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An AQWA Method for Determining the Natural Frequency of Offshore Floating Fans Based on Free Attenuation Analysis

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Abstract: *The semi submersible floating wind turbine platform can be suitable for most offshore sea conditions and has good development prospects. However, in the design and construction process, it is necessary to consider the free attenuation motion response analysis of its foundation to determine its natural frequency. This article uses the ANSYS AQWA Workbench software as a research tool to study the motion response of the OC4 DeepCwind three pontoon floating fan foundation. A simulation was conducted on the free attenuation motion of a three pontoon floating foundation under the action of only ocean current drag force within 1800 seconds. The law of free attenuation motion on the heave degree of freedom of the floating foundation was explored, and the natural vibration frequency of the structure was calculated, providing a basis for the evaluation of its self storage safety and working stability.*

Keywords: *Offshore wind power; Floating foundation; Free decay; Natural frequency; AQWA*

1. Introduction

At present, China mainly plans and constructs offshore wind farms in the South China Sea[1]. Floating offshore wind turbines will face extremely complex sea conditions when working in this area, and their self storage capacity and stability in normal operation are key considerations in the planning and construction process[2]. The natural vibration frequency of the floating wind turbine foundation has a certain impact on its self storage capacity, It is necessary to obtain its natural frequency through accurate free attenuation analysis to provide a basis for evaluating its stability and further improve the construction efficiency of offshore floating wind turbines.

In terms of free attenuation analysis, Yang Lijun et al.[3] discussed the approximate errors of the Froude and Faltinsen methods used to identify linear damping and quadratic damping. By reviewing the detailed derivation of these two methods, the inherent assumptions of these two algorithms were first demonstrated, and the systematic errors in these two methods were quantified. A direct integration method was also proposed and the identification results were discussed based on numerical and experimental data. The results indicate that the Froude method is better than the Faltinsen method in predicting linear and nonlinear damping coefficients. The Froude and Faltinson methods can provide relatively accurate predictions for low damping problems. For high damping problems, the Froude and Faltinsen methods may give a system error greater than 5% in determining linear and quadratic damping coefficients, while the direct integration method shows high recognition accuracy. Zhu Gang et al. established the Kinematics numerical simulation model of Lingshui 17-2 Semi-submersible platform and simulated the free decay motion of different degrees of freedom. At the same time, a pool test was used to verify the authenticity and reliability of the simulation data. Two sets of experimental data under the same working conditions were compared, and the results were self consistent. The damping coefficient of the floating foundation was obtained, and the damping force (moment) time history curve was numerically analyzed. The results indicate that the simulation model can be used to evaluate the sea motion of the Lingshui 17-2 platform.

Huang Chenggeng et al. [4]established an integral floating fan based on the Spar platform, using the NERL 5MW wind turbine as the research object. Through the link between FAST and AQWA, the motion response of wind turbines under wind wave coupling was solved using blade element momentum theory. The study showed that in the free attenuation analysis, the natural frequencies of Spar offshore wind turbines at three degrees of freedom were 0.0419rad/s, 0.2067rad/s, and 0.1496rad/s, respectively, which can effectively avoid typical wave frequencies in the South China Sea. Wu Qiaorui et al. [5]studied the effect of liquid sloshing on the free attenuation motion of liquid cargo ships under different loading rates using a double part filled tank. The impact force, maximum Free surface displacement and angular velocity of the liquid bulkhead in the process of attenuation movement are analyzed, which can provide some references for the design and manufacture of liquid cargo ships. Jiang Yichen et al. studied the free roll damping of the hull with bilge keel. Based on the Open-source software Open Field Operation and Maneuvering (OpenFOAM), a viscous flow field model was established using the Six degrees of freedom (6 DOF) model and dynamic grid technology to solve the ship's motion. The simulated free roll damping curve and damping coefficient were compared with the experimental data, and the vorticity field near the bilge keel was analyzed, explored the roll attenuation mechanism of the bottom keel of the ship.

Zhang Dong et al.[6]studied typical damping models and their influencing factors based on benchmark experimental data. The results indicate that typical damping models cannot reflect the fluid physical characteristics of rolling motion. The conclusion was drawn that all roll angles, angular roll velocities, and angular roll accelerations should be considered when determining the damping model. In order to solve the roll Equations of motion conveniently, a damping model with angle and angular velocity as independent variables was proposed due to the coupling of angle, angular velocity and Angular acceleration in roll. Based on the Prony SS method, a damping model establishment method is proposed. The example of following the program shows good performance. In addition, the effects of forward speed and flow memory on ship roll damping were also discussed. Yang Can et al. studied the aerodynamic damping of a semi submersible FWT using frequency domain analysis and fully coupled attenuation based time domain methods, and verified it through wave basin model experiments. The influence of controller dynamics was discussed, and then the dynamic characteristics of aerodynamic damping in pitch and pitch motion were discussed. The results indicate that compared with time-domain numerical methods, this analysis method can predict aerodynamic damping with sufficient accuracy and extremely high efficiency. In areas with excessive wind speeds, especially in pitch motion, the influence of controller dynamics should be considered. The controller gain can significantly affect the aerodynamic damping in pitching motion in the region beyond the rated wind speed. On the contrary, initial offset and wind turbulence may not be the main influencing factors. Shi Wei et al.[7]proposed a multi input Long short-term memory (MI-LSTM) neural network method to predict the short-term motion response of the floating offshore wind turbine platform. Specifically, numerical simulations were conducted on a 5MW unsupported platform under different environmental conditions, and platform motion response, wave elevation, and mooring force data were selected as input variables. Then, after post-processing the data, establish a training group and a testing group. Subsequently, a single input LSTM (SI LSTM) model and a multi input LSTM model were established to learn the input data. By comparing the overall accuracy of the results, it was found that the additional mooring force and wave height have a positive impact on the platform response prediction results. From the aspects of dispersion and overall accuracy, it is verified that the established MI-LSTM model is also applicable when considering the influence of second-order fluid dynamics. Finally, compared with the prediction results of multi input one-dimensional Convolutional neural network (MI1D-CNN), the advantages of the two different models are expounded from the perspective of training time and accuracy, which provides ideas for the optimization of FOWT motion response prediction models.

The force acting on Large-scale structure of the Universe by steady flow under various degrees of freedom[8] is as follows:

$$F_{XC} = \frac{1}{2}\rho C_{XD} A_{CX} {U_c}^2 \tag{1}$$

$$F_{YC} = \frac{1}{2}\rho C_{YD} A_{CY} {U_c}^2 \tag{2}$$

$$M_{ZC} = \frac{1}{2}\rho C_{MZD} A_{CZ} {U_c}^2 \tag{3}$$

$$M_{XC} = F_{YC}(C_B - C_G) \tag{4}$$

$$M_{YC} = F_{XC}(C_B - C_G) \tag{5}$$

In the equation: ρ is the seawater density in the sea area where the floating wind turbine operates, The flow force coefficients in the F_{XC}, F_{YC}, M_{ZC} direction are respectively C_{XD}, C_{YD}, C_{MZD}, U_c is the relative velocity between the floating fan foundation and the current velocity in the sea area where it is located, A_{CX}, A_{CY} are the effective force area of the current load on the horizontal and vertical upward floating wind turbines, C_B is the point of action for the corresponding direction of the current load on the floating fan foundation.

The offshore floating wind turbine is facing a complex marine environment. When it is set up in the offshore area, it is often subject to more disturbances due to the increase of human Confounding. When designing the foundation of the offshore wind turbine platform, it is often necessary to consider the impact of multiple factors coupling, otherwise the designed floating wind turbine cannot operate under normal sea conditions. Among them, wave current coupling is a typical and important interaction factor.[9]Due to the presence of current loads, some parameters of wave loads often undergo sudden changes, such as wave height and wavelength distortion during propagation. When the waves and currents are in the same direction, the wavelength of the wave height is widened due to the disturbance of the ocean current, that is, the wave height decreases and the wavelength lengthens; On the contrary, when the waves and currents are reversed, the waves are compressed due to the disturbance of the ocean currents, resulting in larger wave heights and shorter wavelengths. Due to the existence of this special mutual disturbance mechanism, there are not only steady waves in the offshore waters, but also anomalous waves that play a role in the operational response of floating wind turbines. Due to the fact that most waves are in the opposite direction to the ocean current, most anomalous waves have larger wave heights than regular waves, and may even reach over 30m. Due to the presence of anomalous waves, the installation, normal operation, and safety assurance of offshore floating wind turbines are full of uncertainties. In addition to the effect of anomalous waves on floating wind turbines, wave current coupling causes extreme changes in the velocity of seawater in the sea area where the wind turbine is located, and small-scale components may be damaged due to significant changes in resistance. At the same time, the presence of ocean currents also has an impact on the diffraction and radiation forces experienced by offshore floating wind turbines. Obviously, for offshore floating wind turbines operating in offshore waters, it is necessary to consider the combined effect of waves and currents, especially the coupling effect between the current load with faster flow velocity and the wave load with higher wave height.[10]

2. Modeling and Simulation

This article will use the ANSYS AQWA Workbench software as the research tool, refer to the specific parameters of the OC4 DeepCwind proposed by the International Electrotechnical Society and the parameters of the NERL 5MW three pontoon semi submersible floating offshore wind turbine, establish a three-dimensional model of the three pontoon semi submersible wind turbine foundation, and explore the free attenuation motion of the foundation under only the drag force of the ocean current to obtain its natural frequency.

The frequency-domain analysis module Hydrodynamic Response in ANSYS AQWA Workbench, time-domain analysis and calculation were conducted on a three pontoon floating foundation under the action of only ocean current drag force. The natural frequency, displacement, velocity, and acceleration under heave, surge, and pitch were obtained, providing a data basis for the stability evaluation of the foundation. The structure of a three pontoon floating foundation are illustrated in Fig.1,and the finite element model of three pontoon floating foundationare are illustrated in Fig.2. The basic parameters of three pontoon floating foundation are listed in Table 1.

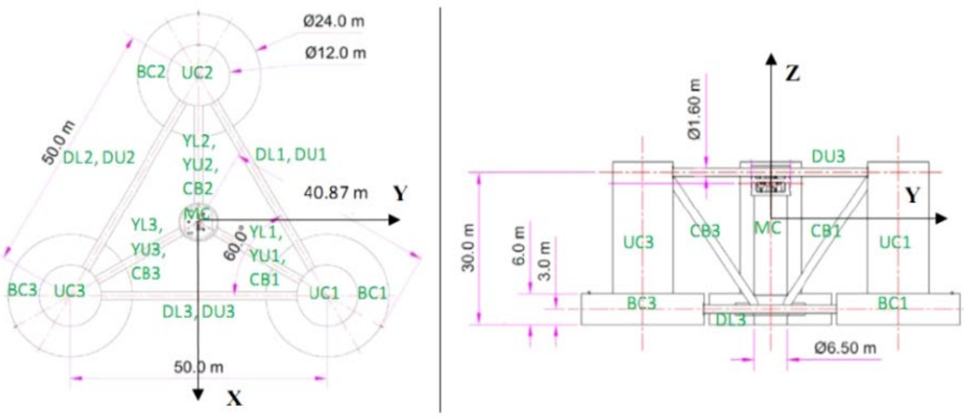

Fig.1 OC4 DeepCwind semi submersible floating foundation structure

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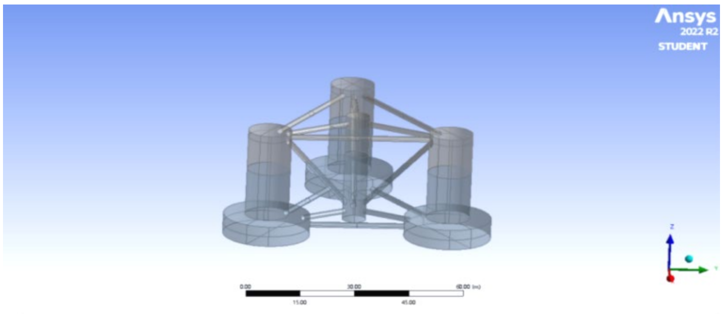

Fig.2 3D model of OC4 DeepCwind semi submersible floating fan foundation

Table 1 Relevant parameters of three pontoon floating foundation

Element Name	Size
Total draft	20m
Elevation above the waterline of the side buoy	12m
Side buoy foundation column radius	12m
The radius of the column on the side buoy	6m
Center line spacing of side buoys	50m
Elevation above the waterline of the main column	10m
Main column diameter	13m
Young's modulus	210Gpa
Shear modulus	80.8Gpa
Horizontal bar(DU)	38m
Horizontal bar(DL)	26m
Horizontal bar(YU)	19.62m
Horizontal bar(YL)	13.62m
Horizontal bar(CB)	32.04m
Basic center of gravity height	-13.46m
Moment of inertia I_{xx}	6.83E+09kg·m^2
Moment of inertia I_{yy}	6.83E+09kg·m^2
Moment of inertia I_{zz}	1.23E+10kg·m^2
Total mass of floating foundation	1.35E+07kg

3. Results and Discussion

When a floating foundation is in a calm and wave free sea state, the drag force of the ocean current is one of the most important factors affecting its motion response. The motion response at various degrees of freedom poses certain potential risks to the self storage safety and working stability of floating foundations. This section conducts research on the free attenuation motion of a three pontoon floating foundation under the action of ocean current drag force within 1800 seconds, explores the law of free attenuation motion on the heave degree of freedom of the floating foundation, calculates the natural vibration frequency of the structure, and provides a basis for the evaluation of its self storage safety and working stability.

3.1. Heave analysis

The research direction was selected as heave, with a step length of 0.1s and a starting position of 5m below sea level. The above parameters were imported into the time domain analysis module Hydrodynamic Response, and the calculation results are shown in Fig. 3-5

Fig.3-5 show the changes in heave coordinates, heave rate, and heave acceleration of a semi submersible floating foundation within 0-1800s under the action of only current drag. Easy to draw conclusions:

(1) After a period of time from the initial position, the heave displacement, heave rate, and heave acceleration of the floating foundation show an unstable fluctuation state, and it is not until around 270s that the three curves gradually stabilize, showing regular periodic changes, and the frequency is about 0.32Hz. Due to the absence of wind and waves, the foundation can be considered to be undergoing small damping free vibration, so this frequency is the natural vibration frequency of the foundation in the heave direction;

(2) When the semi submersible floating foundation tends to stabilize, the amplitude of the heave displacement is about 2.93m;

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(3) The initial phase of the heave rate curve is about 5 seconds earlier than the initial phase of the heave coordinate change curve. When it tends to stabilize, the heave rate is about 0.42m/s;

(4) The initial phase of the heave acceleration curve is about 7 seconds earlier than the initial phase of the heave coordinate change curve. When it stabilizes, the amplitude of the heave acceleration is about $0.2m/s^2$.

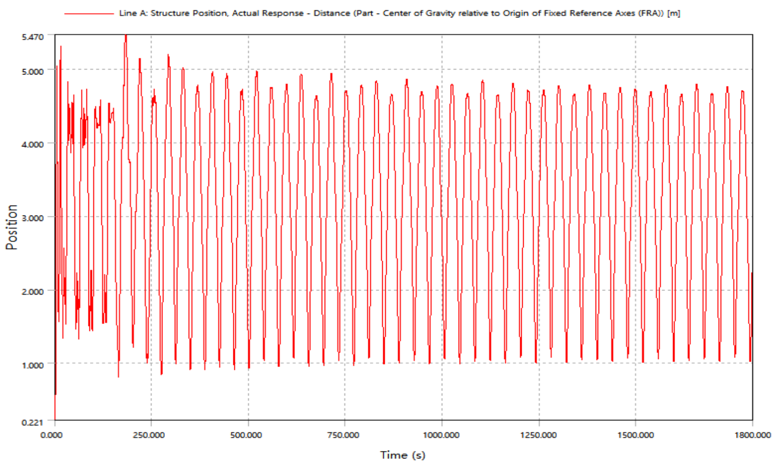

Fig.3 Free decay heave coordinate change

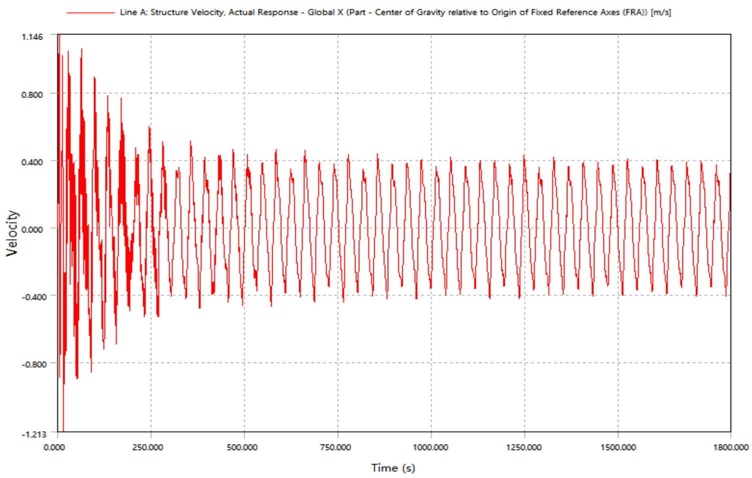

Fig.4 Free decay heave rate change

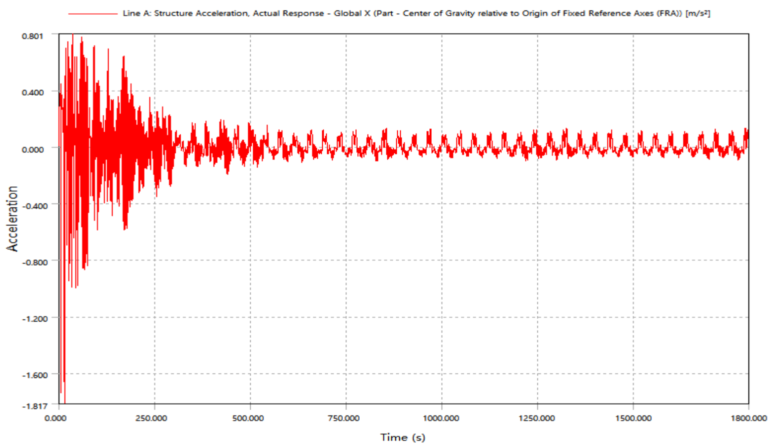

Fig.5 Free decay heave acceleration change

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3.2. Surge analysis

Select the research direction as surge, with a step length of 0.1s, and the starting position is at a distance of 5m from the center of the floating foundation bottom in the X direction. Import the above parameters into the time domain analysis module Hydrodynamic Response, and the calculation results are shown in Fig. 6-8:

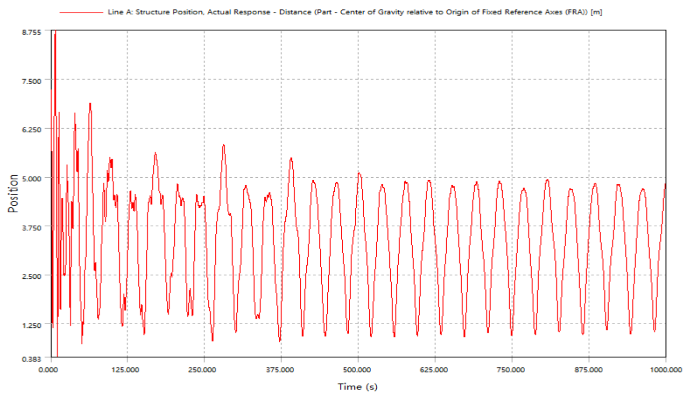

Fig.6 Free decay surge coordinate change

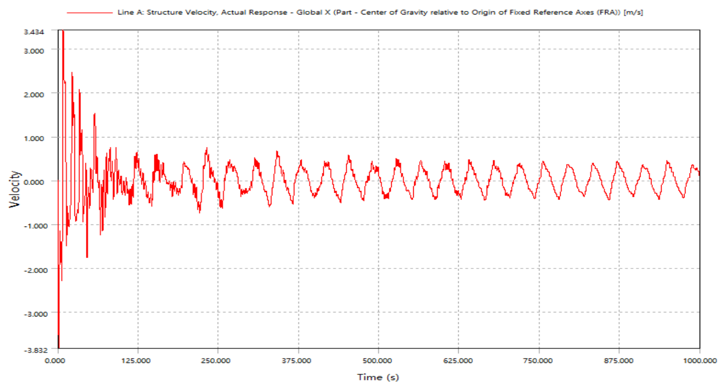

Fig.7 Free decay surge rate change

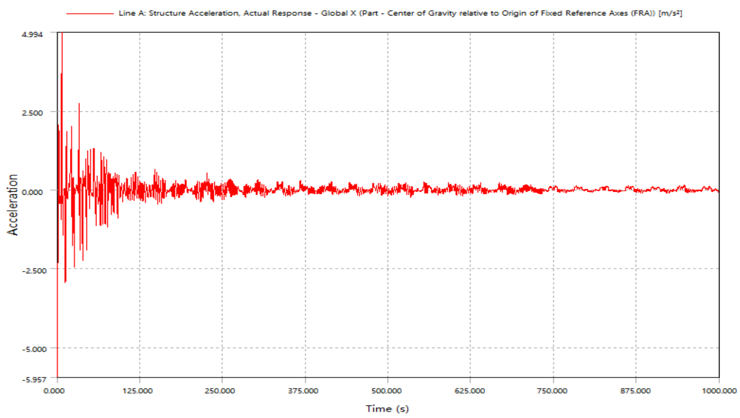

Fig.8 Free decay surge acceleration change

Fig.6-8 show the changes in longitudinal coordinates, longitudinal velocity, and longitudinal acceleration of a semi submersible floating foundation within 0-1800s under the action of only current drag. Easy to draw conclusions:

(1) After a period of time from the initial position, the surge displacement, surge rate, and surge acceleration of the floating foundation show an unstable fluctuation state, and it is not until around

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400s that the three curves gradually stabilize, showing regular periodic changes, and the frequency is about 0.32Hz, which is consistent with the natural vibration frequency in the heave direction, that is, the natural vibration frequency of the foundation in the heave direction;

(2) When the semi submersible floating foundation tends to stabilize, the amplitude of longitudinal displacement is about 2.46m;

(3) The initial phase of the surge rate curve is about 5 seconds earlier than the initial phase of the surge coordinate change curve. When it stabilizes, the surge rate is about 0.5m/s;

(4) The initial phase of the surge acceleration curve is about 7 seconds earlier than the initial phase of the surge coordinate change curve. When it stabilizes, the amplitude of the surge acceleration is about 0.1m/s^2.

3.3. Pitch analysis

Select the research direction as pitch, with a step size of 0.1s and a starting position offset of 10 ° in the RX direction. Import the above parameters into the time domain analysis module Hydrodynamic Response, and the calculation results are shown in Fig.9-11:

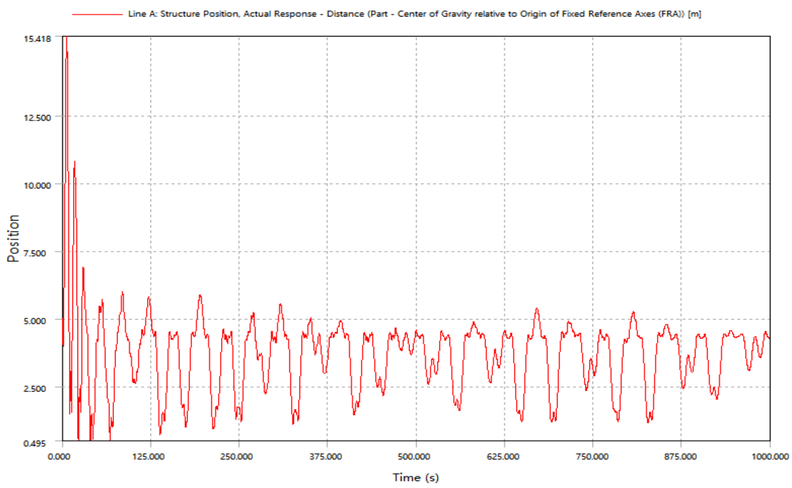

Fig.9 Free attenuation pitch coordinate chang

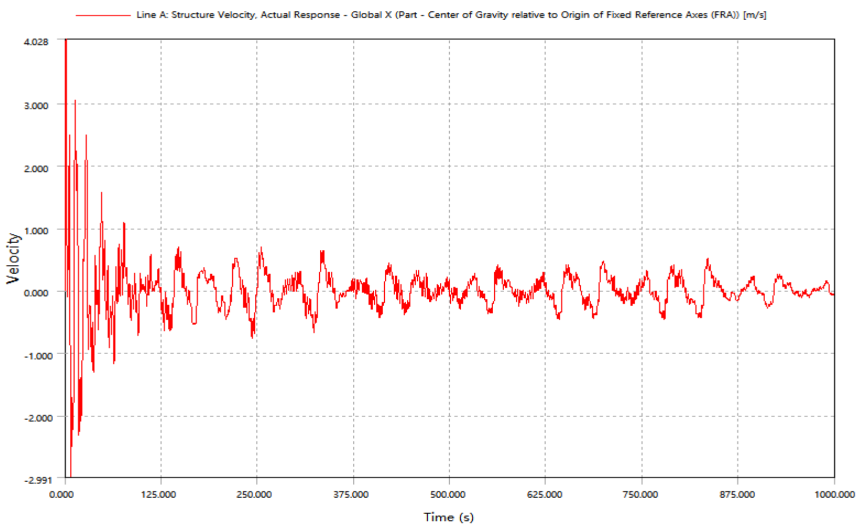

Fig.10 Free decay pitch rate change

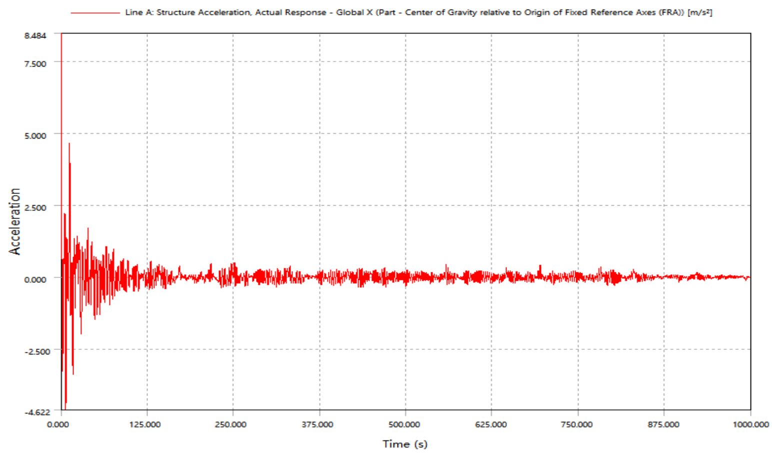

Fig.11 Free attenuation pitch acceleration change

Fig.9-11 show the changes in pitch coordinates, pitch rate, and pitch acceleration of a semi submersible floating foundation within 0-1800s under the action of only current drag. Easy to draw conclusions:

(1) After a period of time from the initial position, the pitch displacement, pitch rate, and pitch acceleration of the floating foundation show an unstable fluctuation state, and it is not until around 375s that the three curves gradually stabilize, showing regular periodic changes, and the frequency is about 0.32Hz, which is consistent with the natural vibration frequency in the heave and surge directions, that is, the natural vibration frequency of the foundation in the pitch direction;

(2) When the semi submersible floating foundation tends to stabilize, the amplitude of pitch displacement is about 2.64 °;

(3) The initial phase of the pitch rate curve is about 5 seconds earlier than the initial phase of the pitch coordinate change curve. When it stabilizes, the pitch rate is about 0.52 °/s;

(4) The initial phase of the pitch acceleration curve is about 7 seconds earlier than the initial phase of the pitch coordinate change curve. When it stabilizes, the amplitude of the pitch acceleration is about 0.1 $°/s^2$.

4. Conclusion

When the floating foundation is only subjected to the drag force of the ocean current, it will undergo a free attenuation motion response. The motion response laws of heave, surge, and pitch are consistent. In the initial stage of response, its displacement, velocity, and acceleration undergo periodic motion with gradually decreasing amplitudes. After the motion gradually stabilizes, its frequency in the three degrees of freedom is consistent, all of which are 0.32Hz. Since there is no wind or waves, this foundation can be considered to be undergoing small damping free vibration, Therefore, 0.32Hz is the natural vibration frequency of the floating foundation; At the same time, the initial phase of the rate curve and the acceleration curve are both before the displacement curve; After a long period of time, the amplitudes of these three parameters in various degrees of freedom are very small, indicating that the influence of ocean current drag force on the wind turbine is not significant. However, when the wind turbine is in the process of installation and establishment, especially when the mooring system is not fully built, special attention needs to be paid to the influence of free attenuation motion response. This article provides data support for it.

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