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Structural Design of Composite Blade and Tower for Small Wind Turbine System

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Abstract : This work is to propose a structural design and analysis procedure for development of the low noise 1kW class small wind turbine system which will be applicable to relatively low speed region like Korea and for the domestic use. The proposed structural configuration has a 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. Structural analysis including load cases, stress, deformation, buckling, vibration and fatigue life was performed using the Finite Element Method, the load spectrum analysis and the Miner rule. In order to evaluate the designed structure, the structural test was carried out and its test results were compared with the estimated results. Moreover Investigation on structural safety of tower was verified through structural analysis by FEM.

Key Words : Sandwich composite structure, Wind turbine blade and tower, Structural analysis

1. Introduction

Although wind power energy has been continuously used since ancient times, wind turbine system is being researched and developed in various ways recently in the midst of a current situation where studies are being actively conducted on alternative energy development resulting from the depletion of fossil fuel. Currently, a significant amount of power supply is being substituted through wind power generation centering on Europe and it is said that over 10% is being covered in regions such as Denmark and Northern Germany [1]. In terms of the research trend of wind power generation, wind turbine systems are being developed in various scales from a small system to a large power generation system. Since a small wind turbine system can be operated independently in a small scale, related studies are being actively conducted in recent [2]. In addition, the use of composite materials has led to the result of a significant improvement of structural strength and fatigue life. However, majority of the blade of small wind turbine system has been developed in advanced countries and the rated wind speed of imported blades is not suitable for the domestic climate condition. Accordingly, there is a need to develop wind turbine system suitable for the domestic climate condition.

This paper performed aerodynamic, structural design and analysis of the horizontal axis blade of low noise 1kW class small wind turbine system that can be operated at homes and designed to display excellent performances in low wind velocity regions such as Korea. In terms of the material applied, glass/epoxy that is both economical and excellent in its performance was applied. Structural test was conducted to verify whether the actual movement of

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the blade designed is consistent with the theoretical analysis result. In addition, structural safety review was performed through the structural analysis of a tower for installing the wind turbine system developed.

2. System Specification and Blade Design

For the purpose of designing wind turbine system, it is necessary to first specify the system specification. As for the specification of the wind turbine system in this paper, it is horizontal axis wind turbine system with rate output of 1kW, rated wind velocity of 12.8m/s and applied airfoil NACA 632-615 이다. The blade diameter is 2.54m and angle of torsion is 22.6° . The turbine system to be applied is a direct-driven AFPM (axial flux permanent magnet) turbine system that can be applied as a high-efficiency energy conversion device even at low wind velocity. Specific aerodynamic design results are specified in Table 1.

Table 1 Aerodynamic design results of small wind turbine blade

Rated power	1 kW
Rotor diameter	2.54 m
Blade root chord	143.42 mm
Blade tip chord	64.84 mm
Blade total twist	22.66 deg.
Airfoil	NACA 63_2-615

Structural design was performed after blade aerodynamic design to evaluate the structural safety of blade through structural analysis and fatigue life analysis. Structural load for structural design includes the aerodynamic load applied to blade and centrifugal load as main load. For the aerodynamic load to be calculated, load conditions specified in Table 2 were considered. The load analysis result confirmed that load case 2 causes the biggest moment to blade. Accordingly, the structural design of the blade in this paper was performed based on the load in load case 2.

Based on the structural design load, skin-spar-foam sandwich structure was adopted as the structural form of blade for the design. In the blade structural design form, skin and spar are stacked in the blade longitudinal with foam applied inside the blade, and it was designed to reduce the number of layers through longitudinal from the root part of blade for weight reduction by calculating section-specific load.

Table 2 Load cases for structural design

Load case	Case 1	Case 2	Case 3
Reference wind speed	12.8m/s	30.0m/s	55.0m/s
Gust condition (±20m/s, ±40°)	without gust	with gust	storm
Rotational speed	500rpm	800rpm	stop

For the structural analysis conducted to evaluate the structural safety of structural design result, finite element commercial code MSC. NASTRAN was used, and Tsai-Wu failure criterion [3] was applied as the failure criterion for the safety review. The result of linear static analysis for each load condition confirmed that it has been designed with a safe structure ensuring sufficient safety factor. Table 3 shows the result of load condition-specific finite element linear static analysis result and the review of according failure. Natural frequency was analyzed to examine any resonance of blade and the result showed that resonance did not occur around operational number of rotations. The result of buckling stability evaluation also confirmed that it is a structure ensuring a sufficient level stability during operation with over 4 times the load. The maximum fatigue load calculated based on Spera's empirical formula for fatigue life analysis was 576.6Nm and the analysis result of stress on fatigue load showed maximum compressive stress of 35.4MPa and maximum tensile stress of 28.0MPa, thereby confirming that a sufficient level of safety rate has been ensured regarding allowable fatigue strength (144.7MPa). Accordingly, the blade design result confirmed that it is a structure that ensured required fatigue life of 20 years.

The structural analysis result was compared with the final structural test result for verification and they were consistent. The linear static analysis result and fatigue life analysis result were specified respectively in Fig. 1, 2.

Table 3 Structural analysis results

		Case 1	Case 2	Case 3
Max. stress [Mpa]	Ten.	27.2	73.0	28.6
	Com.	19.8	69.8	20.2
Max. Disp. [mm]		27.3	82.8	28.3
Tsai-wu failue criterion		0.071	0.278	0.126

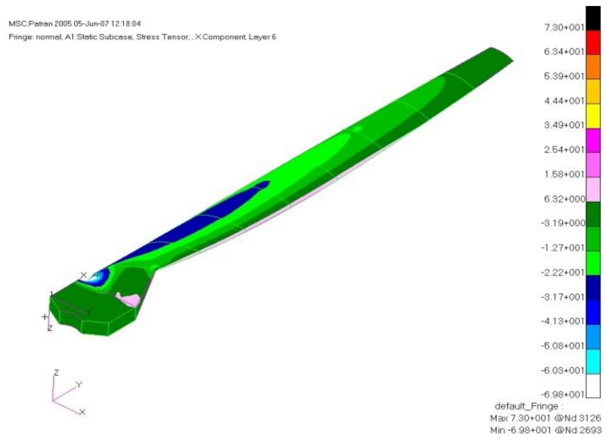

Fig. 1 Stress analysis result of load case 2

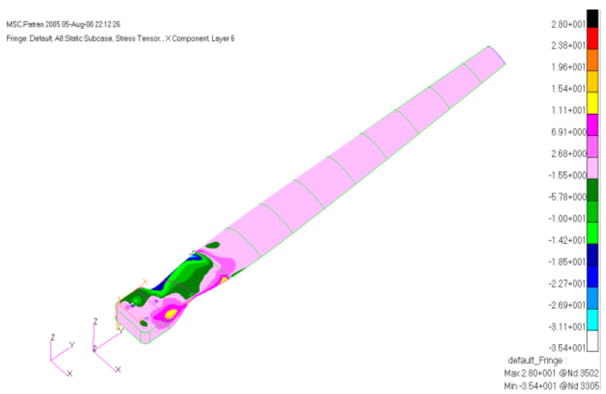

Fig. 2 Stress analysis result of fatigue load

3. Tower Design and Analysis

Structural analysis was performed for the tower that supports the blade system of this study to evaluate its structural safety [4,5]. The structural analysis of tower was performed by first determining load by considering each load condition and analyzing stress and displacement analysis after verifying the validity of load. As for load condition according to each situation, load of tower can be considered according to wind velocity changes.

In this paper, two types of cases were considered with the load placed on tower during normal operation (load case 1) and the load placed on tower when it stopped during a storm (load case 2). Specific loads that need to be considered during tower structural analysis are load from thrust generated as blade rotates, and distributed load placed on tower from wind and load placed from nacelle & blade and tower weight they can be considered as nonuniform load with concentrated load placed in the upper part of tower and distributed load placed on the entire tower. Fig. 3 shows the entire shape of tower. The structural analysis results showed that stress placed on tower during normal operation is 23.4 MPa and the stress on tower when it stopped during a storm is 154 MPa, thereby confirming that it is a structure that ensured a sufficient level of operational safety. Fig. 4, 5 show the results of structural analysis for each load condition .

Fig. 3 Configuration of Tower

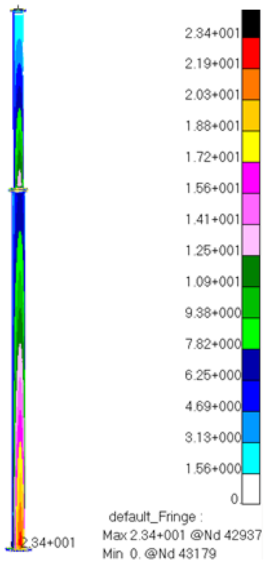

Fig. 4 Stress contour of load case 1

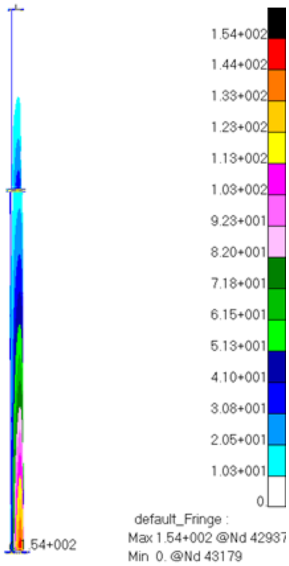

Fig. 5 Stress contour of load case 2

4. Conclusions

This paper performed aerodynamic, structural design and analysis of the horizontal axis blade of low noise 1kW class small wind turbine system that can be operated at homes and suitable for domestic regions. The result of reviewing its structural safety based on structural analysis showed that it is a structure that ensured a sufficient level of safety. In addition, the result of fatigue life analysis showed that it sufficiently satisfied the required life of 20 years. Based on the structural analysis of a tower supporting the blade system, it was confirmed that the tower structural design is a structure that ensured a sufficient level of safety.

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