Finite Element Analysis for the Web Offset of Wind Turbine Blade

Bo Zhou¹, Xin Wang¹, Changwei Zheng¹, Jinxiang Cao¹ and Pingguo Zou¹
¹ Suzhou Nuclear Power Research Institute, 1788 Xihuan Road, Suzhou, China
zhoubbo_2010@cgnpc.com.cn

Abstract. The web is an important part of wind turbine blade, which improves bending properties. Much of blade process is handmade, so web offset of wind turbine blade is one of common quality defects. In this paper, a 3D parametric finite element model of a blade for 2MW turbine was established by ANSYS. Stress distributions in different web offset values were studied. There were three kinds of web offset. The systematic study of web offset was done by orthogonal experiment. The most important factor of stress distributions was found. The analysis results have certain instructive significance to design and manufacture of wind turbine blade.

1. Introduction
Wind energy is the natural resource of the earth. In recent years, as a renewable green energy, because of its vast commercial potential and environmental benefits, the wind energy is developing rapidly in the new energy industry [1]. Wind turbine converts wind energy into mechanical energy through blade, so the quality of the blade is related to the reliability of wind turbine. The stress distribution of the blade is quite complex. Generally, the structure of two webs is used in the blade, which is mainly subjected to shear and torsion. The skin provides the aerodynamic shape of the blade, which is also subjected to torsion [2-5].

The raw material for the web is a bidirectional glass fiber layer, which can improve the blade shear resistance effectively. During the production process of blade, the finished web is bonded into the blade with adhesive. Because of the local deformation of the handmade blade, it is common that the web offsets by extrusion. The blade design safety margin specified in JBT10194-2000 is 15%. The offset of the web changes the stress distribution of the blade. it is necessary to analyze the influence of blade quality. Taking into account the high cost of the blade test, research by simulation is a relatively economical and effective method. Stress distributions in different web offset values were studied by ANSYS.

2. Blade model
A blade with length of 53.8m, rated wind speed of 9.5m/s and rated turning speed of 1.49 rad/s for 2MW turbine was taken as the research object. The model of the blade was built up in the bottom-up way in ANSYS. The blade model was divided into 39 sections with 48 key points in each section. The corresponding key points were fitted into 48 curves by ANSYS command BSPLIN. The final skinning was done by the ASKIN command. The completed model is shown in Figure 1.
Figure 1. Blade geometry model.

The element type is SHELL99 shell element, which is an 8-node 3D shell element. Each element has 6 degrees of freedom, which is suitable for thin-medium thickness of the shell structure. Real constant was referenced by element (the direction and thickness of the composite laminates on different areas) [6]. The real constants and material properties were assigned to all corresponding areas by the MESHING function [7-9]. The finite elements were divided finally.

3. Loads and constraints

According to IEC61400-1[10], the forces on the wind turbine blade mainly include aerodynamic force, centrifugal force and gravity force, driving force and other forces such as wake force, impact force, ice force and so on[11-12]. In order to facilitate the study of the problem, the forces were simplified to aerodynamic force (twisting and bending), centrifugal force (bending, stretching and torsion) and gravity force (bending, tension and torsion).

The aerodynamic force is generated by the wind force acting on the surface of the blade. In order to achieve loading on the force surface of the blade, the method of loading along the blade’s surface was selected to simulate the load condition[13].

\[
\begin{align*}
\frac{dF_y}{d\theta} &= \frac{1}{2} \rho \nu^2 (C_L \cos \alpha + C_D \sin \alpha) \ tdr \\
\frac{dF_x}{d\theta} &= \frac{1}{2} \rho \nu^2 (C_L \sin \alpha - C_D \cos \alpha) \ tdr
\end{align*}
\]

(1)

\(\rho\) - air density; \(\nu\) - rated wind speed; \(C_L, C_D\) - airfoil lift coefficient and drag coefficient; \(\alpha\) - angle of attack of blade.

Centrifugal force is generated when the blade rotation, role in the blade center of gravity. The waving torque of the blade shifts the flexible blade in the downwind direction. The centrifugal force on the blade produces a bending moment in the waving direction that reduces this offset.

\[
\begin{align*}
\frac{dF_x}{d\theta} &= m\omega^2 r \cos \beta \ tdr \\
\frac{dF_y}{d\theta} &= m\omega^2 r \sin \beta \ tdr
\end{align*}
\]

(2)

\(\omega\) - angular velocity of blade rotation; \(r\) - the distance from the centroid of the blade to the center of rotation; \(\beta\) - cone angle of wind wheel.

Gravity force is the force that the blade will always be subjected to during its rotation. The gravity force on each coordinate axis changes cyclically with the different azimuth of the blade rotation. Gravity force makes the bending moment of the edge vary regularly, which is the main source of fatigue when the blade level reaches its maximum and is reversed in direction from one horizontal position to the other.
\[ \begin{align*}
    dF_1 &= mg \sin \theta \cos \chi dr \\
    dF_2 &= mg \cos \theta \sin \beta \cos \chi dr \\
    dF_3 &= mg \cos \theta \cos \beta \cos \chi dr
\end{align*} \]

\( \theta \) - the azimuth of the rotation; \( \beta \) - cone angle of wind wheel; \( \chi \) - inclination of the wind wheel.

The root of the blade is connected with the hub by screws. The whole blade is simplified as cantilever beam model when the six degrees of freedom are fixed. The blade has the largest bending moment in the horizontal position, so this position was selected as the object of study.

4. Calculation and result analysis

There are multiple directional possibilities for the web to be offset in the blade production process. In order to simplify the research, the spacing offset, the center position offset and the verticality offset were taken as the research objects. Two webs design spacing of 53.8-type blade is 400mm. The design value of the beam width is 640mm. The limit offset of the web at the beam edge is 120mm. The middle offset value of 60mm was added as the research object. The stress of five different offset values is shown in Table 1.

| Web spacing offset (mm) | Web center position offset (mm) | Web verticality offset (°) |
|-------------------------|-------------------------------|---------------------------|
| -120                    | -120                          | -3.6                      |
| -60                     | -60                           | -1.8                      |
| 0                       | 0                             | 0                         |
| +60                     | +60                           | +1.8                      |
| +120                    | +120                          | +3.6                      |

The structural features of the blade are illustrated in Figure 2. It can be seen from the results that the maximum stress of the blade occurs at the connection of the main beam and the blade root[14], which is consistent with the results of the blade type test.

![Figure 2. Blade stress distribution.](image_url)
The stress calculation results of different offset of web spacing are shown in Figure 3. It can be seen that the maximum deviation of the stress from the normal value is 9.14%. There is a tendency that the stress becomes larger as the web spacing becomes smaller.

![Figure 3. Stress-to-spacing variation.](image)

The results of the stress calculation of different offset values of web center position are shown in Figure 4. It can be seen that the maximum deviation of the stress from the normal value is 5.70%. There is a tendency that the stress is becoming smaller with the web center position offset to both sides.

![Figure 4. Stress variation with center offset.](image)

The results of the stress calculation of different offset values of web verticality are shown in Figure 5. It can be seen that the maximum deviation of the stress from the normal value is 2.96%. There is a tendency that the stress is becoming smaller with the web verticality offset to both sides.

![Figure 5. Stress variation with verticality offset.](image)

Considering the above three factors, there are 125 combinations. In order to reduce the amount of calculation, the method of L9(3^4) orthogonal test was used. In order to ensure that the offset value of
the three factors superimposed does not exceed the beam edge, the offset value of web space was selected as 40 mm, the offset value of web center position was selected as 40 mm, the offset value of web verticality was selected as 1.2°. The Von Mises value of Orthogonal test is shown in Table 2.

| Web spacing offset (mm) | Web center position offset (mm) | Web verticality offset (°) | Maximum stress value (MPa) |
|------------------------|--------------------------------|---------------------------|---------------------------|
| -40                    | -40                            | -1.2                      | 12.282                    |
| -40                    | 0                              | 0                         | 12.358                    |
| -40                    | +40                            | +1.2                      | 12.368                    |
| 0                      | -40                            | 0                         | 12.05                     |
| 0                      | 0                              | +1.2                      | 12.339                    |
| 0                      | +40                            | -1.2                      | 12.405                    |
| +40                    | -40                            | +1.2                      | 11.839                    |
| +40                    | 0                              | -1.2                      | 11.668                    |
| +40                    | +40                            | 0                         | 12.007                    |

From the stress calculation results of different web offsets, the maximum positive deviation of the stress from the normal value is 1.5%. R1=0.498, R2=0.203, R3=0.064, it can be seen that the web spacing offset has the greatest effect on blade stress, followed by the web center position offset and the web verticality offset.

5. Conclusion
The stress analysis of 2MW wind turbine blade with different web offsets showed that:
1. The blade design safety margin specified in JBT10194-2000 is 15%. From the stress calculation results of different web offsets, the maximum positive deviation of the stress from the normal value is 1.5%. The web offset plays an important role in the quality of wind turbine blade.
2. The web spacing offset has the greatest effect on blade stress, which should be avoided by more measures in the production of wind turbine blade. 1) More machines should be used during the production process to reduce the generation of offsets. 2) Larger positioning blocks can be used to secure the webs when the adhesive is not cured yet. 3) Secondary mold can be used to make the positioning of the web more accurate. Although production efficiency will be affected, it is worth it to improve the quality.

6. References
[1] Wang Yaoxian 2001 Composite structure design Chemical Industry
[2] Otero Alejandro D and Ponta Fernando L 2010 Structural analysis of wind-turbine blades by a generalized timoshenko beam model J Sol Energ 132:011015-1-011015-8
[3] Composites T P I 2002 Parametric study for large wind turbine blades Sandia National Laboratories SAND2002-2519
[4] Griffin D A 2002 Blade system design studies volume I : Composite technologies for large wind turbine blades Sandia National Laboratories SAND2002-1879
[5] Veers Paul S, Laird Daniel L and Sagartz Thomas G 1998 Estimation of uncertain material parameters using modal test data Sandia National Laboratories AIAA-0049
[6] Zhang L, Deng H and Gao J 2014 Influencing analysis on lamination parameters to static structure performance of wind turbine blade Acta Energ Sin 35(6):1059-1064
[7] Chen Yuqi, Wang Tiemin and Su Chenggong 2010 Research on lay-up of wind turbine blade structure Wind Energy (7):56-59
[8] Zehnder N and Ermanni P. A 2006 A methodology for the global optimization of laminated composite structures Compos Struct 72(3):311-320
[9] Lin C C and Lee Y J 2004 Stacking sequence optimization of laminated composite structures using genetic algorithm with local improvement Compos Struct 63(3-4):339-345
[10] IEC 61400 2003 Full-scale structural testing of wind turbine blades IEC
[11] Timmer W A and Van Rooij R P J O M 2003 Summary of the Delft University wind turbine dedicated airfoils J Sol Energ 125:488-496
[12] Yao C S, Lin J C and Allan B G 2002 Flow field measurement of device-induced embedded streamwise vortex on a flat plate Int. Conf.1st AIAA Flow Control
[13] Gyatt G W 1986 Development and testing of vortex generators for small horizontal axis wind turbines NASA CR-179514
[14] Jensen F M, Falzon B G and Ankersen J 2005 Structural testing and numerical simulation of a 34m composite wind turbine blade Development and testing of vortex generators for small horizontal axis wind turbines Int. Conf.ICCM13