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Study on the Influence of Ballast Tank Position on the Hydrodynamic Performance of Offshore Wind Turbine

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Abstract

In order to explore the influence of different parameters of fixed ballast in the fan foundation mechanism on the hydrodynamic performance of single-column floating fan, based on potential flow theory, this paper adopts the surface element method and uses ANSYS AQWA to establish the hydrodynamic model of single-column floating fan, and obtains the amplitude response operators in different directions. By comparing the amplitude response operators of different models, the influence of different parameters of fixed ballast on single-column floating fan is discussed and analyzed, which provides a reference for the design optimization of floating offshore fan.

Keywords

Offshore Wind Turbine; Floating Foundation; AQWA; Hydrodynamic Response.

1. Introduction

At present, with the continuous consumption of traditional energy, the development of Marine renewable energy has attracted more and more attention. Countries around the world have formulated relevant policies to encourage and develop Marine renewable energy. Due to the impact of the goal of "carbon peak and carbon neutrality", the development of clean energy has attracted more and more attention [1]. Wind energy plays an important role in clean energy. At this stage, onshore wind power is facing the problems of insufficient exploitable land resources and being far from the load center, while offshore wind power has the advantages of rich and stable resources and being close to the load center, and has great development potential. At present, offshore fans can be mainly divided into two types according to their basic forms, fixed offshore fans and floating offshore fans. The development of fixed fans has a long history. Since the first offshore wind farm was built in Denmark in 1991, it has been developed for more than 30 years. The development focus of offshore wind power has gradually shifted to the deep sea, and the limitations of fixed fans have gradually revealed [2], so floating fans are the top priority in the future development of offshore wind power.

There are many kinds of floating offshore fans, and the current mainstream classification method is divided into semi-submersible, single-column, tension-leg and barge type according to its basic type. Among them, the single-column fan plays an important role in the research and development of floating offshore wind turbines because of its high stability, easy installation and application in the sea area with large sea depth, and the development prospect is very broad. At this stage, the more mature single-pillar offshore wind turbine projects carried out in the world mainly include Tampen floating offshore wind power project, Goto wind farm, and wind-BOS offshore wind power project. Hallak Thiago S et al. conducted experimental and numerical research on wind-BOS floating offshore wind turbine [3], and proposed different numerical models for analyzing the platform's hydraulic dynamics. The research results provided a detailed comparison of the numerical and experimental motion response of the floating structure in regular and irregular waves. Wang Jiaxing [4] used a combination of

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theoretical analysis and numerical simulation to analyze and study the hydrodynamic performance and motion response of the platform in the frequency domain and time domain. By establishing a three-dimensional model and using the three-dimensional potential flow theory, the hydrodynamic characteristics and motion performance of the platform are analyzed, and the hydrodynamic parameters such as the wave load acting on the platform and the transfer function of the platform motion response are calculated.

Most of the above studies focus on the simulation of the hydrodynamic performance of the single-column floating fan, but less research on the influence of a certain structure such as fixed ballast on the hydrodynamic performance of the whole fan. At present, the research of single-column floating fan in China is still in the initial stage, and the theoretical research is not sufficient. Therefore, based on the analysis of the influence of fixed ballast of different structural parameters and shapes on the hydrodynamic performance of single-column floating fan [6], the influence of fixed ballast of different structural parameters on the hydrodynamic performance of the whole machine is explored. To find the "optimal solution" of wind power structure design is of great significance for the future design optimization of floating offshore wind turbines in China.

2. Model Introduction

The single-column floating fan is mainly composed of blades, tower barrel and foundation. The three-dimensional model is shown in Fig. 1. In this paper, a certain type of 5MW offshore wind turbine is selected, which is a three-blade type. The bottom of the tower barrel is connected with the top of the fan foundation through a flange connection. The foundation part of the single-column floating fan shown here is composed of a fixed ballast tank at the bottom, a variable ballast tank in the middle and a buoyancy tank at the top.

Fig. 1 Single-column floating fan

In order to explore the influence of different structural parameters of fixed ballast on the hydrodynamic performance of the fan, three sets of experimental models were established based on the original model. Among them, model a changes the position of the original fixed ballast tank, and the position of the original fixed ballast tank is improved by 20 m as a whole. The comparison between model A and the original model is shown in Fig. 2. Model b changed the shape of the fixed ballast tank, the diameter of the fixed ballast tank was changed from 15 m to 10 m and the height from 8 m to 18 m. In terms of shape, the change from the original thick

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cylinder to a slender cylinder set inside reduces the diameter of the fixed ballast tank and increases the height. The comparison between model b and the original model is shown in Fig. 3. Model c changes the weight of the fixed ballast. In order to ensure that there is only a single variable of the weight of the fixed ballast and ensure the accuracy of the experiment, the density of the filling material is adjusted so that it is half of the density of the original filling material, so that the weight of the fixed ballast tank becomes half of the original. Since model c changes the density of the filling, while the shape and position of the fixed ballast tank do not change, the fan model in the hydrodynamic simulation is the same as that of the original model, and no schematic diagram is attached. After establishing the three-dimensional models of each experimental group, the center of gravity position of each model and the moment of inertia in each direction are obtained through calculation, which provides the modeling basis for the final hydrodynamic simulation.

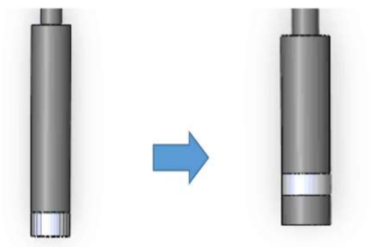

Fig. 2 Comparison of Model a

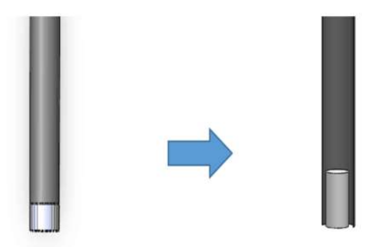

Fig. 3 Comparison of Model b

Table 1. Corresponding variables of different models

serial number	variable
Primary foundation	none
Model a	Fixed ballast tank position raised by 20m
Model b	Decrease diameter increase height
Model c	Change the weight of the fixed ballast tank

3. Hydrodynamic Theory Basis of Floating Fan

3.1. Potential Flow Theory

For the study of large-scale structure such as single-column floating fan, when studying its oscillation in the ocean, the fluid force on the foundation of the floating fan includes the disturbed force of waves, the fluid reaction force caused by the movement of the foundation of the floating fan and the static water restoring force generated by the foundation of the floating fan. In actual calculation, the movement of the foundation of the floating fan determines the fluid force. However, the foundation of the floating fan will be affected by the force movement, and the two problems will affect each other, increasing the difficulty of calculation. In addition, the existence of the basic structure of the floating fan will cause changes in the surrounding flow field [7], resulting in diffraction and reflection of the incident wave. Since the influence of fluid viscosity effect is relatively small, the potential flow theory [8], which takes uniform, inviscous, incompressible and irrotational ideal fluid as the research object, is usually used to approximate the fluid force flow field.

3.2. Panel Method

As a kind of boundary element method, the surface element method is widely used to solve the problem of flow around objects in fluid mechanics. The calculation principle of the surface element method is to discrete the surface of the floating fan, replace the actual surface with a plane or surface after generating the grid, and the generated surface is called the surface

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element. Then, by setting a point source on the surface element, solving the point source strength according to the fixed solution problem to obtain the velocity potential, velocity, pressure, etc., so as to obtain the inertial force, damping force and restoring force of the floating body. Then the motion response of the floating body is solved. There are two main calculation methods for the surface element method, one based on velocity and the other based on velocity potential. In the solution of practical problems, especially in the simulation analysis of offshore wind turbines, most of them choose the surface element method based on velocity potential, which only discretized the surface of offshore wind turbines without considering the flow situation in the entire flow field region. It can also meet the accuracy and accuracy requirements of the calculation of hydrodynamic problems of offshore wind turbines.

4. Simulation Analysis and Result Analysis

In exploring the influence of different structural parameters of fixed ballast on the hydrodynamic performance of the fan, the modeling software SpaceClaim of ANSYS WOERBENCH was first used to establish a three-dimensional surface element model of the single-column floating fan, and the model was simplified to ensure that the structure of the hydrodynamic simulation analysis results would not be affected, such as ladder, workbench, etc. Flanges and bolts were removed to improve the quality of the grid and ensure the accuracy of the simulation, and then grid division was carried out. Because the simulation model was large and only conducted the hydrodynamic analysis of the whole offshore wind turbine, a larger mesh size was used to set the grid for improving the operation speed under the premise of ensuring the accuracy. It is then imported into the hydrodynamic diffraction tool in the ANSYS tool for analysis.

The hydrodynamic diffraction module in AQWA was used to simulate and analyze the hydrodynamic response of the single-column floating fan by setting different parameters of the fixed ballast, and the hydrodynamic performance of the single-column floating fan corresponding to different states was obtained. The hydrodynamic performance of the single-column floating fan was expressed in the form of the ship motion response amplitude operator. Compare the obtained data.

Surge: According to the RAO line chart of different models obtained by the experiment, it can be seen that the response amplitude of model a's surge direction is similar to that of the original model at low frequency, and slightly higher than that of the original model at high frequency. The response amplitude of model a does not change much, and there is no mutation and peak of the original model. The response amplitude of model b's surge direction is similar to that of the original model at low frequency, slightly higher than that of the original model at high frequency, the occurrence of abrupt change and peak value is slightly earlier than that of the original model, and the peak value is smaller than that of the original model. The response amplitude of model c is similar to that of model a, but there is no obvious difference. It can be seen from the figure that the hydrodynamic performance of the three models in the longitudinal direction is better than that of the original model.

Rolling: According to the RAO line charts of different models obtained by experiments, it can be seen that the amplitude of the response of model a in the direction of oscillation is slightly lower than that of the original model at low frequency and little different from that of the original model at high frequency. However, the peak value of model a appears earlier and is much smaller than that of the original model, and the response amplitude of model b is similar to that of the original model in the whole cycle, only the peak value appears slightly earlier than that of the original model. The response amplitude of model c is similar to that of the original model at both low and high frequencies, but the peak value of model c appears earlier and the peak value is larger. It can be seen from the figure that the hydrodynamic performance in the swaying

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direction of model a has been significantly improved, the hydrodynamic performance in the swaying direction of model b has little change, and the hydrodynamic performance in the swaying direction of model c is worse than that of the original model.

Heave: According to the heave RAO line chart of different models obtained by the experiment, the response amplitude of model a and model b is the same as that of the original model, the value of model c is slightly lower at low frequency, the mutation and peak value appear slightly later and smaller than that of the original model, and the value is slightly higher at high frequency than that of the original model. It can be seen from the figure that the hydrodynamic performance in the sag direction of model a and model b has no change compared with the original model, while the hydrodynamic performance in the sag direction of model c is better than that of the original model.

Pitch: According to the line charts of pitch RAO of different models obtained by the experiment, the response amplitude of model a is slightly higher than that of the original model at low frequency, similar to that of the original model at high frequency, the peak value appears earlier and the peak value is smaller than that of the original model, the response amplitude of model b and the original model is similar throughout the cycle, only the peak value appears slightly earlier, and the amplitude of model c is similar to that of the original model at low frequency and high frequency. However, the peak value of model c appears earlier and is larger than that of the original model. It can be seen from the figure that the hydrodynamic performance of model a in the pitching direction is better than that of the original model, that of model b in the pitching direction is similar to that of the original model, and that of model c in the pitching direction is worse than that of the original model.

Rolling: According to the rolling RAO line chart of different models obtained by the experiment, it can be seen that the amplitude of model a is low and no obvious peak appears; the amplitude of model b is similar to the original model in the whole period, only the peak appears slightly earlier than the original model; model c is similar to the original model at low frequency and high frequency, but the peak appears earlier and is smaller than the original model. It can be seen from the figure that the hydrodynamic performance in the roll direction of model a and model c is better than that of the original model, while the hydrodynamic performance in the roll direction of model b is similar to that of the original model.

Roll: According to the line chart of roll RAO of different models obtained by the experiment, the response amplitude of model b and model c is similar to that of the original model in the whole cycle, and the response amplitude of model a is similar to the trend of the original model but the value is slightly smaller. It can be seen from the figure that the hydrodynamic performance of model a in the yawing direction is slightly better than that of the original model, while the hydrodynamic performance of model b and model c in the pitching direction is the same as that of the original model.

5. Conclusion

In this paper, the fluid dynamics diffraction tool in AQWA, an analysis software of ANSYS, is used to conduct a three-dimensional modeling of a single-column floating fan based on potential flow theory and plane element method. The motion response of the fan at six degrees of freedom under different ballast tank structural parameters is simulated by using SpaceClaim. The following conclusions are obtained by analyzing the amplitude response operator obtained:

1) Model a changes the position of the fixed ballast tank, and the center of gravity of the ballast tank is raised by 20m compared with the original model. The horizontal, transverse and longitudinal hydrodynamic performance of the single-column floating fan is better than that of the original model, but the stability of the fan is reduced due to the increase of the center of gravity. Therefore, the pitching and rolling performance of the structure can be optimized by

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appropriately raising the position of the fixed ballast tank on the premise of ensuring the stability of the fan.

2) Model b changes the shape of the fixed ballast tank, but the hydrodynamic performance in all aspects is not much improved, only the peak value in the direction of the surge is reduced, and the shape of the variable ballast tank needs to be adjusted accordingly to change the shape of the ballast tank, which is costly and difficult, and can be considered when the requirements are high in the direction of the surge.

3) Model c changes the density of the fixed ballast filler, and its hydrodynamic performance in the direction of roll and pitch is worse than that of the original model. In other directions, it is similar or slightly worse than that of the original model, and the center of gravity is higher, and the stability is worse. Therefore, under the premise of considering the cost and installation difficulty, the fixed ballast tank can be filled with more dense filler.

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