Structure Design and Manufacturing of the Composite Fan for Ski Jumping Training Wind Tunnel

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Abstract: In order to achieve the wind speed of 35m/s, the structure design of the composite fan blade ware researched, meanwile, Finite element analysis was performed in ANSYS Workbench, the result showed that the structure design is reasonable, the strength and stiffness meet the design requirements. The vacuum assisted resin transfer molding process was used to manufacturing the blade. The three coordinates inspection and the dynamic balance test is provided to ensure the quality of the fan.

1. Introduction

With the pursuit of athletes to challenge themselves, the performance of various sports events is constantly approaching the limit of human ability. Traditional training can hardly help the athletes break through their performance [1,2]. Therefore, technology is becoming more and more important for sports training to provide high performance [3,4]. Therefore, designing a ski jumping training wind tunnel is very necessary. Axial fans are widely used in low-speed wind tunnels[5], for the reason that, we designed an axial fan to achieve the wind speed of 35m/s. Axial fans are mainly composed of fan hub and blade, the blade is made of carbon fiber resin composite material. The fan structure is shown on Figure.1.

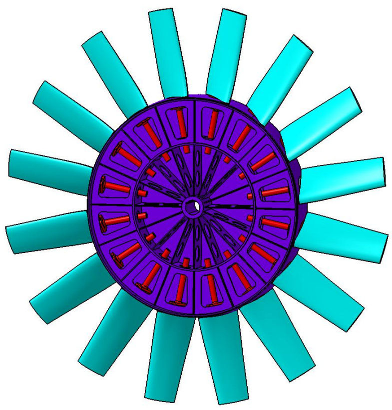

Figure 1: Axial fan.

2. Structure Design

2.1. Fan Hub Structure Design

According to design requirements, we designed the structure of the fan hub disc with CATIA, and meanwhile, the finite element analysis of the hub structure was carried out with workbench17.0. We analyzed the stiffness, strength and natural frequency of the fan hub by applying gravity load, blade weight, blade center of gravity position and rotating speed 950 RPM. The results show that the designed structure meets the design requirements of stiffness and strength. The natural frequency of the fan hub is given in Table 1.

Table 1: The natural frequency of the fan hub.

Order number	Frequency (Hz)	Order number	Frequency (Hz)
1	48.48	4	135.92
2	93.50	5	218.12
3	93.681	6	218.18

2.2. Blade Structure Design

Blade consists of composite blade, foam core and blade handle. The blade structure is shown on Figure 2. Blade handle is mainly composed of clamping part and hollow shaft. Blade handle is used to fix blade and support aerodynamic force and centrifugal load, at the same time, the weight of blade handle is reduced as much as possible [6-8]. The blade handle structure is shown on Figure 3.

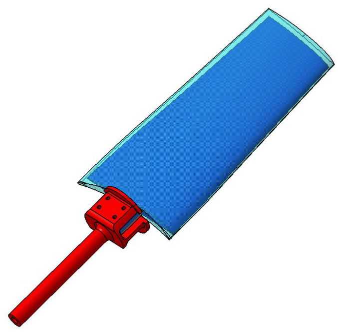

Figure 2: Blade structure (with foam core).

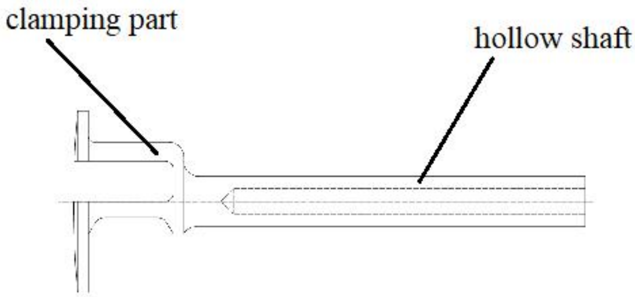

Figure 3: Blade handle structure.

Foam core is a relatively inexpensive craft material consisting of the polymethacrylimide (PMI) foam which with high strength, dimensional stability and isotropy [10,11]. Foam surface is similar to blade surface and bonded to inner surface of composite blade.

Composite blade forms the blade profile which is mainly formed by carbon fiber resin composite, during design, strengthen of inside local structure of the blade, bonded to the foam core[12,13]. The carbon fiber resin composite is made of carbon fiber cloth woven.

The blade's design is a continuous optimization process. Results are:

a. Composite blade composite is T700 carbon fiber cloth, its monolayer thickness is 0.125mm, The total thickness is not less than 10 mm, local thickness is 23 mm;
b. Foam core is used PMI foam, the shape of foam core determined according to the inner surface of composite blade ;
c. The clamping part of blade handle thickness is 20mm and the diameter of hollow shaft is 50 mm.

2.3. Finite Element Analysis

A 3D geometric model was created by CATIA. All finite element calculations are performed in Workbench, including strength, stiffness and modal analysis.

The whole blade model is divided into 20679 elements and 39234 nodes, Of them, the composite blade is divided into 10372 shell elements and 20524 nodes, the foam core is divided into 6906 solid elements and 12144 nodes, the blade handle is divided into 3401 solid elements and 6566 nodes.

PMI foam material properties are given in Table 2.

Table 2: Material properties of PMI foam.

Property	PMI foam	Unit
Density	110	Kg/m3
Young's modulus	157.5	MPa
Poisson's ratio	0.3	
Tensile yield strength	2.85	MPa
compression yield strength	2.85	MPa
Tensile ultimate strength	3.7	MPa
compression ultimate strength	3.7	MPa

T700 carbon fiber cloth material properties are given in Table 3.

Table 3: Material properties of carbon fiber cloth.

Property		PMI foam	Unit
Density		110	Kg/m3
Elasticity	Young's modulus X direction	61340	MPa
	Young's modulus Y direction	61340	MPa
	Young's modulus Z direction	690	MPa
	Poisson's ratio XY	0.04	
	Poisson's ratio YZ	0.3	
	Poisson's ratio XZ	0.3	
	Shear modulus XY	19500	MPa
	Shear modulus YZ	2700	MPa
	Shear modulus XZ	2700	MPa
Stressm limits	Tensile X direction	805	MPa
	Tensile Y direction	805	MPa
	Tensile Z direction	50	MPa
	Compressive X direction	509	MPa
	Compressive Y direction	509	MPa
	Compressive Z direction	170	MPa
	Shear XY	125	MPa
	Shear YZ	65	MPa
	Shear XZ	65	MPa

Blade handle end is fixed constraint; Sets contact pairs between blade handle and composite blade, meanwhile, Sets contact pairs between foam core and composite blade.

Applying gravity load, aerodynamic load and Rotation Speed (700RPM) on Blade .

The result show that the total deformation is 0.97mm, As show in Figure 4(a), of them, the X axis directional deformation is 0.10mm, As show in Figure 4(b), the Y axis directional deformation is 0.70mm, As show in Figure 4(c), the Z axis directional deformation is 0.67mm, As show in Figure 4(d). the maximum deformation is lower than design requirement(3mm).

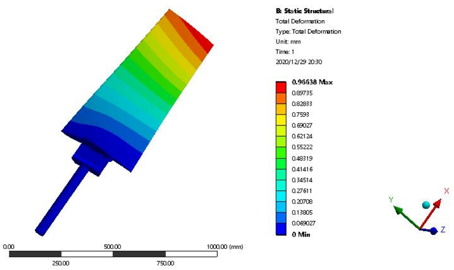

Figure 4: (a) Total deformation.

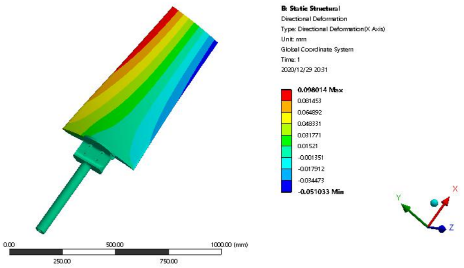

Figure 4: (b) X axis deformation.

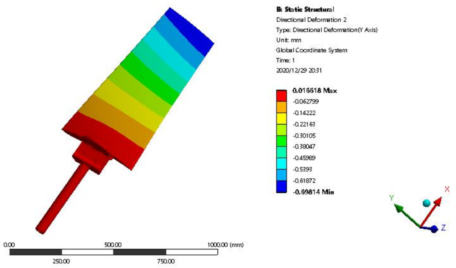

Figure 4: (c) Y axis deformation.

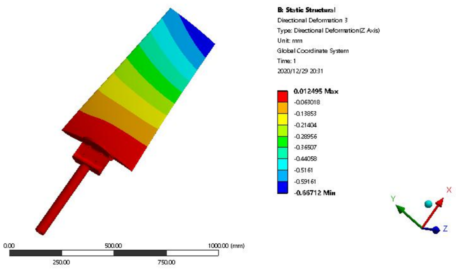

Figure 4: (d) Z axis deformation.

Figure 4: Deformation results

As shown in the Figure 5, the maximum normal stress-X axis observed between composite blade and blade handle is 63.2MPa. The material safety factor which can meet the design requirements and specifications is 12.7. The maximum shear stress-XY is 15.6Mpa. It meets the specifications and design requirements for a 12 safety factor.

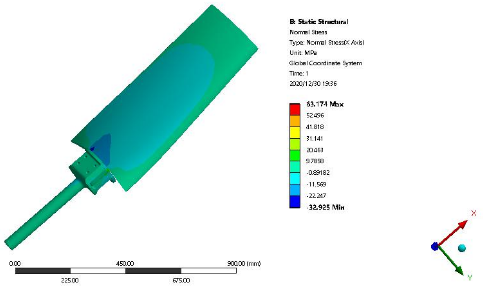

Figure 5: (a)Normal stress-X axis.

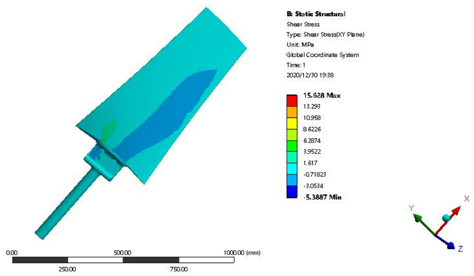

Figure 5: (b)Shear stress-XY.

Figure 5: Stress results.

The natural frequency of the blade is given in in Table 4. This table shows that each order frequency avoids the frequency of the hub fan, and the modal characteristics do not coincide, so this is to avoid resonance phenomenon.

Table 3: Material properties of carbon fiber cloth.

order number	Frequency (Hz)	order number	Frequency (Hz)
1	70.645	4	268.03
2	151.53	5	368.85
3	157.22	6	485.51

The finite element analysis results show that the structure design of blade and lay-up design are reasonable, the strength and stiffness meet the design requirements, and the resonance between the blade and the fan hub is avoided.

2.4. Manufacturing Blades

The blade handle and foam core are processed by 5 axis NC machining center through rough machining, heat treatment and finish machining.

Before the composite blade forming, processing the mould of composite blade by 5 axis NC machining center.

Cutting the fiber cloth and the flow-guide nets according to expanded contour, meanwhile, ensuring that the fiber angle is correct. Ensure compaction between layers in each layer during laying. There are several points needing attention in the process, as follows :

1) Preheating mould Before Laying;

2) The temperature of the resin and curing agent are heating up to 50℃~70℃;
3) Vacuuming the mould and resin before injection to reduce porosity;
4）Maintain vacuum during curing.

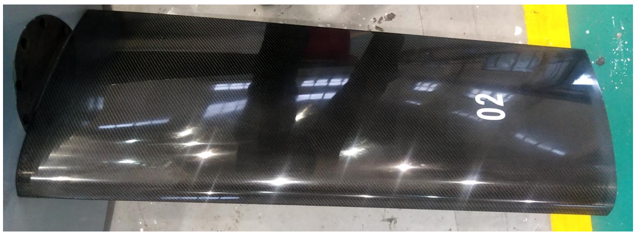

Figure 6: Blade.

Vacuum assisted resin transfer molding (VARTM) process is widely used in carbon fiber resin composites molding process to reduce porosity and increase the resin flow velocity[14,15]. The finished blade is shown in the Figure 6.

2.5. Measuring and Testing

The size of the blade profiles is meet the design requirements by three coordinates inspection, the error not exceeding 0.1 mm.

Weighting each blade and ensure error within 5g.

Assembly blades and hubs together, where the mass of two blades in symmetrical position is as close as possible, then carrying out dynamic balance tests. The dynamic balance level should reach G6.3.

3. Conclusions

The composite fan worked normally for one year in the ski jumping training wind tunnel showed that the structure design of composite fan can satisfy the application requirement of ski jumping training wind tunnel. Finite element analysis of blade can be used to guide blade design. The quality can be obtained by using VARTM molding process which can meet the the application requirement of the ski jumping training wind tunnel.

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