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STRUCTURAL ANALYSIS OF HORIZONTAL AXIS WIND TURBINE MODEL USING QBLADE SOFTWARE

BY

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Abstract. This paper presents a structural analysis of horizontal axis wind turbine model using QBlade software. The structural analysis has been performed with aerodynamic loading at designed point for three different types of blades: hollow blade, hollow blade with spar and solid blade. For these configurations, three materials from QBlade library were chosen: generic double bias material, generic triaxial material and 7000 Series Aluminium material. Natural frequencies obtain from modal analysis for all configurations are in a safety domain and resonance is avoided. The best configuration of wind turbine blade in terms of mass analysis, natural frequencies and von Misses stress is hollow blade with spar, manufactured by generic double bias material.

Keywords: HAWT; blade; modal analysis; structural analysis; QBlade.

1. Introduction

Of all the renewable energy sources, wind energy is one of the most used sources, being the sector with the fastest development and a sustainable mode to reduce the negative effect of fossil fuel consumption. The kinetic

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energy of the wind is converted by wind turbines in useful forms of energy used to: produce electricity, mechanical power and pumping water (Ellabban *et al.*, 2014). Wind turbines are classified in two mainly types depending of rotor shaft rotational axis position: Horizontal Axis Wind Turbine (HAWT) and Vertical Axis Wind Turbine (VAWT) (Rabiul *et al.*, 2019).

In addition to the aerodynamic analysis of a wind turbine blades model or prototype, an important stage is the structural analysis. Structurally, blades failures are the most common type of damage of wind turbines. In order to maintain continuous operation of wind turbines a structural health monitoring system is used (Zhou *et al.*, 2014).

To characterize the dynamics of mechanical systems a modal analysis is used as a preliminary method because providing easy interpretable results. For wind turbine blades, modal analysis identifies natural frequencies and mode shapes for different rotor speed and provides information of structural elements at resonances, in order to understanding the structural behaviour (Larsen *et al.*, 2002; Araújoa *et al.*, 2017; Zahariea *et al.*, 2019).

In this paper a structural analysis of a model of HAWT blade was performing using QBlade software. Will be analysed and evaluated the modal frequencies on flapwise, edgewise, torsional and longitudinal direction and von Misses Stress for three types of blade structures: hollow blade, hollow blade with spar and solid blade and three different material: generic double bias material, generic triaxial material and 7000 Series Aluminium material.

2. Blade Characteristics of Wind Turbine Model

The design of the horizontal axis wind turbine model blade was performed using Blade Element Momentum method. The blade geometry presented in Fig. 1 contain the airfoils names and position along the blade.

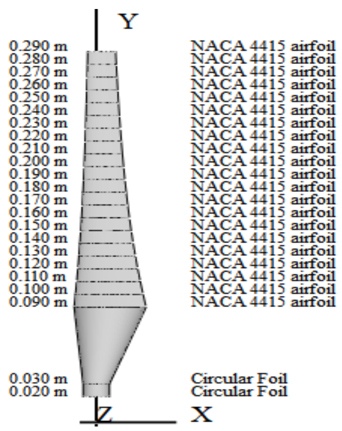


Fig. 1 – Horizontal axis wind turbine model blade geometry.

On the entire length of the aerodynamic zone of 0.20 m, NACA 4415 airfoil was used. The main rated parameters used for accomplishing the design are: wind velocity, 15 m/s, rotational speed, 2700 rpm, Reynolds number, 83000 and tip speed ratio, 5.46 (Husaru *et al.*, 2019).

3. Modal and Structural Analysis

Modal analysis has been accomplished for three different materials and three different blade types: hollow blade, hollow blade with spar and solid blade. The main properties of the materials, density and Young's modulus are presented in Table 1. The hollow blade has a variable shell thickness equal with 2% of chord thickness on the entire blade length. Also, the spar thickness is variable on the entire blade length equal with 8% of chord thickness, at 50% of chord length and with 0 degrees of spar angle. The spar is made of the same material as the blade.

Table 1
Material Properties

Material	Density [kg/m^3]	Young's modulus [Pa]
Generic double bias	1750	1.2e+10
Generic triaxial	1850	2e+10
7000 Series Aluminium	2900	7.3e+10

The masses of the blades for all three materials and three configurations obtained in QBlade software are presented in Table 2. Due to dimensions of the blade the masses are relatively small. The maximum mass blade of 0.088 kg was obtained for solid blade configuration and manufactured of 7000 Series Aluminium material.

Table 2
Mass of the Blades

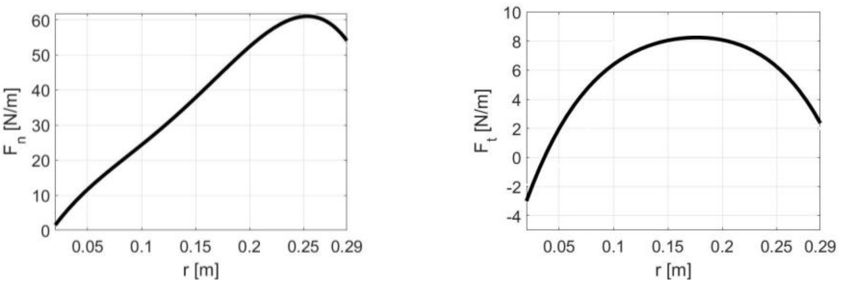
Material	Blade type	Mass [g]
Generic double bias	Hollow blade	15.6
	Hollow blade with spar	19.8
	Solid blade	53.1
Generic triaxial	Hollow blade	16.5
	Hollow blade with spar	21.0
	Solid blade	56.1
7000 Series Aluminium	Hollow blade	26.0
	Hollow blade with spar	32.9
	Solid blade	88.0

At the design point, at 2700 rpm of rotational speed, the excitation frequency of the one blade associated with a complete rotation is 45 Hz, and for three blades is 135 Hz. The values of first two modes of natural frequencies for flapwise, edgewise, torsional and longitudinal direction at designed point are presented in Table 3. In all configurations, the resonance phenomenon does not occur. The most dangerous configuration is on flapwise direction for hollow blade when the modal frequencies are 232.57 Hz for generic double bias material, 250.66 Hz for generic triaxial material, and 296.50 Hz for 7000 Series Aluminium material.

Table 3
Modal Frequencies

Material	Blade type	Modal frequencies [Hz]			
		Flapwise	Edgewise	Torsional	Longitudinal
Generic double bias	Hollow blade	232.57	507.63	1980.27	2831.22
	Hollow blade with spar	246.37	501.45	2146.86	3282.52
	Solid blade	267.09	533.92	2567.59	3666
Generic triaxial	Hollow blade	250.66	530.08	2382.14	3848.06
	Hollow blade with spar	266.76	520.78	2368.30	4117.23
	Solid blade	289.25	565.04	3127.07	4609.23
7000 Series Aluminium	Hollow blade	296.50	603.89	3784.68	12890
	Hollow blade with spar	316.80	584.88	4072.85	6283.81
	Solid blade	339.87	663.56	4642.35	7042.17

The structural analysis has been performed with aerodynamic normal and tangential loading at designed point with rated wind velocity of 15 m/s and rotational speed of 2700 rpm. The distributions of normal and tangential force per unit length along the blade resulting by aerodynamic simulation in QBlade interpolated with 4th degree polynomial are presented in Fig. 2.



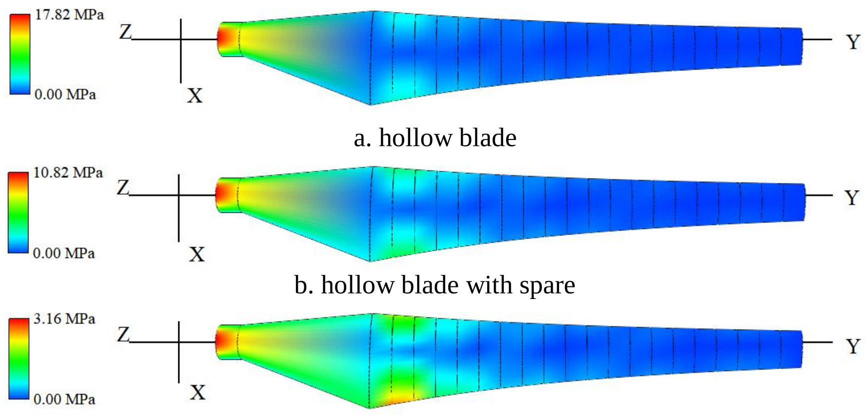
a – normal force *b* – tangential force

Fig. 2 – Distribution of normal and tangential force per unit length along the blade.

The von Misses stress distributions on the blade for all configurations are presented further in Fig. 3 for generic double bias material, Fig. 4 for generic triaxial material and Fig. 5 for 7000 Series Aluminium material.

The highest values of von Misses stress occur at 0.02 m radius (hub radius zone) for hollow blade and hollow blade with spar configurations and at 0.09 m radius (beginning of aerodynamic zone) for solid blade configurations.

The minimum values of von Misses stress occur for solid blade configurations at each material analysed. Their values are 7.79 MPa for 7000 Series Aluminium material, 4.20 MPa for generic triaxial material and 3.16 MPa for generic double bias material.

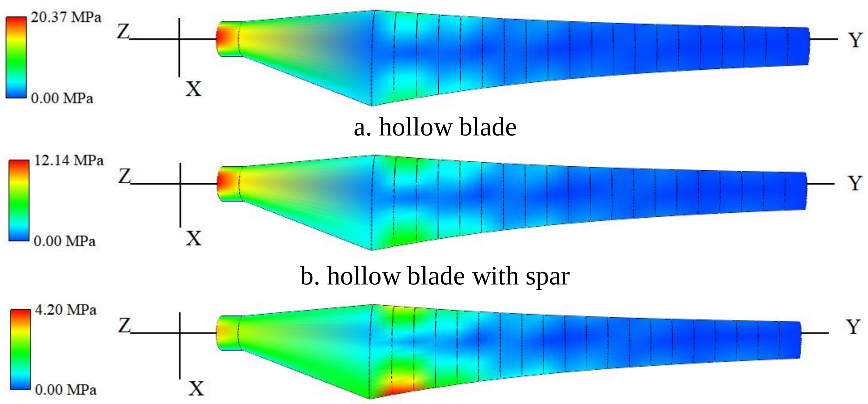


a. hollow blade

b. hollow blade with spare

c. solid blade

Fig. 3 – Von Misses stress-generic double bias material.



a. hollow blade

b. hollow blade with spar

c. solid blade

Fig. 4 – Von Misses stress-generic triaxial material.

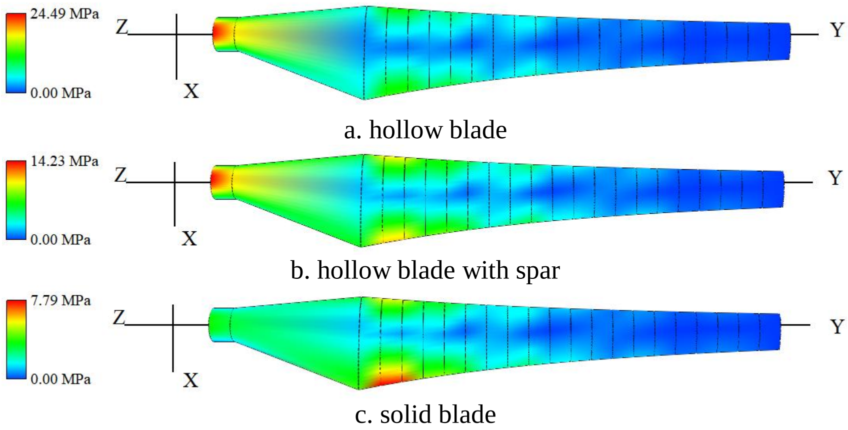


Fig. 5 – Von Misses stress-7000 Series Aluminium material.

The von Misses stress values along the wind turbine model blade in all configuration are presented by comparison in Fig. 6 for hollow blades, in Fig. 7 for hollow blades with spar and Fig. 8 for solid blades. The difference between values of von Misses stress are considerable between the three types of blades analysed. For example, if generic double bias material is used the von Misses stress values are higher with 342% for hollow blade with spar configuration and 564% for hollow blade configuration in comparation with solid blade configuration.

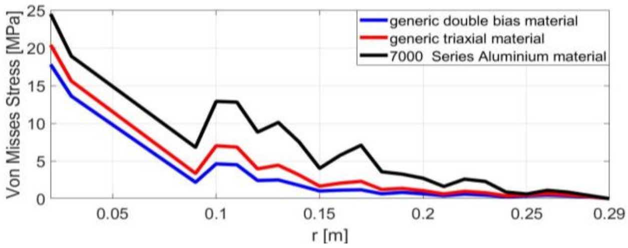


Fig. 6 – Von Misses stress along the hollow blades.

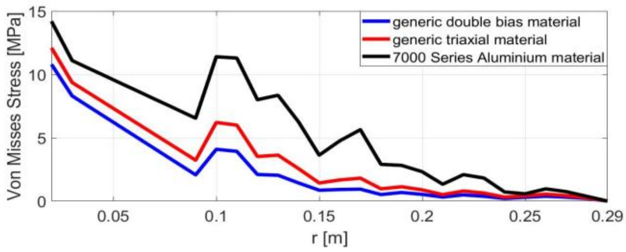


Fig. 7 – Von Misses stress along the hollow blades with spar.

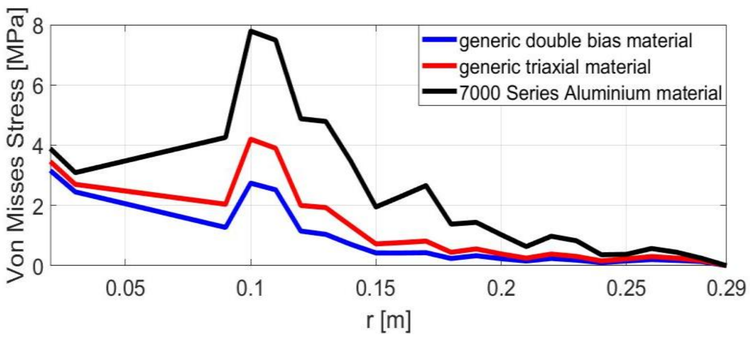


Fig. 8 – Von Misses stress along the solid blades.

4. Conclusions

Structural analysis is an important stage in addition to the aerodynamic analysis for design the wind turbine blades model or prototype. Thus, the modal frequencies and the Von Misses stress can be determined for different types of blades and materials.

According to modal analysis results obtained in QBlade simulations, most dangerous configuration occurs for hollow blades on flapwise and edgewise directions. However, even in this case, the natural frequencies are greater than excitation frequency of the three blades of the wind turbine model rotor associated with a complete rotation with approximatively 175%. Thus, the resonance phenomenon is avoided.

The best configuration of wind turbine blade in terms of mass analysis, natural frequencies and von Misses stress is hollow blade with spar, manufactured by generic double bias material. Where the overall dimensions are relatively small may be considered that solid blade is the best configuration. In this particular case, the others configurations may present difficulties of manufacturing and operation because of small values of mass and shell thickness.

Even if QBlade software libraries does not disposes a wide range of materials for structural analysis, the results obtained can be considered as preliminary for structural design, following to be subsequently verified with other numerical simulations in dedicated programs or through experiments.

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ANALIZA STRUCTURALĂ A UNUI MODEL DE TURBINĂ EOLIANĂ CU AX ORIZONTAL UTILIZÂND SOFTWARE-UL QBLADE

(Rezumat)

Această lucrare prezintă analiza structurală a unui model de turbină eoliană cu ax orizontal, utilizând software-ul QBlade. Analiza structurală a fost efectuată cu forțele aerodinamice rezultate la regimul nomial de funcționare pentru trei tipuri constructive de pală: pală goală, pală goală cu element de rigidizare și pală solidă. Pentru aceste configurații, au fost alese trei materiale din biblioteca QBlade: generic double bias, generic triaxial și 7000 Series Aluminium. Frecvențele proprii de vibrații obținute din analiza modală pentru toate configurațiile se află în domeniu de siguranță, iar fenomenul de rezonanță este evitat. Cea mai bună configurație a palei turbinei eoliene model din punctul de vedere al masei, frecvențelor naturale și tensiunilor echivalente von Misses este pala goală cu element de rigidizare. Datorită dimensiunilor de gabarit reduse ale palelor o a doua opțiune viabilă o reprezintă configurațiile cu pale pline.