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Failure mechanism and vibration control for tower tube of wind generator under extreme climate

The wind power tower is sensitive to wind loads with high aspect ratio. The failure characteristics and failure mechanism of the wind turbine tower structure are analyzed under the extreme climate conditions. Based on the principle of tuned mass damper theory, the suspension damper application in wind turbine tower structure is designed. The appropriate typhoon wind speed spectrum is selected. With the finite element software, the 3D model for tower structure is established and the control effect of the damper structure is analyzed. The maximum displacement and acceleration of the structure under extreme climatic conditions are greatly reduced after the suspension tuned mass damper being given. The efficiency of vibration reduction is 80.26% and 54% respectively. The results show that the response of displacement and acceleration for the damper are obviously decreased, which is beneficial to the safety of the tower structure under the extreme climate condition.

Keywords : Vibration control, tower tube of wind, failure mechanism, extreme climate.

1.0 Introduction

As the new energy technology with great potential, wind power is more mature and has been drawing growing attention. Offshore and littoral areas become the hot spots of wind power development, because of abundant wind energy resource. However, the region is often affected by extreme weather of typhoon. As a tall structure, the tower tube of wind generator often collapses under the action of a typhoon, thus bringing the wind-farm to capsized fracture, which will not only give rise to the destruction of wind turbines but also cause the loss of transportation and installation costs.

The study of tall structures can be traced back to the 1980s. The wind-induced vibration reliability has been researched in [1] in view of the tall structures in civil engineering. The vibration control of towering structure has been discussed in [2]. For the tower tube of wind generator, the towering structure dynamic response and wind vibration control was studied in [3] under the action of typhoon. The application of ball damper in the vibration control of tower tube of wind generator has been presented in [4-6]. But under extreme climate, the mechanical behaviour of tower tube of wind generator is not involved. In this paper, the failure mechanism and vibration control of tower tube of wind generator is described under the influence of typhoon.

2.0 Damage characteristics of tower tube of wind generator

There are 11 typhoons landing for average annual in China. The collapse case of thin wall tower structure of wind generator happened almost every year. There are 30 collapse cases for tower tube of wind generators in 2014-2015, as shown in Fig.1.

Fig.1: Collapsed tower tube of wind generator caused by typhoon 'catfish'

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Fig.2: Destruction of tower tube structure of wind generator

Through the analysis of wind-farm accidents can draw the following conclusion.

From the perspective of the typhoon characteristics, the wind speed of typhoon is high, the impact range is wide and the typhoon lasts a long period.

From the characteristics of tower structure, the structure is slender and bears the larger load.

For the structural damage characteristics, the destroy part is at the one-third or two-thirds of the tower door and the form is as follows.

Due to the foundation size or shallow buried deep, the overall overturning of the structure will take place, as shown in Fig.2(a) and (b).

The stress concentration of tower door or its one-third will cause the local buckling of the structure, as shown in Fig.2(c).

The local buckling of tower tube is located about two-thirds of the structure, as shown in Fig.2(d).

3.0 Failure mechanism of tower tube of wind generator

3.1 Wind load response

The wind load can be divided into two parts: the static load caused by the average wind and the dynamic load caused by pulsating wind. The tower tube of wind generator is a slender flexible symmetrical structure and the maximum stress and displacement will appear along wind.

As shown in Fig.3, the tower tube of wind generator is a bending component. It is subjected to bending moment from the start difference with the axial compressive bar. Bending components are subjected to the bending moment produced by horizontal force *N*, the coupled loads caused by eccentric compression force and the basic bending moment produced by the initial bending moment of components *M*. The displacement caused by the bending moment is called the basic deflection f_0. The Axial force *N* produces the compression and will also generate additional bending moment Nf_0 as the existence of deflection f_0, causing additional deflection f_1. The additional bending moment Nf_1 and additional deflection f_2 will appear again. In the case of constant force, the bending moment and deflection of the component will gradually increase until the equilibrium phase of component bearing capacity or exceeding the carrying capacity.

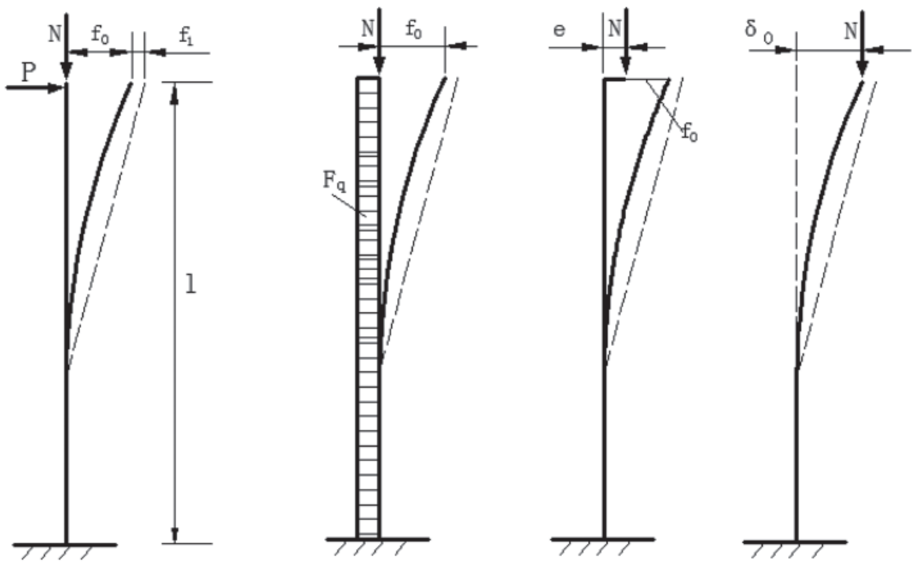

Fig.3: Diagram of tower tube bending component under the action of external load

Therefore, there is a nonlinear relationship between the axial force and deflection of bending components. Although the component is in the elastic scope of work, but the superposition principle is no longer applicable. The nonlinear theory namely the second order approach is used to calculate it.

The pulsating wind speed is formed by the superposition of countless different frequency pulsating wind vibration factors. The corresponding mathematical correlation function is available to describe the stationary stochastic characteristics of wind pressure and this feature is solved by the random vibration theory of the structure [2].

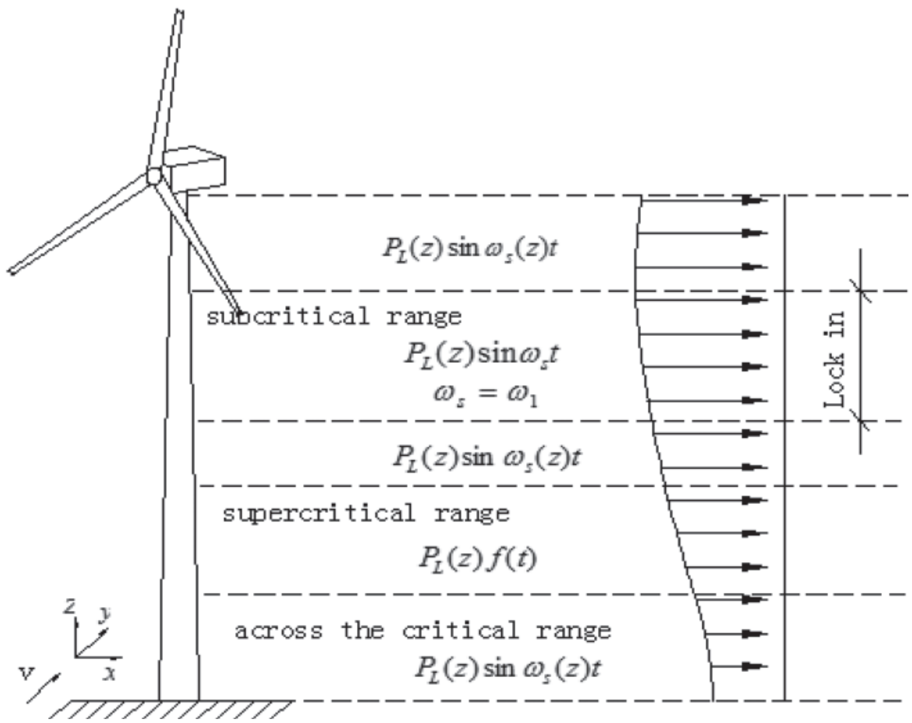

Fig.4: Schematic diagram of transverse wind partition

3.2 Horizontal wind load response

Under the effect of horizontal wind, the circular cross-section tower tube structure will only cause the cross wind response. When the airflow is around the tower drum structure, it will meet again behind the structure and form the vortex and the maximum acceleration of the structure may occur in the transverse direction.

All possible transverse wind of tower drum structure will be in five areas of three regions, as shown in Fig.4.

The wind vibration along transverse direction can be divided into three range according to the Reynolds number size [7]: subcritical, supercritical and across the critical range. The vibration characteristics of different range is different. The vibration caused by the vortex shedding of subcritical and critical range is the deterministic cycle vibration. For supercritical, it is a random vibration. Experimental results show that when the wind speed increases to the natural frequency of the structure vibration that makes the vortex shedding, the frequency remains the same for the wind speed increasing in a range, known as the lock area. Especially when the vortex shedding frequency periodically is consistent with the structural natural frequencies, a great resonance response will be produced.

The appearance of the horizontal wind resonance of wind power structure depends on the resonance speed belonging to the critical range. The vibration period of tower tube structure of wind generator is between 0.5s and 2.5s. The resonance wind speed is between 24m/s and 40m/s, and the wind speed can be appeared in extreme weather conditions.

3.3 Vertical load response

The certain angle of the wind is generally available changing in +10° and –10° relative to the horizontal plane. For the structure, two torques are produced under the vertical load. The vertical wind makes the vertical axial force for the tower tube structure.

In addition to the above three kinds of effects, the instability of wind vibration effect will be taken place under the action of wind which should be given special attention to this phenomenon. Angle of attack may be produced due to the structure of section shape. The structure can produce negative damping structure. When the wind speed reaches a certain critical value, the structure vibration can not bounce back and appears the greater shock, namely producing the instability of wind vibration effect.

4.0 Wind power tower structure vibration control

The vibration control objective of wind power tower structure is to increase structural damping, reduce the structure displacement and acceleration response. The core is a vibration control equipment. The frequency quality modulation controller is composed of mass, springs, damping and mass support system.

In vibration control, the vibration reduction is caused by the inertia force produced by the relative motion of mass and structure, The quality ratio of blocks and the tower drum structure is from 0.005 to 0.02 [9].

The spring system with eight spiral springs is to adjust the frequency of vibration control close to the natural frequency of structure vibration control.

The damping system is used to provide the vibration control damping and has the greater vibration reduction effect. The appropriate damping coefficient is selected from $1\times10^6 Ns/m$ to $12\times10^6 Ns/m$.

The mass support system is the suspension hook. The friction of the hook and the quality piece is smaller for the quality block being free to shake.

The damper is installed in the top of the wind power tower drum, the detailed dimension is shown in Fig.5.

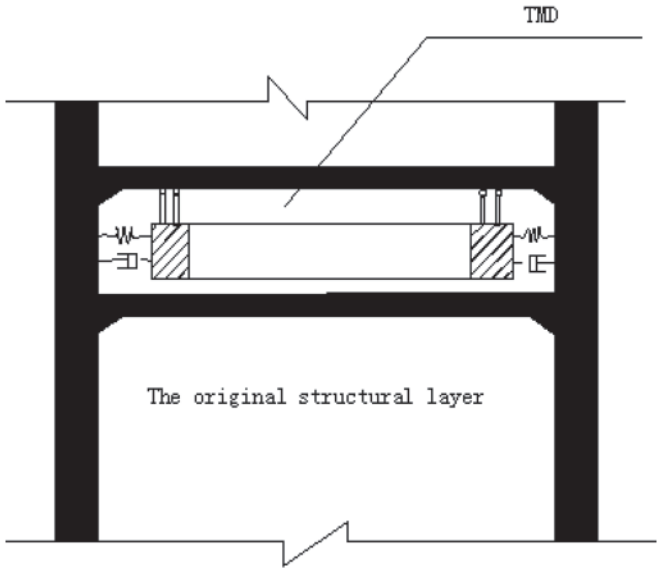

Fig.5: Pendant frequency modulation mass damperof tower tube of wind generator

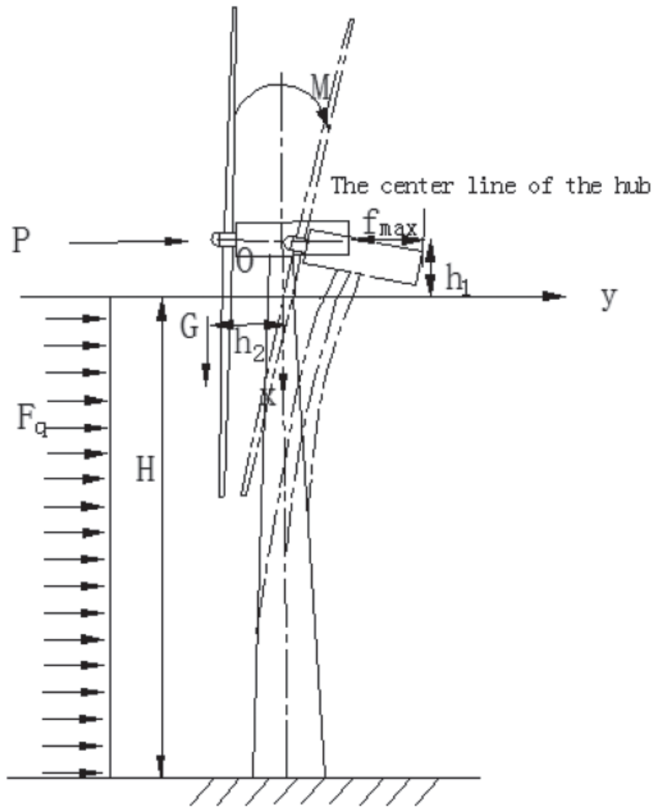

Fig.6: The mechanical model of wind turbine tower

5.0 Example

5.1 Original parameters

The 2MW horizontal axis wind generators produced by a certain manufacturer is as an example and the frustum tower drum structure in the height of 77.85 meters is taken as the research object. The tower drum is made up of welding four steel plate of different thickness from14mm to 24mm, with the flange bolt connection. The steel material is Q345E, the height is 77.85 m and the eccentric is 1200 mm. the detailed dimension is shown in Fig.6.

Calculation conditions:

Condition 1: Rated condition – The wind speed 11.4m/s, the normal operation of the wind turbine is conducted and the wind energy of wind turbine is fully utilized.

Condition 2: Limit state of wind load – The average wind speed is 50m/s in 10 minutes under the limit conditions of wind load for 50 years.

5.2 Two calculations under the rated condition

(1) Theoretical calculation

According to the material mechanics theory, the strength of wind power tower structure is 88.92MPa and the deflection is 361mm under the rated condition.

(2) Finite element calculation

The three-dimensional model of the wind power tower structure is established. With Simulation SolidWorks, the shell element, material Q345E, mechanical model using cantilever beam are selected to analyze the model. The calculated results are shown in Fig.7. The structural strength is 94.7MPa and the deflection is 368.7mm.

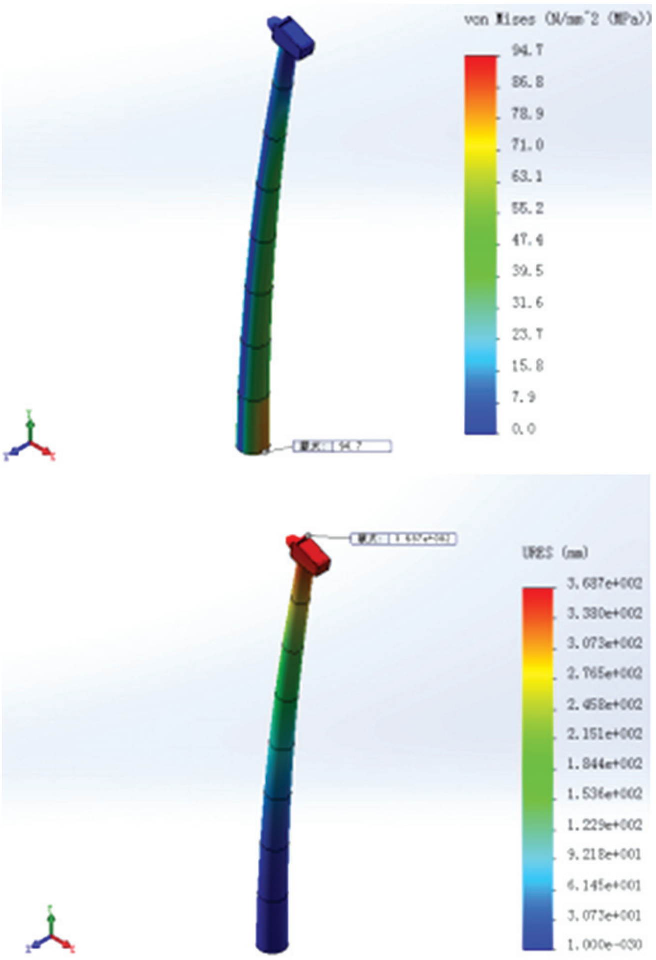

Fig.7 Stress and displacement of tower structure under the rated condition

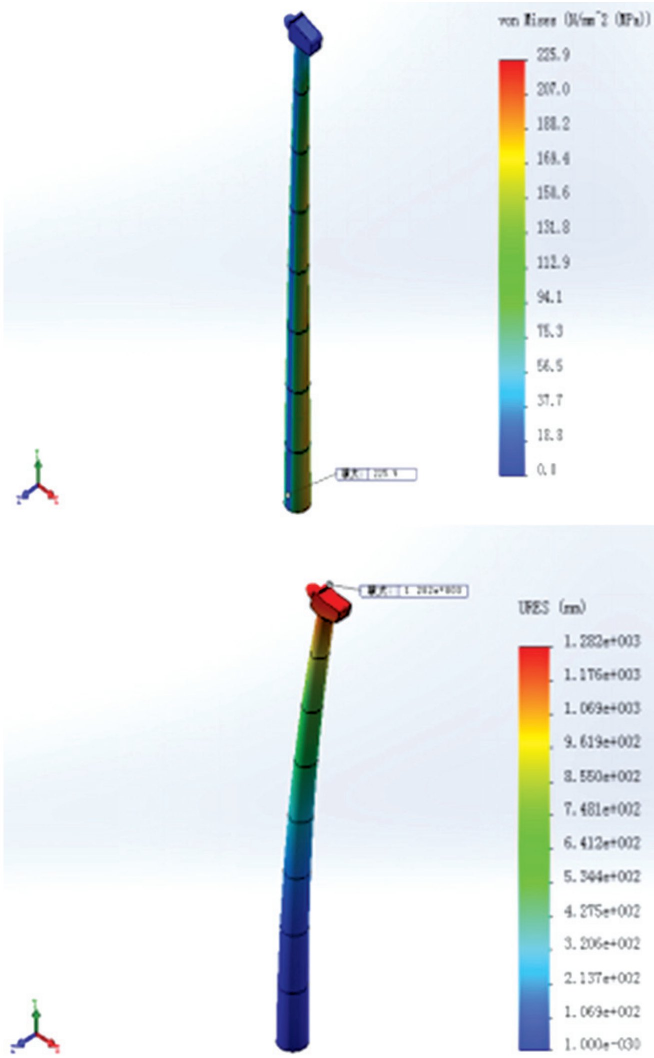

Fig.8: Stress and displacement of the tower structure without damper under the limit condition

Under the rated condition, the stress and displacement of the two calculation methods are not very large, which shows that the finite element model can reflect the mechanical characteristics of the wind power tower. The model can be used in dynamic analysis of structures.

5.3 Two calculations under the limit state

In the frequency domain, the random vibration is used to analyze and calculate the response of the structure without damper, as present in Figs.8 and 9. The calculation results are shown in Table 1.

Table 1: The structural stress and displacement of tower drum in the limit condition

	Stress	Displacement
Without damper	225.9MPa	1282mm
With damper	181.3MPa	692.3mm

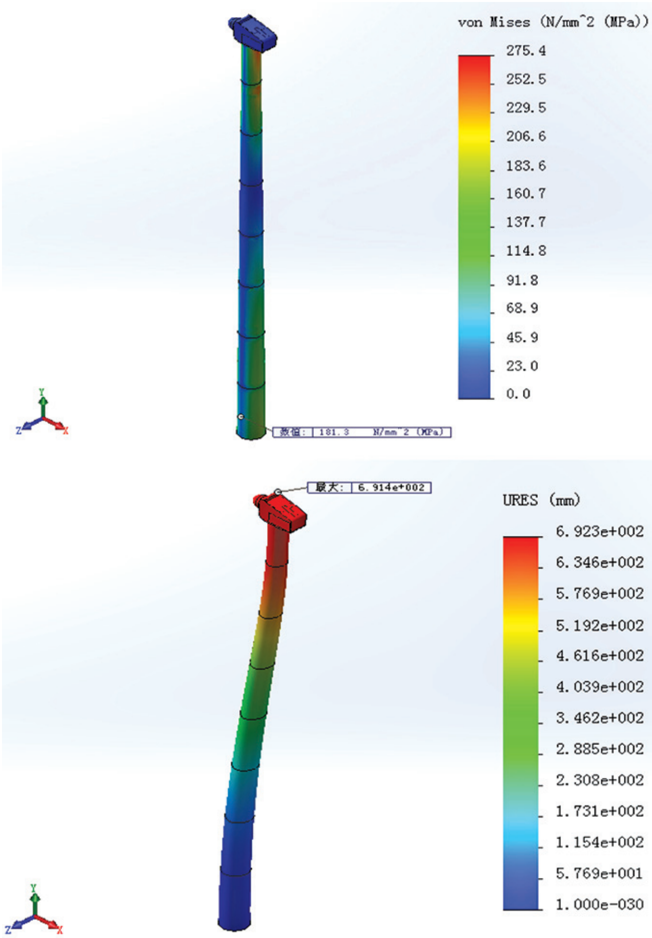

Fig.9: Stress and displacement of the tower structure with damper under the limit condition

From Table 1 it can be obtained that, after set the pendant frequency modulation mass damper, the maximum displacement and acceleration of structures under extreme climatic conditions are greatly reduced.

5.4 Evaluation of the control effect of wind vibration

Using damping efficiency to evaluate the effect of suspension tuned mass damper on wind vibration control of wind power tower [3]

$$\delta = x/x_0 \quad \text{... (13)}$$

Where,

x – Structural response amplitude of with no suspended frequency modulation mass damper

x_0 – Structural response amplitude of with suspended frequency modulation mass damper

δ – Vibration reduction efficiency, the smaller the better the results

Stress damping efficiency: $\delta_1 = 181.3/225.9 = 80.26\%$

Displacement damping efficiency: $\delta_2 = 692.3/1282 = 54\%$

6.0 Conclusions

In this paper, the mechanical characteristics of the destruction of wind turbine tower are analyzed. Structure vibration control equipment under extreme climatic conditions are compared. The main conclusions are as follows:

(1) there are three kinds of force in the structure of the wind power tower, One is to take the along wind as the main force, The other is to take the lateral wind vibration response as the main force, or take the both downwind and crosswind response as the main force.

(2) Three dimensional finite element analysis model of wind power tower is built. The random vibration analysis of structure is carried out. The vibration condition of the structure under extreme climatic conditions is reflected, which provides the basis for wind vibration control.

(3) After set the pendant frequency modulation mass damper, The maximum displacement and acceleration of structures under extreme climatic conditions are greatly reduced, The vibration reduction efficiency is 80.26% and 54% respectively. The results show that the displacement and acceleration response of the damper are obviously decreased, which is beneficial to the safety of the tower structure under the condition of extreme climate.

7.0 Acknowledgements

This paper is supported by the Postdoctoral Startup Foundation of Taiyuan University of Science and Technology (No.20142011), the Doctor Startup Foundation of Taiyuan University of Science (No.20122001), the Postgraduate Technology Innovation Project of Taiyuan University of Science and Technology (No.20145029) and the Education and Research Project of Taiyuan University of Science and Technology (No.11)

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