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Modal Analysis for Blade of Horizontal Axis Wind Turbine

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ABSTRACT

The blade of a wind turbine is very important component of the rotor. Now days the use of wind turbine generator has rapidly spread as the clean energy recourse and its size is also getting larger. Because of the difficulty of the maintenance of such large wind turbine blade the model analysis becomes important. In this work, the model analysis is done on a blade of length 38.95 m which is designed for V82-1.65MW horizontal axis wind turbine (supplied by Vestas). The airfoil taken for the blade is NACA 63_4-221 which is same from root to tip. For doing this model analysis five shapes of spar are used. This analysis is done on finite element analysis software ANSYS 12.0. This approach gives satisfactory results and can be used for vibration analysis of turbo machinery blades and helicopter rotor blades. Natural frequency is lower in the case single web spar.

Key words: Airfoil, modeling, modal analysis, optimal rotor theory, FEM

INTRODUCTION

The design of a wind turbine blade involves many considerations such as strength, stability, cost and vibration. Reduction in vibration is a very important measure for a successful design of blade structure. It may promote other important design goals, such as low cost and high stability level. A good design attitude for reducing vibration is to divide the natural frequencies of the structure from the harmonics of rotor speed. This would avoid resonance where large amplitudes of vibration could severely damage the structure (Tenguria *et al*., 2011). According to Maalawi and Negm (2002), with the growth of wind energy, the problem of destruction of blade caused by the vibration has attracted widespread attention and concern in the engineering field. Hence the designing and modal analysis of the blade has become a key process.

Pritchard and Adelman (1990) described methods for reducing vibration in helicopter rotor blades by determining the optimal sizes and locations of tuning masses through formal mathematical optimization techniques. He developed an optimization procedure that employs the tuning masses and corresponding locations as design variables that are systematically changed to achieve low values of shear without a large mass penalty. Sabuncu and Thomas (1992) investigated free vibration characteristics of rotating, shrouded, pretwisted aerofoil cross-section blade packets using finite element model. One end of the blade is supposed to be fixed at the periphery of a disk rotating about its centre, whereas the other end of the blade is connected by a curved shroud. He neglected shear deformation and rotary inertia effects and derived the expressions for kinetic and strain energies of a pretwisted blade packet subjected to centrifugal force. Bielawa (1992) has presented a review of several approximate methods such as Myklestad method, Galerkin method, Rayleigh-Ritz method, Finite Element Method (FEM), etc., for modal analysis.

Baumgart (2002) derived a mathematical model for an elastic wind turbine blade which is mounted on a rigid test stand and compared it with experimental results. Despite the few degrees of freedom and uncertainties in the model parameters, the mathematical model approximates the measured blade dynamics. Maalawi and Negm (2002) presented an optimization model for the design of a typical blade structure of horizontal-axis wind turbine. The cross-sectional area, radius of gyration and length of each segment are chosen as optimization variables. The main spar is represented by thin-walled tubular beam composed of uniform segments each of which has different cross-sectional properties and length.

Tenguria *et al.* (2010) generated a computer program for designing a blade for 5 KW horizontal axis wind turbine using blade element momentum theory. He used different tip speed ratio for evaluating the power coefficient. Jain and Mittal (2008) has studied the distribution of stress and deflection in rectangular isotropic, orthotropic and laminated composite plate with central circular hole under transverse static loading using finite element methods. Eker *et al.* (2006) investigated the use of composite material in wind turbine blade for making them more resistant to impact. His study was based on theories of wind technology and material science.

Friedman and Kosmatka (1993) developed the stiffness, mass and consistent force matrices for a simple two-node Timoshenko beam element based upon Hamilton's principle. The presented numerical shows that the current element exactly predicts the displacement of a short beam subjected to complex distributed loadings using only one element and the current element predicts shear, moment resultants and natural frequencies better than existing Timoshenko beam elements. Farghaly (1994) investigated the natural frequencies and the critical buckling load coefficients for multi-span beam systems consisting of elastically supported uniform Timoshenko beams which may be loaded with end as well as intermediate masses. The study of Farghaly and Gadelrab (1995) is concerned with an additional expected gain in natural frequencies for a one-span beam with a stepwise variable cross section made of unidirectional fibre composite materials of different fibre volume fraction. The study of Corn *et al.* (1997) is concerned with the dynamic behaviour of Timoshenko beams. He proposed a new method in a simple and systematic manner for constructing a two-node finite element based on Guyan condensation that leads to the results of classical formulations. Rao and Gupta (2001) have derived the stiffness and mass matrices of a rotating twisted and tapered beam element. He assumed angle of twist, breadth and depth to vary linearly along the length of beam and considered the effects of shear deformation and rotary inertia in deriving the elemental matrices. Kisa (2004) has investigated the effects of cracks on the dynamical characteristics of a cantilever composite beam, made of graphite fiber-reinforced polyamide. The finite element and the component mode synthesis methods are used to model the problem.

Vardar and Unal (2006) emphasized the use of individual wind turbine towards meeting the electricity demands of a plant. He revealed the electrical energy demand of the plant and then he used mathematical equations for checking the selected wind turbine for electricity demand. Xu *et al.* (2006) obtained the loss of power supply probability by simulation, which is the index of power reliability. He found the Pareto-optimal solutions by using the elitist non-dominated sorting GA (NSGA-II) and he validated it by solving the multi-objective problem with tangency method, which also belongs to the constraint method.

Izli *et al.* (2007) used a computer program to find fourteen different Reynold numbers, four different NACA profiles and lifting and drifting coefficients. He calculated appropriate sliding rates of wind turbine blade profile for each angle of attack by those values. Hsu (2007) has formulated the dynamic problem of the wind turbine generators by employing the differential quadrature method. He used the Euler-Bernoulli beam model to characterize wind turbine generator blade. The study of Kallesoe (2007) extends partial differential equations of blade motion, by including the effects of gravity, pitch action and varying rotor speed. He also derived equations for describing the pitch action and rotor speeds. Bana Sharifian *et al.* (2008) studied maximum power control of wind turbine and induction generator which are connected with two back to back voltage source converters to grid. Wang *et al.* (2008) developed a mathematical model using both beam finite element and thin-walled structure theory to predict the natural frequency and blade behaviour of a horizontal axis wind turbine under constant wind speed and turbulence condition.

Babainejad and Keypour (2010) have developed a model of the variable speed wind turbine with doubly fed induction generator as a compact block in the simulation tool i.e., MATLAB/SIMULINK. The parameters which he has been considered are rotor resistance, stator resistance, leakage stator, rotor inductance and mutual inductance. Vertical axis wind turbine is also attracting many researchers. Beri and Yao (2011) showed the effect of camber airfoil on self starting of vertical axis wind turbine at low Reynolds number. He used moving mesh technique to investigate two dimensional unsteady flows around turbine.

In the present study first of all, a computer program is developed on the basis of Glauert's optimal rotor theory for getting the dimensions of 38.95m wind turbine blade. After this model analysis of blade is done with the help of ANSYS 12.0 using different shape of spars. E-Glass/Epoxy pre-preg material is chosen as material and the properties are taken from the work of Brondsted *et al.* (2005). The objective of this study is getting natural frequency of wind turbine blade with different shapes of spar.

COMPUTATIONAL METHODS

The Finite Element Method (FEM) is very useful and has traditionally been used in the development of wind turbine blades for investigating the global behavior in terms of Eigen frequencies, tip deflections and global stress/strain levels, respectively. The FE-simulation usually predicts the global stiffness and stresses with a high-quality accuracy. Local deformations and stresses are often more difficult to predict and little work has been published in this area. The reason is that the highly localized deformations and stresses can be non-linear, while the global response appears linear for relatively small deflections. Another reason is that a relatively simple shell model can be used for representing the global behavior, while a computationally more expensive 3D-solid model may be necessary to predict this localized behavior. Even with a highly detailed 3D solid model it would rarely be possible to predict deformations or stresses accurately without calibration of the FE-model. This calibration is required due to large manufacturing tolerances. Features such as box girder corners and adhesive joints often vary from specifications. Geometric imperfections are often seen and can cause unexpected behavior, especially relating to the strength predictions but also the local deformations can be affected. A big advantage of using FEM is that, once the model is set up and calibrated, complex load cases representing actual wind conditions can be analyzed. Only idealized loads can be imposed in a full-scale test and in this study the critical flap-wise load case is evaluated. The 8-noded shell 63 element type with 6 degree of freedom has been used with an element thickness provided 30 mm.

TWIST, CHORD AND THICKNESS DISTRIBUTION

The twist of a wind turbine blade is defined in terms of the chord line. It is a synonym for the pitch angle. However, the twist defines the pitch settings at each station along the blade according to the local flow conditions. The pitch angle (β) is large near the root (where local speeds are low) and small at the tip (where local speeds are high). The wind angle varies along the blade due to the increase in blade speed with increase in radial distance. Hence to maintain optimum angle of attack of the blade section to the wind, it must be twisted along its length. According to Hau (2006), the twist distribution is maintained such that the lift coefficient will be maximum at every station Fig. 2 is showing the twist distribution of the designed blade which is varying exponentionally from root to tip. The maximum value of twist is at root (38.12°) and the minimum value occurs at tip (-3.6°). Chord direction is perpendicular to the span direction and lies in the plane extending through the leading edge and the trailing edge. The behavior of the curves for chord and thickness distribution is same both are increasing from root to shoulder than reducing exponentionally. The maximum value of the chord at the shoulder is 6.24 m and at the tip is 1.36 m. As we can see from Fig. 1 shoulder is the point where chord is maximum and it is minimum at the tip of the blade. Stresses are maximum at the blade root so that the blade root is the thickest portion of the blade. The variation of thickness is shown in Fig. 3, which is calculated in terms of percentage of length

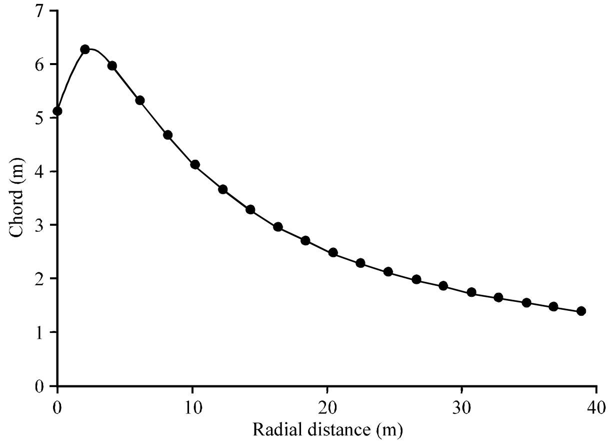

Fig. 1: Chord distribution

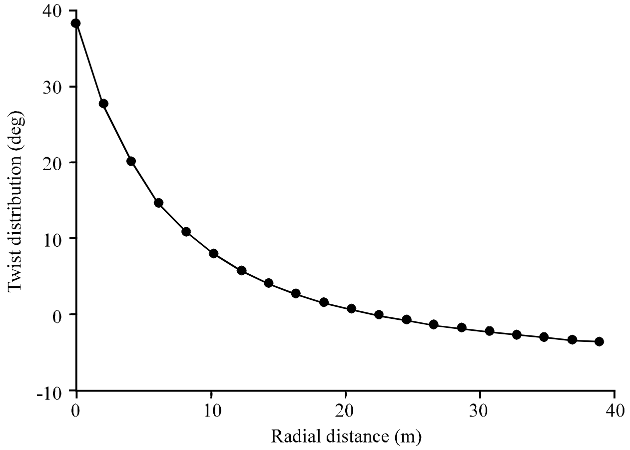

Fig. 2: Twist distribution

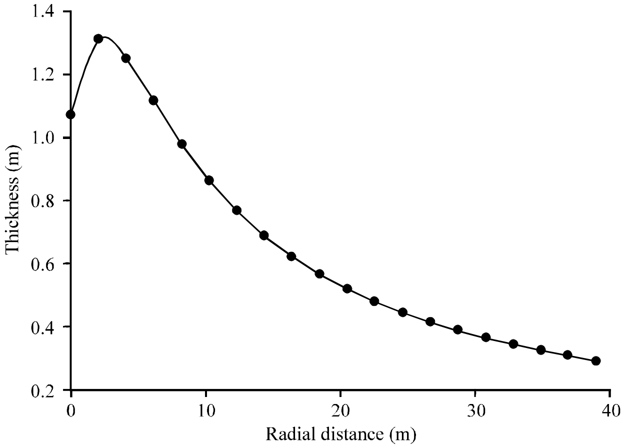

Fig. 3: Thickness distribution

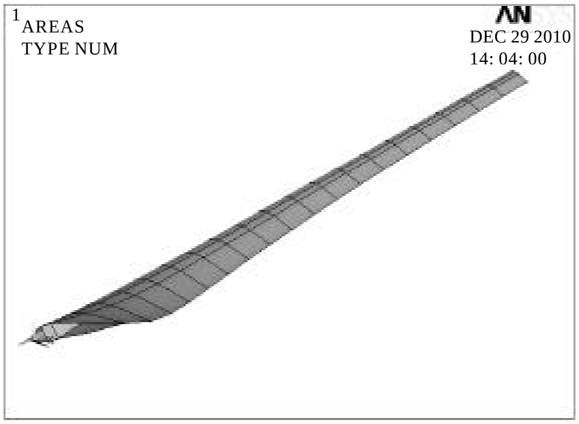

Fig. 4: Blade model

of chord and it is being calculated at all stations of the designed blade. The chord is calculated on the concept used by Ryu and Kim (2004).

Blade properties: The aerodynamic profiles of wind turbine blades have vital control on aerodynamic efficiency of wind turbine. In this work, the length of the blade is 38.95 m and the analysis is done for five shapes of spar. In the study of Kooij (2003) it is given that the location of the main spar with the location of the stiffening ribs will have the biggest effect on the bending modes of the blade. In this study, the model of blade is made of shell element as shown in Fig. 4. According to Guidelines GDWT (2002), the blade is to be twisted around the elastic axis. The position of elastic centre can be varied by modifying the location of spars and its shape. The geometry of blade is modeled in ANSYS to obtain the required properties of the blade and position of spars. The blade is divided into 19 sections. Twist of the blade decides the value of aerodynamic loads and also the direction in which the blade will vibrate. In this work the spar is also twisted according to airfoil. The blade with twisted spars is shown in Fig. 5 to 9.The boundary condition taken is this analysis is same as cantilever beam.

Natural frequency: Figure 10 shows the first six lowest natural frequencies obtained from ANSYS for the blade with different shapes of spar. As we can observe from the Fig. 10, natural

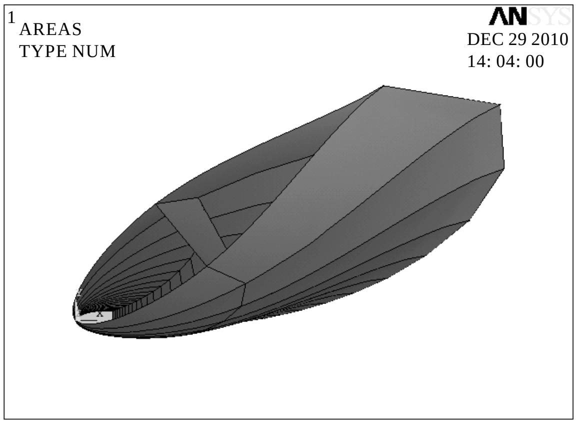

Fig. 5: Blade with single web spar

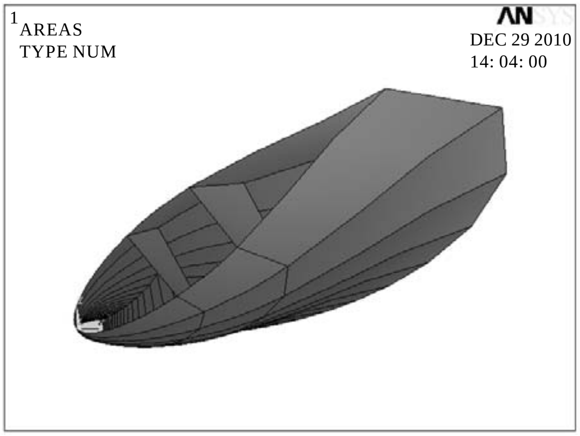

Fig. 6: Blade with double web spar

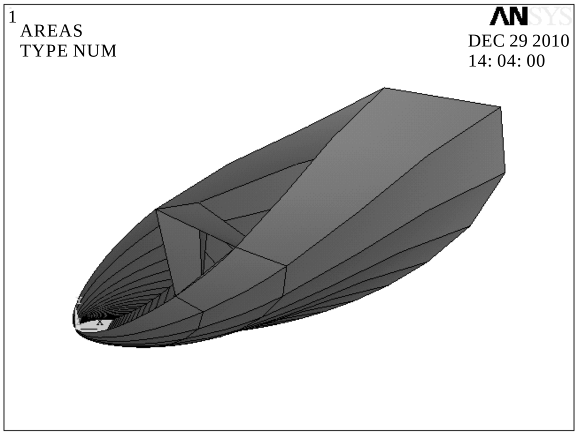

Fig. 7: Blade with triangular spar

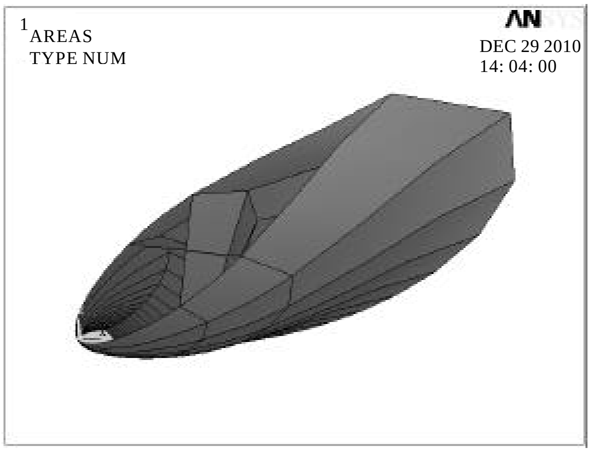

Fig. 8: Blade with cross shape spar

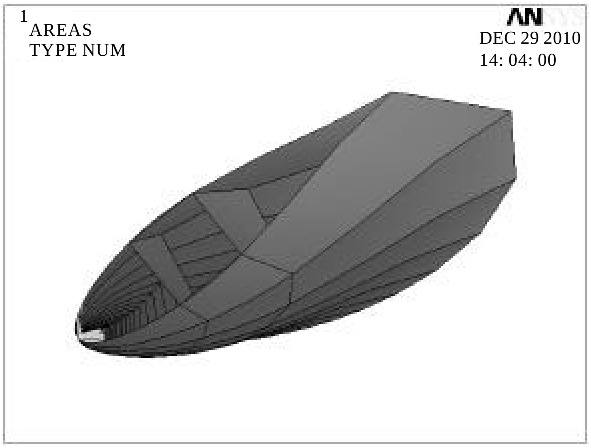

Fig. 9: Blade with square shape spar

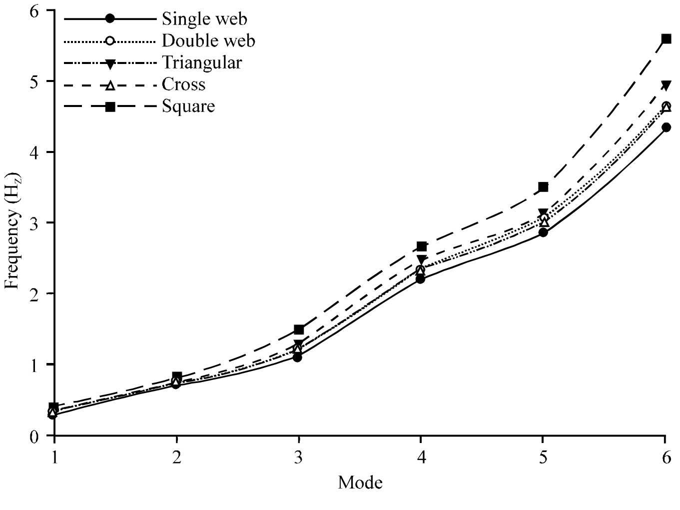

Fig. 10: Natural frequency

frequency for the blade with single web spar is less than other shapes of spar. The behavior of the graph for all spar shape is same. The natural frequency is increasing from mode 1 to 6. Natural frequency of single web spar for mode 1 is 0.2814 and for mode 6 is 4.3091.

CONCLUSION

In this study, a blade is designed for horizontal axis wind turbine by using Glauert's optimal rotor theory. For designing blade the lift coefficient is taken constant throughout the blade. Reduction of vibration is a good measure for a successful design of blade structure. It may foster other important design goals, such as low cost and high stability level. A good design philosophy for reducing vibration is to separate the natural frequencies of the structure from harmonics of rotor speed. This would avoid resonance where large amplitudes of vibration could severely damage the structure. In this study, model analysis is performed on a typical pre-twisted wind turbine blade with a non-uniform cross section and the cantilever boundary condition at the root. Figure 10 show that the weight of blade increases natural frequencies increases.

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