FINITE ELEMENT ANALYSIS OF COMPOSITE WIND TURBINE BLADE

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Abstract : The wind turbine blade is becoming more and more important. Modelling and stress analysis of the wind turbine blade are very critical for the further design and the application of wind turbine blade. The small-scale wind turbine blade was focused on, considering the glass fibre reinforced plastic material. Based on the parameters of airfoil and the geometrical parameters of the blade, the three-dimension(3D) model of the blade was established with the modelling software solidworks. Then the model has been exported to ANSYS workbench 19.1 software to carry out the FEM analysis. In this project the objective is to find the maximum Stress, Modal analysis and Dynamic analysis is carried out on the modelled wind turbine blade comparing the results to experimental results.

***IndexTerms* - Wind turbine blade, Stress analysis, Modal analysis, Dynamic analysis, GFRP, Airfoil, Solidworks, Workbench 19.1.**

I. INTRODUCTION

As a clean, non-polluting, renewable green energy, wind energy is the most promising energy for large-scale development and engineering utilization, and it is also one of the most competitive scale energy [1] . Wind turbine blade is the key part of the capturing of wind energy, which is one of the key components of wind turbine, and accounts for about 20% of the cost of the whole wind turbine. The design quality of the blades has a direct impact on the performance and life of the wind turbine and the components [2]. With the development of wind power generation, wind turbines become larger and larger, it aims to seek the blades with large, lightweight and long life. Therefore, the blade shape, structural design and analysis are particularly important for wind turbine. As a typical aerodynamic component, the blade suffers not only from the mechanical vibration but also from the aerodynamic while rotating. So during the application and design of wind turbines, analysis of the performances of the blade strength, rigidity and service life are very important. Modeling and FEM analysis from engineering software are a kind of effective means to improve the performance of the wind turbine blades.

Wu et al. developed a GUI interface to construct the blade model for the stress analysis using ANSYS, and proposed a simple iterative method to design the structure of the composite blade based on the numerical stress analysis of the turbine blade [3]. Song et al. referred to the actual layer structure, proposed a modeling method of combining SolidWorks with ANSYS, and then performed the dynamic analysis for the blade by using the finite element method [4] Liu et al. used model and harmonic analysis of FEM, studied the vibration characteristics and the characteristics of the harmonic response under different phases of the circumferential and axial forces [5]. Bayoumy et al. derived a continuum based three dimensional finite element model of an elastic wind turbine blade using the absolute nodal coordinates formulation [6]. Nitin et al. used finite element method to analyze the root segment and transition segment of the designed blade, then the result obtained from ANSYS was compared with the experimental work [7]. Zhang et al. used finite element method based on composite laminate theory, through analyzing their stress and strain; the optimal lay-up schema was confirmed [8].Turaj et al. used a finite element model to find out the design drivers for large scale wind turbine blades, and proposed some design guide lines [9]. Zheng et al. analyzed the dynamic response of a flexible wind turbine blade by FEM methods [10] and carried out the modal analysis of horizontal axis wind turbine blades [11].

There is stress analysis for the wind turbine blades, and stress analysis of the blade is very important for the strength and design of the wind turbine blade. In this paper, the FEM method will be used to analyze the stress of the wind turbine blade, based on the three-dimension modeling of wind turbine blade, which can serve for the design of wind turbine blade. And the outlines are arranged as: structural parameters of the wind turbine blade, three-dimension modeling of wind turbine blade, finite element analysis by ANSYS and conclusion in the end.

II. STRUCTURAL PARAMETERS OF THE WIND TURBINE BLADE

The wind speed range is decided between 2m/s - 6m/s, which can meet the needs of the areas of different wind. Therefore, the annual average wind speed was determined as 4.2m/s. The blade was firstly divided into nine sections along the spanwise direction from the tip to the root of the airfoil. There are ten cross-sections in all and each section is 0.125m long. Then the WiLson design method was used to calculate the chord length C and twist angle ‘θ’ of every blade elements.

The geometric parameters of blade were shown in Table 1 [12]:

Table 1. The Distribution of Geometry Parameters of Blade

No.	Position of cross section (r/R)	Chord length C (mm)	Twist Angle θ/(°)
1	1	58.5	0.31
2	0.9	64.7	0.99
3	0.8	72.22	1.85
4	0.7	81.84	2.93
5	0.6	94.26	4.34
6	0.5	110.6	6.29
7	0.4	132.8	9.09
8	0.3	163.9	13.36
9	0.2	203.4	20.53
10	0.1	218.97	33.34

The airfoil of NACA0012 was applied to facilitate the modeling and analysis of the blade. This airfoil structure is relative simpler, the maximum relative thickness and the maximum camber relative position are both 0, and the maximum relative thickness is 12%.

III. THREE-DIMENSION MODELING OF WIND TURBINE BLADE

A. Modeling Parameters:

NACA0012 blade airfoil was applied here, whose airfoil data was left out here. Then the airfoil data (x0, y0) of NACA0012 was transformed into the coordinates (x1, y1) whose origin is the aerodynamic center.

Then, considering the blade length, combined with the chord length and twist angle (Table 1), the actual coordinates were calculated to obtain the coordinate values of every blade element of the blade according to Equation (1).

Where: x,y,z are the three dimension coordinates of the blade element, l is the chord length, θ is the twist angle, r local radius of the blade x_1, y_1, z_1 is the coordinates of wind airfoil whose origin is the aerodynamic center.

$$x = l * \sqrt{(x_1^2 + y_1^2)} * \cos\left(arctan\frac{y_1}{x_1} + \theta\right)$$

$$y = l * \sqrt{(x_1^2 + y_1^2)} * \sin\left(arctan\frac{y_1}{x_1} + \theta\right) \qquad (1)$$

$$z = r$$

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B. 3D Modeling of Blade

On the basis of the three-dimensional coordinates of each blade element determined before, the profile curve of the blade element can be drawn as Figure 1 using the 3D design software.The CAD software SOLID WORKS is selected to prepare the solid model of the NACA0012 wind turbine blade. The CAD model is shown as figure 1. The blade geometry is similar about the axis of blade. In general a turbine assembly consist of three blades identical in design parameters and manufacturing. Blades are fixed in a turbine hub subjected to various loading conditions according to speed. Loading condition is shown in the figure 3.

Figure 2 shows the profile curves of blade elements along the spanwise direction, it can be seen that the chords of each blade element changes along the spanwise direction.

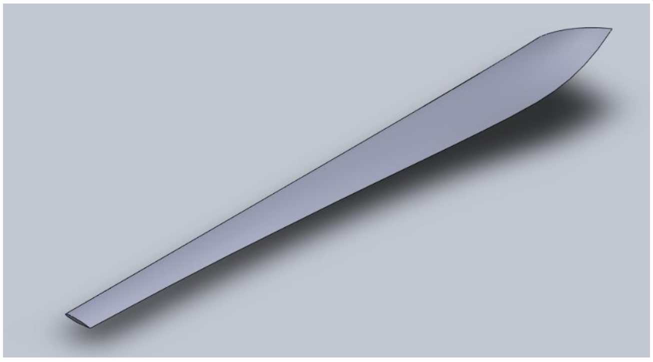

Figure.1The 3D CAD Model of the wind turbine Blade

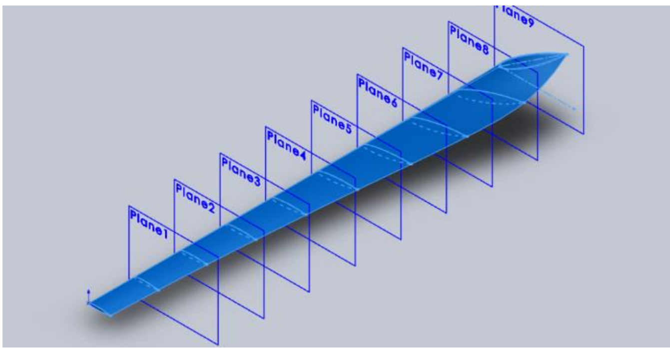

Figure.2 The Profile Curve of Blade Elements along the Direction Spanwise

IV. FINITE ELEMENT ANALYSIS BY ANSYS

4.1.Finite Element Modeling and Meshing of the Blade

(1) Import the finite element model

In order to facilitate the analysis of ANSYS, the 3D model of wind turbine blade should be saved in the form, such as: IGS format, which can be imported into the ANSYS software [13].

(2) Define the material parameters

Material used for the blade in the paper is glass fiber reinforced plastics, whose material parameters were shown in Table 2.

Table 2. Material Parameters of Glass Fiber Reinforced Plastics

Density(kg/m^3)	Poisson's ratio	Tensile modulus of elasticity (GP)	Modulus of elasticity of vertical and horizontal shear(GP)
1690	0.17	1.76	2.08

(3) Define the type of analysis and boundary conditions

The structural analysis was chosen, one end is fixed and pressure is applied on the upper surface of the blade is shown in figure 4

(4) Meshing

The grid can be automatically divided, and the model after meshing was shown in figure 4.

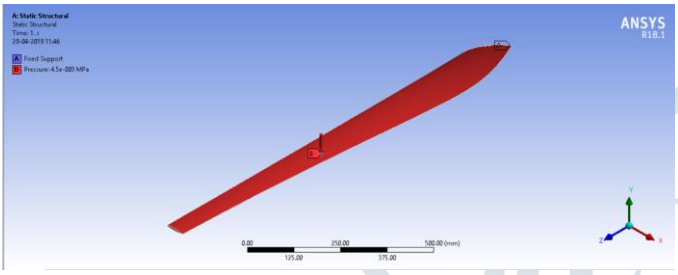

Figure.3 Boundary condition

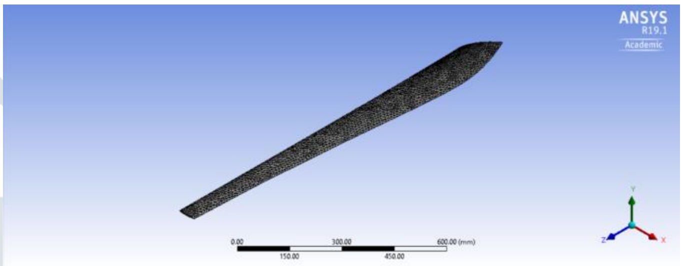

Figure.4 Meshed model

4.2. Apply Loads

The blade bears the gravity, centrifugal force and aerodynamic force while it is working. As gravity and centrifugal force is small, they can be ignored during analysis. The wind loads on wind turbine can be decomposed into a normal force which is perpendicular to the plane of wind. turbine, and a tangential force which acts on the plane of the wind wheel. Due to the flat section of the blade, the impact of tangential force on the bending and strength of blade is small, it can also be neglected. So among the loads of the wind turbine, only the normal force of wind load should be considered, which was given by Equation (2).

$$P = \frac{1}{2}\rho v^2 \tag{2}$$

Where : ρ is the air density (ρ=1.29kg/m^3), v is normal wind speed (v=4.7m/s)

4.3. Solution to the Mises stress

The static structural analysis is done by using ANSYS 19.1 workbench. The one end of wind turbine blade is supported by the hub that is fixed end and another end is free in air. In this study the hub end is provided a constant angular velocity of 4 m/sec and different values of deformations and stresses are calculated.

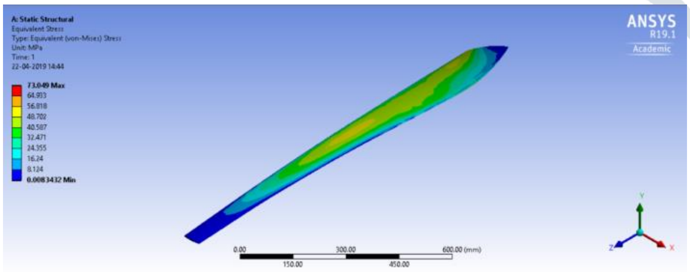

Figure.5 The Von mises Stress Distribution of the Blade

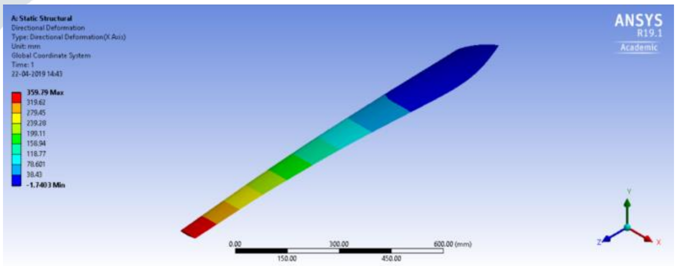

Figure.6 The Distribution of Displacement of the Blade along the X Axis Direction

The stress distribution of blade under the wind load was obtained through the ANSYS. Figure 5 shows the distribution diagram of Mises stress of the blade. The picture illustrates that there is a stress concentration near the central of the blade. Obviously, the middle of the blade is the most easily damaged place when it is working under the aerodynamic loads, the second is the root of the blade. The maximum stress appears in the central position of the blade, about 73.049MPa. This value is lower than 325MPa ,which is the tensile strength of the glass fiber reinforced plastic materials.

Figure 6 shows the distribution of displacement of the blade that is 359.79mm. Along the X axis direction, the displacement of the tip is relatively large. In addition, the X axis is the normal direction of blade, and the normal is the most dangerous in the direction of the displacement of the blade. From Figure 7 and Figure 8 it can be seen, the maximal displacement of the blade tip is 0.36m, which is in a safe range.

4.4. Modal Analysis

ANSYS 19.1 workbench is selected for modal analysis. The first 06 order vibration mode of wind turbine blade is shown in figure 7 to figure12 and shown in the table 4.

Table 3 Eigen frequency for 9m blade of length

No of modes	Frequency in Hz
1	4.20
2	9.57
3	18.29
4	29.77
5	43.66

Table.4 Eigen frequency and deformation for 12.5m blade of length

No of Modes	Frequency in Hz	Deformation in mm
1	3.901	109.51
2	12.778	106.51
3	20.8	105.33
4	34.806	116.19
5	54.296	107.52
6	71.68	136.44

The experimental work is done on 9m blade and obtained different frequencies as shown in the table 3[14] and those frequencies are compared with the blade length of 12.5m as shown in the table 4 Compared frequency values gives good result.

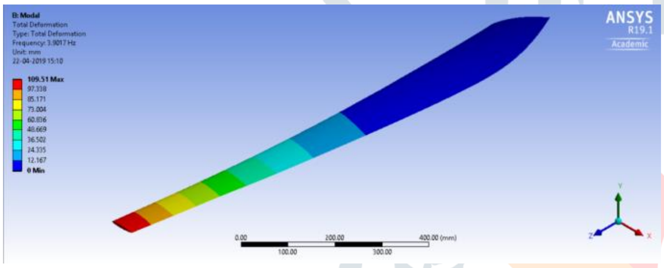

Figure.7 Mode-1

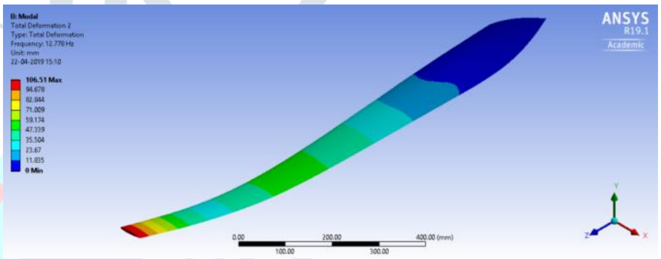

Figure.8 Mode-2

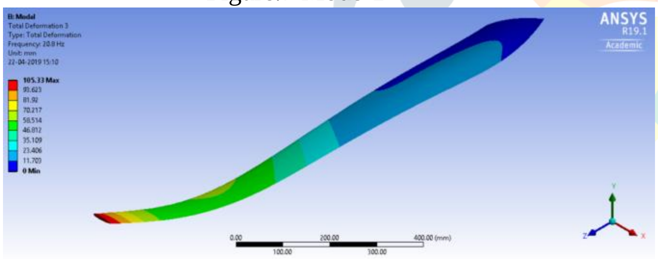

Figure.9 Mode-3

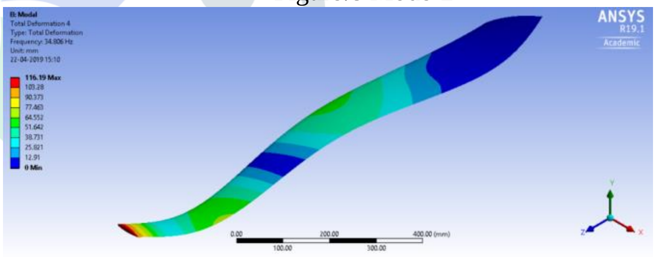

Figure.10 Mode-4

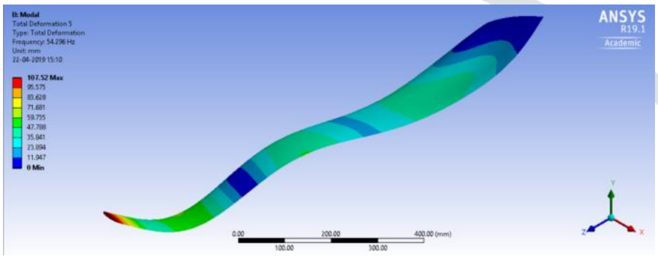

Figure.11 Mode-5

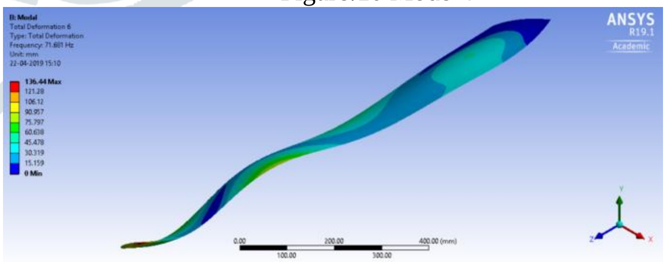

Figure.12 Mode-6

Composite NACA0012 wind turbine blade is subjected to forced vibration conditions. There are two motion supported boundary conditions for which simulations are performed. In free-free boundary conditions all DOF of boundaries are subjected to variations. In the displacements of boundaries are set to automatic under the materials conditions, fixed boundary conditions guarantee that all degrees of freedom are constrained in boundaries. The FEM based software ANSYS.19.1version solved the NACA0012 wind turbine blade modal analysis and we find the natural frequency and mode shapes.

4.5. Explicit Dynamic Analysis

Table.5 Total maximum deformation and maximum stress

No of cycles	Total maximum deformation in mm	Maximum stress in Mpa
10000	0.2519	0.7009
$1e^5$	1.1086	1.1944
$5e^5$	2579	1.33

Explicit dynamic used to know the structural behavior under cyclic conditions. The pressure is kept constant of 0.0045Mpa for different cycles from 10000 cycles to $5e^5$ cycles. Total maximum deformation and maximum stress is shown in the figure 13 to figure 14

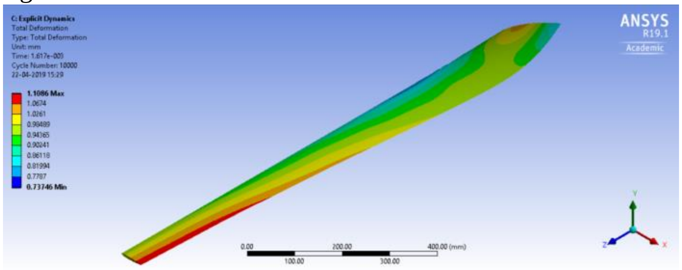

Figure.13 Total maximum deformation for 10000 cycles

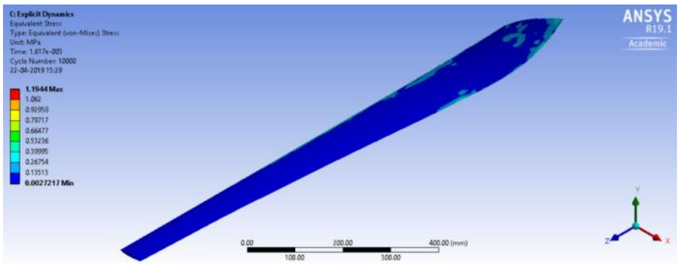

Figure.14 Maximum stress for 10000 cycles

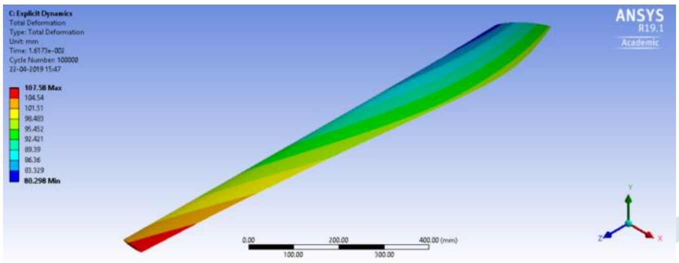

Figure.13 Total maximum deformation for $1e^5$ cycles

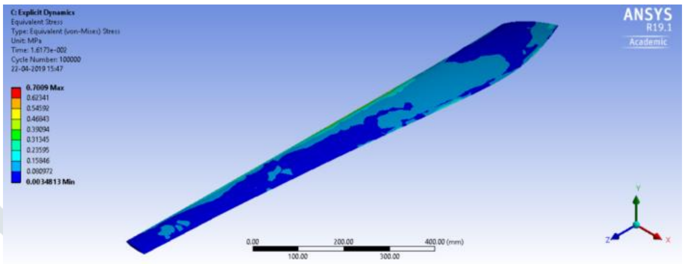

Figure.14 Maximum stress for $1e^5$ cycles

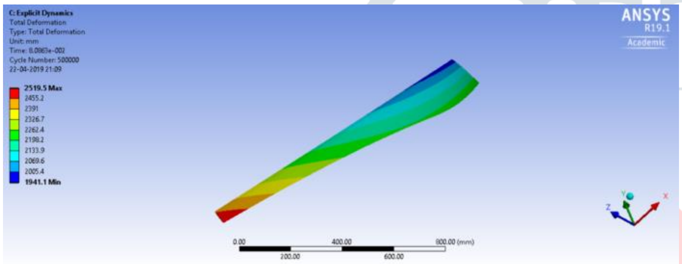

Figure.13 Total maximum deformation for $5e^5$ cycles

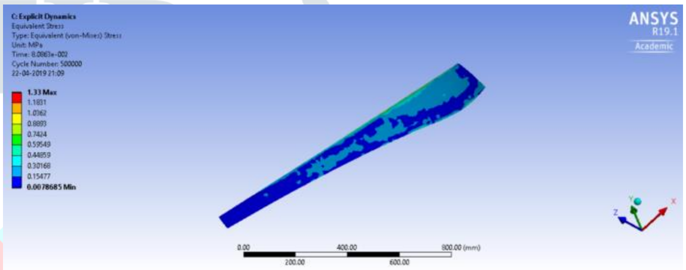

Figure.14 Maximum stress for $5e^5$ cycles

V. CONCLUSION

The NACA0012 airfoil data was applied to create the three-dimension(3D) model of the wind turbine blade. Then the finite element model of the blade was established for the further FEM analysis of the wind turbine blade. By solving the compressive stress, it can be seen that the biggest stress occurs in the center of the blade, but the maximum stress is less than the tensile strength of the glass fiber reinforced plastic(GFRP). According to the displacement solution of blade, the maximal displacement occurs in the blade tip while working, but it is less than the safety displacement of wind turbine allows. The present investigation has demonstrated that essential dynamic properties of wind turbine blades, like natural frequencies and mode shapes, can be theoretically determined by use of the modal analysis technique. Total maximum deformation and maximum stress has been determined for 10000 cycles, $1e^5$ cycles and $5e^5$ cycles.

VI. ACKNOWLEDGEMENTS

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