Study on the Gyroscope Effect of Floating Offshore Wind Turbine Based on Modal Analysis

Yugang Li, Fengdong Chi, Jingjie Chen, Xin Zuo and Gangjun Zhai

ABSTRACT

In order to study the influence of gyroscope effect on floating fan, the DTU 10 MW fan is chosen as the research object, the floating platform is ITI energy barge platform, and the equivalent model is established by ANSYS finite element software. The state of floating fan at sea is simulated and modal analysis is carried out to determine the natural frequency and mode shape, so as to effectively avoid the occurrence of resonance, and to compare the working state with the non-working state. The influence of gyroscope effect on the natural frequency and vibration mode of fan is determined. By drawing Campbell diagram to determine the critical speed of the wind turbine, the rationality of the actual working speed of the wind turbine is confirmed.1

INTRODUCTION

The problems of population, environment and energy are the main problems that our country is faced with whether to carry on the sustainable development effectively. Because our country is a country with a large population, the per capita distributable energy is relatively small. At the same time, a series of conventional energy sources, such as coal, oil, natural gas and so on, are limited in storage quantity, and these energy sources will produce a certain amount of exhaust gas in the process of consumption, which will have a certain impact on the environment [1].

1Yugang Li, Fengdong Chi, Gangjun Zhai, Deepwater Engineering Research Center, Dalian University of Technology, Dalian, Liaoning, PRC
Jingjie Chen, Xin Zuo, School of Naval Architecture, Dalian University of Technology, Dalian, Liaoning, PRC
Compared with the traditional land fan, the floating fan at sea is faced with complex marine environmental [2] conditions. Under the combined action of the large amplitude motion of the floating fan and the rotation of the wind turbine, a torque in the direction of the tower and tube, that is, the gyroscopic moment, will be produced. The influence of gyroscopic moment on floating fan has become the focus of attention. Up to now, there is no discussion on the influence of gyroscopic moment on the frequency and mode of floating offshore fan. In order to discuss this problem, the finite element software can be used to simulate the floating offshore fan.

In this paper, the model of 10 MW floating fan at sea is established by using ANSYS software. The natural frequency and mode shape of each order are obtained by modal analysis, and the working and non-working conditions of the fan are compared. The influence of gyroscope effect on floating fan is studied. By drawing Campbell diagram to determine the critical speed of the fan, the rationality of the working speed of the floating fan is verified.

**THEORY OF GYROSCOPE EFFECT ANALYSIS FOR FLOATING FAN**

The general kinetic equation is

\[
[M][\ddot{U}] + [C][\dot{U}] + [K][U] = \{F\}
\]

(1)

Where \([m]\), \([c]\) and \([k]\) are mass, damping and stiffness matrices, \(\{f\}\) is an external force vector, respectively.

In the process of fan rotation, if the gyro effect and rotational damping are increased, the dynamic equation will be changed to

\[
[M][\ddot{U}] + ([C] + [G])\dot{U} + ([K] + [B])[U] = \{F\}
\]

(2)

The gyro matrix \([G]\) depends on the rotational speed, and it will have a certain influence when analyzing the dynamic problem of fan rotation. The matrix is necessary in the analysis of rotor dynamics, and the rotational damping matrix \([B]\) is also dependent on the rotational speed, and the stiffness of the structure will be changed obviously, and the unstable motion of the structure can be produced [4].

**MODAL ANALYSIS OF FAN AND DETERMINATION OF CRITICAL SPEED**

Modal analysis is mainly used to determine the vibration characteristics of structures or machine components, that is, the natural frequencies and modes of structures, which are important parameters in the structural design of structures
subjected to dynamic loads. At the same time, modal analysis is also the basis of other dynamic analysis [5].

By analyzing the frequency and vibration pattern of the wind turbine with a speed of 0 and a nominal speed of 9.6 rpm, the deformation effect of the gyro torque on the floating fan can be compared under both the platform sloshing and the wind wheel rotation in Table I and Table II.

It is not difficult to find out the influence of gyro effect on each order mode by observing the different states of each vibration mode when the speed of wind turbine is 0 and 9.6rpm. With the increase of wind wheel speed, the gyro effect is enhanced, and the gyro torque produced on the tower and cylinder will be increased significantly. The bending along z direction in the original first order mode is rotated under the action of gyroscope torque and becomes bending along x direction. In the same way, the bending along x direction in the second order vibration mode rotates under the action of gyroscope torque and becomes bending along z direction. Under the action of gyro torque T in 9.6rpm, the tower and cylinder also rotate around y axis. Therefore, the third order vibration mode changes from the torsion of the original transmission system, the bending of the tower tube along the z direction, to the torsion of the transmission system with the tower tube, and then the bending direction of the tower tube is the new direction in which the torsion occurs. That is, the bend in the x direction.

The natural frequencies of each order have changed because the gyroscope matrix [G] and the rotational damping matrix [B] in formula (2) have been changed when the wind wheel rotates and the fan swings simultaneously, which will obviously change the stiffness of the structure. And it can make the structure unstable motion. The natural frequency changes with the speed of the wind wheel, that is, Campbell diagram, as shown in figure 2.

![Figure 1. ANSYS element model.](image1.png)

![Figure 2. Campbell diagram.](image2.png)
Critical speed is the rotational speed associated with the response frequency of the structure. When the natural frequency is equal to the exciting frequency, the critical speed will occur. The rotor of the rotating system will vibrate in operation, the amplitude of the rotor increases with the increase of the rotational speed, and the amplitude reaches the maximum at the critical speed, that is, resonance occurs. The amplitude decreases with the increase of the critical speed and is stable within a certain range. Therefore, in order to ensure that the floating fan does not resonate in the operating range, the critical speed should deviate from the operating speed of 9.6 rpm. It can be seen from the diagram that the extraction speed line of this ANSYS finite element model intersects the first order frequency near 12rpm and the second order frequency near 14 rpm, then the first order critical speed of floating fan is 12rpm and the second order critical speed is 14rpm, which is far from the working speed. The resonance effect is avoided well, which provides a precondition for the floating fan to work safely and stably.

**CONCLUSIONS**

The natural frequency and mode of floating fan and the critical speed of fan are studied. The influence of gyroscope effect on floating fan is studied by comparing the two states of fan working and non-working. The conclusions are as follows:

1. The natural frequency and mode shape of floating fan will change under the influence of gyroscope effect. The first order natural frequency increases and the second order natural frequency decreases. The change of mode shape can be explained by the effect of gyroscopic moment, and the overall modal mode is ideal.

2. The first order critical speed and the second order critical speed of the floating fan are 12rpm and 14rpm respectively. In order to ensure the safe and stable operation of the fan, the fan speed should be far away from the critical speed. The working speed of the DTU 10MW fan is 9.6 rpm, so the rationality of the fan speed is verified.
ACKNOWLEDGEMENTS

Fund Project: National Natural Science Foundation of China (No. 51409040); Fundamental Research Funds for Central Universities (DUT17JC13)

REFERENCES