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3D Analysis of Machining of Wind Turbine Blade Using CAD/CAM Software Part 1. Selection of Aerodynamic Profile of a Wind Turbine Blade

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Summary. This work analyzes the process of construction and manufacturing of a blade used in a wind turbine. The calculation scheme is presented for forces generated on the blade of a wind turbine and parameters are determined of weather conditions in which the designed element would be working. Subsequently, for the chosen aerodynamic profile the characteristics are calculated of its aerodynamic coefficients, which enables the establishing of the angle of attack which impacts the yield of wind engines. The presented process is an introduction to 3D modelling of a wind turbine's blade and simulation of its creation in a CAM environment.

Key words: blade, wind turbine, aerodynamics, calculations.

INTRODUCTION

Wind is one of the most common and most commonly used sources of power available in nature. Power plants based on this energy carrier are the largest and fastest growing Renewable Energy Source (OZE) sector in Poland [20]. Every year new investments provide work for thousands of people and significantly increase the energy security of the country. In order to maintain the growth of wind power industry, the designers have to meet the expectations of investors related to quality and optimization of the proposed solutions [2, 13]. Therefore the market is characterized by significant growth of competitiveness and the resultant innovativeness, better operating parameters, longer lifecycles, increased efficiency and, first and foremost, better prices [7, 11, 12]. Design offices use state-of-the-art software to achieve all the above-mentioned benefits. Example of such software are the CAD design tools (Computer Aided Design) which enable creation of 2D and 3D sketches that are used to manufacture construction elements [8]. Usage of these tools determines the accuracy and reliability of works performed and enables creation of a large number of variants and calculations, which makes possible selection of construction characterized with the required parameters [15, 19]. In the next design phase, utilization of appropriate software enables simulation of machining of the designed elements. Software used for this purpose is based on the CAM system (Computer Aided Manufacturing) [1, 4]. The basis for operation of such a system is the shape generated in the CAD module, which serves as basis for the CAM machining patch on a CNC machine [5]. A finished simulation enables, among other things, to check the adequacy of machining process, the correctness of the underlying assumptions, to eliminate production faults and to analyze the roughness of created surface.

The key element of a wind turbine is its blades. The blades directly receive energy from the wind. No matter if they are in motion or remain stationary, the blades carry very heavy loads caused by the wind pressure. Their geometry and creation is a complicated process which requires high degree of knowledge and accuracy. During the design stage it is necessary to utilize the available calculation software and simulation systems to ensure that the designed blade can be manufactured and that it meets both the aerodynamic and the energy conditions.

CHARACTERISTICS OF THE SUBJECT OF RESEARCH

The subject of research is analysis of creation process for a wind turbine blade on a 5-axis CNC machine. This cycle is based on a number of sequential steps. The first one is selection of an aerodynamic profile of the blade and analysis of the work characteristics of the chosen profile under given weather conditions. Next, the output values serve as basis for a 3D model of the blade in a CAD system. Finally, the machining of the designed element is simulated using software based on CNC control system.

The basis for blade's geometry are aerodynamic calculations [3. 17]. These are, in turn, based on the forces impacting the profile of the blade (Fig. 1).

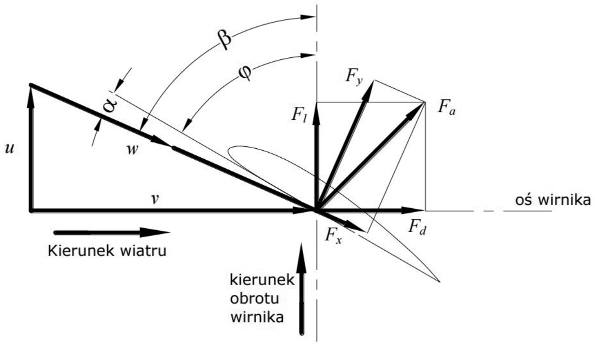

Fig. 1. Forces generated in an aerodynamic profile [6]

All the described values are calculated analytically using the equations given below (equation 1, 2, 3):

$$F_x = C_x * \rho * A * w^2 * (2)^{-1} \text{ [N]}, \quad (1)$$

$$F_y = C_y * \rho * A * w^2 * (2)^{-1} \text{ [N]}, \quad (2)$$

$$F_a = (F_x{}^2 + F_y{}^2)^{1/2} \text{ [N]}, \quad (3)$$

where:
Cy – aerodynamic coefficient of the lift force Fy,
Cx – aerodynamic coefficient of the lift force Fx,
ρ – air density [kg/m³],
A – surface of the i-th section of the blade,
w – relative speed of the airstream.

The aerodynamic coefficients of the lift force and the friction are selected on the basis of the characteristics of the aerodynamic profile and the angle of attack α [10, 14].

The relative speed of the airstream is equal to (equation 4):

$$w = (v^2 + u^2)^{1/2} \text{ [N]}, \quad (4)$$

where:
v – speed of wind with direction perpendicular to the rotor,
u – lifting speed of the blade, dependant on the movement of the rotor.

The lifting speed of the blade is calculated as presented below (equation 5):

$$u = (2 * \pi * r * n) * 60^{-1} \text{ [m/s]}, \quad (5)$$

where:
n – rotational speed in [rev/min],
r – distance of the profile from the axis of the rotor.

All those correlations will be calculated using the WIATRAK 1.1 software, which is available on the market and is a dedicated tool for calculation of geometry of blades for small wind engines up to 15-20 m the related forces and analysis of operating conditions of a HAWT type wind turbine. The software bases its analysis on the defined blade profile, a set wind speed and the required span of the rotor.

On the basis of geometry calculated in the CAD software a 3D model of the blade will be created. For its creation, Solidworks software will be used. It enables creation of a 3D model on basis of an existing 2D aerodynamic profile. Compatibility of the file type created in the above-mentioned system with the CAD system makes it possible to utilize it in simulation of CNC machining in ESPRIT software. This software enables the realization of processing in a 5-axis system, including the selection of the working tool, determination of required machining parameters, ongoing verification of the process on the screen and, most importantly, it eliminates the need for expensive trial runs of the machine.

The whole machining environment, including the material, tooling and clamps will be generated in the dynamic computer graphics with shaded solids. The kinematic operation of the machine is displayed in real time giving accurate verification of the machining process. Using the included part control system it is possible to compare the originally designed part with the machined element in order to ensure accuracy of the part [22].

WEATHER CONDITIONS FOR THE OPERATION OF WIND TURBINE BLADE

The blade is designed assuming operation in small wind engines with a rotor consisting of three blades. The length of such a blade should not exceed 15-20 m [18]. However, taking into limited element size for CNC machining the blade length was chosen to be 2.5 m. Another assumption is the wind speed which was assumed to be 8 m/s. This value makes the wind between moderate and strong. The assumptions aer presented on Fig. 2.

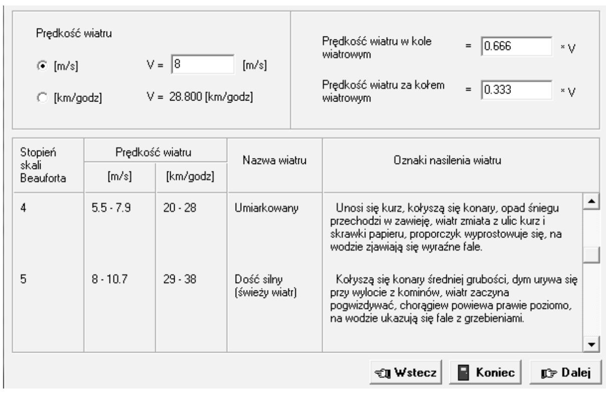

Fig. 2. Assumed wind speed – WIATRAK 1.1 software [own elaboration]

Additionally, the engineering practice assumes that the speed of wind in the rotor blades and behind them are from 1/3 to 2/3 of the total flow of air – therefore the calculations utilize such values.

The remaining values necessary for calculating the values needed for the blade's geometry are presented on Fig. 3 and 4.

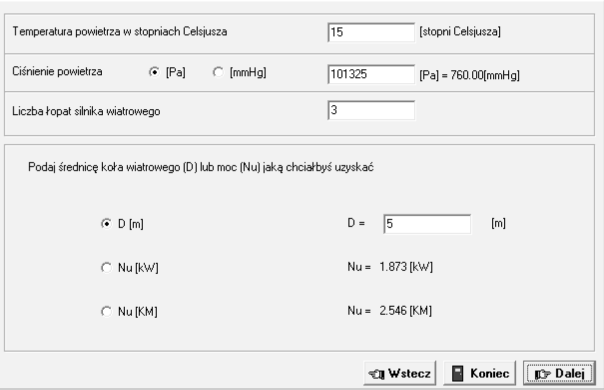

Fig. 3. Assumed temperature, air density, no of blades, diameter of the windwheel – WIATRAK 1.1. software [own elaboration]

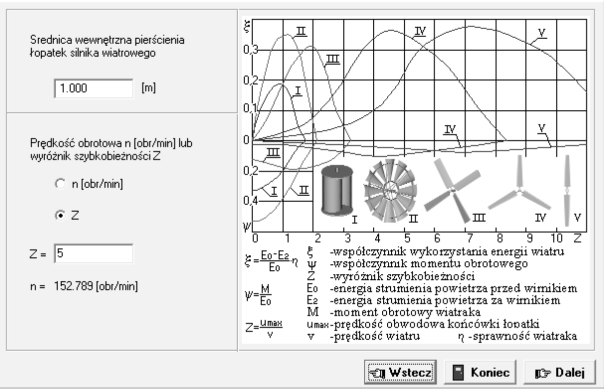

Fig. 4. Assumed blade ring diameter, Specific speed Z – WIATRAK 1.1 software [own elaboration]

SELECTION OF THE AERODYNAMIC PROFILE OF A WIND TURBINE BLADE

The shape of the blade and values of forces generated are determined by the aerodynamic profiles [9, 16]. These elements are normalized by Aerospace Institutes and are freely available. Detailed parameters of profiles can be downloaded using Airfoil Investigation Database and utilize them for creation of a blade model.

One of the most popular aerofoil profiles – CLARK Y was chosen for further analysis. Such profiles are well-suited for wind power solutions and their parameters are appropriate for small engines. Fig. 5 presents a 2D model of the profile.

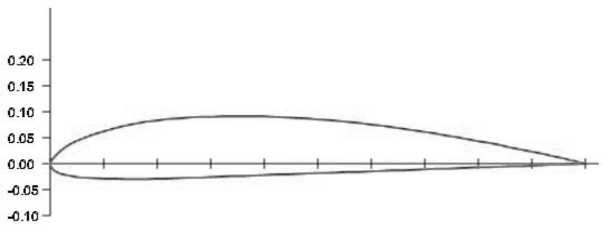

Fig. 5. Geometry of aerofoil profile CLARK Y [21]

Using the graph presented in the Cartesian coordinate system, the parameters were introduced to WIATRAK 1.1 (Table 1) which resulted with the characteristics necessary to read the aerodynamic coefficients: C_y and C_x shown in Fig. 6, 7 and 8.

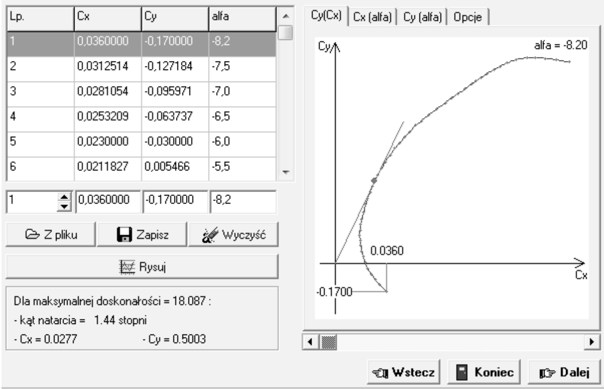

Fig. 6. Cy(Cx) characteristics – WIATRAK 1.1 software [own elaboration]

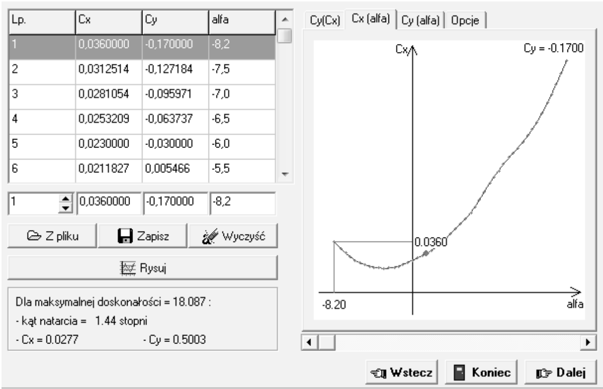

Fig. 7. Cx(alpha) characteristics – WIATRAK 1.1 software [own elaboration]

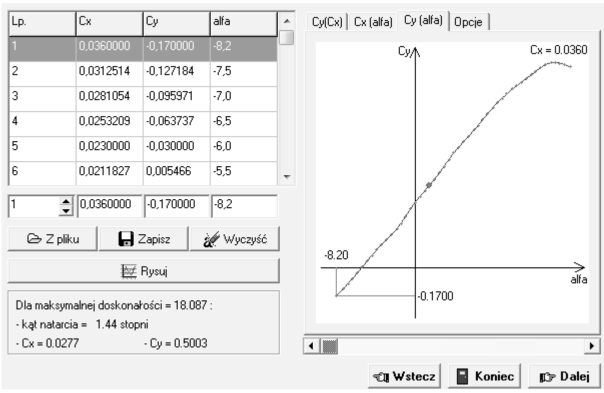

Fig. 8. Cy(alpha) characteristics – WIATRAK 1.1 software [own elaboration]

On the basis of the resultant curves, for the maximum L/D angle, i.e. the maximum relation of coefficients C_y = 0.0277 and C_x = 0.5003, the angle of attack $\alpha = 1.44^o$ was calculated. Additionally, using the sliders placed below every graph it is possible to determine any other point located on the curve. The graphs presented above show the reading of the first point of the graph.

CONCLUSIONS

The work presented considerations related to the mechanism governing the creation of forces that determine the working parameters of wind turbine blades. The analyzed elements included the geometry and the design of a wind turbine blade on the basis of standard aerofoil profiles.

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ANALIZA 3D OBRÓBKI SKRAWANIEM ŁOPATKI TURBINY WIATROWEJ PRZY WYKORZYSTANIU OPROGRAMOWANIA CAD/CAM CZ. 1.: DOBÓR PROFILU AERODYNAMICZNEGO ŁOPATY TURBINY WIATROWEJ

Streszczenie. Praca stanowi analizę konstruowania i wykonania łopaty turbiny wiatrowej. Przedstawiono schemat obliczeniowy sił powstających na łopacie turbiny wiatrowej oraz określono parametry warunków atmosferycznych, w jakich projektowany element będzie wykonywał swoją pracę. Następnie dla dobranego profilu aerodynamicznego wyprowadzono charakterystyki ich współczynników aerodynamicznych, co umożliwiło wyznaczenie kąta natarcia, który ma wpływ na uzyski silników wiatrowych. Przedstawiony proces stanowi wstęp do modelowania 3d łopaty turbiny wiatrowej, a następnie symulacji jej wytworzenia w środowisku CAM.

Słowa kluczowe: łopatka, turbina wiatrowa, aerodynamika, obliczenia.