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Structural Design on Small Scale Sandwich Composite Wind Turbine Blade

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Abstract

Even though the recent development trend of wind turbine systems has been focused on larger MW Classes, the small-scale wind turbine system has been continuously developed because it has some advantages due to easy personnel establishment and use with low cost and energy saving effect. This work is to propose a specific structural design and analysis procedure for development of a low noise 500W class small wind turbine system which will be applicable to relatively low wind speed region like Korea. The proposed structural feature has a skin-spar-foam sandwich composite structure with the E-glass/Epoxy face sheets and the Urethane foam core for lightness, structural stability, low manufacturing cost and easy manufacturing process. Moreover this type of structure has good behaviors for reduction of vibration and noise. Structural analysis including load cases, stress, deformation, buckling and vibration was performed using the Finite Element Method. In order to evaluate the designed blade structure the structural tests were done, and their test results were compared with the estimated results.

Key Words : Wind turbine blade, Structural design and analysis, Skin-spar-foam sandwich composite structure

1. Introduction

Recently, development of alternative energy instead of the fossil fuels is very hectic. Among them, especially, because the wind energy is a strong candidate due to unlimited natural energy resource and clean, lots of studies on the wind turbine system using the wind energy are actively carried out in worldwide. Current development trend of the wind turbine system are mostly several MW class large scales. Large scale wind turbine systems over several MW need some special requirements, for instance, provision of large wind turbine site, expensive manufacturing facility and equipment's. However, even though the small scale wind turbine system produces relatively a small electric energy, it has been continuously developed due to many advantages such as easy manufacturing, low cost, personnel handling and operation, etc.

Because most recent commercialized small scale wind turbine systems have been designed at the rated wind speed more than 12 m/s, they show a great reduction of aerodynamic performance in low wind speed region like Korea.[1,2] Therefore the proposed wind turbine system in this study has the proper rated wind speed, i.e., 8 m/s.

This work shows an aerodynamic and structural design result for the 500W-class wind turbine system with the low noise character for local area use. Material for this wind blade is the glass/epoxy that has good structural performance such as long fatigue life and low cost.[3] Prototypes of the designed blades are manufactured by autoclave curing process. The structural test is performed to evaluate the structural design and analysis results with the real structural behaviors.[3]

2. System Specification and Aerodynamic Design Results

Table 1 shows the wind turbine system design specification including rated power of 500W, rated wind speed of 8m/s, cut-out wind speed of 20m/s, number of blades of 3 and blade material of glass/epoxy. For electric power generation, the gearless direct drive type AFPM(Axial Flux

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Permanent Magnet) generator will be used for design simplicity. Aerodynamic design results including the using airfoil of DU 93-W-210, the blade diameter of 2.47m, the twist angle of 24.353 degrees, the blade tip and root chords are shown as Table 2.

Table 1 Design specification of 500W wind turbine system

Type	Horizontal axis wind turbine system
Rated power	500 W
Operation envelope	Rated wind speed: 8 m/s Cut-out wind speed: 20 m/s
Number of blades	Three
Blade material	Glass/epoxy composite

Table 2 Aerodynamic design results of small wind turbine blade

Rated power	500 W
Rotor diameter	2.47 m
Blade root chord	149.208 mm
Blade tip chord	42.727 mm
Blade total twist	24.353 deg
Airfoil	DU 93-W-210

3. Lightweight Blade Design

The aerodynamic loads and the centrifugal forces are mainly acting on the blade. The centrifugal forces can be simply calculated from rotational speed, and the aerodynamic loads are calculated by aerodynamic coefficients in several load cases which are in Table 3. The bending loads can be defined by the normal force distribution acting on each section of the blade, and their variations depend on the wind speed and the incidence angle. Therefore, the bending loads must be calculated by consideration of operating conditions. According to the load analysis, the load case 2 is the most severe condition. Hence the structural design was performed on the basis of the load case 2. Figure 1 shows the flapwise moment distribution of the design load case 2. The blade adopts the skin/spar/foam sandwich type structure, and the skin and spar are layered with the proper lamination angles and thicknesses.[4]

By the composite design method such as the netting rule and the rule of mixture that was propped at the previous study.[2] , the initial structural design is carried out, and then the initial design feature is repeatedly modified by structural analysis using the finite element method. Table 4 shows the final structural design results.

Table 3 Load cases for structural design

Load case	Case 1	Case 2	Case 3
Reference Wind speed	8 m/s	20 m/s	55.0 m/s
Gust condition (±20m/s, ±40°)	Without gust	With gust	Storm
Rotational speed	43 3rpm	1069 rpm	stop

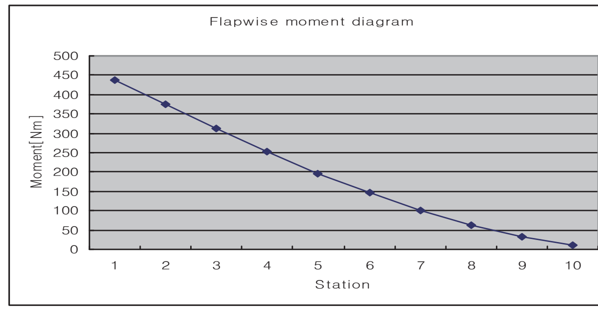

Fig. 1 Permanent Magnet and Hysteresis Damper Set-up

Table 4 Load cases for structural design

	Thickness(mm)			
	Upper surface		Lower surface	
1	Skin1.00t	Spar6.75t	Skin1.00t	Spar6.75t
2	Skin1.00t	Spar2.25t	Skin1.00t	Spar2.25t
3	Skin1.00t	Spar2.7t	Skin1.00t	Spar2.7t
4	Skin1.00t	Spar3.15t	Skin1.00t	Spar3.15t
5	Skin1.00t	Spar3.15t	Skin1.00t	Spar3.15t
6	Skin1.00t	Spar3.15t	Skin1.00t	Spar3.15t
7	Skin1.00t	Spar3.15t	Skin1.00t	Spar3.15t
8	Skin1.00t	Spar1.35t	Skin1.00t	Spar1.35t
9	Skin1.00t	Spar0.45t	Skin1.00t	Spar0.45t
10	Skin1.00t	Spar0.225t	Skin1.00t	Spar0.225t

4. Structural Analysis

In order to perform the structural analysis, a finite element code, MSC Patran/Nastran, is used. In this analysis, the linear static stress analysis, the eigenvalue analysis and the buckling analysis are carried out. The intra-lamina 'Tasi-Wu' failure criterion is used to find the structural safety.[5] In the finite element analysis, the boundary condition is assumed that the blade root is fixed. Distributed aerodynamic loads were applied on the blade along length direction and centrifugal body force also applied. According to the analysis results, it is confirmed that the blade is safe from the strength. Table 5 shows the linear static structural analysis result for the load case 2. The natural frequency and buckling analysis results are presented in Table 6. Stress distribution and deformed blade shape at the load case 2 are shown in Figure 2 and 3. The first and second flap and lead-lag natural frequency mode shapes are shown in Figure 5 and 6, respectively. In this analysis, it is confirmed that the final structural design feature is safe from strength, the deformed blade tip clearance requirement, buckling, resonance possibility and maximum strain requirement for fatigue life.

Table 5 Static stress analysis results at load case 2

		Case 2
Max. Stress [MPa]	Ten	68.6
	Com	25.5
Max. Disp.[mm]		166
Weight[kg]		1.24
Tsai-wu Failure criterion		0.24

Table 6 Results of natural frequency and buckling analysis

First flap mode	22.034 Hz
Second flap mode	79.037 Hz
First leadlag mode	44.818 Hz
Second leadlag mode	148.16 Hz
First buckling factor	1.2073
Second buckling factor	4.4946

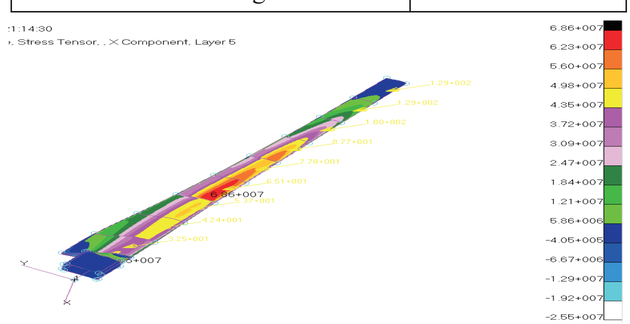

Fig. 2 Stress distribution at load case 2

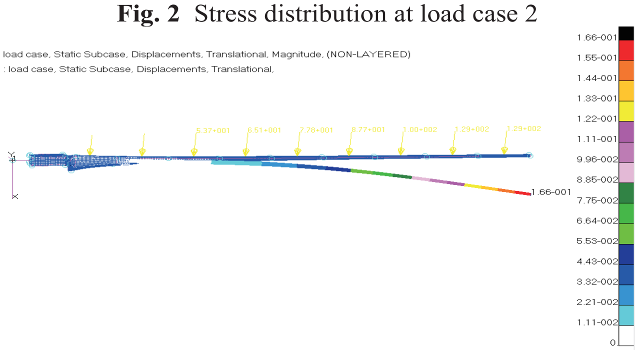

Fig. 3 Deformed blade shape at load case 2

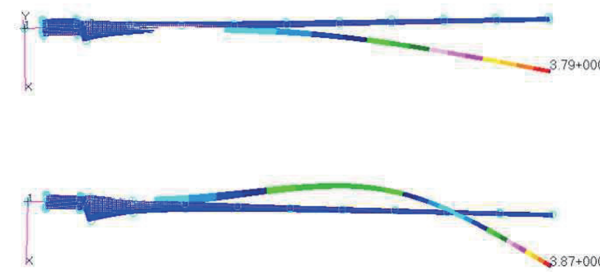

Fig. 4 First and second flap natural frequency mode

Fig. 5 First and second lead-lag natural frequency mode

5. Prototype Blade Manu

In order to manufacture the prototype blade, the autoclave curing method is adopted. In the manufacturing process, styrofoam mold is firstly manufactured using steel plate template and hot wire, and then glass fabrics are layered-up after special coating for second mold. In the next, the glass fabrics are layered-up on the second mold once again for last mold, and then glass fabrics for the upper and lower surface skins are layered-up on the mold according to the structural design result. The cured upper and lower surface skins are bonded by epoxy, then urethane form is injected into the space between the upper and lower skins. After completely curing the blade, the proper coating is applied. In order to evaluate the analysis results, the structural test must be performed. Therefore, the structural test results are compared with structural analysis results. The structural test of prototype was conducted by the hydraulic structural test equipment which can adjust the applying loads and speeds by 3 hydraulic cylinders and controller. In this test, three point loads are applied to the prototype for test simplicity. Table 7 shows comparison between the FEM analysis results and the structural test results of prototype. This comparison shows that analysis results are well agreed with the experimental results.

Table 7 Comparison between the static analysis results and the test results

Item	Analysis result	Test result
Stress	29.1 MPa	27.4 MPa
Tip deflection	166 mm	152 mm

6. Conclusions

In this work, structural design, analysis and test of the 500W-class wind turbine blade were performed. Through the structural analyses, it was confirmed that the final structural design feature is safe from strength, the deformed blade tip clearance requirement, buckling, resonance possibility and maximum strain requirement for fatigue life.

Prototypes of the designed blades were manufactured by autoclave curing process. The structural test was performed to evaluate the structural design and analysis results with the real structural behaviors. Through the comparison, it was found that analysis results are well agreed with the experimental results

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