FIELD MEASUREMENT OF BLADE TIP RESPONSE OF A MEDIUM SIZE WIND TURBINE IN OPERATION

Kichiro Kimura[+1], Hiroshi Torikai [+1], Masao Hosomi[+2] and Eijiro Yukoku [+2]
[+1]Tokyo University of Science, Noda, Japan
[+2]KOMAIHALTEC Inc., Osaka, Japan

The blade tip flap-wise displacements of a medium sized horizontal axis wind turbine during its operation were tried to be measured with relatively simple setup. Motion pictures of the rotor were taken by two high speed cameras and a motion capture software was used to obtain the time histories of the tip locations. Then the coordinates were transformed to obtain the flap-wise component of the blade tips. The calibration was made by pointing the blade tips when the rotor was fixed at four positions respectively and relating them with their known coordinate value. The approximate approaching wind speed was measured with a Doppler lidar at 4Hz sampling rate. The wind turbine used for the measurement is KWT300 of KOMAIHALTEC, with rated power of 300kW, rotor diameter of 33m, and Hub height of 41.5m. The response analysis was conducted with an open source software FAST, which is developed in NREL. The measured wind speed was used as an input, and only vertical wind speed profile was considered, i.e., wind speed was assumed to be fully correlated regardless of the spatial location. Generally, measured tip displacements seem to have taken local minimum values when the blade passed in front of the tower. The three blade tips often took similar response traces when they passed at the same location. On the other hand, the three blade tips sometimes took similar responses at the same time. The cause of these different response characteristics is still not clear. Generally, the amplitude of the measured responses was larger than the analysis, and higher frequency fluctuating components were included in the measurement. These tendencies are probably due to the assumption of full correlation of the wind velocity at different locations in the analysis.

Keyword: wind turbine, motion capture software, blade tip displacement, Doppler lidar, FAST

1. INTRODUCTION

Improving the accuracy of wind turbine response analysis procedure is beneficial, and the response data of actual wind turbine in operation are indispensable to verify the accuracy of the analysis[1)]. The objectives of this study are to obtain the blade tip flap-wise displacement data of a medium size wind turbine during operation, and to compare the data with analysis.

2. FIELD MEASUREMENT METHOD

The field measurement was conducted with a KWT300 of KOMAIHALTEC Inc. (Fig. 1 and Tab. 1). It is a horizontal axis upwind type turbine with rated power of 300kW, rotor diameter of 33m, and hub height of 41.5m. It is located in Futtsu Factory of the company in Chiba Prefecture, Japan.

Relatively simple measurement method of blade tip displacements was used, where motion pictures taken by two high speed cameras (HAS-D72, DITECT Corp.) and a motion capture software (DIPP Motion V, DITECT Corp.) are used to obtain the time history of the coordinates of the blade tips. The calibration was made by pointing the three blade tips when the rotor was fixed, and the procedure was repeated for the four fixed positions of the rotor. The tips' coordinates were calculated from the position and size of the rotor for the positions and they were used for the calibration as well. The calibration relates the blade tip location on the

[+1]kichiro@rs.tus.ac.jp

motion pictures with known coordinate value.

The accuracy of the measurement procedure was tried to be clarified by pointing locations that slightly deviated from the blade tips during calibration, and the sensitivity of the measured tip displacements caused by the error in the calibration was checked. Depending on the error during calibration, the diameters of the rotor based on the measurement traces varied as shown in Fig. 2, and they were between 22 and 48 cm larger than the actual value. With those calibration errors, the measured tip displacements differs as shown in Fig. 3. The variation of the tip displacements shown in Fig. 3 can be thought as the possible error in the measurement.

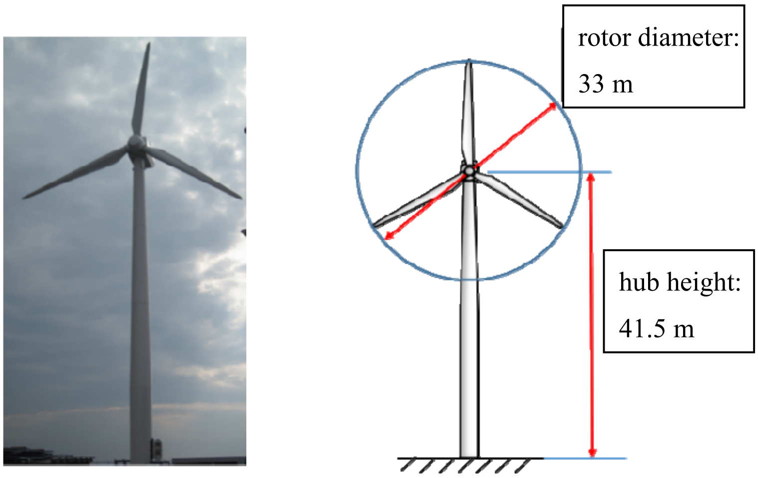


Figure 1: Overview of the wind turbine (KWT300).

Table 1: Specifications of KWT300.

rated power	300 kW
rated rotation rate	40.5 rpm
rated wind speed	11.5 m/s
cut-in wind speed	3.0 m/s
cut-out wind speed	25 m/s
survival wind speed	70 m/s

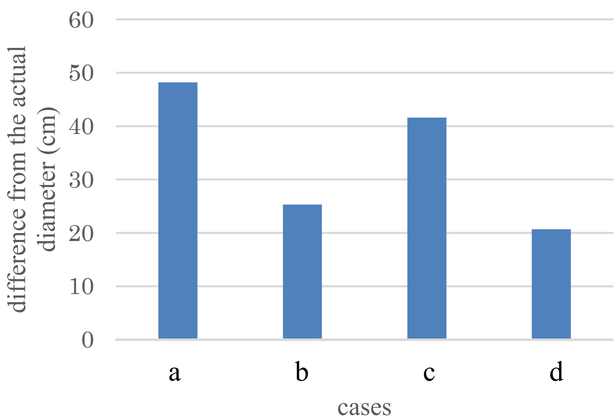


Figure 2: Difference from the correct rotor diameter.

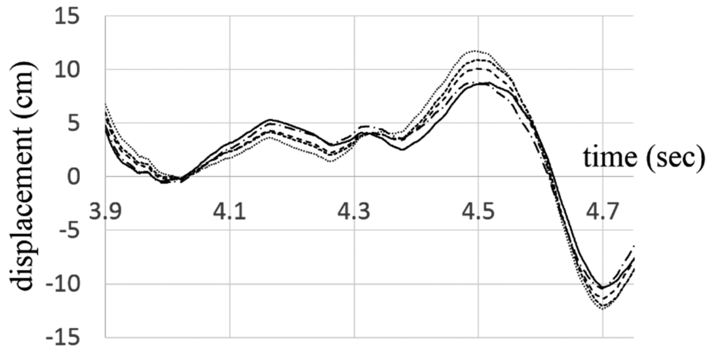


Figure 3: Time histories of blade tip displacements with errorneous calibrations.

The approximate approaching wind speed at the hub height was measured with a Doppler lidar of Mitsubishi Electric Corp. at 4Hz sampling rate. The measured wind speed was at the location about 120 m windward of the turbine. The time history of the wind data was corrected so that it approximates the wind speed at the wind turbine rotor in the following way by assuming that an air volume flows with the same speed as that was measured at the 120 m windward location. The wind speed data was integrated with time, and when the integration reached 120 m, the timing was assumed to be the air mass reached the wind turbine rotor, and the measured wind speed at the beginning was assumed to be observed at the rotor location with that timing. Actually, the measured wind velocity component was inclined by about 20 deg. from horizontal, but it was treated as the horizontal component of the wind speed. These approximations were made to increase the sampling rate as much as possible, with relatively simple setup where the lidar was located at the bottom of the wind turbine tower.

3. WIND-INDUCED RESPONSE ANALYSIS

Analytical results were obtained by using an open source software FAST, which is developed in NREL (National Renewable Energy Laboratory)[2]. The version of FAST was v8.08.00c-bjj (2014.6). For the modeling of the turbine, structural data for the design stage were used. The natural frequencies of the FAST model and design value were (the latter in parentheses) 1st tower mode: 0.81 (0.81) Hz, 2nd tower mode: 5.74 (5.36) Hz, 1st flap-wise mode: 2.72 (2.64) Hz, 2nd flap-wise mode: 7.58 (7.79) Hz, and 1st edge-wise mode: 4.71 (4.66) Hz. The natural frequencies of the design value and the mode more or less agreed. The measured wind speed was used as an input, and only vertical wind speed profile was considered, i.e., the wind speed was assumed to be fully correlated regardless of the spatial location.

4. MEASURED RESULTS COMPARED WITH ANALYSIS

(1) Example of measured response

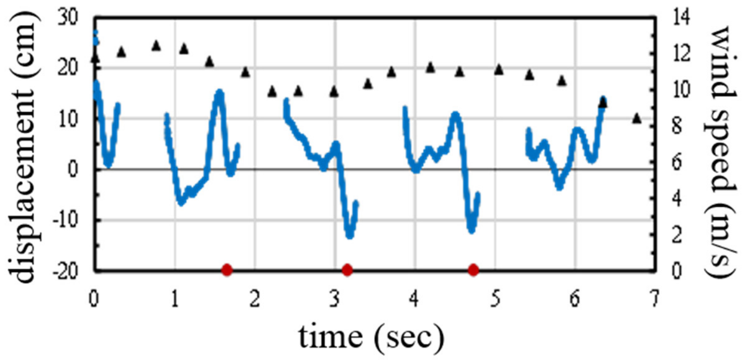
The coordinates of the measured tip displacements by the motion capture software were transformed to obtain the component parallel to the rotor axis, which is nearly equal to the mean wind direction. This component is supposed to be dominant in the response and it is presented in the followings. Examples of measured tip responses of the three blades are shown in Fig. 4 and 5 together with the wind speed. Positive tip displacement is defined toward the leeward direction. The gaps between the tip displacement data are due to the timing where the blade tip could not be seen clearly from the camera, and accurate data could not be obtained at those timings. The red dots on the horizontal axis show the timing that the blade passed in front of the tower. Generally, tip displacements seem to take local minimum values when the blade passed in front of the tower. The three blade tips often showed similar response traces when they passed at the same location as in Fig. 4. In this case, the responses of three blades differed with phase lag of 120 degrees. On the other hand, the three blade tips sometimes showed similar responses at the same time (i.e., no time lag) as shown in Fig. 5. The cause of these different response characteristics is still not clear.

(2) Comparison of measured and computed responses

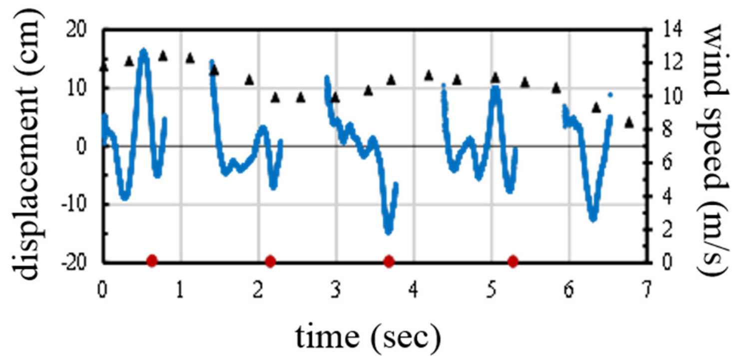
Some of the measured tip displacements are compared with analytical results as shown in Fig. 6. Generally, the amplitude of the measured responses was larger than the analysis, and higher frequency fluctuating components were included in the measurement. These tendencies are probably due to the omission of consideration of spatial wind velocity correlation in the analysis that is actually less than 1 at each location.

5. CONCLUDING REMARKS

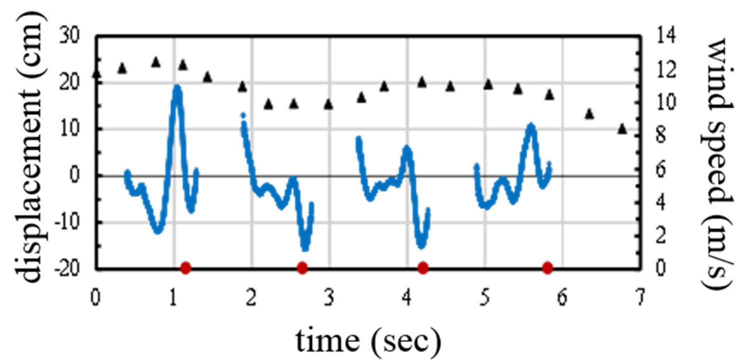
More data are planned to be taken in future together with the operation data of the wind turbine such as rate of rotation, pitch angle, acceleration at the tower top. Those data can be used to confirm the agreement of the analysis with the measurements. In addition, the formulation of the aerodynamic forces will be studied and more suitable formulation will be sought. Hopefully, more accurate response predictions such as blade tip displacement and so on will be obtained by the formulation even in different wind condition.



(a) blade 1



(b) blade 2



(c) blade 3

Figure 4: An example of measured blade tip displacements (Nov. 18, 2014).

ACKNOWLEDGMENT

This study has been supported by JSPS Grants-in-Aid for Scientific Research Grant Number 26289146, and it is gratefully appreciated.

REFERENCES

1) Ozbek, M., Meng, F. and Rixen D.J. : Challenges in Testing and Monitoring the In-Operation Vibration Characteristics of Wind Turbines, *Mechanical Systems and Signal Processing*, Vol. 41, pp. 649-666, 2013.
2) Jonkman, J.N. and Buhl Jr., M.L. : FAST user's guide, NREL/EL-500-38230, 2005.

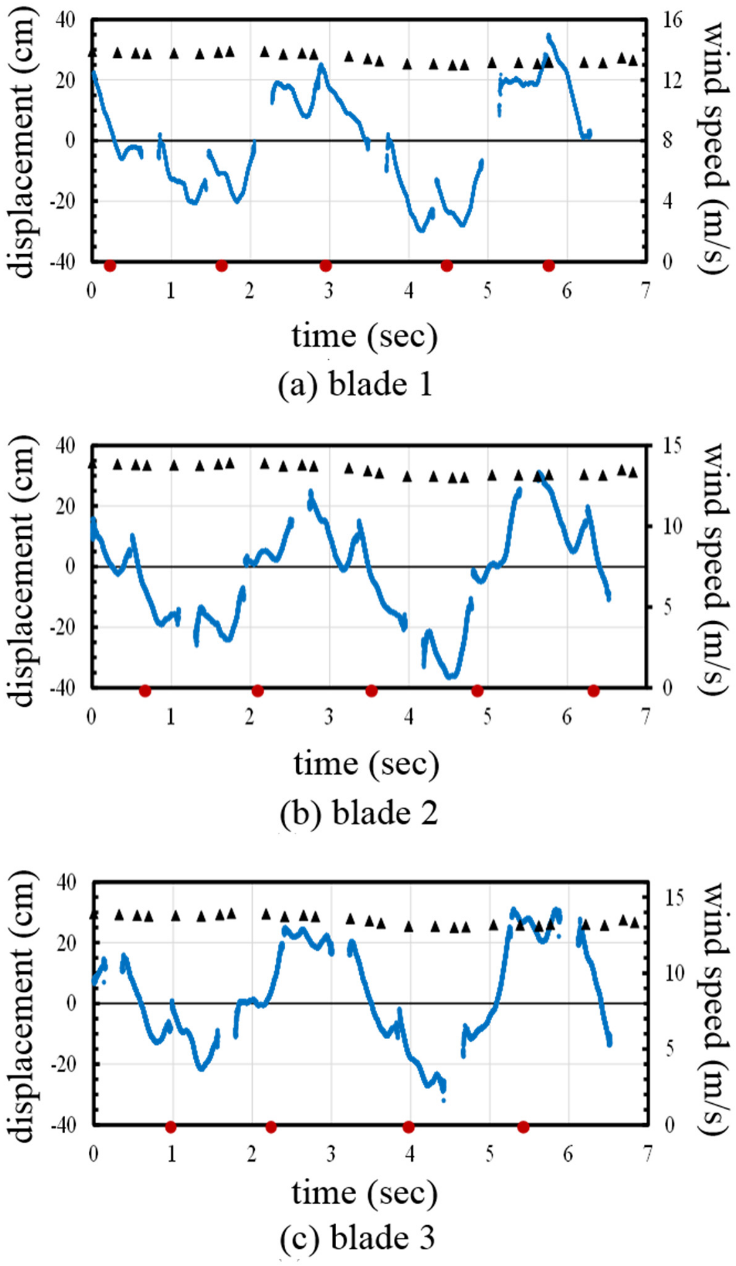


Figure 5: An example of measured blade tip displacements (Dec. 2, 2014).

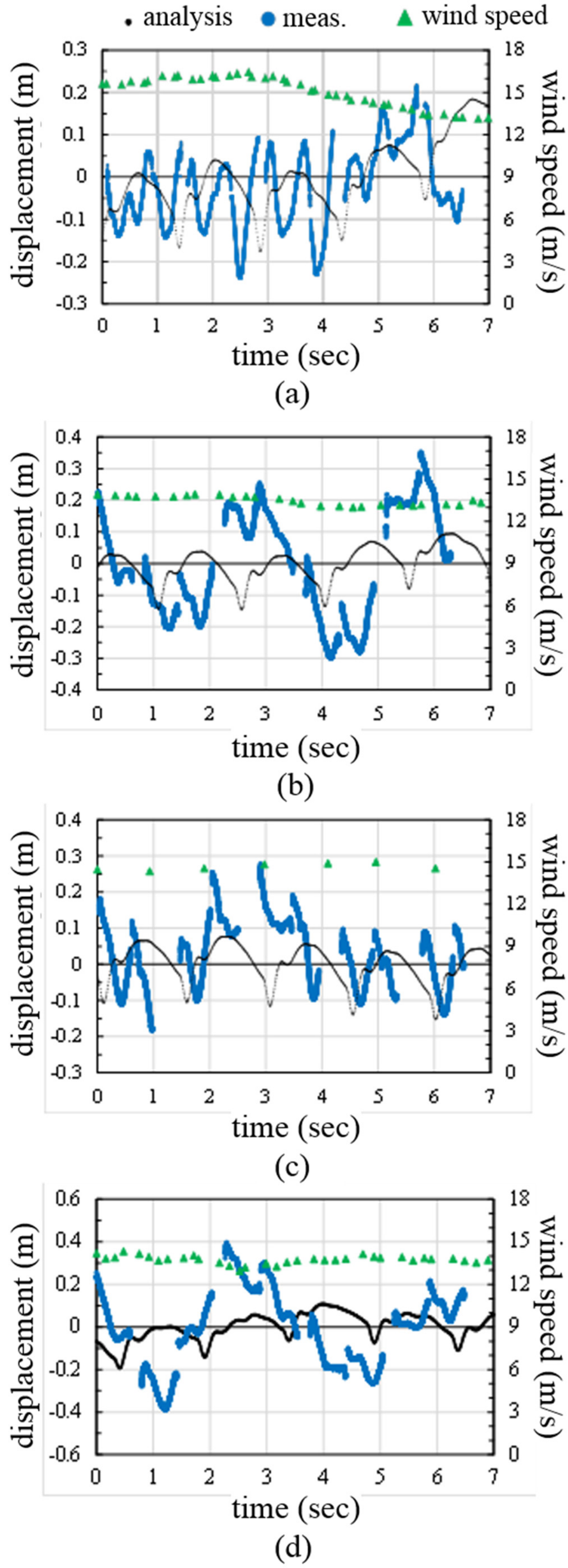


Figure 6: Comparison of measured and analyzed tip displacements.