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Mode Analysis of Horizontal Axis Wind Turbine Blades

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Abstract

This paper presents a recently developed the finite model method for analysis of horizontal axis wind turbine blades. Free vibration equation is proposed based on theory of the classical lamination and Lagrange method. A 40 m rotor blade was chosen as a example study to validate the static and dynamic behaviour predicted by shell model built in ANSYS,Given uncertainty of material properties involved, an accurate agreement was found for static deformation curves, as well as a good prediction of the lowest frequency modes in terms of resonance frequencies, the highest (eighth) frequency modes show only a fair agreement as expected for an FE model, Flap-wise, edge-wise and torsional natural frequencies of a variable length blade have been investigated. The results show that the approach used in this study is very efficient and produces improved designs as compared with a reference or baseline design.

Keywords: *wind turbine blade, finite element method, composite layer, natural frequencies*

1. Introduction

With the energy crisis and environmental problems intensifying,the wind power generation technology has become a subject of considerable interest. Blades are the main components that differentiate wind turbines from other machinery, increasing with the length of the blade. Vibration is important in wind turbines because of partially elastic structures,which they operate in an unsteady environment that tends to result in a vibrating response [1-2]. Blades should be designed to avoid the resonance region of the tower and other components. Modal analysis was carried out to check whether the mechanical properties of the blade meet certain safety requirements. Which is used to identify natural frequencies, especially low-order frequencies and vibration modes of wind turbine blades. From the modal we can learn in which frequency range the blade will be more sensitive to vibrate. Blades should be designed to avoid the resonance region with the tower and other components in order to prevent some destruction of related components. Wind turbine blade layer directly affects the reliability and life of the whole wind turbine. Hence, a good wind turbine design is to minimize vibrations by avoiding resonance [3-4]. Study the dynamic characteristics of the structure vibration. Dynamic design has the very vital significance. However, It is very difficult to calculate the strength of blade and stiffness with simple calculation accurately because of designability, high strength, corrosion resistance and composite layers.

In this paper, Classic laminated plate theory and the structural design of the composite material theory are used to study on the leaf layer affection on the structural dynamics performance of wind turbine blade.Modal analysis is used to identify natural frequencies, especially low-order frequencies a vibration modes of wind turbine blades. On the mode shapes, we can get in which frequency ranges the blade will be more sensitive to vibrate. Wind turbine blade natural frequency is far away from the requirement of vibration frequency, the frequency can be adjusted by structural adjustment, through changing natural frequencies, which is away from the excitation frequency, random load will lead to vibration. Which is mainly bending vibration, the structural dynamic characteristics of wind turbine blades design has become a research focus. Modal, From the modal shapes, we can obtain in which frequency range the blade will be more sensitive to vibrate.It is effective method for structural optimization design of blade.

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2. FEM Model of Wind Turbine Blade

Wind turbine blades are mainly manufactured using multilayer laminate composites, each lamina having arbitrary thickness, elastic properties and fibre orientation. Blade parameters show in Table 1. In order to an accurate simulation of structural dynamic performance [5-6]. It is necessary to establish the FEM model of wind turbine blade, parametric FE model show Figure 1.

Table 1. Blade Parameters

Rated power (kW)	1500
maximum chord length (m)	40
maximum Chord (m)	3.046
Hub height (m)	65
maximum torque (deg)	13.48°

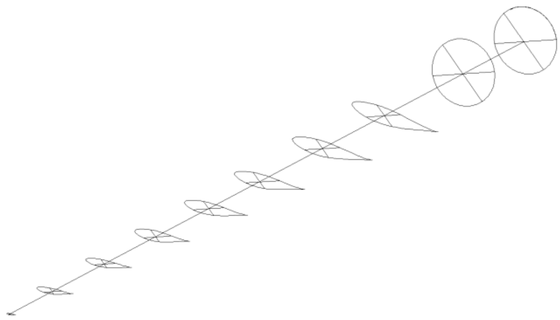


Figure 1. Parametric FE Model

Blades layer affect the structural dynamic properties Beam cap is main load-carrying part which could bear more bending load and the tension. The shell unit Shell 99 was chosen to simulate the composite layer structure of the blade surface. Some real constants were created to define the materials, angle and thickness of the blade and material properties were approximately defined as orthotropic, the layer direction can change, layer angle are 0°, 45° or 90°, Matlab is used to calculate the layer thickness, the section is divided into three blocks, front, main beam, trailing edge.Which are independent of each other, Free Mesh was set. The created FEM model of the blade consisted of 1634 elements and 3715 nodes. Wind turbine blade mainly subjected to aerodynamic load and centrifugal load, aerodynamic loads of wind turbine blade under bending and torsion, gravity centrifugal force makes the blade under tension. The blade structure design, which is simplified as the cantilever beam fixed root, under gravity, centrifugal force and aerodynamic load caused by the tensile, bending and torsion joint action. Layer main parameters are shown in Table 2.

Table 2. Layer Main Parameters

Material name	Elastic Modulus (Gpa)	Allowable stress (Mpa)	Density(kg/m^3)	Poisson's ratio
unidirectional cloth	38	250	1900	0.3
bidirectional cloth	13.9	60	1900	0.3
Sandwich layer	3.5	1.5	125	0.3

2. Natural Vibration Analysis

It is assumed here that finite element unit is elastomer which is under small deformation, The free natural vibration characteristics are obtained by suppressing all of the forcing functions [7-8]. Vibration equation is educed based on standard displacement and Lagrangian method, which can be written as follows:

$$[M]\{\ddot{q}\}+[C]\{\dot{q}\}+[k]\{q\}=\{F\} \quad (1)$$

Where [M]and[K] are the element's mass and stiffness matrices, [C] is a hysteretic damping matrix, $\{F\}$ is a vector of nodal forces. $\{\ddot{q}\}$, $\{\dot{q}\}$ and $\{q\}$ are accelerations, velocities and nodal displacement, respectively. These matrices and vectors are expressed as:

$$[K]=\begin{bmatrix} K_{11} & K_{12} & K_{13} & K_{14} \\ & K_{22} & K_{23} & K_{24} \\ & & K_{33} & K_{34} \\ sym. & & & K_{44} \end{bmatrix} \quad [M]=\begin{bmatrix} M_{11} & M_{12} & M_{13} & M_{14} \\ & M_{22} & M_{23} & M_{24} \\ & & M_{33} & M_{34} \\ sym. & & & M_{44} \end{bmatrix} \tag{2}$$

In the practical engineering, owing to the damping on the structural natural vibration frequency and vibration mode have little effect, when we discuss the structure of the inherent characteristic neglected damping effect. if $\{F\}$=0, the blade is in the status of free vibration. Thus, the damping effect is usually neglected and eigenvalues which can be expressed as:

$$-\varpi^2[M]\{\phi\}\sin(\varpi t+\theta)+[K]\{\phi\}\sin(\varpi t+\theta)=\{0\} \tag{3}$$

Where $q=\{\phi\}\sin(\varpi t+\theta)$ .After substituting for q from Equation (1) and considering the following geometric relations can be get as:

$$([K]-\varpi_t^{\,2}[M])\{\phi_i\}=0 \tag{4}$$

Where parameters $\{\phi_i\}$ and ϖ_t represent the first order mode vector the first order modal of the natural frequency respectively. The connection between wind turbine blade and the wheel hub can be considered permanent connection. That means that the degrees of freedom of blade root node is constraint, as well as means the root node and angle are zero. Equation (3) in the above constraint conditions, with using simulation wave-front subspace iteration method, we can obtain the eighth order natural frequency and vibration mode.

3. Modal Analysis of the Blade

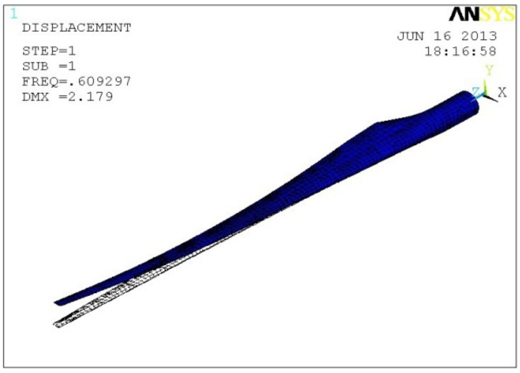
Dynamic finite element analysis of the blade mainly refers to the vibration modal analysis using the finite element theory [9]. Model 1 was based on ANSYS 3D Shell99, which widely used in the industry for design purposes. This type of element allows defining an arbitrary number of layers in a single unit, each layer having specific material properties, fibre orientation and thickness, Modal 1, was discretited in 3442 elements and 8534 DOF, with the hypothesis in terms of rigid connections of blades and hub could, So it is only need to restrict all DOFs of the blade root, the frequency range is of 0~999Hz. Finally, The eight vibration modes and frequencies of blades can be obtained by post processor.

Table 3. Frequencies of the First Eight Orders

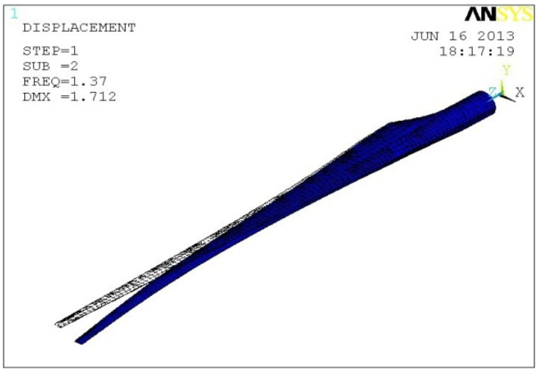
Mode	1	2	3	4	5	6	7	8
Freq.HZ	0.61	1.37	1.85	3.71	4.02	6.38	8.7	9.7
rpm 20	0.68	1.42	1.91	3.81	4.23	6.48	8.92	9.91

In the designed condition with rated wind speed V=10.4m/s, the blade tip speed is 78 m/s, the exciting frequency of the rotating rotor with three blades shall be calculated as 7.45Hz. As can be seen from Table 3, the first natural frequency is far away from exterior exciting frequency. So no resonance will happen when blades run at rated wind speed.

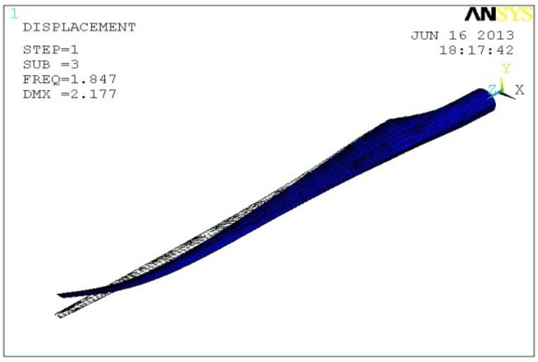
Based on Figure 2(a-h), we can also make a few observations about the blade to blade variation in the modle parameters, the natural frequency of first flap-wise is of concern for this modal. The range between 0.5 Hz and 10 Hz is of relevance to wind turbine blades. Although the first eight natural frequencies have been obtained. Higher flap-wise natural frequencies, Natural frequencies of edge-wise and torsional are out of range. The first mode may coincide with the excitation frequencies, therefore during operation this range of frequencies should be avoided for the model proposed (See Table 3).



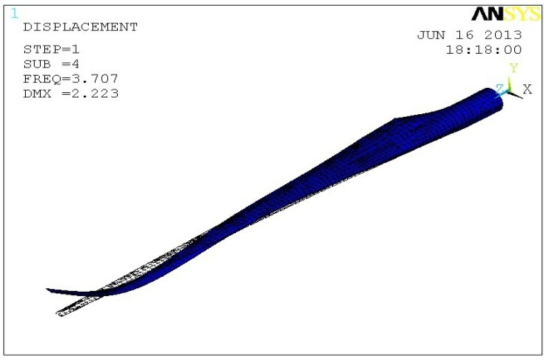
(a) Mode 1



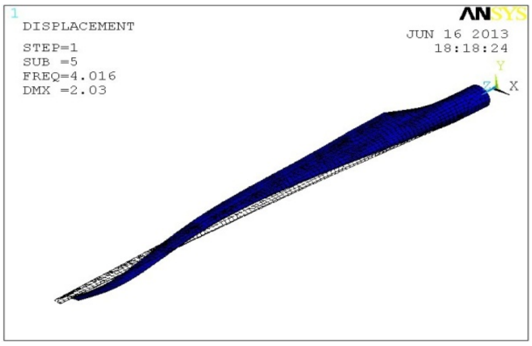
(b) Mode 2



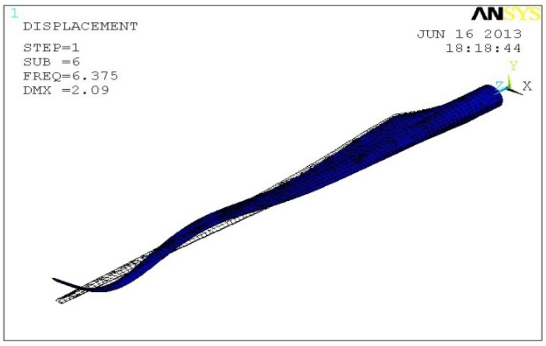
(c) Mode 3



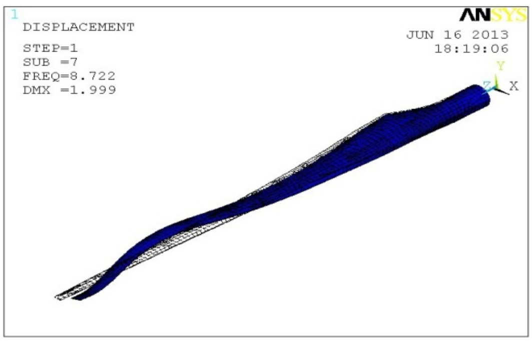
(d) Mode 4



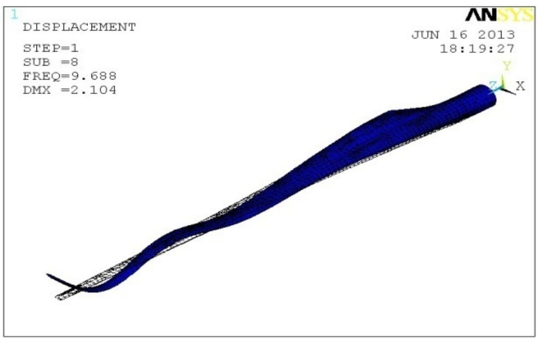
(e) Mode 5



(f) Mode 6



(g) Mode 7



(h) Mode 8

Figure 2. The First Eighth Mode Shapes

4.Conclusion

An analysis for the free vibration of composite blade is developed. Flap-wise, edge-wise and torsional natural frequencies of a variable length blade have been identified. Therefore designers can ensure that natural frequencies will not be close to the frequency of the main excitation forces in order to avoid resonance.It concluded that vibration and swing vibration frequency is low, the torsional frequency high vibration, torsional vibration of the impact is not great. Modal frequency of wind turbine blade at rated speed is higher than the natural frequency is static, because dynamic stiffness may lead to modal frequencies increase.

Acknowledgement

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