Design and Evaluation of Glass/epoxy Composite Blade and Composite Tower Applied to Wind Turbine

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Abstract. In the study, the analysis and manufacturing of small class wind turbine blade was performed. In the structural design, firstly the loading conditions are defined through the load case analysis. The proposed structural configuration of blade has a sandwich type 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. And also, this work proposes a design procedure and results of tower for the small scale wind turbine systems. Structural analysis of blade 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. Moreover, investigation on structural safety of tower was verified through structural analysis by FEM. The manufacturing of blade and tower was performed based on structural design. In order to investigate the designed structure, the structural tests were conducted and its results were compared with the calculated results. It is confirmed that the final proposed blade and tower meet the design requirements.

1. Introduction
The technology for wind energy was being studied and researched in many methods in the midst of the recent state where researches were being widely performed on alternative wind power research and development results from the exhaustion of fossil fuel. Recently, the supply of electric power was being substituted through wind turbine technology in Europe and that is said that over 10 percent is being covered in areas of Germany and Denmark[1]. In the studied tendency of electric energy from wind, wind turbine technologies were being studied in many sizes from the small scale to large electric powers. Since the small scale wind turbine can be operated individually in a small size, involved researches are being carried out lately[2]. Moreover, a utilization of composites has led to the result of important betterment of structural configuration. But, many researched blades of small scale wind turbine technologies were studied in Europe countries. Accordingly, the rated wind velocities are not suitable for the domestic condition. Therefore, there is the necessity to research and develop wind turbine blade suitable for the local climate conditions. And also, tower design is very important for wind turbine system. Even though the towers are simple structural type to other structures, development of a cost effective tower is important because the tower has 25% of the whole wind turbine technology.

In this work, design, analysis and manufacturing of the blade and composite tower of wind turbine was performed. It can be worked at domestic region and manufactured to display good performance in low wind velocity region. Manufacturing about prototype and structure tests were performed to
investigate whether real motion of designed blades are consistent with the theoretical calculated results. And also, investigations on safety of structure were carried out through the FEM analysis method of the tower for developed small wind turbine.

2. Composite blade design and manufacturing

For blade design, the specification of blade system was investigated. The type of wind turbine system is 1kW class in this study. And also, the horizontal axis system for blade was adopted. The rated wind speed is 12 m/s. The used airfoil is NACA 632-615[3]. The diameter of blade is 2.54 m. The torsion angle is 22°. Wind turbine blade system to be adopted is a direct-driven axial flux permanent magnetic equipment. This magnet equipment has high energy conversion technology at low velocities. Specific aerodynamic designed results are specified in Table 1. Figure 1 shows designed aerodynamic configuration.

The design and analysis blade structure was carried out after investigation on aerodynamic configuration to investigate the structural configuration safety and stability of composite blade through stress analysis using FEM method. Structural designed load includes the aerodynamic calculated loads of blade and rotational load as major load. For aerodynamic loads 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.

![Figure 1. Designed aerodynamic results of composite blade](image)

**Table 1.** Designed results of blade

|                | 1,000 W |
|----------------|---------|
| Power          |         |
| Diameter       | 2.54 m  |
| Root chord     | 143.42 mm |
| Tip chord      | 64.84 mm |
| Twist          | 22°     |
| Airfoil        | NACA 632-615 |

The skin and foam core sandwich composite structural type were applied as the structural configuration based on the design load. In structural designed configuration, spar and skin were laminated number of layers through longitudinal direction from the root area of blade for weight reduction by calculated sectional loads.
Table 2. Design loads

| Load cases            | 1      | 2      | 3      |
|-----------------------|--------|--------|--------|
| Wind velocity         | 12.8m/s| 30.0m/s| 55.0m/s|
| Gust (±20m/s,±40°)    | No gust| With gust| Storm |
| Rotational velocity   | 500rpm | 800rpm | Stop   |

For the analysis of blade structure performed to investigate the safety of structural design configuration, finite analysis method, MSC. NASTRAN software was used, and failure criteria index theory [4] was adopted as the failure criterion for the safety. The structural analysis results for each load condition defined that it was designed with a safe structural configuration ensuring sufficient safety rate. Table 3 shows the result of load condition-specific finite element linear static analysis result and the review of according failure. Eigenvalue analyses were analyzed to examine any resonance problem of blade and a result showed that resonance problem didn’t happen around worked conditions. The evaluation of buckling stability also confirmed that it is a structure ensuring a sufficient safety and stability during work with over the maximum loads. The maximum loads of fatigue were investigated based on equations of Spera for fatigue life estimation result was 577Nm and the fatigue estimation result showed 35.4MPa. This value is maximum compressive stress. The stress of tensile is 28MPa. Therefore, the designed blade was safe as allowable fatigue strength (1445MPa)[5]. A result of structural designed blade was confirmed that it is the blade that ensured required fatigue life.

The results of structural designed blade were compared with structural tested result for verification. The stress, deformation and fatigue life analysis result of designed blade were investigated respectively. Figure 2 shows first flap mode configuration and frequency and Fig. 3 shows prototype blade.

Table 3. Structural analysis results

| Results                        | 1       | 2       | 3       |
|--------------------------------|---------|---------|---------|
| Maximum Stress [MPa]           | Tension | 27.2    | 73.0    | 28.6    |
| Compressed                     | 19.8    | 69.8    | 20.2    |
| Max. Disp. [mm]                | 27.3    | 82.8    | 28.3    |
| Tsai-wu failure criterion      | 0.071   | 0.278   | 0.126   |

Figure 2. First flap mode shape and frequency
3. Evaluation of designed tower

Safety evaluation of tower was carried out. In this study, it was evaluated structural safety of supported system for the blade[6,7]. Firstly, the investigation of tower structure were carried out by determining design loads by considering each loading conditions and analyzing deformation and stress analysis after verifying the load. As for various loading condition according to each cases, the tower loads can be defined.

In the study, two conditions were investigated with the loads placed on tower during normal operation condition and the loads placed on tower when it was stopped during the storm condition. Critical loading that need to be investigated during structural analysis of tower are load from thrust occurred from blade rotating and distributed load placed on tower from wind and load placed from blade weight, generator weight and tower weight. They can be considered as non-uniform load with concentrated load placed in the tower upper section and distributed load placed on the whole structure. Figure 4 shows load configuration of tower. W is weight of blade and nacelle. P is load of wind turbine and q is distributed load of wind. The analysis results of tower showed that stress placed on tower during normal operation is 23MPa and the stress analysis result when it stopped during a storm is 154MPa, thereby identifying that it is a tower that ensured a sufficient state of operational safety. Figure 5 and Fig. 6 show the results of natural frequency analysis.

Figure 3. Manufactured prototype blade

Figure 4. Load of tower
4. Conclusions
In this work, structural design and manufacturing of blade system was carried out. Firstly blade design was performed and then tower design was conducted. It can be worked in domestic region and manufactured to display good performances in low wind speed regions such as Asia. Manufacturing of prototype and experimental tests were performed to verify whether the real motion of the designed blade and tower is consistent with the theoretical calculated result. In addition, investigations on structural safety were carried out through the FEM of the blade and tower for installing the developed small wind turbine.

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