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Mechanical Analysis of a 1.2 MW — 40 m Long Horizontal Axis Composite Material Wind Turbine Blade by S-N Fatigue Cycle and Goodman Diagrams in Windpower Engineering

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The critical issue for generating electricity device driven by kinetic energy of the wind remains as the design of the wind turbine blade and its structure. A 1.2 MW and 40 m long blade horizontal-axis wind turbine with a hybrid composite configuration by carbon and glass fiber ply was developed to analyze structural design in virtual environment imitating extreme wind speed conditions. When designing a wind turbine, using finite element analysis modeling by ANSYS may help produce the desired simulation of the structure so as to ensure a certain level of structural safety. A few literatures are openly accessible on the physical design activity of multi-megawatt blades as it is held private by the designer and engineers. In this report, von Mises criteria, fatigue analysis and Goodman diagram for a fiberglass material of comprehensive wind turbine blade model was established and examined with regard to typical failure conditions to identify the structural modules of the wind turbine blade. The wind blade was exposed to finite element analyses to show its capability to survive the intense loading circumstances i.e. varying heavy mechanical loads, stresses and strain due to more difficultness to cope with static loads as the material becomes fatigued. The computational evaluation outcomes displayed that the designed turbine blade structure was safe, and the stress and strain value was low.

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PACS/topics: finite element method, composite material, mechanical stress and strain

1. Introduction

The wind turbine blades are exposed to particular loads and stresses [1]. Because of heavy mechanical loads and the nature of the wind, the mapping of stress and strain of wind turbines and the dynamic effect of the fatigued structure become critical [2]. The wind turbine blade design activities that have a dispersive impact on the performing structure of the wind blade are presented related to the research explained in this paper. While planning a wind turbine, the point is to accomplish the most important conceivable energy yield in specific climatic circumstances and this relies on the blades geometrical shape [3]. The modification of the geometrical profile of wind turbine blade, and dynamic/mechanical properties of composite material [4] are the strategies to adjust rigidness and steadiness, however it might impact aerodynamic effectiveness of wind turbine. Next section explains the 1.2 MW horizontal axis composite material wind turbine blades by finite element analysis — the Goodman diagrams in wind power engineering.

2. Materials and methods

Computational fluid dynamics (CFD) and structural modeling module ANSYS LS-DYNA tools were used to analyze aero-dynamical stresses characteristics on wind turbine blade [5]. Adapting the location of spurs and its features can vary the position of elastic core. The geometry of wing turbine blade was modelled in ANSYS to acquire the vital properties of the blade and location of spurs. The finite element method is verified for computing numerous loads for structural robustness on the wind turbine blade. The important purpose was to minimalize mass and cost while maximizing the power output of the wind blade.

The research of the blades aerodynamic and structural optimization was essential for the new configuration of the entire wind turbine blade. A commercial wind turbine blade with a length of 40 m and a mass of 4580.4 kg was used for a case study in this research. Figure 1 shows the geometry shape of the blade, which can be explained in three regions: root, transition part, and aerodynamic part.

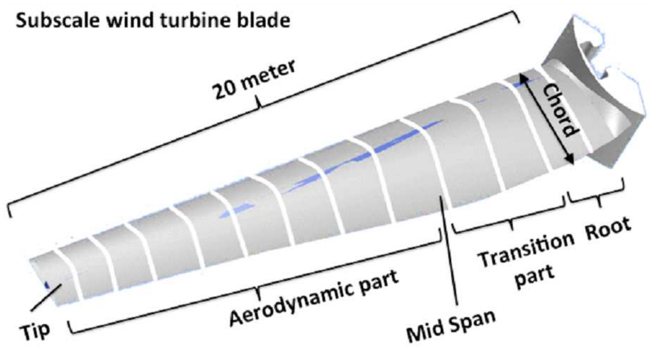

Fig. 1. Wind turbine and describing elements.

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Throughout the full-scale simulation experiment was realized with different deformation patterns. The wind blade was divided of 20 m length size (40 m in total length) into three parts. This consists of root part (0–3 m), transition part (3–7 m), box girder part (7–20 m) as subparts of wind turbine blade. The web unit distortion is because of the gravity load, which bases the web to display a nonsymmetrical performance before loading in this new approach.

A model was structured for a span wise part of the blade. It was experimentally discovered that 0–3 m part is utmost dangerous segment for ultimate deformation. The frame boundary conditions of blade assumed in the sub-model were depending on the displacement area captured of finite element analysis (FEA) model with a nonlinear displacement. The glass epoxy material used by handling load of box girder of the wind blade was created as presented in Fig. 2.

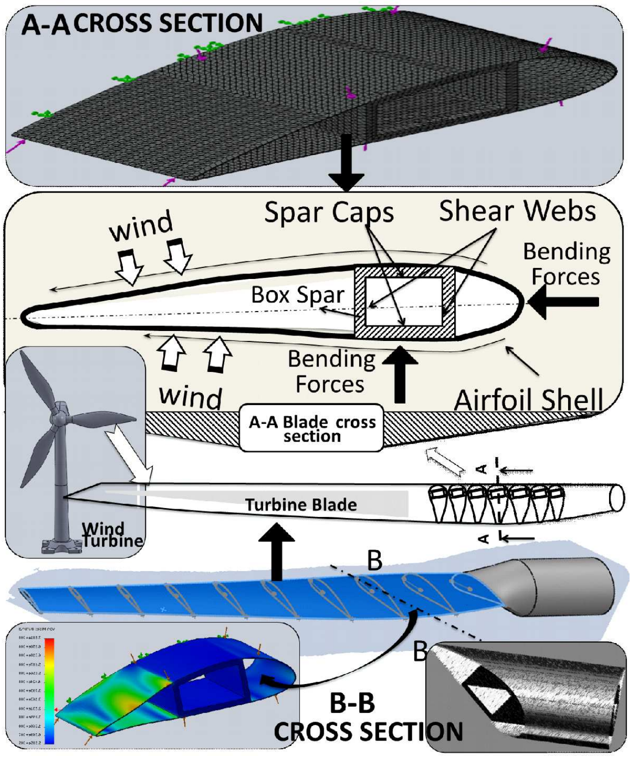

Fig. 2. Wind turbine blade cross-section.

The graphite, S-glass, E-glass were also used in composite material as the high rigidity to weight proportion for blade supporter and glass fibre strengthened spur. The shell elements for both parts were applied to the spur that was formed as square shape. The wind turbine blade entails of two surfaces of suction and stress side that combined and strengthened by adhesives for shear webs as spur, box-beam, I-section as displayed in Fig. 2. The FEA model generated as the model of the turbine blade includes 129314 elements, 99865 nodes and 149 parts meshed in ANSYS v18. The 58-element type, 8-nodded shell with 6 degrees of freedom was handled as an element thickness of 20 mm. The computational simulation of the static and fatigue assessment of wind turbine blades was established in accordance with the standard ISO 17025 and Part-1 of IEC 61400 standard [6] to meet international design standards for the structural safety.

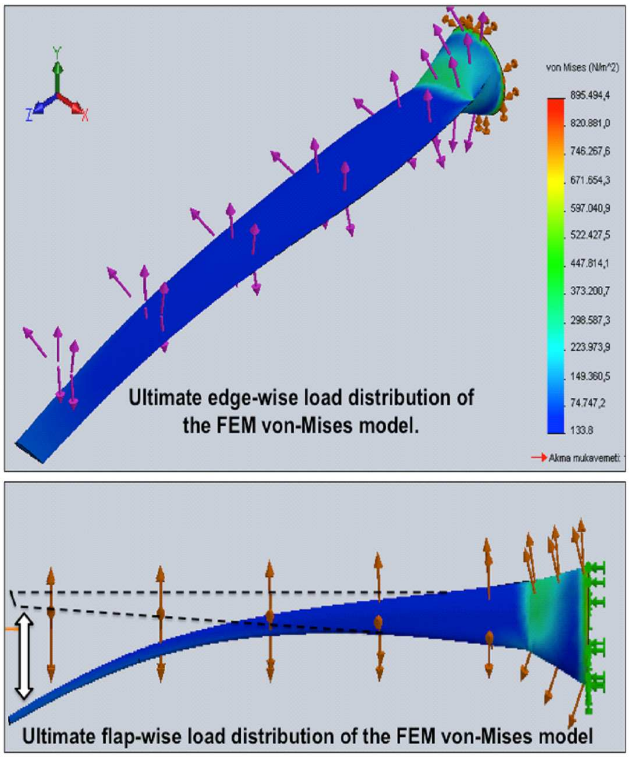

Fig. 3. Equivalent von-Mises stress.

Figure 3 displays the von Mises stress on the blade at different sections. These stresses are higher in the root part of the blade model and considerably enhanced. The equivalent stress of epoxy carbon maximum case is 10.514 mm and minimum is 0.036428 mm and this von Mises stress or equivalent stress plays a vital role to design the any kind of structure. The directional deformation in x-axis at maximum position is 729.46 mm and minimum position is 0 mm. The directional deformation at y-axis found to be in maximum case 0.56259 mm and minimum case −25.469 mm. The directional deformation at z-axis maximum is 10.426 mm and minimum is 6.3219 mm. From Fig. 4, the deformations about x and y axis maximum at tip of the blade and minimum at other end and similarly for z axis the maximum deformation and minimum deformations occurred at same point near the left side edge. The total deformation of epoxy carbon maximum case is 729.9 mm and minimum is 0 mm and this deformation plays a key role to design any structure. The safe design with less deformation shows the impact on the structure. At stationary position, the fluent analysis was applied to wind turbine blade in terms of 3.5 m/s wind velocity. The maximum structural pressure was 219.6 Pa.

The S-N data for load of 10^8 cycles for fatigue performance was shown in Fig. 4. The fatigue analysis as safety factor [4] value was experimented. After this analyses as a more advantage to the designer, maximum value was discovered as 15 at shell part and 10 at the central core. The very high cycle S-N fatigue data was explored and was presented in Fig. 4.

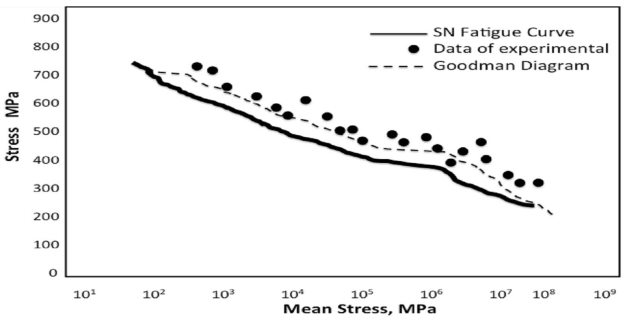

Fig. 4. Fatigue life cycle S-N diagram.

For range loading calculations, a more comprehensive Goodman diagram was established with added values R. The fatigue cycle R-value in Eq. (1) was stated as

$$R = \frac{\sigma_{\rm min}}{\sigma_{\rm max}}, \tag{1}$$

where the minimum to greatest stress proportion in a cycle called R as illustrated in Fig. 5. σ_{max} was accepted as the maximum stress while the minimum stress was σ_{min}. In tensile test, the value R is close to 1.0 for low cycle fatigue data.

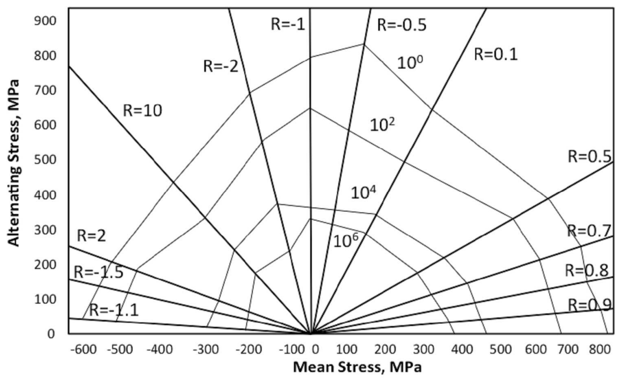

Fig. 5. The Goodman diagram for wind turbine.

For the investigation of S-N information, the depiction is the Goodman approach appearing in Fig. 5. These figures are exhibited in expanding level of information about the S-N conduct of the fiberglass composite material. This graph was the most point by point to date, and it incorporates a few stacking conditions. Fiberglass composite matrix material was used according to the standard IEC 61400 Part 23 and ASTM D 5379.

3. Conclusions

A horizontal axis composite material wind turbine blade was proposed by the analysis tools FEM, S-N fatigue and Goodman approach. A computational model was established for calculation of the chord, thickness and twist distribution of the wind turbine blade. The aerodynamic design of wind turbine is virtually improved by about 5% design in simulation environment. The bulk decrease of 21.4%, reduction of maximum deformation of 17.2% and maximum stress reduction of 11.4% were seen in the remodeled design. The numerical analysis of beam box of wind turbine results confirmed the design to have acceptable performance with regard to maximum and minimum stress-strains. The structural components of wind turbine are presented along with the resulting max-min strains, deflections and von Mises criteria by FEA.

Acknowledgments

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