The 2012 World Congress on
Advances in Civil, Environmental, and Materials Research (ACEM' 12)
Seoul, Korea, August 26-30, 2012

Parametric Investigation of Dynamic Characteristics of Mooring Cable of Floating-type Offshore Wind Turbine

Yang-Uk Cho[1)], Myeong-Woo Seo[1)], Jin-Rae Cho[2)] and [*]Weui-Bong Jeong[1)]

[1)]*School of Mechanical Engineering, Pusan National University, Busan 609-735, Korea*
[2)]*Research & Development Institute of Midas IT, Gyeonggi-Do 462-807, Korea*

ABSTRACT

This paper deals with the analysis of dynamic characteristic of mooring system of floating-type offshore wind turbine. A spar-type floating structure which consists of a nacelle, a tower and the platform excepting blades, is used to model the floating wind turbine and connect three catenary cables to substructure. The motion of floating structure is simulated when the mooring system is attached using irregular wave which is Pierson-Moskowitz. The mooring system is analyzed by changing cable length, cable position of floating structure and the position of center of mass. The dynamic behavior characteristics of mooring system are known comparing with cable tension and 6-dof motion of floating structure. These characteristics are much useful to initial design of floating-type structure. From the simulation results, the optimized design parameters that are cable length and cable position of connect point of mooring cable can be obtained.

1. INTRODUCTION

The necessity of developing new renewable energies is coming to the front and investments in development of new renewable energies is on a increasing trend world-widely because of international environmental problems and a sudden rise of an oil price. Above all kinds of new renewable energies businesses, the wind power market is being expanded, so investments and interest in a wind power industry from a lot of nations are expected.

The United Kingdom promotes offshore wind turbine as a core industry to attain the goal that the UK is going to supply 15% of all power by new renewable energies by 2020. German government is going to build forty offshore wind turbine farms including thirty wind farms in the North Sea and ten wind farms in the Baltic Sea, and to build from five thousand to six thousand 5MW-power plants per year for an expansion of the power capacity as 25,000~30,000MW by 2030. An expansion of new renewable energies is expected to reduce carbon emissions and to contribute to

[*] Corresponding Author, Email: wbjeong@pusan.ac.kr, Fax: +82-51-517-3805

climate protection. In further sea from land winds are superior in quality and noise problems could be solved, so many fixed-type offshore wind turbine in shallow water are being built now. After this, floating-type wind turbine will be built in the far ocean finding wind much more superior in quality.

The floating-type wind turbine needs a mooring system because it floats on the sea water. Mooring system for a floating-type wind turbine is maintaining its position not to go drifting on the sea and minimizes the movement of wind turbines. In this study, a floating-type wind turbine was modeled and parametric study was performed to evaluate the characteristics of mooring system.

2. WAVE MODELING

A wave spectrum is the distribution of wave energy as a function of frequency. It describes the total energy transmitted by a wave-field at a given time. The Pierson-Moskowitz spectrum is an empirical relationship that defines the distribution of energy with frequency within the ocean. The Pierson-Moskowitz spectrum is one of the simplest descriptions for the energy distribution. It assumes that if the wind blows steadily for a long time over a large area, then the waves will eventually reach a point of equilibrium with the wind. This is known as a fully developed sea. Pierson-Moskowitz wave spectrum equation used in ANSYS AQWA as follow.

$$S(\omega) = \frac{1}{2\pi} \frac{H_s^2}{4\pi T_z^4} \left(\frac{2\pi}{\omega} \right)^5 \exp\left(-\frac{1}{\pi T_z^4} \left(\frac{2\pi}{\omega} \right)^4 \right) \tag{1}$$

Where ω is the wave frequency(rad/sec), H_s is significant wave height and T_z is zero crossing period. The Pierson-Moskowitz spectrum is shown in Fig. 1.

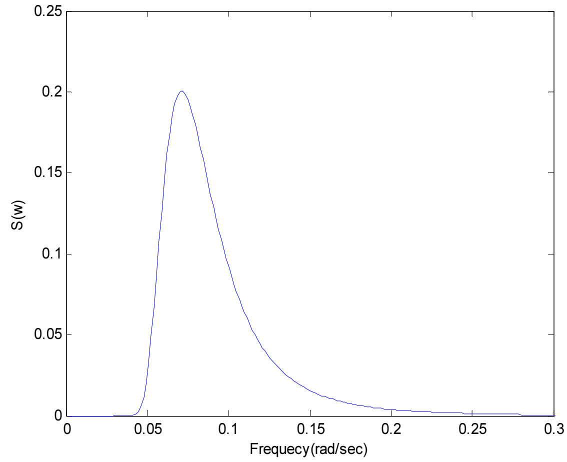


Fig. 1 Pierson-Moskowitz spectrum

Given the wave spectrum, the time histories of irregular wave are generated by linear superposition of frequency which has wave height and phase angle from the spectrum.

$$\eta(x,t)=\sum_{n=1}^{N}\frac{1}{2}A_n\cos(k_n x-2\pi f_n t+\phi_n) \quad (2)$$

Where k_n is wave number, A_n is wave amplitude and ϕ_n is phase angle. The relationship between the spectrum $S(\omega_j)$ and the wave amplitude A_j for a wave component j is :

$$\frac{A_j^2}{2}=S(\omega_j)\frac{\omega_{\max}-\omega_{\min}}{N} \quad (3)$$

The maximum frequency($\omega_{\max}$) and the minimum frequency($\omega_{\min}$) are determined in Pierson-Moskowitz spectrum. And frequency is divided by the number of N.

3. ANALYSIS MODEL

Floating offshore wind turbine is chosen as the spar type. The specifications are shown in Table 1.

Table 1. Spar type wind turbine properties

Blade mass	30,600 kg
Nacelle height	3.2 m
Tower mass	146,000 kg
Tower height	65 m
Tower top diameter	3.5 m
Tower bottom diameter	4.5 m
Tower mass	170,000 kg
Platform height	65 m
Platform top diameter	8 m
Platform bottom diameter	8 m
Platform mass	2,684,000 kg
Center of buoyancy (from water line)	32.5 m
Center of mass (from water line)	42.5 m

The three mooring lines are placed at intervals of 120 degrees for the mooring system, and mooring lines are modeled as shown in Table 2.

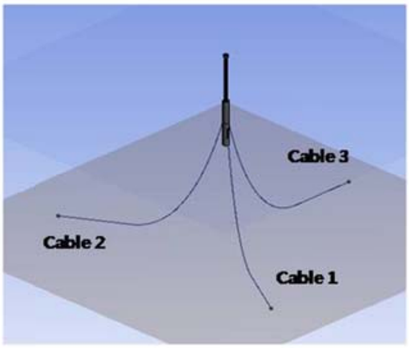


Fig. 2 Mooring system modeling

Table 2. Mooring system properties

Number of mooring lines	3
Angle between mooring lines	120˚
Water depth	200 m
Cross sectional area	0.02 m^2
Mass/unit length	90 kg/m
Stiffness,EA	1.0E+9 N
Maximum tension	1.0E+7 N
Longitudinal drag coefficient	0.025

4. NUMERICAL ANALYSIS

6-DOF motion of the vessel is shown in Figure 3. In case of angle of incidence of the waves is 0 degrees, the movement of surge and pitch is dominantly large in the 6-DOF motion of the spar type structure. In this study only compared the movement of surge and pitch.

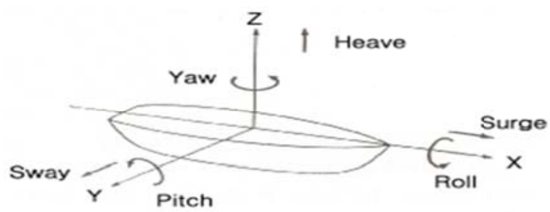


Fig. 3 6-DOF motion of the vessel

Numerical analysis uses the commercial software ANSYS AQWA. To determine the dynamic behavior characteristics of mooring cable, parametric studies increasing the length of the mooring cable and changing the connection point of the mooring cable were carried out.

4.1 Cable length analysis

For the first parametric study, connection point of cable is fixed on center of buoyancy and expanding the length of the mooring cable by 10m, the cable is analyzed. When the length of mooring cable is 300m, the responses of surge and pitch are shown in Fig. 4.

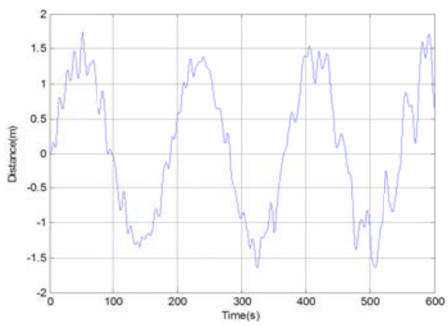


Fig. 4(a) surge time response

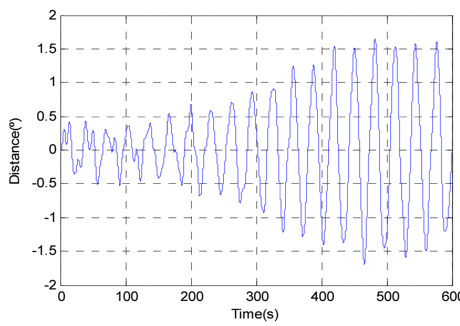


Fig. 4(b) pitch time response

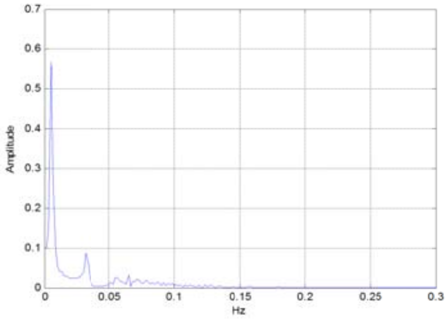


Fig. 5(a) surge frequency response

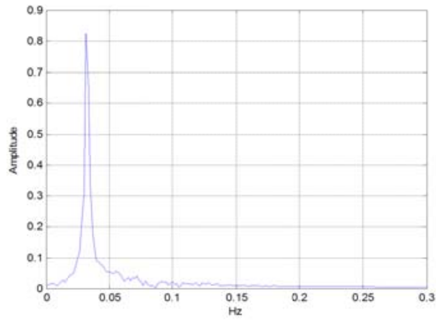


Fig. 5(b) pitch frequency response

The time responses of surge and pitch are shown in frequency domain by fourier transform(Fig. 5). There are two peaks in fig. 5(a), the first peak is judged that it is made by the waves. Comparing to the second peak value of surge response and the first peak value of pitch response by the length of cable, they are equal to 0.375 Hz and shown in the graph(Fig. 6). The length of mooring cable was increased by 10m from 260m to 350m.

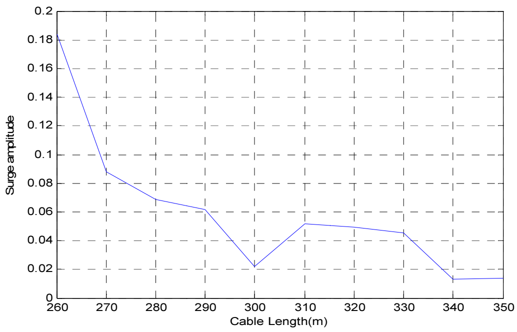


Fig. 6(a) Surge response

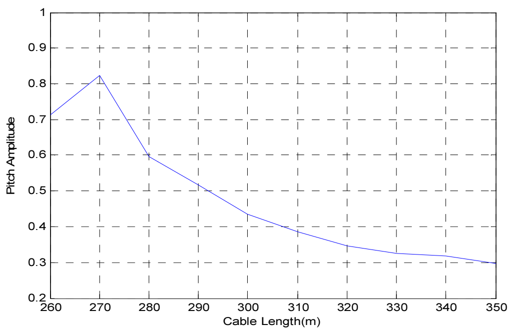
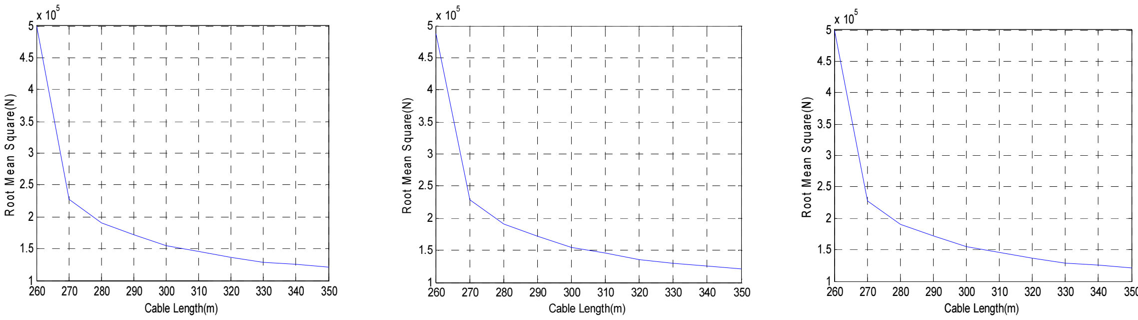


Fig. 6(b) Pitch response

Fig. 6(a) shows the responses of surge by the length of the cable, the responses of surge are decreasing as the length of the cable is being lengthened. This means the response of surge decreases as the cable is longer. Likewise, Fig. 6(b) shows the responses of pitch, the movement of pitch decrease as the mooring cable is longer.

Also, the tension of the mooring cable compared RMS(Root Mean Square) of the time response of the cable is shown as a graph. The position of cable 1,2,3 is shown in Fig. 2.



(a) cable 1 (b) cable 2 (c) cable 3

Fig. 7 Mooring cable tension analysis according to cable length

Decreasing the mooring cable tension is known from the Fig. 7 as the mooring cable is being lengthened.

4.2 Cable length analysis

For the second parametric study, the length of cable is fixed to 300m and being changed the connection point of the mooring cable, the cable is analyzed(Fig. 8).

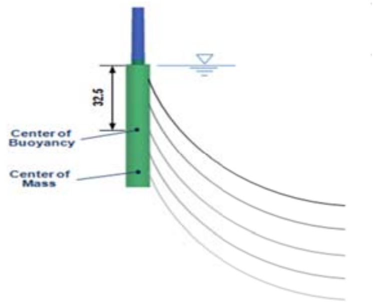


Fig. 8 Connection point of mooring cable

Case 1	22.5 m
Case 2	27.5 m
Case 3	32.5 m
Case 4	37.5 m
Case 5	42.5 m

Table 3. Positions of connection point

The positions of the connection point of the mooring cable are shown in the Table 3, and the peak values were compared by fourier transform of the response of surge and pitch as same as the first parametric study.

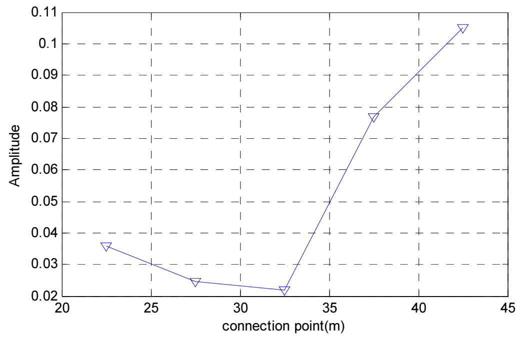


Fig. 9(a) Surge response

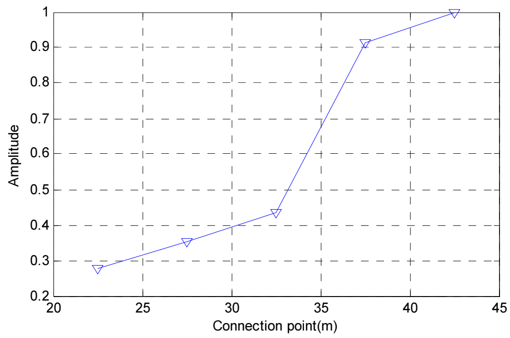
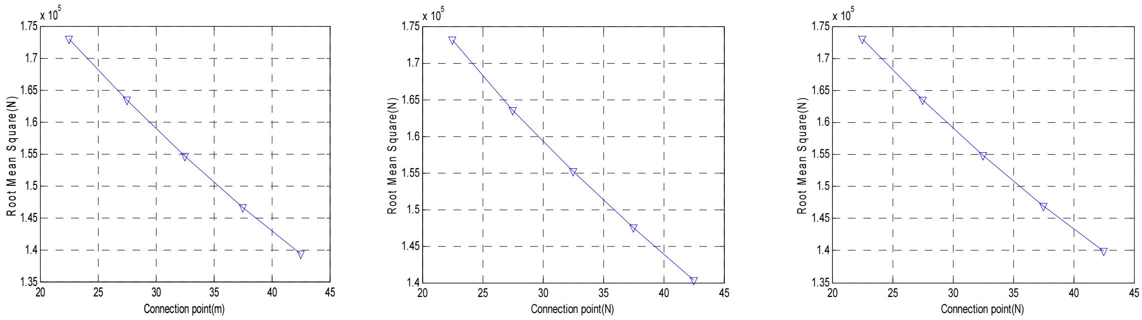


Fig. 9(b) Pitch response

Fig. 9(a) has shown the responses of surge moving connection point of the mooring cable, the responses of surge are increasing as the connection point is below the platform. This means the response of surge increases as the connection point is below the platform. Likewise, Fig. 9(b) has shown the responses of pitch, the movement of pitch increase the connection point is below the platform. One distinct point is that when the connection point is located below the center of buoyancy, the movement of surge and pitch dramatically increase. Thus, the location of connection point is good to locate at the center of buoyancy or slightly above the center of buoyancy.

Also, the tension of the mooring cable compared RMS(Root Mean Square) of the time response of the cable is shown as a graph. The position of cable 1,2,3 is shown in Fig. 2.



(a) cable 1 (b) cable 2 (c) cable 3

Fig. 10 Mooring cable tension analysis according to connection point

Decreasing the mooring cable tension is known from the Fig. 9 as the connection point is below the platform.

ACKNOWLEDGEMENT

This work was supported by the New & Renewable Energy of the Korea Institute of Energy Technology Evaluation and Planning (KETEP) grant funded by the Korea government Ministry of Knowledge Economy (No. 2011T100100320).

REFERENCES

Kim, C.J. and Yu, H.S.(1992), “Dynamic interaction of waves with a moored structure”, *Journal of Ocean Engineering and Technology,* **6**(2), pp. 254~262.

Kim, Y.C. and Hong, J.S.(1991), “A study on the dynamic stability of the long vertical beam subjected to the parametric excitation” *Transactions of SNAK,* **28**(1).

Kim, M.Y.(2001), “Dynamic analysis of steel jackets under wave and earthquake loadings I : Linear and non-linear F.E formulation” *Earthquake Engineering Society of Korea,* **21**, pp.1-11.

O. M. Faltinsen(1990), *Sea load on shops and offshore structures,* University of Cambridge.

Shin, H. and Kim, D.S.(1995), “A study on the static analysis of multi-leg spread mooring systems” *The Korean Society of Ocean Engineers,* **18**, pp. 53-60.

Shin, H.K. and Kim, K.M.(2011), “Motion analysis of 5-MW floating offshore wind turbine” *Korean Society of Ocean Engineers,* **25**(5), pp. 64-68.

Shin, S.H, Kim, H.J. and Lee, H.S.(2011), “A preliminary design of mooring system for floating wave energy converter” *Journal of the Korean Society for Marine Environmental Engineering*, **14**(3), pp. 184-191.