NUMERICAL STUDY OF A COMBINED WIND TURBINE BLADE

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This article is devoted to a numerical study of the power elements of Magnus wind turbines. The improved blade shape is made in the form of a combination of a cylindrical element with a fixed blade, which helps to increase overall efficiency and increase the lifting force of the power element. The aerodynamic coefficients of a combined blade are investigated depending on the angle of the fixed blade in the range from 0° to 60°. It is determined that the maximum lifting coefficient reaches 1.2 at an angle of 0°. With this angle value, there is also a minimum value of the coefficient of drag force equal to 1.5. Based on the data obtained, the optimal angle of the fixed blade is from 0° to 30°.

Keywords: wind turbine, numerical study, combined blade, ANSYS Fluent, aerodynamic coefficients

In the context of the need to accelerate the transition to alternative energy sources and reduce dependence on fossil fuels, the development of wind energy and "green" energy is an urgent task. In this regard, special attention should be paid to improving the design and materials of wind turbines, in particular, optimizing their power elements – blades. The modern scientific literature contains many studies devoted to the study of the geometry of wind turbine blades of various configurations. These studies include the analysis of the shape, materials and angles of attack of the blades in order to increase the output power and efficiency of the installation [1].

Moreover, [2] conducted numerical studies and optimization of blade parameters using CFD methods and various optimization algorithms (genetic, gradient-based, and evolutionary). Their findings indicate that the precise selection of the angle of the fixed blade, chord length, profile thickness, and blade shape can improve the overall efficiency of the installation.

Studies by Kornilov and Lysenko examine the aerodynamic flow around cylindrical bodies under different flow regimes (supersonic, subsonic). While their results are primarily related to high-speed flow modeling, they highlight the importance of a comprehensive approach to describing airflow-body interactions. Some of these methodologies may be adapted for analyzing low-speed flow typical of wind energy applications [3].

Alongside conventional solutions, the literature also discusses unconventional blade designs, such as rotating cylinder-based blades utilizing the Magnus effect. These installations achieve a higher lift coefficient at relatively lower angles of attack. However, the structural complexity of such systems and the need for an additional drive to rotate the cylinders can negatively affect their economic feasibility [4].

In practical applications, the key to increasing overall wind turbine efficiency lies in balancing lift force (which drives rotor rotation) and drag force (which extracts useful energy and reduces efficiency). The optimization of blade shape, angle of attack, and orientation within the airflow are critical factors in maximizing wind energy potential.

However, turbine efficiency depends not only on blade shape and size but also on operating conditions (rotational speed, wind speed range, and flow turbulence characteristics). Therefore, to determine optimal parameters and aid in wind turbine design, computational fluid dynamics (CFD) methods are a valuable tool, allowing for detailed analysis of velocity and pressure fields around the blade and the calculation of aerodynamic coefficients at different angles of attack.

Thus, despite the abundance of research on blade design and optimization, several practical challenges remain unresolved, including identifying and validating the optimal range of angles of attack for specific profile shapes [5].

The objective of this study is to obtain quantitative dependencies of (Cy) and (Cx) variations on the blade profile's angle of attack within a wide range (0°–60°) and to identify regions where optimal aerodynamic efficiency is achieved.

The investigation utilized an averaged blade profile typical for small-scale wind energy installations. Geometric parameters (chord length, relative thickness) were selected based on recommendations for aerodynamically efficient rotor profiles.

Numerical modeling was conducted in ANSYS Workbench (using Design Modeler, Meshing, and Fluent modules). A 3D model of the blade section was created in Design Modeler with a smooth transition to the blade tip. A computational domain (a parallelepiped) was defined around the blade, ensuring an adequate flow capture (distances from the blade to the domain boundaries were set to at least six characteristic chord lengths).

The mesh model was generated in Ansys Meshing, primarily using tetrahedral elements with local refinement near the blade surface. To ensure result accuracy, three different mesh densities (ranging from 1.5×10^5 to 5×10^5 cells) were tested. The results showed that increasing the number of cells beyond a certain point had an insignificant effect on the lift coefficient (less than a 2% change). Consequently, a medium-sized mesh ($\sim3\times10^5$ cells) was used for the main calculations (Figure 1).

The calculations were conducted in a steady-state formulation using the Reynolds-averaged Navier–Stokes (RANS) equations. The Realizable k–ε turbulence model was chosen due to its strong performance in airfoil flow simulations. The boundary conditions were defined as follows:

- Inlet (velocity inlet): A uniform airflow with a velocity of $V = 10$ m/s. To vary the angle of the fixed blade α, the blade profile was rotated within the selected range of 0°–60°.

- Outlet (pressure outlet): The outlet pressure was set to atmospheric pressure, with a pressure difference defined as $p = 0$ Pa (relative to the atmosphere).

- Blade surface (no-slip boundary): No-slip condition was applied, ensuring zero relative velocity at the blade surface.

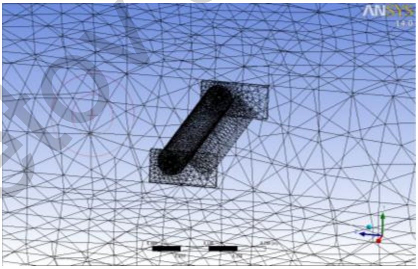

Figure 1. Mesh model of the blade

The convergence criterion for residuals was set to 10^{-4} for the momentum and turbulence equations. The number of iterations was selected to ensure that the solution reached a steady-state level for the investigated coefficients.

To analyze the blade's efficiency, the following were calculated:

The drag coefficient was determined using equation (1):

$$C_x = \frac{2F_x}{\rho u^2 S} \qquad (1)$$

The lifting force coefficient is calculated using the formula (2):

$$C_y = \frac{2F_y}{\rho u^2 S} \qquad (2)$$

where ,

F_x - drag force;

F_y - lifting force;

ρ – air density;

u - flow rate;

S – the area of the midsection.

Figure 2 demonstrates the influence of the angle of inclination of the fixed blade on the coefficient of lift.

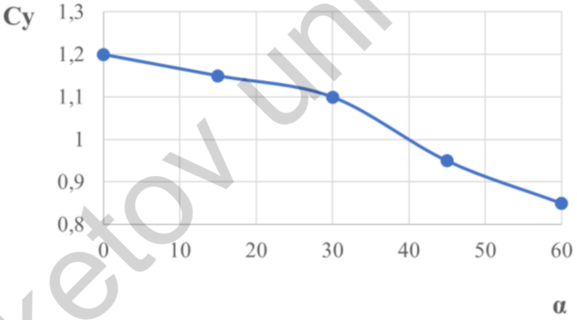

Figure 2. The influence of the angle of inclination of the fixed blade on the coefficient of lift

It can be seen that at α = 0 °, the maximum value of Cy is about 1.2. As the angle of the fixed blade increases to 60 °, the coefficient decreases to about 0.8. The decrease in lifting force is explained by the strong separation of the flow on the upper surface at high angles of attack and, accordingly, the growth of the reverse flow zone.

Figure 2 demonstrates the influence of the angle of inclination of the fixed blade on the drag coefficient.

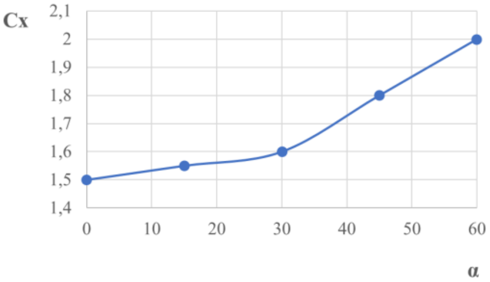

Figure 3. The influence of the angle of inclination of the fixed blade on the drag coefficient

As α increases from 0° to 60°, Cx increases from 1.5 to 2.0 on average. The main reason is an increase in the "shading" area of the profile and the recirculation area at the trailing edge of the blade.

Thus, at the lowest angle of attack, the highest Cy and the lowest Cx are achieved. From the point of view of aerodynamic quality K =Cy /Cx, the optimal angle of attack (for a given flow velocity and profile shape) lies in the range of 5°-15°. At α>15°, the resistance increases rapidly and the lifting force decreases, which generally worsens the efficiency of the wind power plant [5].

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ЖЫЛУ АҒЫНЫН ӨЛШЕУГЕ АРНАЛҒАН ҚҰРЫЛҒЫЛАРДЫҢ СЕЗІМТАЛ ЭЛЕМЕНТІ ТЕРМОЖҰПТАРДЫ ОҢТАЙЛАНДЫРУ

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Жылу ағынын өлшеуге арналған құрылғыларды әзірлеу үшін екі әртүрлі өткізгіштен тұратын терможұптар негізгі сезімтал элемент болып табылады. Терможұптар — температураны өлшеу үшін қолданылатын маңызды құрылғылар, олар әртүрлі ғылыми және техникалық зерттеулерде, сондай-ақ өнеркәсіптік қосымшаларда кеңінен пайдаланылады. Терможұптардың дәлдігін арттыру үшін олардың градуирлеуі қажет, яғни термоэлектр қозғаушы күшінің (термо-ЭҚК) температураға тәуелділігін анықтау керек. Осы зерттеу аясында мыс-константан типті терможұптар градуирленіп, температураның ауытқуларын дәл өлшеу үшін қажетті мәліметтер алынған. Мыс-константан жұбының термо-ЭҚК мәндері төмен температурада тұрақты және сенімді болатыны белгілі, бұл оны көптеген жағдайда қолдануға тиімді етеді. Сонымен қатар, мыс-константан терможұпы 70°С-қа дейінгі диапазонда жақсы сезімталдыққа ие, әрі қолжетімді және арзан материал ретінде бағаланады. Зерттеу нәтижелері терможұптардың тиімді түрін таңдауға, оның ішінде мыс-константанның артықшылықтарын анықтауға мүмкіндік береді.

Кілт сөздері: жылу ағыны, термо-ЭҚК, терможұп, мыс-константан терможұбы, температура айырымы.