EWEA 2015 Annual Event - Abstract

Blades fatigue loads analysis of a wind turbine with a teetered hub by wind tunnel test

Shuji Suzuki, Shigemitsu Aoki, Kenichi Sakurai, Tetsuya Kogaki, Chuichi Arakawa, Makoto Iida*

Shuji Suzuki, Chuichi Arakawa and Makoto Iida, The University of Tokyo, 7-3-1 Hongo, Bunkyo-ku, Tokyo, Japan

Shigemitsu Aoki, Kenichi Sakurai and Tetsuya Kogaki, National Institute of Advanced Industrial Science and Technology, 1-2-1 Namiki, Tsukuba-shi, Ibaraki, Japan

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1. Introduction

In order to reduce power generating cost, wind turbines are increase in size owing to use the relatively high wind velocity of the upper sky. When designing further bigger size of the wind turbine, they become the problem that the construction costs of a wind turbine and increasing fatigue loads occurring in a shaft axis. One of the methods to solve this problem, it is thought that reducing the number of blades from general wind turbines that have three blades. It is expected that reduction of the number of blades makes it possible to reduce the production costs of blades and the construction costs of the wind turbine by the decrease of the nacelle weight in comparison with a three-bladed wind turbine. However, two-bladed wind turbines have some issues such as increasing fatigue loads and noise. Increasing noise is not so important when installing wind turbines in a sea area. So, to implement larger size of off-shore wind turbines, reducing fatigue loads is important.

As one of the methods that reduce fatigue loads, a teetered hub is noticed. A teetered hub enables blades to rotate on a central axis of the hub, a teeter axis, like a seesaw (it is called "teeter movement"). The mechanism of a teetered hub and definitions of teeter axis, teeter angle and etc. are shown in Fig. 1. From a past study, by this movement, the difference of aerodynamic loads between two blades is balanced and load fluctuations on blades root and shaft makes lower than conventional wind turbines with rigid hub [1-3]. However, it is scarcely the case that comparing a wind turbine with a conventional hub and a wind turbine with a teetered hub under the same input condition and initial condition on experimental tests.

2. Approach

In this study, producing a sample small wind turbine that can permute type of hubs, a teetered hub and a conventional hub. Using this sample wind turbine, we reveal the characteristics of blades root vibration with a teetered hub by wind tunnel test. In addition to wind turbine test, we reveal the characteristics of blade root vibration by aero elastic model about the conditions that is hard to be reproduced in wind tunnel, for example wind shift and a gust of wind. This paper is especially referred about the result of wind tunnel test.

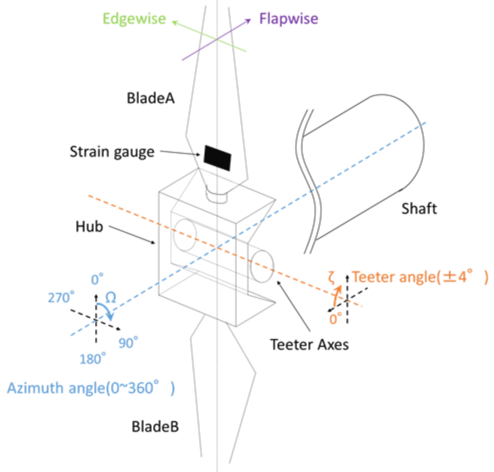

Fig. 1 Teetered hub

3. Main body of abstract

3.1 Sample wind turbine

The sample wind turbine which is used by this experiment is two-bladed horizontal axis type up wind type wind turbine. The rotor diameter is 1.6 m and the hub height is 1.1 m. We adopted the Avistar airfoil as sample blades which the degradation in the low Reynolds number domain had a characteristic to be relatively small.

The Avistar airfoil's profile is shown in Fig. 2. The blade thickness is approximately 14.5 %. The Reynolds number of the sample blades on the basis of a blade tip is about 1.6×10^5 under conditions of most suitable circumferential speed ratio 8. In a past study using the form of same blade section, things more than 1.0×10^5 with the Reynolds number with a few changes of the lift coefficient curve are shown [4]. Therefore, it is thought that the sample blade shows appropriate performance in this experiment condition.

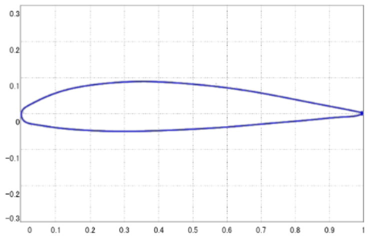

Fig. 2 Avistar airfoil

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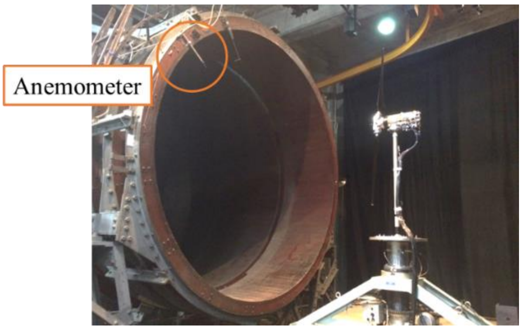
* Corresponding author.

E-mail: shuji.suzuki@gg.cfdl.t.u-tokyo.ac.jp (Shuji Suzuki), iida@ilab.eco.rcast.u-tokyo.ac.jp (Makoto Iida)

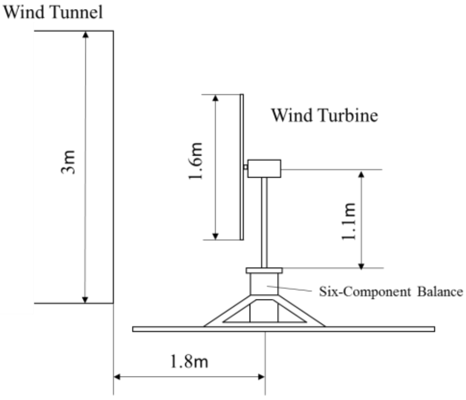
3.2 Wind tunnel test

The over view of the wind tunnel test device is shown in Fig. 3(a). This experiment set up a sample wind turbine to the 3 m wind tunnel which Research center for advanced science and technology in the University of Tokyo held. This wind tunnel is an opening type, 3 m nozzle diameter, and the model is Gottingen expression. The wind tunnel wind velocity installs a heat-type anemometer in the position to show in the figure and measure it. Before wind tunnel test enforcement, a supersonic wave anemometer was installed in the sample wind turbine's Nasser position and carried out the proofreading of the heat-type anemometer.

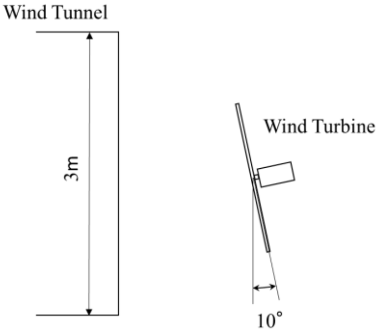
The sample wind turbine is installed in the position is shown in Fig. 3(b). In this experiment, pitch angle is designed the most suitable corner, the mainstream wind velocity is 5 m/s, the rotor speed perform every 50 rpm between 100 to 500 rpm and yaw misalignment is 10 degree like Fig. 3(c). Because of yaw misalignment, the relative wind velocity to flow into the sample wind turbine changes periodically and a periodic load change occurs in blades root.



(a) Over view



(b) Side view



(c) Top view

Fig. 3 Experimental system

3.3 Experimental results

3.3.1 Teeter direction behavior

Teeter direction behavior of the blade in case of 300 rpm is shown in Fig. 4. The horizontal axis is the azimuth position of the blade, the vertical axis is the position of teeter direction and the error bar is standard deviation. In this study, the flap direction bending moment of the blade root is measured in 500 μs. From this results, the mean bending moment and the standard deviation for one minute. In addition, about the azimuth position of the horizontal axis is averaged bin width as 15 degrees. This is similar about the following figure.

Show it in Fig. 4, the blade is displaced in the in the windward when the azimuth angle is 90 degree and the leeward when the azimuth angle is 270 degree. From this results, by introducing a teetered hub, the circumferential speed ratio change with the rotor turn to occur because of yaw misalignment is effective in being relieved. The main factor of the load to occur in the flap direction of the blades is thrust power and thrust power is power with a positive correlation of circumferential speed ratio. Therefore, from a result of Fig. 4, a circumferential speed ratio change is buffered by introduction of a teetered hub and the band of thrust power becomes small. So, it is predicted that fatigue load to occur in the blade root is reduced.

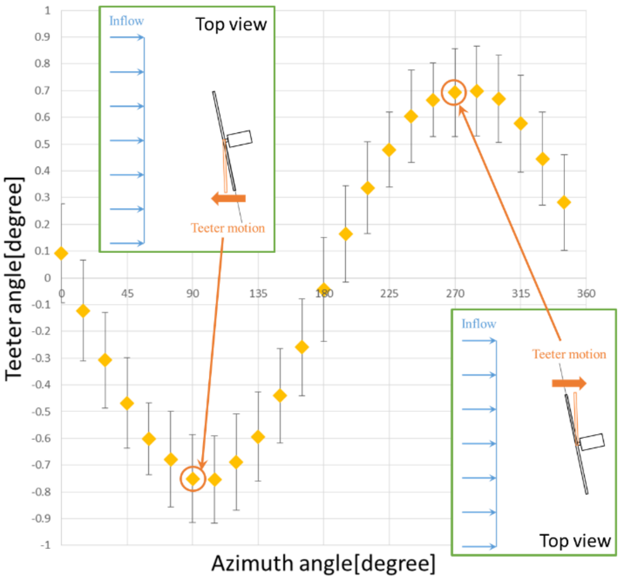


Fig. 4 Teeter direction behavior

3.3.2 Flap direction bending moment in the blade root

Flap direction bending moment in the blade root in case of 300 rpm is shown in Fig. 5. The horizontal axis is the azimuth position of the blade, the vertical axis is flap direction bending moment and the error bar is standard deviation. Show it in Fig. 5, by introducing a teetered hub, the band of load fluctuation in the blade root becomes small.

3.3.3 *Damage Equivalent Fatigue Loads* in the blade root

The effective of fatigue decreasing by buffering of the fluctuation when introducing a teetered hub is estimated using *Damage Equivalent Fatigue Loads* (*DEFL*). *DEFL* is expressed in expression (1).

$$DEFL = \sqrt[m]{\frac{\sum_i F_i{}^m n_i}{N}} \qquad (1)$$

At this expression, F_i is a load amplitude, n_i is frequency, m is the value to be found from the degree of leaning of the S-N diagram of the blade material and N is a number of rotor revolutions of the wind turbine driving period. F_i and n_i are calculated by rain flow method using Crunch [5-6]. Crunch is the software that is purveyed by National Renewable Energy Laboratory (NREL). In this study, the value of m is considered 10 (CFRP) and the value of N in case of a teetered hub and that in case of a rigid hub are the same value. Because the concrete value of N is unidentified, DEFL is normalized as expression (2) using the case that the hub type is a rigid hub and rotor speed is 500 rpm that condition is almost most suitable tip speed ratio 8.

$$Normalized\ DEFL = \frac{DEFL}{DEFL_{rigit\ hub,500\ \mathrm{rpm}}} \qquad (2)$$

Normalized DEFL is shown in Fig. 6 which is derived from an expression (1) and (2).

By comparing the case of a teetered hub with the case of a rigid hub, the case of a teetered hub turned out have a small *DEFL* in all conditions.

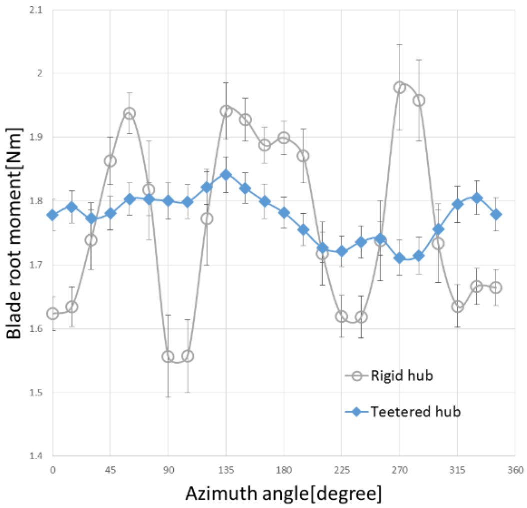


Fig. 5 Blade root moment of a flap direction

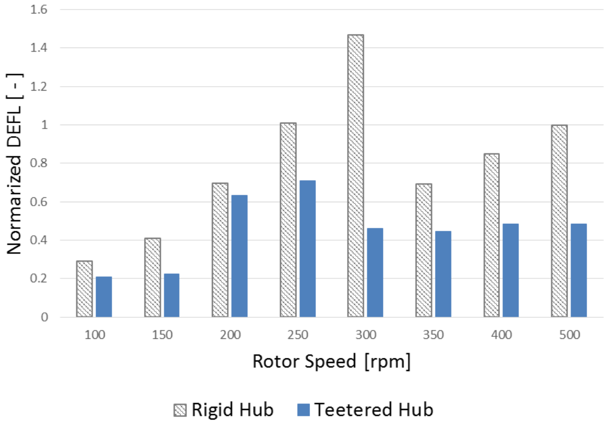


Fig. 6 *Normalized DEFL*

4. Conclusion

For each case of a teetered hub and a rigid hub, flap direction bending moment is measured by strain gauge in same condition. Comparing the results, the influence to give fatigue load in the blade root of introducing a teetered hub is evaluated. Provided results are shown below.

By introducing a teetered hub, the band of the circumferential speed ratio change becomes small.

By introducing a teetered hub, the amplitude of the flap direction bending moment in the blade root is reduced.

By introducing a teetered hub, *DEFL* in the blade root is buffered.

5. Learning objectives

As examination of the feasibility study of the two-bladed large wind turbine, the technique of a teetered hub is researched. Through this study, it is intended to contribute to two-bladed large wind turbine development.

References

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