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Design and Manufacturing Method of GFRP Blades for Vertical Axis Wind Turbine

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Abstract. Today, environmental protection and the rational use of natural resources have become growing challenges. One of these aspects is energy producing with less impact on the environment. For some applications the small wind turbines can be a solution. In this paper are presented some aspects regarding the design and manufacturing technology of 500 W vertical axis wind turbine blades. The turbine will be installed in the urban environment so that requirements regarding rotor aesthetics and noise level will be considered. The optimal geometric parameters of the turbine rotor were determined by specialized MathCAD and elaborated in 3D modelling software. For the blades the NACA 0018 airfoil was used with the chord length of 110 mm and is constant throughout the length of the blade. The blades are helical and are 1800 mm long. To estimate the aerodynamic performance of the turbine rotor, a computational fluid dynamics model was developed using ANSYS CFX finite element analysis software. The authors proposed a new method for rapid prototyping of blades using fused deposition modelling procedure. In order to increase the mechanical properties, the blades were covered with several layers of glass-fibres reinforced polymer. Estimation the blade strength to operating loads was performed using Ansys Workbench software. The modelling of the composite material architecture on the blade surface was performed using the special ANSYS Composite PrepPost module. Several simulations were performed with different number of layers and stacking sequences. In order to prevent rotor over engineering the maximum rotation speed of 400 min^{-1} was accepted (equivalent to ≈12 m/s wind speed). Simulation of the blade strength to operating loads indicate values of around 40 MPa for shear stress (50% less than failure shear stress) and around 80 MPa principal stress (60% less than failure tensile stress). The maximum blade deformations of 3 – 4 mm shows that the blade is stiff enough at imposed operation conditions. For the blade manufacturing, based on the numerical analysis results, the configuration of the strength structure composed of 5 layers of GFRP was selected, which forms a total blade weight of 1895g.

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1. Introduction

Environment protection is one of the most important factors of sustainable development. Energy production without harming the environment is an ongoing concern of research centers. The wind turbine in last period has a very impressive development. Different authors traded in papers research regarding the evolution, design or behavior of wind turbine generators. Using different airfoils the positioning of attack angle of the blades were obtained different performance and efficiency. Numerical modeling and simulation of blades rotation are a challenge and different authors proposed some solutions in order to obtain the best blades geometry, airfoils, curved-bladed and helically twisted configuration [1, 2]. In [2] the authors presented analysis for H-rotor Darrieus turbine as a low speed wind energy converter. The numerical analyze presented in [3] can be adapted like solution in order to simulate the blades motion. The vertical axis of wind turbine generators are studied in [3-4] from numerical analyses point of view. In this paper are presented aspects regarding the design, Computational Fluid Dynamics (CFD) analysis, blade strength structure evaluation, and manufacturing method for vertical axis wind turbine blades. To obtain the blade prototype an additive manufacturing methodology was used [7-10]. Using a Fused Deposition Modeling (FDM) solution a plastic prototype from ABS was manufactured. The prototype of the blade was covered by Glass Fiber reinforced Polymer (GFRP) in order to improve the mechanical properties of the blades.

2. Design and manufacturing

2.1. Design of vertical axis wind turbine rotor

The parameters required to develop the wind turbine rotor with aerodynamic blades are the following: the airfoil, airfoil chord (which defines the rotor solidity), aspect ratio, rotor diameter and its height. For this rotor the symmetrical NACA 0018 airfoil was chosen which is among the most used one for VAWTs. The airfoil selected is good one for low values of Reynolds numbers (Re < 200 000) and show reasonably constant performance, in terms of lift and drag coefficients Cl/Cd ratio, for a large range variation of the angle of attack and unsteady wind conditions, according to *airfoiltools* publicly available database. The VAWT's solidity is the ratio between the blade's area and turbine's swept area. The blade's area is considered the area of one side of it. For a straight bladed VAWT, the blade's area is calculated as chord's length and blade's height, thus the solidity σ is:

$$\sigma = (N \cdot c \cdot L)/A = (N \cdot c)/D \qquad (1)$$

Where: N – the number of blades; c – the chord length; L – blade's length; D – turbine's diameter.

Solidity directly influences the turbine's performance depicted by the power coefficient as well as tip speed ratio TSR. The TSR is the ratio between the blade's tangential speed and unperturbed wind speed. The optimal length of the airfoil chord was determined with the special applet QBlade. Several rotor simulations were performed for decent wind speed - 7 m/s (Re <100,000). At this speed the rotor should generate about 30% of its rated power. The results are presented in the diagram of the dependence of the power coefficient and the tip speed ratio, figure 1. From the diagram 1 we can observe that high solidity rotors have an improved self-starting ability, but their tip speed ratio (TSR) is lower compared to those with a low solidity.The rotor diameter and its height were determined approximately from the power calculation relation. The power output P of a wind turbine is directly proportional to its swept area:

$$P = \frac{1}{2} \cdot Cp \cdot \rho \cdot A \cdot U^3 \qquad (2)$$

Where: ρ – air density; U – wind speed, A – the swept area of the rotor; Cp – the power coefficient which in efficiency terms can takes values ranging from 0 to 0,593 (Betz limit).