Simulation research of a wind turbine using SolidWorks software

Dawid Cekus¹, Renata Gnatowska², Paweł Kwiaton³ and Michal Šofer³

¹ Department of Mechanics and Machine Design Fundamentals, Czestochowa University of Technology, Czestochowa, Poland
² Department of Thermal Machinery, Czestochowa University of Technology, Czestochowa, Poland
³ Department of Applied Mechanics, VŠB – Technical University of Ostrava, Ostrava-Poruba, Czech Republic

E-mail: kwiaton@imipkm.pcz.pl

Abstract. The paper presents wind turbine simulation tests using SolidWorks software. The geometrical model of the HAWT wind turbine was developed based on a real object. It consisted of three selected parts: shell, bearing girders and stiffening ribs. The wing profile of the analyzed object was modelled using NREL’s and NACA airfoils. A numerical analysis was carried out to determine the strength of the tested structure under specific wind speed. Stresses were calculated according to the Huber-Mises hypothesis.

1. Introduction

In recent years, significant development of renewable energy sources in Europe has been noticed. This is caused, among others, due to the policy implemented by the European Union and global warming related to the emission of harmful substances into the atmosphere [1-3].

Currently, wind energy is one of the most dynamically developing branches of the renewable energy sector in Poland. Among the biggest advantages of wind energy are no emissions of toxic compounds to the atmosphere, small losses in energy transmission, low operating and maintenance costs. However, despite the many advantages of wind farms, the biggest disadvantage is the large investment costs [4].

The rapid technological development of computers has introduced a number of tools to the engineering industry to support the work of designers. In addition to computer-aided design (CAD) and manufacturing (CAM) systems, one of the tools to reduce unnecessary cost resulting from design errors is computer-aided engineering (CAE). It allows conducting appropriate strength tests and identifying the most vulnerable parts of the structure [5, 6].

In literature, the most frequently discussed theme of wind turbine’s simulation research is computational fluid dynamics (CFD). In work [7], a numerical analysis of a Savonius-rotor vertical axis wind turbines using Fluent software was carried out. Papers [8, 9] present the aerodynamic performance and the aerodynamic attitude of vertical axis wind turbines (VAWT). The effects of wind velocity, various numbers of rotor’s blades and the rotor’s diameter were studied. Blade material effect on wind turbine efficiency was compared in article [10]. The effect of turbine enclosure on torque characteristics of vertical axis wind turbine with a straight blade was analyzed in paper [11]. Simulation tests with the use of software based on the finite element method (FEM) have been presented in the works [12, 13].
Article [12] analyses the causes of wind turbine tower failure. In this case, a non-linear simulation of the failure area was carried out. Paper [13] shows the FEM analysis of composite wind turbine blades under operating conditions.

This work concerns the numerical analysis of a wind turbine rotary blade using CAE software. A geometrical model was developed based on a real object. Simulation tests were performed in the Simulation module of SolidWorks program to determine the strength of the tested structure under specific wind speed.

2. Geometrical model and mechanical properties

The most commonly used classification of wind turbines is classification due to the position of the rotor axis: a horizontal axis of rotation (HAWT – horizontal axis wind turbine) and a vertical axis of rotation (VAWT – vertical axis wind turbine) [14]. In this paper, the strength of the horizontal wind turbine (HAWT) was analyzed.

![Geometric model of a HAWT rotary blade](image1)

Figure 1. Geometric model of a HAWT rotary blade

The geometrical model of a HAWT rotary blade (Fig. 1) was modelled based on the real object which mechanical properties are shown in Table 1. Mechanical properties of blade’s material were taken from the literature [15]. Model of HAWT blade consists of three selected parts: shell, bearing girders and stiffening ribs. Selecting elements in the blade’s model allows them to set different thicknesses and material properties [16].

| Blade’s material | Diameter rotor | Number of blades | Hub radius | Max. power | Constant losses |
|------------------|----------------|------------------|------------|------------|----------------|
| Glass fiber      | 15.95m         | 3                | 0.275m     | 40kW       | 1.41kW         |
| Aluminum         |                |                  |            |            |                |

Table 1. Mechanical properties of analyzed HAWT.

The blade’s profile (Fig. 2) of the analyzed object was modelled using NREL’s and NACA airfoils, which are one of the most commonly used profiles in the industry [17]. Airfoil characteristics such as span, twist, chord and thickness were selected according to the properties of the real horizontal wind turbine with maximum power 40 kW.

![Airfoil types of wind turbine wing](image2)

Figure 2. Airfoil types of wind turbine wing
The force \( F \) acting on the wind turbine blades can be determined using the formula for aerodynamic resistance [18, 19]:

\[
F = \frac{1}{2} \rho A V^2 C_D
\]

where: \( \rho \) is the density of air, \( A \) is a variable reference area, \( V \) is the wind velocity and \( C_D \) is a dimensionless drag coefficient.

3. Simulation tests

The paper presents only simulation tests of a wind turbine rotary blade, which after using the appropriate SolidWorks tools provide a full description of mechanical phenomena in the analyzed horizontal wind turbine. Simulation tests included static and dynamic analysis of the tested structure.

In static analysis it was assumed that the model (Fig. 3) was affected by the force of gravity and centrifugal force caused by blade’s rotation. The wind force was also taken into account in accordance with formula (1). It was assumed that the blade’s coating (shell) was made of fiberglass, while bearing girders and stiffening ribs were made of aluminum. The thickness of the blade’s coating, ribs and girders in the numerical model was set to 3 mm. Cyclic symmetry fixture was set as the boundary condition, which allows simplification of the simulation model by analyzing only one rotary blade. The generated mesh of finite element simulation was a curvature-based mesh with 323 445 nodes and 175 719 elements. For the purposes of simulation, the following measures were adopted: \( V=20 \text{ m/s} \) (wind speed), \( \tau=15 \text{ 980 kNm} \) (torque), \( n=60 \text{ rpm} \) (rotor speed).

![Figure 3. Boundary conditions (green color) and loads (red color) during simulation](image)

![Figure 4. Von Mises equivalent stress distribution in the wind turbine rotary blade](image)
As the result of the numerical calculations, distribution of von Mises stresses (Fig. 4), displacements (Fig. 5) and strains (Fig. 6) fields of the HAWT rotary blade were obtained. The highest stress value equals 16 MPa were noticed at the place of the blade and turbine hub connection. An increase in stress at the transition point of two NACA 63-215 and NACA 62-218 airfoils was also observed. The largest displacement was seen for the smallest cross-section area and was equal to 27.56mm. The values of maximum strains coincide with the place of maximum stresses.

**Figure 5.** Displacement field in the wind turbine rotary blade (with superimposing model on the deformed shape and deformation scale = 3)

**Figure 6.** Strain field in the wind turbine rotary blade

The second part of the simulation tests concerne d dynamical analysis, on the basis of which the natural frequencies and the corresponding modes were determined. The analysis was carried out without
taking into account the additional static load – the system was only under the influence of its own weight. Figure 7 shows the first three modes of structure free vibrations. The values of resonant frequencies are presented in Table 2.

Table 2. Free vibration frequencys

| No. | 1     | 2     | 3     |
|-----|-------|-------|-------|
| Eigen frequencies [Hz] | 4.261 | 12.794 | 16.629 |

Figure 7. The results of modal analysis for the first three eigenfrequencies (scale of deformation = 3)

4. Summary
The paper presents a geometrical model and simulation tests of a horizontal axis wind turbine. The geometrical model was prepared based on a real HAWT object using SolidWorks environment. Based on data received, the rotary blade’s profile consisting of 7 NACA and NREL’s airfoils was determined. The created blade model consisted of three elements: aluminium girders, a fiberglass coating and aluminum ribs. For numerical analysis, the Simulation module of the SolidWorks software was used. The model was divided into tetrahedral parabolic finite elements with curvature-based mesh. Stresses were calculated according to the Huber-Mises hypothesis. The influence of wind force was determined using the force of aerodynamic drag. In addition, the dynamic analysis was performed to determine the first three natural frequencies of the analyzed structure.

Analyzing the results of the numerical simulations (Fig. 4), the most vulnerable place is the connection of the rotary blade to the turbine’s hub. It is also the place where the largest strains were observed (Fig. 6). The largest displacement (Fig. 5) was noticed at the rotor blade’s tip. It is caused by the decrease in cross-section along the length of the blade. The obtained results clearly indicate that effective stresses of tested turbine do not exceed the allowable stresses. In other words, the analyzed turbine can perform work at wind values up to 20m/s.
This work will be improved by conducting CFD analysis and experimental research on a scale model in a wind tunnel using the PIV method. Fatigue analysis is also predicted to determine the operating time of the analyzed wind turbine.

Acknowledgements.
The study has been carried out within statutory research of Czestochowa University of Technology. Publication supported financially under Contract No. 944/P-DUN/2019 from funds of MNiSW intended for dissemination of science (DUN).

References
[1] Armaghan A, Elahi Z, Babar M 2013 CAD-CAE Integration of Horizontal Axis Wind Turbine Adv. Energy Power 1 (2), 56-61
[2] Kowalczyk Ł, Elsner W, Niegodajew P 2015 The application of non-gradient optimization methods to new concept of power plant Proc. 6th IC-EpsMSO
[3] Chen Z, Guerrero J.M., Blaabjerg F 2009 A Review of the State of the Art of Power Electronics for Wind Turbines IEEE Trans. Power Electron. 24 (8), 1859-1875
[4] Gnatowska R, Wąs A 2017 Wind Energy in Poland - economic analysis of wind farm E3S Web Conf. 14 01013
[5] Kolbasin A, Husu O 2018 Computer-aided design and Computer-aided engineering MATEC Web Conf. 170 01115
[6] Cekus D, Posiadała B, Waryś P 2014 Integration of modeling in Solidworks and Matlab/Simulink environments Arch. Mech. Eng. 61 (1), 57-74
[7] Belmili H, Cheikh R, Smail T, Seddaoui N, Biara RW 2017 Study, design and manufacturing of hybrid vertical axis Savonius wind turbine for urban architecture Energy Procedia 136, 330-335
[8] Cristobal URN, Gallegos-Munoz A, Manuel RAJ 2012 Numerical Analysis of a Rooftop Vertical Axis Wind Turbine Proc. ASME 5th Int. Conf. Energy Sustainability, 2059-2068
[9] Douvi EC, Douvi DC, Margaris DP, Drosis IE 2016 Performance and Aerodynamic Attitude of KIONAS, a New Configuration of a Vertical Axis Wind Turbine Int. Rev. Mech. Eng. 10 (3) 8873
[10] Petružela M, Blazek V, Mišák JVS 2018 3D analysis of vertical axis wind turbine with enclosure IEEE Int. Sci. Conf. Electric Power Eng. (EPE), 1-5
[11] Ozdamar G, Mertcan M, Ozdamar A 2018 Numerical Comparison of the Effect of Blade Material on Wind Turbine Efficiency Acta Phys. Pol. A 134 (1), 156-158
[12] Alonso-Martinez M, Adam JM, Alvarez-Rabanal FP, del Coz Diaz JJ 2019 Wind turbine tower collapse due to flange failure: FEM and DOE analyses Eng. Fail. Anal. 104, 932-949
[13] Tarfaoui M, Nachtane M, Boudounit H 2020 Finite Element Analysis of Composite Offshore Wind Turbine Blades Under Operating Conditions J. Therm. Sci. Eng. Appl. 12 (1) 011001
[14] Kumara EAD, Hettiarchachi NK, Jayathilake KGRM 2017 Review Paper: Overview of the Vertical Axis Wind Turbines Int. J. Sci. Res. Innovations Technol.. 4 (8), 56-67
[15] Fejdiš M, Landwijt M 2010 Technical fibres reinforcing the composite material Tech. Textiles 18 (1), 12-22 (in Polish)
[16] Świtoński E, Jureczko M, Meżyk A 2007 Optimal design of the composite wind turbine blade Acta Mech. Autom. 1 (1), 129-132 (in Polish)
[17] Xudong W, Licun W, Hongjun X 2015 An Integrated Method for Designing Airfoils Shapes Math. Prob. Eng. 2015, 838674
[18] Cekus D, Gnatowska R, Kwiaton P 2019 Impact of Wind on the Movement of the Load Carried by Rotary Crane Appl. Sci. 9 (18) 3842
[19] Cekus D, Gnatowska R, Kwiaton P 2018 Influence of wind on the movement of the load J. Phys.: Conf. Ser. 1101 012005