachments.

Key words: Straight wing vertical-axis wind turbine, wind tunnel test, icing, attachment, revolution, power performance

1. Introduction

Recently, there is resurgence of interests regarding straight wing vertical axis wind turbine (SW-VAWT) [1]. Researchers in many universities and institutions have carried out their researches on this lift type VAWT, especially in Canada, USA and Japan [2-5], etc. It is usually installed on the roof of high buildings in city, urban areas and high mountain areas as independent electric power supply. This is not only for its advantages of simple design and low cost，but also wind direction independency comparing with the horizontal system. However, when SW-VAWT is installed in cold regions, the icing, snow and other attachments on blade surface will affect its performance [6-8]. Therefore, it is important to make it clear of the mechanism of icing and to prevent icing. Because the situation of icing on blade is very complex and is affected by many factors, the condition of icing on the leading edge of blade surface was firstly considered in this study, and the situation of icing there was thought as a kind of attachment in a sense, and was simulated by clay for its good adhesion and deformability. Wind tunnel tests were carried out on a test model of SW-VAWT and the effects of attachment on the rotational performance and power performance of SW-VAWT were measured and discussed.

2. Experimental Details

2.1 Test model of SW-VAWT

A small model of SW-VAWT with three straight wings was designed and made in this study for wind tunnel test. The wing had the blade aerofoil of NACA0018. Figure 1 shows the geometry of blade airfoil, and their main sizes are listed in table 1.

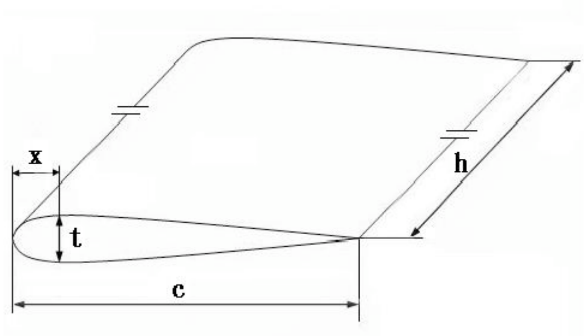

Fig.1 Blade airfoil of SW-VAWT model

Table 1 Sizes of blade

Position	Size（m）
Length of blade span (h)	0.325
Blade chord (c)	0.07
Maximum blade thickness (t)	0.013
Position of maximum thickness (x)	0.02

2.2 Attachment

To simulate icing, clay was selected as the attachment for its good adhesion and deformability. The clay was adhered on the leading edge of blade surface along the span direction as shown in Fig.2. To research the effects of mass and thickness of attachment, the situation of clay were decided to be two kinds listed in Tab. 2.

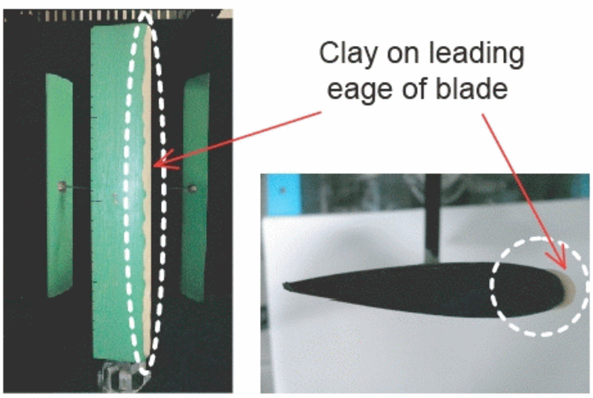

Fig.2 Position of clay attached on blade

Table 2 Mass and thickness of clay

Mass（g）	Thickness（mm）
15 (25％ of blade mass)	2 (3％ of chord)
30 (50％ of blade mass)	4 (6％ of chord)

2.3 Experimental methodology

Wind tunnel tests were carried out in Faculty of Regional Sciences of Tottori University in Japan. The wind tunnel used in this study is an open type one with an outlet of 0.4m×0.4m. Figure 3 shows a schematic diagram of the experimental system. Test model was placed at the same center of the wind tunnel outlet and 0.5m downstream from the outlet. Torque was measured by a digital torque detector (ONO SOKKI, SS-002), which was located between the test model and an induction motor. The main tests included: (1) the effects of attachment on the steady revolution by changing clay weight under different wind speed (U=5.0m/s～7.0m/s); (2) the effects of attachment on the power performance by changing clay weight at the wind speed U=7.0m/s.

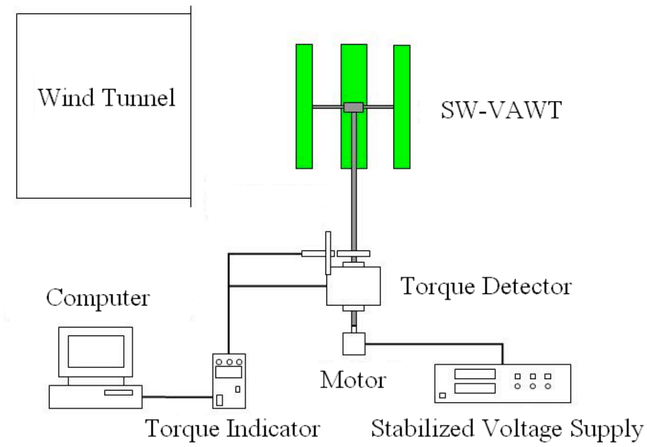

Fig.3 Schematic diagram of experimental system

3. Results and discussions

3.1 Effects of attachments on rotational performance

Usually, wind turbine can generate electric power only when it reaches certain revolution. Therefore, it is important to research the effects of attachment on the rotational performance of SW-VAWT. The tests were carried out at 5 kinds of wind speed. As an example, the revolutions of test model with or without attachment are shown in Fig.4. According to the results, it is clear that the steady revolution of the turbine without attachment is the largest. The steady revolution of the turbine with attachment became small, and reduced more with increasing the weight of clay.

Figure 5 shows the steady revolution of the turbine with or without attachment at all test wind speeds. The steady revolutions were averaged value of the results of five times of test. For all situations, the steady revolution increased with the increasing of wind speed. However, the increasing degree became lower for the existence of attachment, and this tradition became clear as the weight of clay increased. Here, reducing rate of steady revolution (R_R) has been defined as bellow:

$$R_R = \frac{R_A - R}{R} \times 100\% \qquad (1)$$

Where R_R is the reducing rate of steady revolution; R is the steady revolution of the turbine with no attachment; R_A is the steady revolution of the turbine with attachments.

Figure 6 shows the R_R of the turbine with attachments (15g and 30g) on the base of the steady revolution of test model without attachment. On the occasion of 15g, the increasing of wind speed did not bring large effect to R_R, for it kept almost -5% at all test wind speeds. On the other hand, for the occasion of 30g, R_R became lager with the increasing of wind speed, and the maximum value reached -22%. Therefore, it can conclude that the existence of attachment on the leading edge of blade surface reduces the rational performance, and the effects become larger with the increasing of wind speed and weight of attachment. The reason can be considered as two main factors. One is that the existence of attachment changes blade airfoil, and then changes the aerodynamic characteristic which reduces turbine's performance. The other one is that the attachment increases the weight which leads to the unbalance of force and torque on turbine and thus reduces its performance.

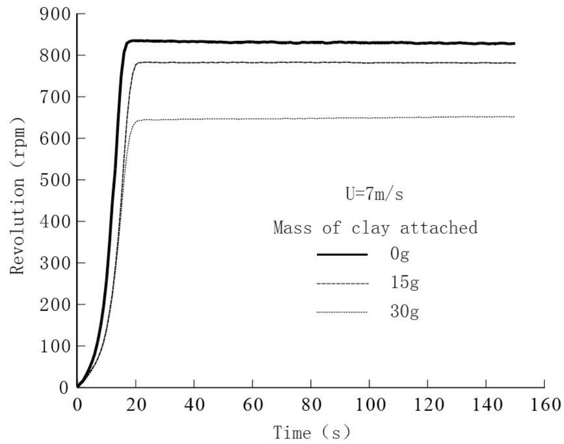

Fig.4 Revolution at U=7m/s

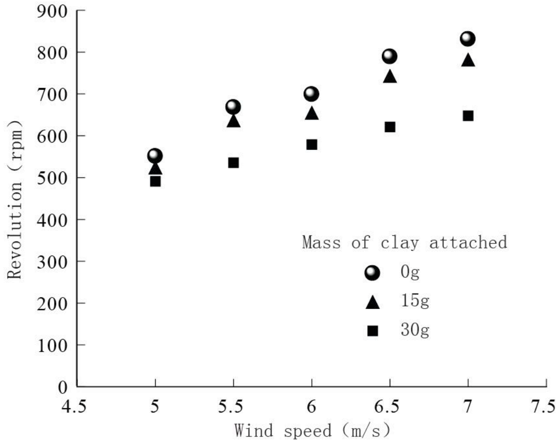

Fig.5 Steady revolution at different wind speeds

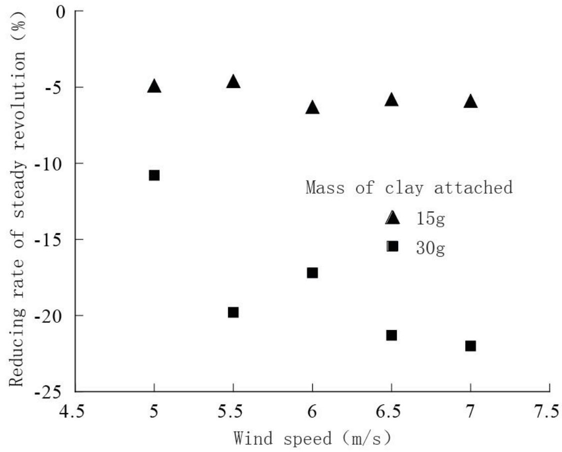

Fig.6 Reducing rate of steady revolution

3.2 Effects of attachments on power performance

Figure 7 shows the power coefficient C_p of test model with or without attachment as a function of tip speed ratio λ at the wind speed of 7m/s. The C_p and λ are defined as bellow:

$$C_p = \frac{P}{\frac{1}{2}\rho A U^3} \qquad (2)$$

$$\lambda = \frac{\omega D}{2U} \qquad (3)$$

Where：P is power； ρ is density of air，kg/m^3；A is swept area or turbine，m^2；U is wind speed，m/s； D is diameter of turbine，m； ω is angular speed of turbine，rad/s。

Future more, as the same definition of R_R, reducing rate of power coefficient (R_P) has been defined as bellow, and the R_p of test model with attachments (15g and 30g) on the base of the C_p of test model without attachment are shown in Fig. 8.

$$R_P = \frac{P_A - P}{P} \times 100\% \qquad (4)$$

Where R_P is the reducing rate of power coefficient; P is the power coefficient of the turbine without attachment; R_A is the power coefficient of the turbine with attachments.

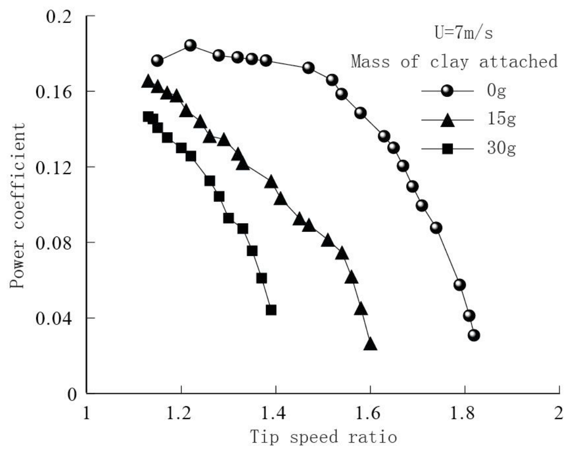

Fig.7 Power coefficients

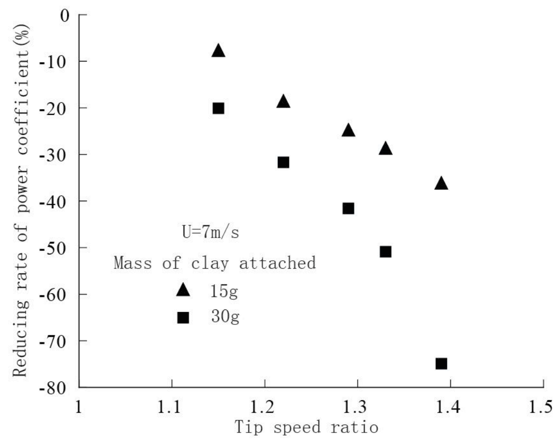

Fig.8 Reducing rate of power coefficients

According to Fig.7, the power coefficients of the turbine with attachments are much smaller than that of the turbine without attachment. With the increasing of clay weight, the power coefficient reduced rapidly. This can be seen in Fig.8 clearly. It can be also found that the power coefficient reduce more at high tip speed ratio. According to the analysis above, the attachment on blade surface will reduce the power performance of SW-VAWT. The reasons can be also explained as above in Chap.3.2.

4. Conclusions

In order to investigate the performance effects of icing on SW-VAWT, wind tunnel tests were carried out by attaching clay on the leading edge of blade surface for simulating the situation of icing in this study. The results can be summarized as follows:

(1) The attachment will reduce the steady revolution of SW-VAWT, and the reducing rate of steady revolution becomes larger with the increasing of wind speed and the weight of attachment. Therefore, the attachment on the leading edge of blade surface will make the rotational performance of SW-VAWT worse.

(2) The power coefficient reduced by the existence of attachment, and the reducing rate of power coefficient became lager as the weight of attachment

increased and the revolution of SW-VAWT increased. Therefore, the attachment on the leading edge of blade surface will make the output power performance of SW-VAWT worse.

For the changes of blade airfoil and weight are the main factors caused the performance down, the future works for authors are to make it clear of the effect degree between the two factors.

Acknowledgements

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