Experimental Study on Cyclic Pitch Hub

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1. Introduction

Offshore wind power has huge energy potential. Currently offshore wind power is utilized in shallow water by foundation based type. However there are not enough shallow water area around Japan for utilizing offshore wind energy, so floating offshore wind turbines are expected to be introduced. In order to introduce floating wind turbine, the wind turbine motions by fluctuating force are important. To suppress undesired turbine’s motion, the rotor thrust control is one of options.

This study deals the possibility of thrust control to obtain the dynamic stability of floating offshore wind turbines. In this study, the rotor thrust was controlled by cyclic pitch control. The idea of apply cyclic pitch control system to the wind turbine was supposed to decrease load of wind turbine. This study shows the aerodynamic characteristics of the wind turbine’s rotor which operated in cyclic pitch control by a wind tunnel testing.

2. Approach

The test is performed with a model wind turbine in a wind tunnel. A two-bladed HAWT is used for this measurement. The model wind turbine has a cyclic pitch mechanism with swash plate. Aerodynamic effect of the cyclic pitch control is measured by the three-component balance at bottom of nacelle. Two types of connection between tower and nacelle are also tested. For the balance measurements nacelle is connected rigidly. Another connection utilizes the hinge of yaw and tilt. When the aerodynamic force control is achieved for yaw and tilt, the nacelle can be connect with hinge.

3. Main body of abstract

Methods of pitch control

In this experiment two kinds of pitch controls were tested. One is a collective pitch control and the other is a cyclic pitch control. The collective pitch control sets the blade pitch angle independent from for azimuthal position. The cyclic pitch control sets the blade pitch angle dependent on blade azimuth.

Fig.1 shows schematic view of the rotor hub mechanism. The blade pitch angle is set by a pitch lever connected to swash plate. If the swash plate stays perpendicular to rotational axis, the blade pitch angle is the same for azimuthal position. If the swash plate inclines to rotational axis, the axial position of connecting point changes with azimuth angle. So, blade pitch angle changes with azimuth angle. The relation between pitch angle and azimuth angle is determined by geometrical relation between the pitch lever fulcrum and swash plate connection point.

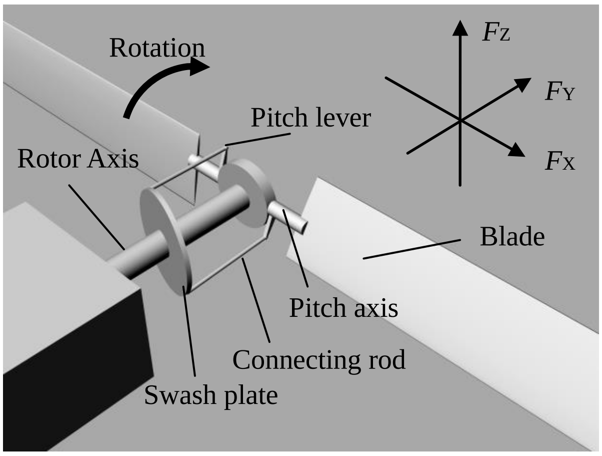

Figure 1 Rotor hub mechanism

Experimental devices

Fig.2 shows experimental apparatus. The experiment is performed in an open-jet type wind tunnel with outlet diameter of 1.67m. A two-bladed horizontal axis downwind turbine with diameter of 0.7m is set in the test section. Test blade is no tapered and no twisted blade. The blade length is 0.325m. The blade chord length is 32.4mm. The thickness of airfoil section is 14 percent. Rotational speed of rotor is controlled by a variable speed generator, which can be set up to 2000 rpm. To detect the aerodynamic forces on the rotor, a 6-components balance is mounted on the top of supporting tower. The measurements are performed at fixed wind speed of 7 m/s measured by a pitot tube. The rotor azimuth angle is defined as zero when target blade is vertically upward. The azimuth angle is positive in rotational direction. The blade pitch angle is defined as the angle between the blade chord and rotational plane. When leading edge inclines toward upstream, pitch angle is positive.

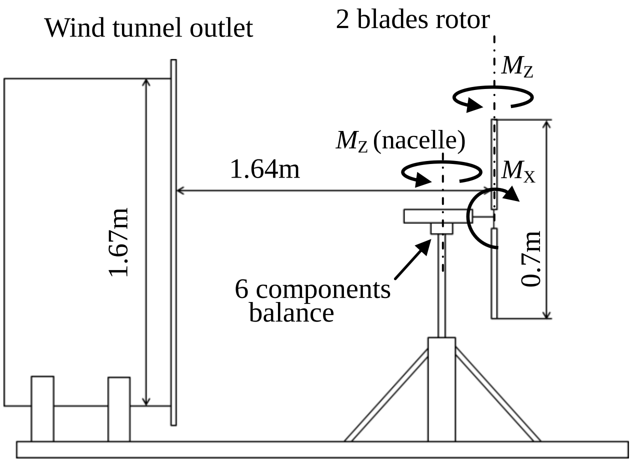

Figure 2 Experimental setup (side view)

Wind turbine power performance test

Fig.3 shows power performance test results. The free stream velocity is set at 7m/s and the rotational speed of rotor and pitch angle are changed variously. The results shows that the maximum power coefficient is 0.31 at pitch angle θ =4° and λ=8.3. In this test, the model wind turbine has rectangle and no twisted blades. The Reynolds number of blade cross-section is rather small. So, the maximum power coefficient is around 0.3. From the test results, reference pitch angle is set as θ=4° and reference operation tip speed ratio is set as λ=8.3.

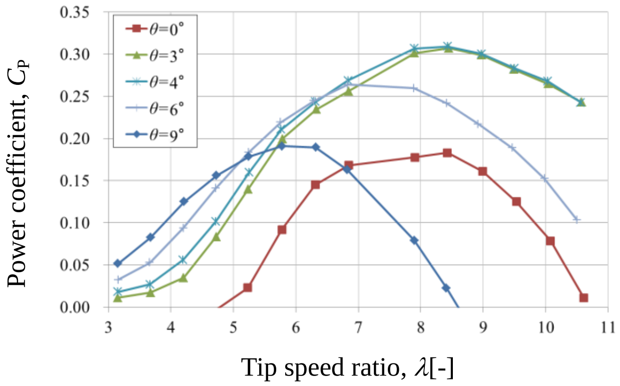

Figure 3 Power curve with various pitch setting

Collective pitch for thrust control

Fig. 4 shows the thrust control test results with collective pitch. The free stream velocity is set at 7m/s and rotational speed of rotor is fixed at λ=8.3. As increase of pitch angle, the thrust coefficient decreases with almost linear function. This is because that according to the pitch angle increasing the attack angle of wind turbine's blade is decreasing. Then, rotor thrust force can be controlled by collective pitch control.

Fig. 5 shows power coefficient with the same condition as Fig.4. Power coefficient is maximum at pitch angle θ=4° and the power coefficient is gradually decreased, when pitch angle increase or decrease from θ=4°.

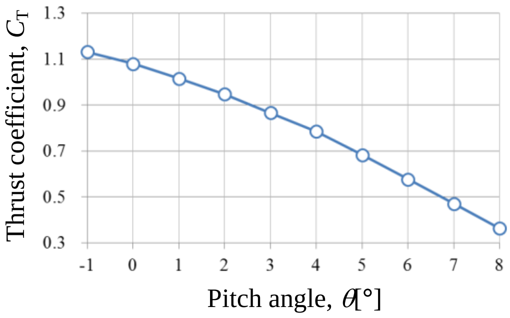

Figure 4 Collective pitch control testing result
Relationship between pitch angle displacement
and thrust coefficient

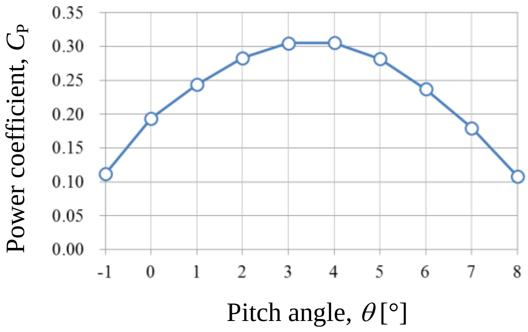

Figure 5 Collective pitch control testing result
Relationship between pitch angle displacement
and power coefficient

Cyclic pitch definition

In cyclic pitch test, the pitch angle is set depending on blade azimuth position φ which is represented in Eq. (1). Where ξ is azimuth angle at maximum pitch angle position, b is averaged pitch angle, a is pitch displacement.

$$\theta(\varphi) = a\cos(\varphi - \xi) + b \qquad (1)$$

Cyclic pitch for yaw moment control (ξ=135°, b=2°)

Fig.6 shows relation between azimuth angle and pitch angle, when ξ=135° and b=4°. Fig.7 shows the relation among tilt moment coefficient C_{MX}, yawing moment coefficient C_{MZ} and pitch angle displacement. Pitch displacement a is changed from -4 to +4 degrees with intervals of 1 degree. From the figure, the tilt moment coefficient C_{MX} decreases linearly as increase of pitch displacement. However, the yawing moment C_{MZ} shows stable value with various pitch amplitude. Therefore, the direction of moment can be arbitrarily controlled by setting maximum pitch angle position for using cyclic pitch control.

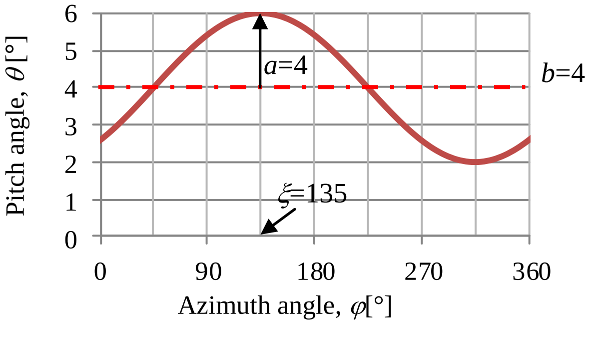

Figure 6 Relationship between azimuth angle and
pitch angle

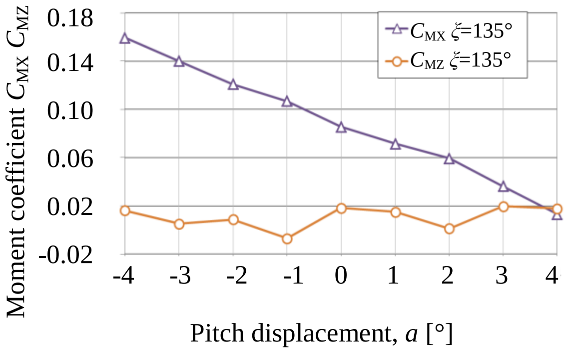

Figure 7 Relationship between aerodynamic moment
and pitch amplitude

Behaviors of hinged nacelle with cyclic pitch control

Fig. 8 shows the picture of hinged nacelle. The yaw and tilt motions are permitted by the hinges. The yaw axis and tilt axis is set at the center of gravity for nacelle. Yaw and tilt axes are set on the rotor axis. For both axes there are no spring and no damper functions. Yaw angle is set positive for clock-wise seeing from top. Tilt angle is set positive when the rotor goes upward.

Fig. 9 shows relation among nacelle yaw, tilt and pitch displacement. The pitch displacement *a* is changed from -2 to +1.5 degrees with intervals of 0.5 degrees. The yaw angle decreases with increase of pitch displacement. During yaw angle change by cyclic pitch control, the tilt angle does not change. Then, the cyclic pitch control with free yaw system enables the control of nacelle yaw. In this figure, the tilt angle stays around -10 degrees, it seems that the existence of tower makes the rotor thrust asymmetrical features.

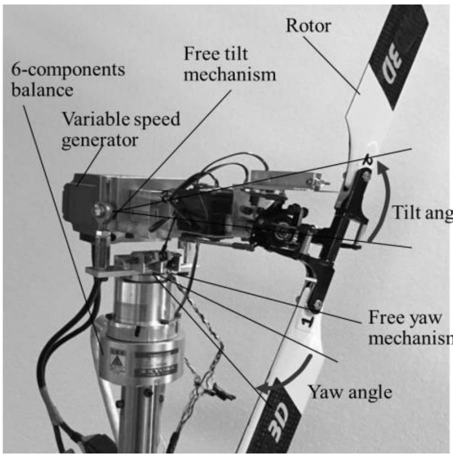

Figure 8 Hinged nacelles

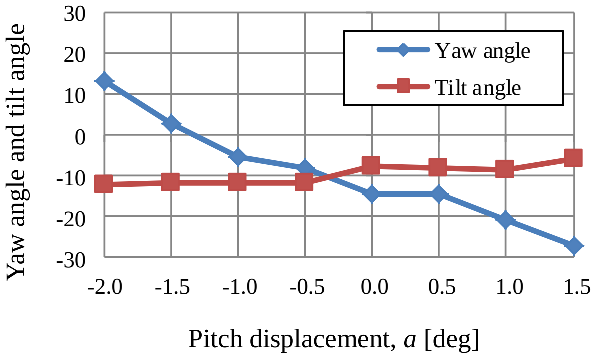

Figure 9 Relation among nacelle yaw, tilt and pitch displacement

4. Conclusion

From the wind tunnel experiment, the rotor thrust can be controlled cyclic and collective pitches. The conclusions are shown below:

(1) Thrust force and wind turbine power can be controlled by collective pitch control.
(2) The direction and magnitude of rotor moment can be arbitrarily controlled by cyclic pitch control.
(3) With free yaw system, the cyclic pitch control enables to change yaw of nacelle.

5. Learning objectives

This study aimed the effective attitude control of floating wind turbine. The largest aerodynamic force act on wind turbine is rotor thrust. The rotor thrust can be controlled by changing blade pitch angle. To stabilize floating offshore wind turbine, generally the floating structure becomes huge in both scale and cost. This cyclic pitch control hub may contribute to stabilize floating wind turbine and reduce the size and cost of floating structure. In this paper the possibly of rotor thrust control by cyclic pitch hub is shown with experimental data.