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# Fatigue Analysis of an Optimized HAWT Composite Blade

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**Abstract:** *The objective of this work is to study the fatigue behavior of an optimized composite wind turbine blade of a previous research. This work employs methodologies using classical theory, as well as probabilistic and numerical techniques for the study of the wind turbine blade. Rainflow cycle counting technique and Palmgren-Miner's sum are used to estimate the fatigue service lifetime of the blade. Fatigue analysis for the blade results showed that the service lifetime of the blade until failure is about 17 years for the turbine operating speed of 36 rpm, and about 15.8 years for the operating speed of 47 rpm, which are less than the expected service life of 20 years by 14.7% and 20.9% respectively.*

**Keywords:** Wind Energy; Composite Materials; Blade Design; Fatigue.

## 1. INTRODUCTION

Wind power is an alternative to fossil fuels. Its environmental effect is much less problematic than that of nonrenewable sources of energy. For that reason, wind energy is one of the dominant topics of research nowadays. Research in this field is based on improvement of the efficiency of energy extraction from the wind, reducing the stresses on the rotor blades, and reducing the weight of the blade itself.

## 2. PROBLEM STATEMENT AND METHODOLOGY

The wind turbine blade subject to study in this work is a result of a previous study [1]. The composite material Horizontal Axis Wind Turbine (HAWT) blade was optimized using genetic algorithm to determine the number of layers of the composite laminate, fibers orientation in each layer, fiber volume fractions, and layer thickness. The optimized laminated material resulted in 21-35% stresses reduction, 10-28% blade deformations reduction, and about 25% blade weight reduction, compared to the equivalent aluminum blade for the same wind turbine. The design was based on a static loading only. A specific position for the blade and a wind speed of 10 m/s was used to predict the pressure distribution over the blade. Then this pressure distribution was used for design and analysis. In reality, the rotor blade is subject to dynamic loads, due to the variation of wind speeds, directions, intensities, and also for the centrifugal effect of the blade rotation. These dynamic loads must be considered because they affect the lifetime of the wind turbine, and that is the point of research in this work; a fatigue analysis for the optimized composite blade following the work made in another research [2].

Analysis is made using QBlade [3], an open source turbine calculation software with a FAST (Fatigue, Aerodynamics, Structure and Turbulence) simulation tool seamlessly integrated into it. The aerodynamic loads are calculated using Blade Element Momentum theory (BEM) for a variety of wind conditions, and then a structure analysis is made on an equivalent isotropic model for the wind turbine blade. FAST simulation results in time series for different loads and wind velocities over the wind turbine blade. These time series are used for post-processing on MLife [4], a MATLAB® based tool to estimate the fatigue lifetime of the turbine blade.

## 3. SIMULATION

Simulation is made for the wind turbine subject to study. It has a 19 m diameter, 100 kW nominal power, and two operating speeds; 36 and 47 rpm. Study was made for both operating speeds to estimate the lifetime for each one. The mass and stiffness distributions are calculated per unit length of the blade. This can be shown in Fig. 1 and Fig. 2.

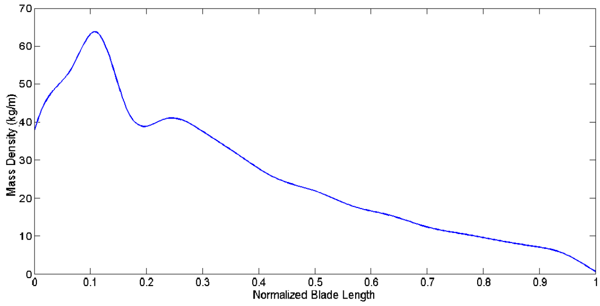

Figure 1 Mass per unit length of the blade

It may be noticed that there is a drop in the mass at about 20% of the blade length; this indicates the end of the hub section and the beginning of the effective part of the blade. This will also apply for the stiffness distributions.

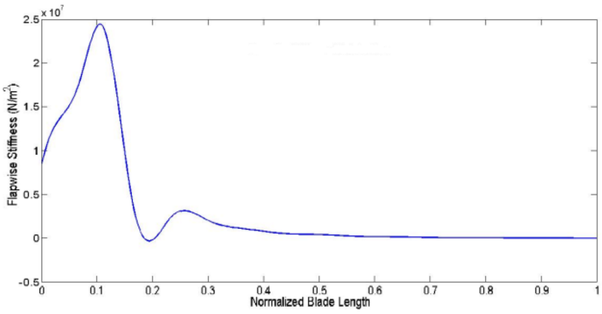

Figure 2 Flapwise stiffness distribution

Before performing FAST analysis, a turbulent wind field is generated using Sandia method (Also known as Veers Method). It is important to have an environment similar to that the wind turbine faces in reality, where it is subject to turbulence, wind shear, and tower effect. The wind field simulation is made, the maximum wind speed is 16.8 m/s and the highest wind spectrum frequency is 0.8333 Hz.

FAST simulation parameters are set for a simulation time of 60 s with time step 0.05 s for the operating speed of 36 rpm to obtain time series for wind velocities and loads over the blade length. Then a Fast Fourier Transform (FFT) analysis is performed for each time series to figure the dominant frequencies for each load over the blade. Fig. 3 to Fig. 6 show sample time series and their FFT analyses.

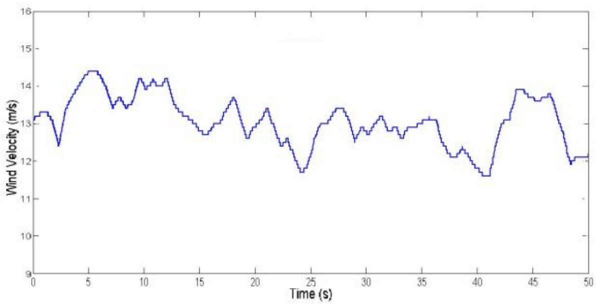


Figure 3 Total wind velocity at hub height time series

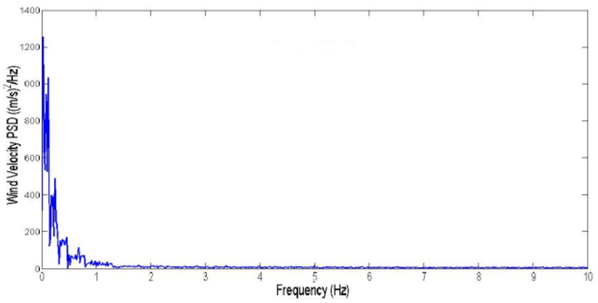


Figure 4 FFT analysis for wind velocity at hub height

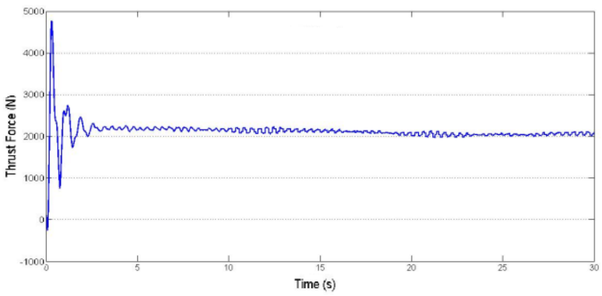


Figure 5 Rotor thrust force time series

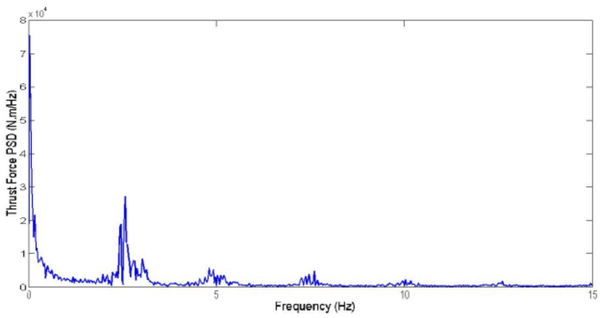


Figure 6 FFT analysis for the thrust force

From Fig. 5, we may observe that the thrust force fluctuates severely for the first 5 seconds before damping; this indicates the effect of the operation start, which has a great effect on the blade dynamics. We may also observe from the FFT analyses that the dominant frequencies in the frequency domain, is nearly equal to 0.83 Hz which is the same as the generated wind field spectrum frequency.

## 4. POST PROCESSING

FAST simulation time series are post processed using MLife to estimate the fatigue lifetime of the blade. The input file to MLife is a Design Load Case (DLC) file, including the time series in a certain template provided by the software developers. The fatigue analysis tool uses the Rainflow counting technique and Palmgren Miner's sum. MLife analysis follows this general outline: i) Processing all input data files, ii) computing aggregate statistics across all data files, iii) determining the fatigue cycles for each time-series using rainflow counting, iv) computing the short-term damage rates and damage equivalent loads (DEL), v) summing the damage contribution of each time series, vi) extrapolating the damage contribution of each time series to determine the lifetime damage, and finally vii) computing the time until failure [4].

MLife accumulates the fatigue damage due to load variation assuming a linear behavior with the load cycles. Fatigue analysis is made for two DLCs; DLC_1, and DLC_2 corresponding to the two operating speeds of 36 and 47 rpm respectively.

## 5. RESULTS AND DISCUSSION

The results of the total service time estimation and the deviation percentage from the design service time of 20 years are presented in Table 1

Table 1. Service lifetime until failure for two load cases

| Load Case | Service Lifetime (Seconds) | Service Lifetime (Years) | Deviation % |
|---|---|---|---|
| DLC_1 36 rpm | 530720000 | 17 | 14.7 |
| DLC_2 47 rpm | 491608936 | 15.8 | 20.9 |

Fatigue analysis of the wind turbine blades showed that the service lifetime of the blades until failure is about 15.8 years for the operating point of 47 rpm, which is deviated from the design point of 20 years of service time by 20.9%. This is somehow acceptable as it is not too large deviation from the design point. However, for less deviation, few modifications to the blade design like changing the composite laminate structure, change the type of the fibers, or the matrix; would result in improving the lifetime of the blade

## 6. REFERENCES

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