Studying Mechanical Properties of Wing Blade with Hole Based on Reverse Engineering

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ABSTRACT

The paper is establishing a model of wind blade by Reverse Engineering(RE), which can obtain the fitting surfaces of complex structure. In order to investigate the mechanical behaviors of blade with circular hole, the digital model is applied to the finite element calculation. Then the static loading tests are carried out to obtain strains at different positions of surfaces by Fiber Bragg Grating sensors. By comparing the finite element simulation value with the experimental value, it is verified that the finite element modeling based on Reverse Engineering is suitable.

Keywords: Reverse Engineering; wind blade; Finite Element Method

1.Instruction

With the development of the green energy, wind power generation is one of the most effective approach to get power[1].However, under the influence of external factors, the structural health of the wind blades will gradually degrade. In order to avoid the loss of economy and personnel, it is necessary to research the mechanical behaviors of wind blades.

Due to the complex characteristics of wind blade with hole, the free-form surfaces can not be rebuilt by Computer- Aided Design(CAD).Reverse engineering can be used to recover the actual geometric model of products with special structure. Therefore, the Reverse Engineering is more suitable for modeling in this case[2]. Besides, using the reverse modeling, the error of structural parameters is reduced.

In order to decrease the counting amount about the high order element[4], Mindlin proposed the shell theory which applies for laminate structure. In this paper, the finite element method is used to simulate the static loading test. For improving the accuracy of measurement, the Fiber Bragg Grating sensors are applied[3].It researches mechanical behaviors of composite laminate structure under the different loading through combining the measuring results with the simulation value. This study aims to research the influence of stress concentration, which provides the basis for the failure study of blade.

2.Reverse Engineering

Reverse Engineering uses three measuring instruments to acquire data from existing products and collect the data to reconstruct the model[2], the process of which can be divided into the following stages(Fig.1):

1.Data acquisition: the use of three-dimensional measuring instruments to measure the physical model of the model surface 3D data。

2.Data preprocessing: Pretreatment of measurement data, simplification, filtering, triangulation and so on;

3.Data segmentation: Because the measurement model is usually composed of a number of different geometric features of the surface, so it is necessary to block the measurement data;

4.Surface reconstruction: According to the geometric characteristics of the sub-surface, the surface is fitted, and the complete surface model is obtained;

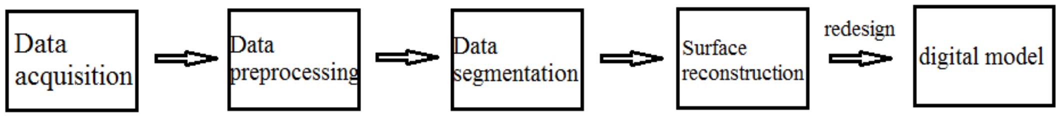

Fig.1.Reverse engineering process

If the existing complex model can be rebuilt, the requirement for the equipment precision is high. In this experiment, the scanning equipment MetraSCAN 3D is manufactured by Creaform with the seven laser cross-line, which adopts the portable design to get rid of the scanning method of the traditional mechanical arm. The highest scanning accuracy can reach 0.030mm, the scanning area of the measurement speed can reach 480000 times/sec.

3.Reserve Modeling

Because of Geomagic Studio containing the comprehensive functions, the processing applied the software to rebuild the wind blade. In the paper, the main challenge is the topology of the original surface is preserved, while sharp features and surface boundaries are hard to reproduce accurately in the reconstructed surface. Thus, the following ways are adopted to solve problems:(1)The key structure are scanned several times, and the points cloud data are spliced by the curvature variation of local features, which can reduce the influence of variable density, noise and outliners in one acquisition process.(2)If several triangular patches with sharp feature scan not match the actual model, the patches must be filled from the surface boundary that has been constructed, in order to conform to curvature variation of geometric boundary structure.

The pre-processing can get regular surface patches. Then the project finds smooth surface with repairing steps to remove the spindle, relax the boundary and simplify processing. Finally, the surface model can be used for finite element modeling. The software interface is shown in Fig.2.

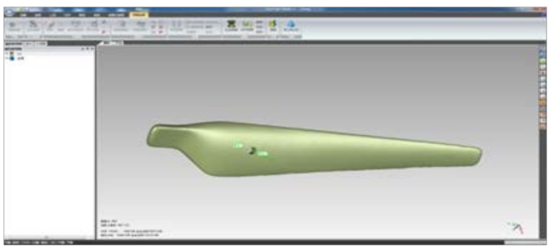

Fig.2.Geomagic Studio software interface

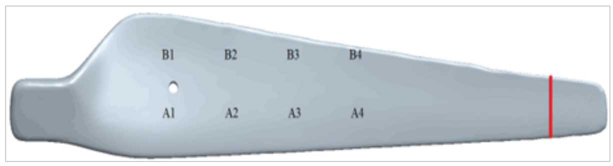

Fig.3.The position of the sensors and the load

4.Mechanicas Behaviors of The Wind Blade

Figure 3 is a three-dimensional digital model of the blade used in the experiment, the red is the loading position and the static loads are 1.8kg, 2.8kg, 3.8kg, 4.8kg, 5.1kg, 7.1kg, respectively. The clamping length of root is 50mm,the distance between the hole (D=13mm) and the blade root is 270mm, which is located in the center of the chord length. The direction of the A-group sensor and the B-group sensor is parallel to the blade orientation. A1 is located below the chord long line of the hole and B1 is located down it. The vertical distances from hole to A1 and B1are 24mm and 32mm respectively. The distances between A1, A2, A3, and A4 are 240mm, 125mm and 130mm.

The relationship between the wavelength variation $\Delta\lambda_B$ and the axial strain ε of the fiber grating can be expressed by the equivalent conversion coefficient p_e into the following formula:

$$\varepsilon = \frac{\Delta\lambda_B}{p_e} \times 1000 = \frac{\lambda_B - \lambda_0}{p_e} \times 1000 \tag{4-1}$$

The range of center wavelength of the Fiber Bragg Grating demodulator is 1510-1590nm, the strain of the small wind blade does not exceed 3000 micro strain. In order to ensure that the wavelength of each measuring point is not confused in the demodulation, the wavelength interval between different measuring points is set 6nm. The center wavelengths corresponding to the above-mentioned Fiber Bragg Grating (FBG)[4] sensors are shown in Table.1.

Table.1.The central wavelength of the measurement points in different groups

Sensor Number	A1	A2	A3	A4	B1	B2	B3	B4
Central wavelength/nm	1541	1547	1532	1538	1556	1535	1538	1552

The displacement vector of the shell element's deformation in Mindlin Theory is defined as[4]:

$$\begin{cases} u_x(x,y,z) = u + z\theta_y \\ u_y(x,y,z) = v + z\theta_x \\ u_z(x,y,z) = w \end{cases} \tag{4-2}$$

In this equations, $u = u(x,y)$ and $v = v(x,y)$ are the displacements in the x and y directions of the mid-plane; $\theta_x = \theta_x(x,y)$ and $\theta_y = \theta_y(x,y)$ are respectively x- axis negative direction of rotation angle andy- axis positive direction of rotation angle ; $w = w(x,y)$ is deflection variation.

Strain-displacement relation and mid-plane tensile strain are shown as:

$$\begin{Bmatrix} \varepsilon_{xx} \\ \varepsilon_{yy} \\ \gamma_{xy} \end{Bmatrix} = \begin{Bmatrix} \varepsilon_{x0} \\ \varepsilon_{y0} \\ \gamma_{xy0} \end{Bmatrix} + z \begin{Bmatrix} \kappa_{x0} \\ \kappa_{y0} \\ \kappa_{xy0} \end{Bmatrix} = e(u) + zk(u) \tag{4-3}$$

$$e(u) \equiv \begin{Bmatrix} \varepsilon_{x0} \\ \varepsilon_{y0} \\ \gamma_{xy0} \end{Bmatrix} = \begin{bmatrix} \frac{\partial}{\partial x} & 0 & 0 & 0 & 0 \\ 0 & \frac{\partial}{\partial y} & 0 & 0 & 0 \\ \frac{\partial}{\partial y} & \frac{\partial}{\partial x} & 0 & 0 & 0 \end{bmatrix} \begin{Bmatrix} u \\ v \\ w \\ \theta_x \\ \theta_y \end{Bmatrix} \equiv L^e u \tag{4-4}$$

The fiber volume ratio of blade composites is 0.45, the material properties used in this study for the glass fiber include a Young's elastic modulus of 72GPa, a shear modulus of 40Gpa, a longitudinal Poisson’s ratio of 0.2,and the epoxy matrix include a Young's elastic modulus of 3.45GPa, a shear modulus of 3.89Gpa, a Poisson’s ratio of 0.35. By the finite element analysis, strains in loading direction and equivalent stresses are shown in Fig.4. The experimental data of the measured positions and the calculated strains in loading direction are provided in Fig.5.

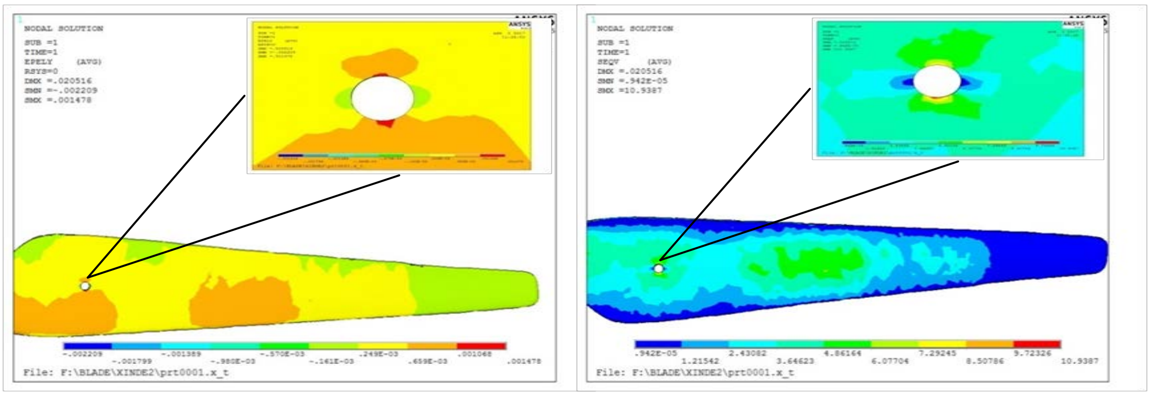

Fig.4. strain and stress contour plot

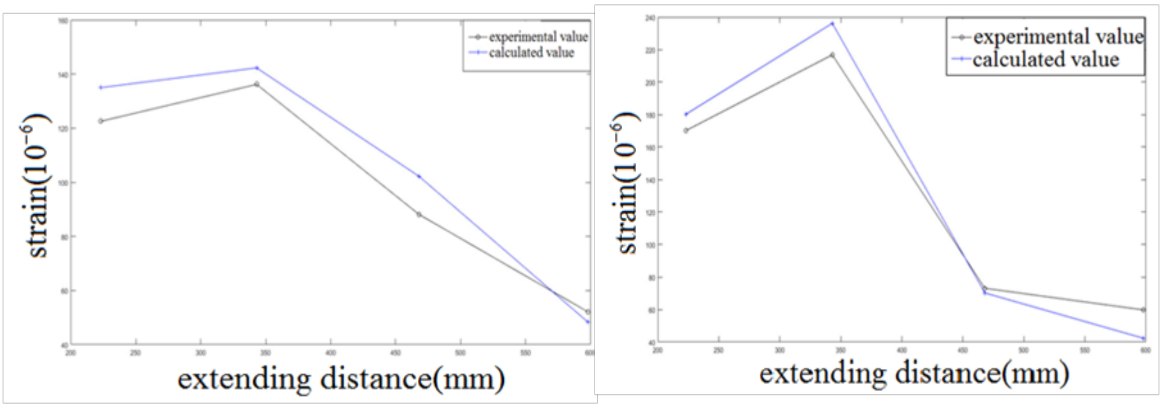

Fig.5.Comparing experimental strains with calculated strains in A group and B group under loading 5.1kg

5.Conclusion

In this paper, the Reverse Engineering is applied to study the mechanical properties of wind blades. The results of finite element analysis are compared with the experimental tests, which lays a good foundation for the study of complex structures. To improve calculation precision, the simulation should apply the higher-order elements with Finite Element Method. While it takes more time to get accurate results, choosing the proper method is also useful for mechanical behaviors of composite laminate.

Acknowledgements

This work was supported by the National Natural Science Foundation of China(Nos.51675397, 51305320)andNaturalScienceBasicResearchPlaninShaanxiProvinceofChina(No. 2015JQ5146), the 111 Project B14042.

Reference

[1] EWEA. World wind energy report 2009[R].Bonn: World Wind Energy Association,2010.

[2] Josef Hoschek and WErner. Reverse Engineering[J].Stuttgart:Teubner,1996

[3] Schoeder K, Ecke W, Apitz J, et al. A Fiber Bragg Grating sensor system monitors operational load in a wind turbine[J]

[4] Ziekiewicz OC, Taylor RL. The finite element method[M], 5th ed, volume 2: solid mechanics,2000