STRUCTURAL ANALYSIS OF 38.95 M HORIZONTAL AXIS WIND TURBINE BLADES

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ABSTRACT
The wind turbine blade is a very important part of the rotor. Extraction of energy from wind depends on the design of blade. In this work, the analysis is done on a blade of length 38.95m which is designed for V82-1.65MW horizontal axis wind turbine (supplied by Vestas). The airfoil taken for the blade is NACA 63–221 which is same from root to tip. The analysis of designed blade is done in flap-wise loading. Two shapes of the spar are considered in this work one of them is of square shape and the other one is combination of square and cross shape. The blade and spar are of the same composite material. The Finite element analysis of designed blade is done in ANSYS. This work is focused on the two segments of blade, root segment and transition segment. Result obtained from ANSYS is compared with the previously done experimental work.

Keywords: Design, Material, Chord, Twist, Blade.

1. INTRODUCTION
Wind turbines are subjected to very specific loads and stresses. Due to the nature of wind, loads are highly variable. Varying loads are more difficult to handle than static loads because the material becomes fatigued. Moreover as a working medium the air is of low density so that the surface required for capturing energy must be large. When designing a wind turbine, the aim is to attain the highest possible power output under particular atmospheric conditions and this depends on the shape of the blade. The work of Badran et al. (2011) presents two parts; the first part utilizes fuzzy logic methodology to assess wind sites in Jordan and to decide which sites should be given the highest priority with respect to their benefits and costs, and to predict the annual generation for different turbines in the best sites. The change of the shape of blade is one of the methods to modify stiffness and stability, but it may influence aerodynamic efficiency of wind turbine. Dynamic and mechanical properties can also be changed by modifying the composite material of wind turbine blade. A quasi-static crush analysis of an unmanned aerial vehicle (UAV) fuselage section made of woven e-glass/epoxy has been conducted by Yidris et al. (2010), using the finite element simulation via ABAQUUS. Abdullah et al. (2009) simulated residual stiffness and the residual strength model. The model approach is in way; the damage growth rate-a measure for stiffness loss- is expressed by two separate terms representing the initiation and propagation phase of damage respectively.

Jensen et al. (2006) worked on structural analysis and numerical simulation of 34 m composite wind turbine blade, the material taken in his work is Glass- Epoxy. Jensen et al. (2006) observed the ovalization of the load carrying box girder in the full scale test. A global non-linear FE-model of the entire blade was prepared and the boundaries to a more detailed sub-model were extracted. The FE-model was calibrated based on full-scale test measurements. A probabilistic model for analysis of the safety of a wind-turbine rotor blade against failure in ultimate loading is presented by Ronold et al. (2000). In his work Ronold (2000) only considered the failure in flap-wise bending during the normal operating condition of the wind turbine. The model is based on an extreme-value analysis of the load response process in conjunction with a stochastic representation of the governing tensile strength of the rotor blade material. The probability of failure in flap-wise bending of the rotor blade is calculated by means of a first-order reliability method, and contributions to this probability from all local maxima of the load response process over the operational life are integrated. Jureczko et al. (2005) took the problem of the multi-criteria optimum design of wind turbine blades and developed a computer program package that would enable optimization of wind turbine blades with regard to a number of criteria.

In this work a blade of length 38.95m for V82-1.65MW horizontal axis wind turbine (supplied by Vestas) is designed by Glauert’s optimal rotor theory. A computer program is developed for getting the dimension (Twist, chord and thickness). This work focuses on the deflection of cap and web of spar at root and transition segment of the blade when flapwise loading is applied on the blade. In the first part of this work square shape spar is taken for blade and for verification FEM results are compared with the results of Jensen et al. (2006) for the same segment (root and transition). In the second part of this work the spar taken is the combination of two shapes of spar first one
is of square shape and the other one is of cross shape as we can see in figure 6. Finite element analysis of the blade structure is done in ANSYS software. In this work the material taken is E-Glass/Epoxy pre-peg material and the properties taken from Brondsted et al. (2005). The properties of the material are shown in Table 1.

| Sr. No. | Properties                                      | Value  
<table>
<thead>
<tr>
<th></th>
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<th></th>
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<tbody>
<tr>
<td>1</td>
<td>Tensile modulus along X-direction ((E_X)), MPa</td>
<td>3400</td>
</tr>
<tr>
<td>2</td>
<td>Tensile modulus along Y-direction ((E_Y)), MPa</td>
<td>6530</td>
</tr>
<tr>
<td>3</td>
<td>Tensile modulus along Z-direction ((E_Z)), MPa</td>
<td>6530</td>
</tr>
<tr>
<td>4</td>
<td>Tensile strength of material, Mpa</td>
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<tr>
<td>5</td>
<td>Compressive strength of material, Mpa</td>
<td>450</td>
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<tr>
<td>6</td>
<td>Shear modulus along XY-direction ((G_{XY})), MPa</td>
<td>2433</td>
</tr>
<tr>
<td>7</td>
<td>Shear modulus along YZ-direction ((G_{YZ})), MPa</td>
<td>1698</td>
</tr>
<tr>
<td>8</td>
<td>Shear modulus along ZX-direction ((G_{ZX})), MPa</td>
<td>2433</td>
</tr>
<tr>
<td>9</td>
<td>Poisson ratio along XY-direction ((NU_{XY}))</td>
<td>0.217</td>
</tr>
<tr>
<td>10</td>
<td>Poisson ratio along YZ-direction ((NU_{YZ}))</td>
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<tr>
<td>11</td>
<td>Poisson ratio along ZX-direction ((NU_{ZX}))</td>
<td>0.217</td>
</tr>
<tr>
<td>12</td>
<td>Mass density of the material ((\text{kg/mm}^3))</td>
<td>2.6×10^6</td>
</tr>
<tr>
<td>13</td>
<td>Flexural modulus of the material, Mpa</td>
<td>4000</td>
</tr>
<tr>
<td>14</td>
<td>Flexural strength of the material, Mpa</td>
<td>1200</td>
</tr>
</tbody>
</table>

### 2. 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 localised deformations and stresses can be nonlinear, 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 behaviour, 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 behaviour, 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 idealised loads can be imposed in a full-scale test and in this paper the critical flap-wise load case is evaluated. The FE model of the wind turbine blade with a NACA 634-221 airfoil is created using APDL language in ANSYS. The created model of the blade with square shape spar consists of 147197 elements, 138139 nodes and 176 areas meshed and the blade consist spar of combined shape have 147197 elements, 142705 nodes and 214 areas meshed. The 8-noded shell 63 element type with 6 degree of freedom has been used with an element thickness provided 30mm.

### 3. 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 \((\beta)\) is large near the root (where local speeds are low), and small at the tip (where local speeds are high). The apparent wind angle changes along the blade due to increase in blade speed with increasing distance outboard. 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. Chord direction is perpendicular to the span direction and lies in the plane extending through the leading edge and the trailing edge. A 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 thickness distribution is calculated in terms of the chord where the total thickness of the blade at any station will be a percentage of the chord length at that station. Figure 1 shows the chord distribution for the blade. Figure 2 and 3 shows the twist and thickness distribution for the blade. Both chord and thickness are reducing from root to tip. The chord is calculated on
the concept used by Ryu (2004). Technical data of wind turbine are: diameter 82 meters, nominal revolutions 10.8 RPM, number of blades 3, cut-in wind speed 2.5 m/s and nominal wind speed 13 m/s.

4. 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 two shapes of spar. In the report (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. The model of blade (see Figure 4) made of shell element is used in this work. According to guidelines (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 modelled 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 Figure 5 and Figure 6.
5. RESULT AND DISCUSSION
Jensen et al. (2006) prepared a model using shell and brick element and it was developed for a span-wise segment of the blade. Jansen found that 0-13 m segment is most important part for final failure. The boundary condition used in the sub model was based on the displacement field taken from global FE-model. Generally the linear displacement field is used in sub-modeling techniques but in his case this technique can not be used since nonlinear effect dominates.

Jensen et al. (2006) worked on the blade manufactured by SSP-Technology A/S and the length of blade in his work is 34 m. The SSP-blade is made of glass epoxy pre-preg material and is designed with load carrying box girder shown in figure 7. In this work, a blade of airfoil NACA 634-221 is prepared using APDL language in ANSYS with two shapes of spar first one is of square shape and the other one is having combined shape (square and cross). First test is performed on blade with square shape spar and for validating the result deflection of cap and web at root and transition segment is compared with experimental work done by Jensen et al. (2006). The comparison of web deflection in figure10 and figure 11 and cap deflection in figure 12 and figure 13 shows that there is very slight difference in deflection of cap and web when using the square shape spar. For reducing the deflection second analysis is performed on a new combined shape of spar (Box and cross).

Figure 6 Twisted blade with spar (Combined square and cross)

Figure 7 Blade with a load carrying main spar. Jensen et al. (2006)

Figure 8 Blade with load carrying spar (Square)

Figure 9 Sketch of non-symmetric Jensen et al. (2006)

Figure 10 Relative web deflections versus load Jensen et al. (2006)
5.1 GEOMETRIC DEFORMATIONS

Different deformation patterns were observed by Jensen (2006) during the full scale test. In his work he divided the blade of 34 m length into three segments.

- Root segment (0-4 m)
- Transition segment (4-8 m) from root to box girder segment
- Box girder segment (8-34 m)

The blade length taken for analysis is 38.95 m which is not same as the length of blade taken for experimental work. Then for purpose of validation of deflection with experimental, the modeled blade length has been shifted at root and transition segment in proportion to experimental blade length. This work is focused in the two segments.

- Root segment (0-4.1 m)
- Transition segment (4.1-8.2 m)

In the experimental work done by Jensen (2006) part of the web deforation are due to the gravity load, which causes the web to show a non-symmetric behavior before loading. A sketch of non symmetric web deflection is given in Figure 9 of Jensen (2006) and the deflection measurement is given in Figure 10. In this work, web deflection is shown in figure 11 at a distance 4.1 m from root which is the root segment of the blade. Gravity, aerodynamic, inertia, centrifugal and damping loads are not considered in present work.

Outward cap deformations were measured by Jensen (2006) during the full scale test shown in figure 12, and figure 13 gives the result obtained by author with the help of ANSYS. For validation the deflection calculated at root and transition segment has been compared with experimental work. The calculated result shows good agreement with experimental work.

5.2 SPAR USED

For reducing the deflection of cap and web the spar used in the blade is of combined shape (box and cross). Figure 11 and 13 represents the differences in deflection of cap and web. It is clear that the deflection for the new spar is less than the square shape spar.

6. CONCLUSION

In this work, a horizontal axis wind turbine blade is designed with the help of Glauert's optimal rotor theory; a computer program is developed for getting the chord, thickness and twist distribution while maintaining the lift coefficient constant throughout the blade. The blade is divided into 19 sections and each section has the same length. Blade is modeled with
APDL language in ANSYS with airfoil NACA 63–221. Material taken for the blade is E Glass-epoxy. The analysis of the blade is performed in ANSYS. First analysis of the blade is done with the spar of square shape and for validation results are compared with experimental work. A new shape of spar of combined shape (box and cross) is used for second analysis and the results shows that the deflection of cap and web reduces at both root and transition segment.

REFERENCES