Modal Analysis and three-dimensional modeling of 100kW horizontal axis wind turbine blades

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Keywords:wind turbine blade; three-dimensional modeling; finite element model; modal Analysis; Resonance.

Abstract. In order to analysis the modal of wind turbine blades, we need to build a three-dimensional model of wind turbine blades, and then using the finite element analysis software ANSYS three-dimensional model established meshing, build fan blades finite element model, and finally to analysis the modal of 100kW horizontal axis wind turbine blade. The results show that the wind turbine keep in stable operation at rated speed and the resonance does not occur; the maximum stress on the blade is less than the allowable stress design requirements. Meet the design requirements, it provides the basis for the blade vibration characteristics and structural optimization.

1. Introduction

Wind energy is a kind of abundant, widely distributed, renewable clean energy, the growth of wind power generation in the new energy and renewable energy industry in the fastest way of generating electricity, with large-scale development and commercial development prospects. Due to the improvement of the ecological environment, optimize the energy structure, promoting sustainable economic and social development of the prominent role, countries all over the world in the further development and research of wind power generation and its correlative technology of [1]. China is rich in wind energy resources, national wind energy reserves of about 3.2×10^9 kW, the total amount of wind energy resources can be developed using up to 2.5×10^8 kW.

Wind turbine blade is a key component to absorb wind energy, but also the complex stress bearing parts, often appear vibration exceed the standard problem, the main factors are various incentive outside, causes the wind machine produce force imbalance, affecting the smooth running of the fan. In addition to a good balance of the rotor to reduce the external excitation force, but also the natural frequency of in-depth study of the wind turbine, in order to avoid resonance of the system [2] .In the process of operation, in order to avoid the blade vibration fault, analysis of it is necessary to carry out the vibration characteristics in the design and development process of leaf, that is, modal analysis [3]. With the fan product diversification and variety of personalized market demand, the finite element analysis theory and method has been gradually used in the structural design of wind turbine and wind power blades [4-5] .This paper takes 100kW fan blade as the object of study, using the finite element analysis software ANSYS to study the inherent frequency and vibration analysis of blade type. Below on the 100kW 3D modeling and modal analysis of horizontal axis wind turbine blade are introduced.

2. Three dimensional modeling of wind turbine blades

The wind power generator is generally made of blades, hub, gearbox, generator, engine room, tower, yaw system, restricting and safety mechanism and the energy storage device component. While the blade design and manufacturing is crucial, section of wind turbine blade shape is more complex, the section of the blade shape is different in different position, cross section and plane of projection angle is different, so it is difficult to use 2D graphics visual expression of spatial shape of blade. With the popularization and application of various modeling software, 3D modeling of the wind turbine blade become the research emphases of analysis of wind turbine blade [6] [7] [8]. Wind turbine blade modeling process as shown in figure 1.

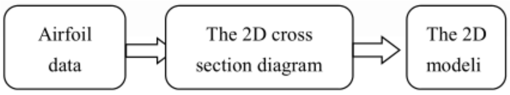


Fig.1: Wind turbine blade modeling process

In this paper, according to the NACA 63812-63825 airfoil data, combined with the Wilson design method to calculate the chord length and installation angle, obtain each blade element section data, draw the blade section of the two-dimensional graph, and then coordinate transform point based on the calculated coordinates in 3D coordinates in the blade section, finally 3D modeling of blade by using SolidWorks software, as shown in figure 2. By the relevant selection and calculation of related parameters in this paper, the following 100kW wind turbine, vane number is N=3, coefficient CP=0.4 and utilization of wind energy, the design wind speed U=13m/s, the transmission efficiency η=0.81, air density ρ=1.225kg/m3, blade diameter d= 17.09m.

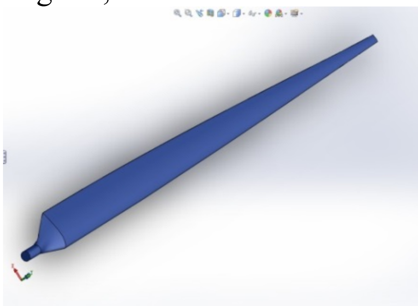
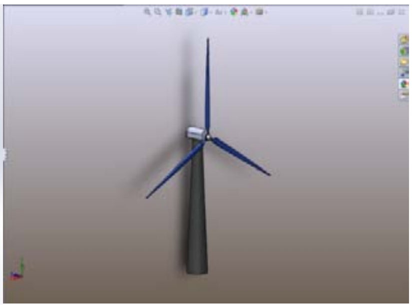



Fig.2: The 3D model of bladeFig.3: The 3D model of wind turbine

3. MODAL ANALYSIS OF WIND TURBINE BLADE

The blade is one of the key components of wind turbine and facing more aerodynamic problems. Blade aerodynamic efficiency is an important factor to be considered in design of the blade and the working safety is more important factor. The power source of the wind wheel is the natural wind which has strong randomness, the blades often run in the stall condition, the dynamic process of the system has strong randomness, the power input transmission system very irregular, main structure parts subjected to fatigue loads several times higher than usual in rotating machinery, the formation of dynamic characteristics of wind turbine characteristic. The structure and strength of the blades plays an important role in the reliability of wind turbine. With the advent of large wind turbine power, the theory and method of finite element numerical analysis has been applied to the structure design of a wind turbine [9][10]. Modern wind turbine blade shape and internal structure is complex, it is necessary to study more accurate analysis method of the calculation model and the blade structure dynamics. Wind turbine blade as an elastic structure, load on it having AC variable and random, thus occurring vibration is inevitable, it is necessary to research the vibration characteristics. Using finite element analysis software ANSYS, the effects of 100kW wind turbine blade vibration characteristics and single blade modal analysis, and its ultimate aim is to analysis the vibration characteristics of recognition system, diagnosis and forecast the vibration fault, provide the basis for the optimization design of structural dynamic characteristics.

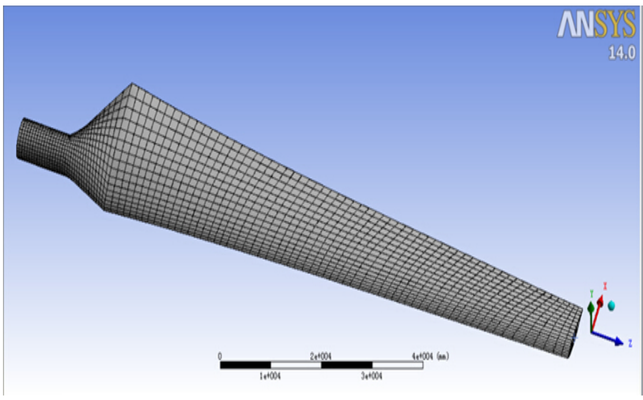


Fig.4: Leaf blade finite element mesh

3.1 Establishment of finite element model of the blade

As the blade shape complex and irregular, using of pretreatment of the ANSYS 3D model directly to generate the geometry can be difficult, so the establishment of the first leaf SolidWorks. After imported into ANSYS, According to its shape and the blades of glass steel material characteristics, the use of ANSYS MESHING function, and then divide the finite element grid respectively in the span wise direction, radial and tangential three directions, generation of 100kW blade grid as shown in figure 4.

3.2 Basic theory of blade modal analysis

In under the action of external force, the differential equations of motion of the blade is [11-12]

$[M]\{\ddot{u}\}+[C]\{\dot{u}\}+[K]\{u\}=\{F(t)\}$(1)

Where,[M],[C],[K] are quality, damping, stiffness matrix of the system;$\{u\}$,$\{\dot{u}\}$,$\{\ddot{u}\}$are displacement, velocity, acceleration matrix; {F (t)} is external matrix.

Assume that the fan blade is free vibration and vibration damping is ignored, for without external excitation and damping, the expression is

$[M]\{\ddot{u}\}+[C]\{\dot{u}\}+[K]\{u\}=0$ (2)

As the free vibration of any elastic body are composed of a series of simple harmonic vibration superposition and type (2), then the solution is simple harmonic vibration

$\{u\}=\{\phi\}_i \cos \omega_i t$ (3)

Where, $\{\phi\}_i$is a feature vector of structure mode in the I order natural frequency; $\omega_i$for the I order natural frequency value; t is the time.

The formula (3) into type (2)

$(-\omega_i[M]+[K])\{\phi\}_i=\{0\}$ (4)

Type (4) of the equivalent results is $|-\omega_i[M]+[K]|=0$ or$|\{\phi\}_i|=0$, Because of the absence of the significance of this research, so the result of type (4) is

$|-\omega_i[M]+[K]|=0, i=1, 2\ldots$(5)

Thus obtain the n natural frequency, That is,$\omega_1, \omega_2, \ldots, \omega_n$.$\omega_i$ Is generalized eigenvalue, By Rayleigh commercial law can be calculated, the following natural frequency.

$f_i=\omega_i/2\pi$ (6)

Where,f_i is I order natural frequency.ω_iSubstituted in equation (4), the solution is$\{\phi\}_i$, it is the modal.

3.3 The constraint conditions and the modal equation

Complete the meshing in ANSYS and then choose the constraint conditions. The blade root restriction, usually reaches the supporting incomplete constrained in part by a transition surface, in a single blade in the process of the calculation can be simplified as a whole root section for complete restraint. The generalized eigenvalue problem, there are 7 kinds of solution module in ANSYS, as the LANCZOS method is the most effective method at present to solve large eigenvalue problems, so this paper chooses BLOCK LANCZOS method for solving .

3.4 Modal analysis results of wind turbine blade

Open the structure static analysis in ANSYS and create pre-stress modal analysis project, post processing for the results: setting mode shapes from one-order to six-order. Solve and display the solving result. As shown in figure 5.

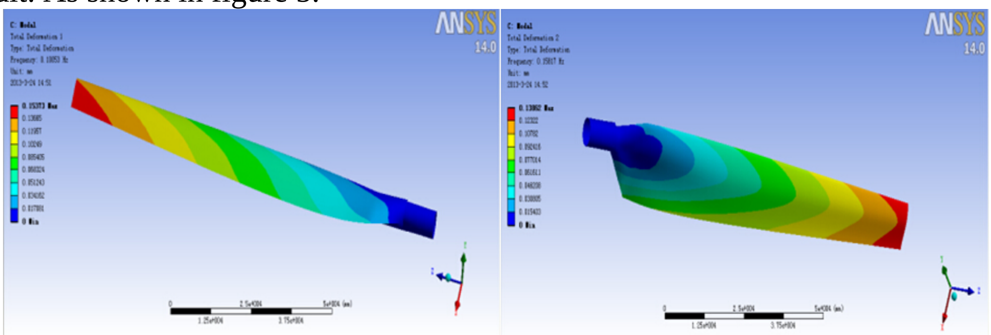
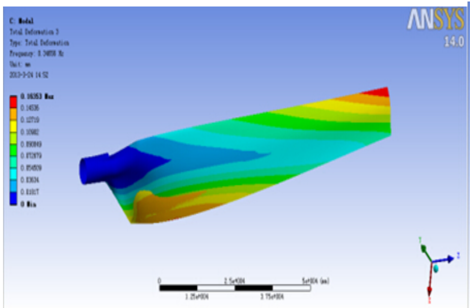


Fig.5 (a): first order mode vibration modelFig.5 (b): two order mode vibration model



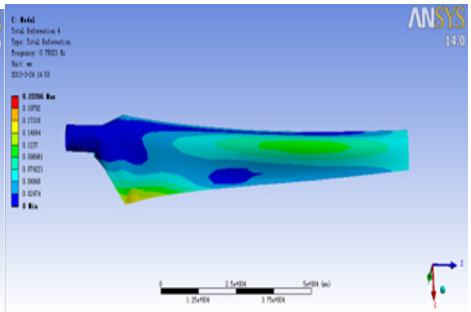
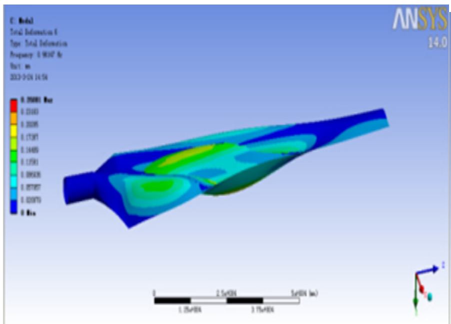


Fig.5(c): three order mode vibration modelFig.5 (d): four order mode vibration model



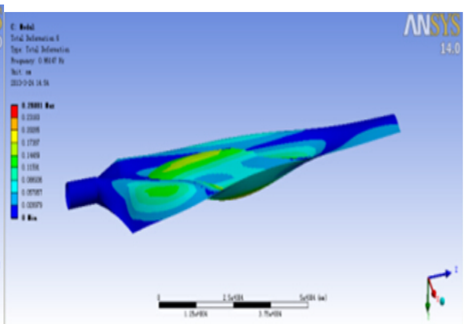


Fig.5 (e): five order mode vibration modelFigure.5 (f): six order mode vibration model

For more than one to six order modal shape, it can be seen natural frequencies for the first order, blades display bending vibration, namely the waving vibration, also in the second order natural frequency is also dominated by waving vibration; in the third order natural frequency of blade vibration mainly for the flap and lag coupling vibration; fifth natural vibration type was manifested mainly in the torsional vibration around the blade axis based with waving vibration; sixth order for the performance of coupled vibration flap and torsion; therefore, according to the theory of vibration, the vibration process of energy is mainly concentrated in the first, two order, therefore, brandished vibration is the main vibration of fan blade. It provides technical reference for the optimization design of the blade.

4. Conclusions

From analysis of the simulation above, the following conclusions can be drawn.

(1) The 100kW wind turbine work at a rated speed and run stable and no resonance occurs; the maximum stress of leaf blade is less than the material allowable stress, so it meet the design requirements;

(2) Natural frequency of the blades as speed increases. In the actual operation of the process, when the rotational speed is adjusted, it is necessary to fully consider the influence of natural frequency and avoid resonance;

(3) Natural frequency of single blade has large difference between natural frequencies of wind wheel in the rated speed. Therefore, it cannot be substituted by natural frequency of single blade in the calculation of the natural frequency of wind wheel.

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