Structural Strength Check Analysis of Core Moving Parts of Semi-submersible Floating Wind Turbine Based on Finite Element Calculation

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Abstract: In this paper, the finite element analysis method is used to simulate the stress distribution and deformation of wind turbine under various loads such as wind, wave and current by establishing a fine finite element model. At the same time, combined with the design standards and actual working conditions, the structural strength is comprehensively checked and evaluated. The research results show that the core moving parts of semi-submersible floating wind turbine show good structural strength as a whole, but stress concentration and high stress still exist in some areas. In view of these problems, this paper puts forward the improvement measures of structural optimization and material selection, which effectively improves the safety and reliability of the structure. To sum up, in this paper, the structural strength of the core moving parts of semi-submersible floating wind turbine is deeply studied by finite element analysis method, and a series of valuable research results are obtained, which provides useful reference for technological progress and industrial development in related fields.

1. Introduction

With the continuous optimization of global energy structure and the rapid development of clean energy, wind power generation, as a renewable and pollution-free energy form, has been widely concerned and applied around the world [1]. Especially in countries rich in marine resources, offshore wind power generation has become a new energy development hotspot [2]. Under this background, semi-submersible floating wind turbine, as a new type of offshore wind power equipment, its research and development and application have important strategic significance [3].

Wind power generation is one of the fastest developing new energy sources in the world [4]. On the coastlines of Europe, North America and Asia, a large number of offshore wind farms have been built or are being planned [5]. Compared with traditional fixed offshore wind turbines, floating wind turbines have better adaptability and flexibility, and can be deployed in deep-sea areas, thus greatly expanding the development scope of offshore wind power [6].

Semi-submersible floating wind turbine is an important form of floating wind power technology, which supports the wind turbine through semi-submersible floating structure, so that it can run stably in harsh marine environment [7]. This structure combines the stability of floating platform with the high efficiency of wind turbine, and is an important direction of offshore wind power development in the future [8]. However, the semi-submersible floating wind turbine is faced with complex load conditions and harsh marine environment during its operation, and the structural strength of its core moving parts directly affects the safety and reliability of the equipment. Therefore, it is of great engineering practical significance and theoretical research value to check and analyze the structural strength of the core moving parts of semi-submersible floating wind turbine. The purpose of this study is to check and analyze the structural strength of the core moving parts of semi-submersible floating wind turbine by finite element calculation method.

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2. Theoretical basis

The finite element method is a numerical calculation method, and its basic principle is to discretize a continuous physical problem into a combination of finite elements, and approximate the solution of the whole problem by approximate solution of each element. In structural strength analysis, finite element method is widely used to solve various complex structural problems, such as stress distribution, deformation, stability analysis and so on [9]. The basic steps of finite element method include establishing geometric model, meshing, applying boundary conditions and loads, solving finite element equations and post-processing. When dividing the grid, it is necessary to choose the appropriate cell type and grid density according to the complexity of the problem and the requirements of calculation accuracy. When applying boundary conditions and loads, it is necessary to accurately simulate the constraints and forces under actual working conditions. When solving finite element equations, direct method or iterative method can be used to solve them. Post-processing is the process of visual display and data analysis of calculation results.

Structural strength checking is a process of evaluating the bearing capacity of a structure under a given load. In the checking process, it is necessary to select appropriate strength evaluation criteria according to the structural characteristics and stress conditions, such as stress criterion, strain criterion and energy criterion. At the same time, it is also necessary to consider the influence of mechanical properties of materials, manufacturing technology and environmental factors on structural strength. The basic steps of structural strength check are shown in Figure 1.

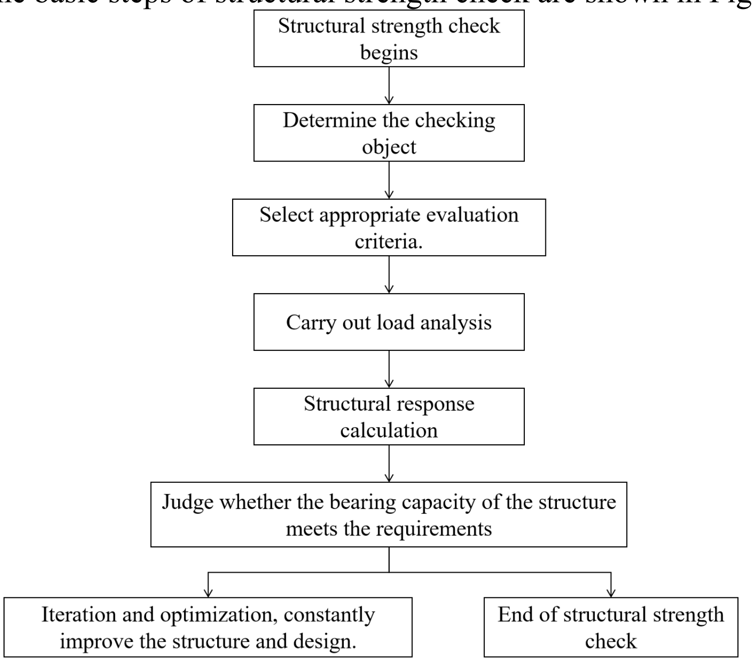

Figure 1 Basic steps of structural strength check

In the process of checking, if it is found that the bearing capacity of the structure is insufficient or there are potential safety hazards, it is necessary to optimize or strengthen the structure.

3. Overview of semi-submersible floating wind turbine

After decades of development, wind power generation technology has formed a variety of types and application scenarios of wind turbines. Among them, semi-submersible floating wind turbine, as a new type of wind power equipment adapted to deep-sea environment, has attracted much attention for its structure and technical characteristics. This section will introduce the basic structure and core moving parts of semi-submersible floating wind turbine in detail.

3.1. Basic composition of wind turbine

Wind turbine is mainly composed of the following parts: wind wheel, generator, tower, control system and infrastructure. The wind wheel is a component that captures wind energy. It consists of several blades and a hub. When the wind blows over the blades, the blades are rotated by the wind, thus driving the generator to generate electricity. The generator converts the mechanical energy rotated by the wind wheel into electrical energy. The tower is a structure that supports the wind wheel and the generator, and it needs sufficient strength and stability to ensure the safe operation of the wind turbine. The control system is responsible for monitoring and controlling the running state of the wind turbine to ensure its efficient and stable operation under various wind conditions. For land wind turbines, the infrastructure mainly refers to the tower foundation and grounding system; For floating wind turbines, the infrastructure includes floating bodies, mooring systems and submarine cables.

As a special type of wind turbine, semi-submersible floating wind turbine is mainly characterized by its floating structure. Semi-submersible floating body usually consists of two or more pontoons and beams connecting them. This structure makes the floating body have good stability and motion performance under the action of waves. In addition, the semi-submersible floating wind turbine has the advantages of adapting to the deep-sea environment and being convenient for transportation and installation, so it has broad application prospects in offshore wind power development.

3.2. Introduction of core moving parts

The core moving parts of semi-submersible floating wind turbine mainly include wind wheel, generator shaft and yaw system. These components play an important role in the operation of wind turbines.

As a component to capture wind energy, the structural characteristics of wind turbine mainly include airfoil design, blade length and material. The airfoil design of blades directly affects the aerodynamic performance of the wind turbine, while the blade length and material determine the strength and weight of the wind turbine. In the design process, these factors need to be considered comprehensively to realize the efficient and stable operation of the wind turbine. The generator shaft is the key component connecting the wind wheel and the generator, and it needs to have enough strength and rigidity to bear the huge torque generated when the wind wheel rotates. At the same time, the dynamic characteristics of the generator shaft will also affect the overall performance of the wind turbine. Therefore, it is necessary to optimize the structure and material of generator shaft in the design process. The yaw system is responsible for adjusting the direction of the wind wheel to make it always aim at the wind direction to obtain the maximum utilization rate of wind energy. Yaw system usually consists of yaw bearing, yaw drive device and yaw controller. Yaw bearing needs to have enough bearing capacity and good sealing performance to ensure the reliable operation of yaw system; The yaw drive device needs to have enough driving force and accuracy to realize the accurate adjustment of the direction of the wind wheel; The yaw controller is responsible for monitoring and controlling the running state of the yaw system.

4. Establishment and analysis of finite element model

4.1. Model construction

As a powerful numerical calculation method, finite element analysis plays a vital role in structural strength evaluation. For semi-submersible floating wind turbine, its structure is complex and subjected to various loads. Therefore, it is the key to ensure the safety of the equipment to establish an accurate and reliable finite element model and conduct in-depth analysis. When constructing the finite element model, the actual structure needs to be simplified and assumed reasonably first. Due to the complexity of wind turbine structure, it is neither feasible nor necessary to model the wind turbine completely according to the actual details. Therefore, it is necessary to ignore some detailed features that have little influence on the overall structural strength, such as small chamfers and rounded corners, while retaining the main load-bearing structure and connecting parts.

Mesh generation is one of the key steps in the construction of finite element model. Reasonable grid division can improve the calculation efficiency while ensuring the calculation accuracy. When dividing the grid, it is necessary to select the appropriate element type and grid density according to the structural characteristics and stress conditions. For stress concentration areas and key connection parts, it is necessary to use finer grids to improve the calculation accuracy.

The setting of boundary conditions is also an important link in the construction of finite element model. Correct boundary conditions can simulate the constraints and forces of the actual structure, thus ensuring the accuracy of the calculation results. When setting the boundary conditions, it is necessary to consider the floating body support mode, mooring system and the connection mode between the wind wheel and the generator.

4.2. Finite element analysis of load, working condition and structural strength

Semi-submersible floating wind turbine is subjected to various loads such as wind, wave and current during operation. When calculating these loads, it needs to be determined according to the actual sea conditions and the operating state of the wind turbine. For wind load, factors such as wind speed, wind direction and aerodynamic performance of wind wheel need to be considered; For wave load, factors such as wave height, period and hydrodynamic performance of floating body need to be considered. For the flow load, it is necessary to consider the speed and direction of the water flow, the shape and size of the floating body and other factors. In actual operation, wind turbines may encounter various complex combinations of working conditions. In order to comprehensively evaluate the strength of the structure, it is necessary to select representative working conditions for load combination and analysis. Usually, extreme sea conditions, maximum wind speed conditions and equipment failures can be selected for combined analysis according to design specifications and practical experience.

After the construction of finite element model and load calculation, it is necessary to analyze the strength of the structure. This mainly includes the calculation and analysis of stress distribution and deformation. Through finite element calculation, the stress distribution nephogram and deformation diagram of the structure under given load conditions can be obtained, so as to intuitively understand the stress situation and deformation trend of the structure. In order to judge whether the structure meets the strength requirements, it is necessary to calculate the safety factor and strength check. The safety factor is usually determined according to design specifications and experience, which reflects the safety reserve of the structure. Strength check is to compare the calculated stress with the allowable stress of the material to judge whether the structure is damaged or failed. Through finite element analysis, the strength of the structure can be comprehensively evaluated and checked, thus providing an important basis for the design and optimization of equipment.

5. Check results and discussion of structural strength

5.1. Check results display

Through finite element calculation, the stress distribution and deformation of semi-submersible floating wind turbine under given load conditions are obtained. After obtaining the stress distribution and deformation, the stress and deformation of key parts are further extracted and compared with the design standard (as shown in Table 1).

Table 1 Stress value and deformation display of key parts

Serial number	Area	Stress value (MPa)	Design standard stress value (MPa)	Deformation amount (mm)	Design standard deformation (mm)	Assessment result
1	Mean beam	150	180	2.5	4.0	Meet a criterion
2	Pillar	120	150	1.8	3.0	Meet a criterion
3	Connection site	160	150	3.0	2.8	Exceed the standard
4	Stress concentration area	145	140	2.2	2.0	Exceed the standard
5	Other areas	100-130	100-150	1.5-2.5	2.0-4.0	Meet a criterion

Through comparison, it is found that the stress and deformation in most areas are within the design standard range, indicating that the structure has good strength performance. However, in some local areas, such as connection parts and stress concentration areas, the stress value is slightly higher than the design standard, and the design needs to be further optimized.

5.2. Results analysis and discussion

In order to further analyze the check results, this paper compares the stress values obtained by finite element analysis with the design standards in detail (as shown in Table 2).

Table 2 Comparison between stress value and design standard

Serial number	Area	Stress value of finite element analysis (MPa)	Design standard stress value (MPa)	Assessment result	Remarks
1	Main structure area 1	120	150	Meet a criterion	Sufficient safety reserve
2	Main structure area 2	110	140	Meet a criterion	Sufficient safety reserve
3	Connection site	165	160	Exceed the standard	Structural design needs to be optimized
4	Stress concentration area 1	155	150	Exceed the standard	Material selection or structural optimization
5	Stress concentration area 2	148	145	Approaching the standard	Need attention
6	Other minor areas	80-120	100-130	Meet a criterion	Sufficient safety reserve

Through comparison, it is found that the stress values in most areas are lower than the design standards, indicating that the structure has sufficient safety reserves in these areas. However, in the local high stress areas, such as the connection parts and stress concentration areas mentioned above, the stress value is slightly higher than the design standard. This may be caused by unreasonable structural design or improper material selection.

In view of these problems, this paper puts forward the following suggestions for improvement: Optimize the structure of local high stress areas, such as adding stiffeners and optimizing connection methods; Consider using higher strength materials instead of existing materials to improve the bearing capacity of the structure; Strengthen the manufacturing process and quality control to ensure that the actual performance of the structure meets the design requirements.

5.3. Analysis of uncertainty and influencing factors

In the process of finite element analysis and structural strength check, there are some uncertain factors that may affect the results. First of all, model simplification and assumptions will bring some errors. For example, when establishing the finite element model, this paper simplifies and assumes the actual structure, which may lead to some deviation between the calculated results and the actual situation. In order to reduce this error, we can adopt more detailed models and more accurate assumptions in the follow-up research.

Secondly, external environmental factors will also have an impact on structural strength. For example, the magnitude and direction of wind, wave, current and other loads will change with the change of time and sea conditions, which may lead to the difference between the stress situation of the structure in actual operation and the calculated results. In order to consider this effect, more complex load model and more comprehensive working condition combination can be used to simulate the actual operating conditions in the calculation.

6. Conclusions

Through the finite element analysis and verification of the structural strength of the core moving parts of semi-submersible floating wind turbine, this paper finds that the core moving parts of semi-submersible floating wind turbine show good structural strength in design and manufacture as a whole. Under normal working conditions, these components can effectively withstand complex loads such as wind, waves and currents, and ensure the stable operation of wind turbines. Some local stress concentration and high stress areas found in the research process have been effectively improved by structural optimization and material selection. These improvement measures not only improve the safety of the structure, but also provide useful reference for the design and manufacture of similar equipment. In addition, the research results are of great significance to promote the technical progress and industrial development of semi-submersible floating wind turbines. Through in-depth understanding of the structural strength characteristics of core moving parts, it can provide strong support for equipment design optimization, manufacturing process improvement and operation and maintenance. In the future, we will expand the research field and pay attention to the fatigue life, dynamic characteristics and intelligent operation and maintenance of wind turbines.

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