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EXPERIMENTAL STUDIES OF THE PERFORMANCE EFFICIENCY OF A WIND TURBINE WITH COMBINED BLADES

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Abstract. *This article studies the aerodynamic characteristics of a wind turbine at different streamline parameters. For this purpose, an experimental sample of the plant with combined power elements in rotating cylinders form with fixed blades was fabricated. The airflow velocity was varied, ranging from 3 to 12 m/s. The results of the experiment to study the variation of the angle α of the fixed blade position relative to the cylinder from the air flow velocity were analyzed. The changes in aerodynamic forces from the air flow velocity are graphically presented. It was found that at the optimal angle α = 0 ° of the fixed blade relative to the cylinder, the maximum values of aerodynamic forces were obtained. Graphs of the dependence of aerodynamic coefficients on the Reynolds number are also constructed, in which it is established that, at α= 0º, the minimum value of the lift coefficient is 0.012 N and the maximum value of the drag coefficient is 10.07 N at* $Re = 1 \cdot 10^5$. *The presented results show the effectiveness of the combined use of the and the fixed blade. The experimental results obtained on the aerodynamic parameters of a wind turbine can be used in the development of prototypes of installations designed for low wind speeds.*

Keywords: wind turbine, combined blades, wind tunnel T-1-M, flow velocity, drag force, lift force, Reynolds number.

1. Introduction

Wind energy is a promising project in the power generation sector due to its clean energy production and extensive wind resources around the world. Wind turbines can be installed at any scale to reduce the increasing energy demand [1]. Today, wind energy in many countries has become an independent branch of the economy and no longer requires additional subsidies. The wind energy development, a non-conventional source of energy, along with the energy problem in the country, helps to solve many economic as well as environmental issues. In particular, in the field of alternative energy, less money is spent each year with the work done. As a result, fossil fuel reserves are limited and do not have a negative impact on global climate change [2].

Kazakhstan has also voluntarily committed to reducing harmful carbon dioxide emissions to zero by 2050. Kazakhstan has renewable energy sources, including hydropower, wind and solar energy. The number of implemented renewable energy projects is growing every year [3]. Kazakhstan has the ability to build wind turbines. Because the climate is favorable and there are enough areas for wind turbines to have a wind speed of more than 5 m/s.

Wind turbines serve in energyfield, which deals with the development of theoretical foundations, methods and technical means of converting wind energy into mechanical, thermal or electrical energy.The existing types of wind turbines differ in the design of installations, in power, as well as in the speed of rotation and location of the wind wheel. According to the axis of rotation of the wind wheel, there are two types: with a horizontal (HAWT) and vertical axis of rotation(VAWT) [4].

For vertical installations, i.e., the axis of rotation is located vertically relative to the earth, for horizontal installations, the axis of rotation is directed parallel to the axis of the earth. In practice, wind turbines are increasingly used with a horizontal axis of rotation[5]. In addition, there are other ways to convert wind energy. For example, the Savonia Rotor wind turbines [6] Bernoulli wind turbine utilizes the dynamic pressure effect and the Horizontal Flow Rotor [7] utilizes the momentum exchange effect.

This research paper presents a Magnus HAWT. A distinctive feature from other installationsis that the power elements are in the form of combined blades consisting of a rotating cylinder and a fixed blade.

2. Materials and research method

The aim of the work is to analyze the aerodynamic characteristics of a three-bladed wind turbine containing combined power elements. Experiments were conducted in a wind tunnel (Figure 1), which are channels in which an artificial airflow is created using a fan [8]. A wind tunnel is an apparatus that investigates the phenomena accompanying the rotation of bodies by creating a flow of air or gas for an experiment. The process when the movement of a body relative to air (or liquid) can be replaced by the movement of air flowing into a stationary body is the basis of the principle of reversibility of the process, which is the basis for conducting experiments in a wind tunnel.

To carry out the research work, a model of a wind turbine with combined blades has been developed. Combined blade operating mechanism - electric motors connected to the cylinders drive the cylindrical blades into rotational motion under the action of airflow, they rotate the wind wheel along with the fixed blades. To eliminate physical phenomena such as flow deformation behind the form cylinders of swirling flow, a fixed blade was added. Figure 1 shows a schematic diagram and an image of the experimental setup arrangement on the working part of the wind tunnel, where the fixed blade is located at different angles with respect to the cylinder axis rotation.

a) b)

Fig. 1. A scheme (a) and a photo from the side of the wind turbine model (b) with combined blades: 1-generator, 2-cylinder, 3 - instantaneous blade, 4-mast.

The installation operation principle is based on the creation of a lifting force due to the difference in pressure on the blades. When a rotating cylinder is streamlined transversely, a reduced pressure is created on one side of the blade and an increased pressure on the opposite side, resulting in a lift force.

The new wind turbine design has the ability to increase lift by combining two force effects - rotation of a cylindrical element using the Magnus effect and a fixed blade (Figure 2). The wind wheel has cylinders that are activated by electric motors and begin to rotate around their axis. When the cylinder rotates, an additional force arises due to the Magnus effect, which interacts with the fixed blades and causes the entire wind wheel to rotate. During the circular motion in the airflow in the upper part of the cylinder, the air flow velocity and the cylinder surface velocity are equal and add up, which leads to an acceleration of the flow and an increase in its velocity.

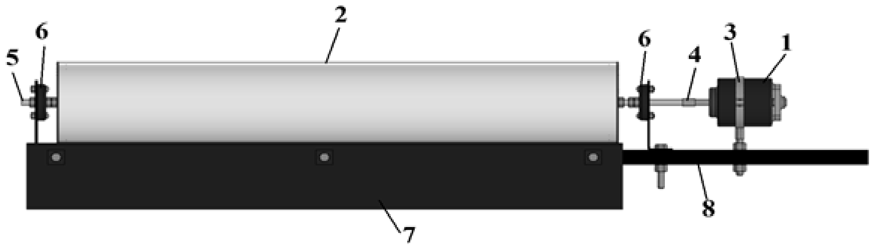

Fig. 2. The design of the combined blade: 1 - electric motor; 2 - cylinder; 3 - electric motor mount; 4 - coupling; 5 - connection between cylinder and engine; 6 - bearings; 7 - fixed blade; 8 - blade base.

The process of operation of this device can be explained as follows:

When voltage is applied to the electric motor (1), rotation is transmitted through the coupling (4) to the axis of rotation (5) and the cylinder (2) mounted on bearings (6). Bearings (6), a fixed blade (7) and an electric motor mount (3) are fixed to the base (8).

The geometric dimensions of the wind turbine layout are shown in Table 1.

Table 1. Geometric dimensions of the wind turbine layout

Parameter	Value
Cylinder length	205 mm
Cylinder diameter	50 mm
The length of the fixed blade	225 mm
Width of the fixed blade	25 mm
Diameter of the wind wheel	450 mm
Mast length	420 mm

The measurement error of aerodynamic forces and their moments is (5-7)%.

3. Calculation of aerodynamic characteristics

The lightweight construction minimizes aerodynamic drag and provides higher wind energy efficiency. The device starts operating at wind speeds of 3-5 m/s and operates effectively at wind speeds of 8-12 m/s.

The lift coefficient is found by the next formula [9]:

$$C_y = \frac{\Delta F_y}{\rho \cdot \frac{u^2}{2} \cdot S}, \text{ or } C_y = \frac{2F_y}{\rho u^2 \cdot S}. \quad (1)$$

And the drag coefficient is determined by the following formula:

$$C_x = \frac{\Delta F_x}{\rho \cdot \frac{u^2}{2} \cdot S}, \text{ or } C_x = \frac{2F_x}{\rho u^2 \cdot S}. \quad (2)$$

Here ΔF_x – drag force, [N]; ΔF_y – lift force, [N]; ρ – air density, [kg/m^3]; u– air flow velocity, [m/s]; S – midsection area, [m^2].

As a similarity criterion, the ratio between the inertia force and the viscosity force used to determine is the Reynolds number:

$$\mathrm{Re} = \frac{u \cdot d_c}{\nu}, \quad (3)$$

where dc – cylinder diameter, [m]; ν – kinematic viscosity of air, [m^2/s].

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Constant values of density and viscosity were used in laboratory experiments: ρ=1,21 kg/m^3, $\nu = 1.49 \times 10^{-5}$ m^2/s, accordingly.

4. Discussion of results

The maquette aerodynamic characteristics such as drag force and lift force of the wind turbine were determined at flow velocities ranging from 3 m/s to 12 m/s (Figures 3 and 4).

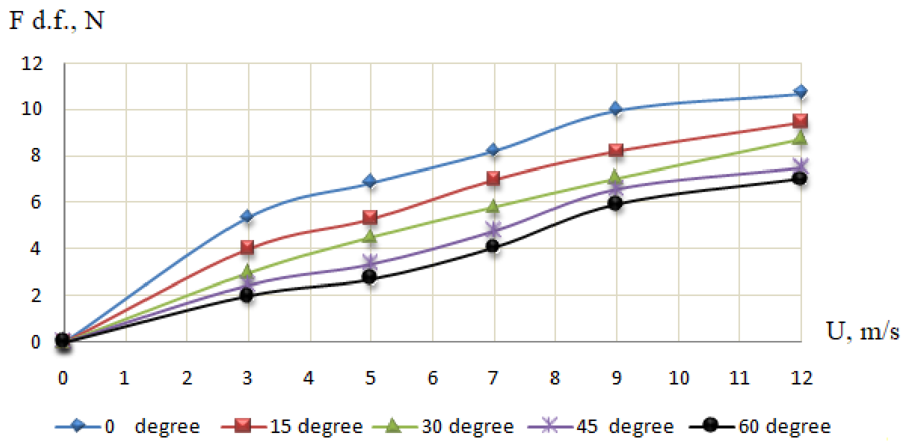


Fig. 3. Dependence of drag force on flow velocity

Figure 3 shows that the drag force also increases with increasing air flow velocity when the fixed blade is located at different distances relative to the cylinder axis rotation. The reason for the increase of drag force is that a flow travelling at a certain velocity action on the surface of a body that is exposed in its path. The magnitude of this force is directly proportional to the flow velocity. The drag force is inversely related to this action. As the flow velocity increases, the drag force of the investigated wind turbine under the pressure force also increases. Hence, the drag force increases with increasing airflow velocity. The drag force of the cylinder is also affected by the number of rotations.

Figure 4 below shows the change in the lifting force of the installation from the flow rate and angle. In Figure 3, we see an increase in lift force from 0.01-0.2 N to 0.41-1.07 N as the flow velocity increases from 3 m/s to 12 m/s. It can be seen on the graph that when the air flow rate increases, the lifting force decreases by almost 20-30% with increasing angle.

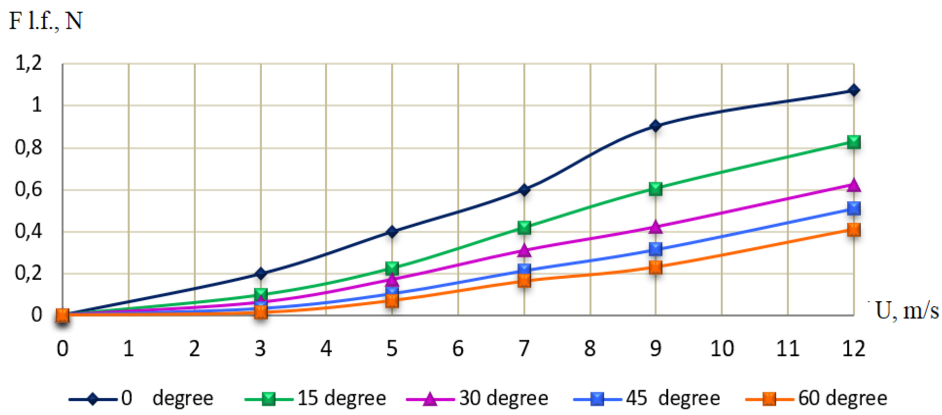


Fig. 4. Dependence of lift force on flow velocity

The explanation for this is the process of slowing down the flow at the back of the rotating cylinder [10]. The dependence shows that, at the maximum speed at 12 m/s the lift force is equal to 1.07 N, 0.83 N, 0.62 N, 0.51 N, 0.41 N, further the lift force stabilises, i.e. no increase is observed.

The nature of the growth of the lines of the obtained results of the dependencies of aerodynamic forces does not contradict the previous results [11,12]. Compared with the Magnus wind turbine [13], there are blades in the form of cylinders, the obtained values of the drag force are 1.5 times lower, but the lift values are 0.7-9 times higher.

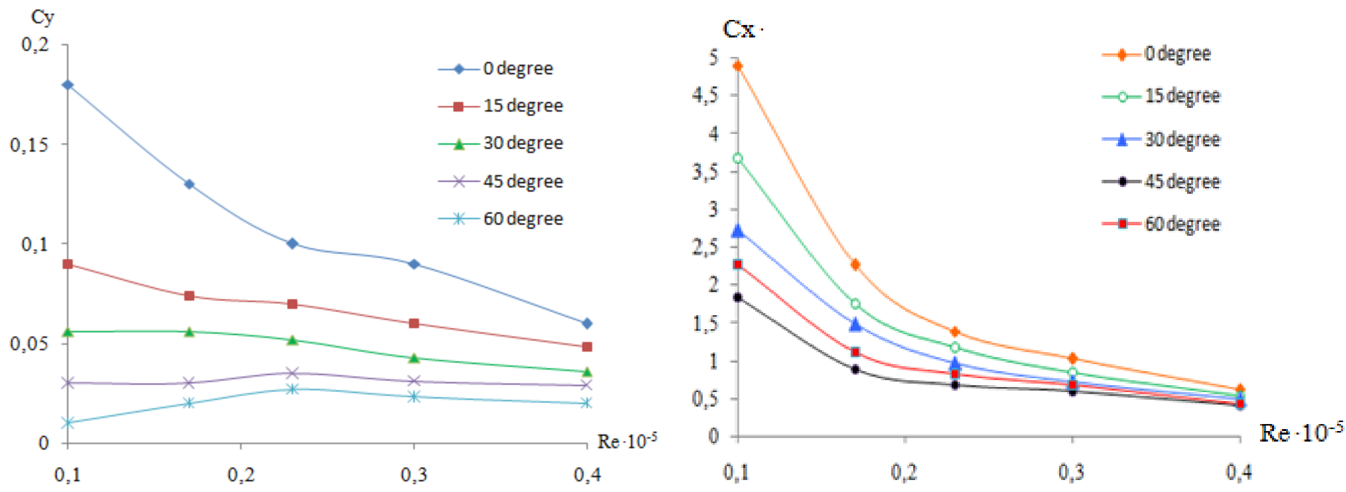
The measurement uncertainty was analyzed [14] in order to find the true measurement value, and measurement errors were calculated (Tables 2).

Table 2. The results of calculating the uncertainty of the drag force.

U, m/s	**Arithmetic mean**	**Uncertainty by type A**	**Uncertainty by type B**	**Total standard uncertainty**	**Standard deviation**	**Confidence interval**	**Error rate, %**
3	5.5	±0.01	±0.02	±0.02	0.02	0.02	7.03
5	6.9	±0.01	±0.02	±0.02	0.02	0.02	7.13
7	8.2	±0.02	±0.03	±0.03	0.02	0.02	6.98
9	10.01	±0.01	±0.05	±0.05	0.03	0.03	7.10
12	10.5	±0.01	±0.06	±0.06	0.04	0.05	7.08

Table 3. Results of the calculation of the uncertainty of the lifting force.

U, m/s	Arithmetic mean	Uncertainty by type A	Uncertainty by type B	Total standard uncertainty	Standard deviation	Confidence interval	Error rate, %
3	0.2	±0.01	±0.01	±0.01	0.02	0.02	7.01
5	0.4	±0.01	±0.01	±0.01	0.03	0.03	7.04
7	0.6	±0.02	±0.03	±0.03	0.03	0.03	6.96
9	0.9	±0.02	±0.04	±0.04	0.02	0.02	7.07
12	1.05	±0.01	±0.06	±0.06	0.03	0.03	7.10



a) b)

Fig. 4. Dependences of lift coefficient a) and drag force coefficient b) on Reynolds number

As shown in Figures 4a and 4b, when the fixed blade is positioned at an angle of 0 degrees relative to the cylinder, the optimum values of lift, and at Reynolds number $1 \cdot 10^{-5}$ are obtained drag force coefficients equal 0.18 and 4.9. Compared to the other three samples at 15º, 30º, and 45º, at 60º, the combined blade produces maximum drag force and minimum lift force. Under the influence of rotational movements of the cylinders, a vortex zone is formed behind the cylinders with a sufficient volume of reverse air flows, and their dimensions change at the flow rate.

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5. Conclusion

In performing experimental studies to determine the efficiency of a wind turbine with combined blades:

-a wind turbine consisting of three combined blades with a rotating cylinder and a fixed blade was developed;

- the lift force and drag force dependence on the velocity when changing the degrees of the fixed blade has been determined;

-it is established, at the location of the fixed blade at 0 degrees relative to the cylinder Fd.f.= 10,7 N and Fl.f. = 1,074 N;

- it is established that the values of drag and lift force coefficients depending on the Reynolds number are optimal at α=0 degrees.

Conflict of interest statement

The authors declare that they have no conflict of interest in relation to this research, whether financial, personal, authorship or otherwise, that could affect the research and its results presented in this paper.

CRediT author statement

Tleubergenova A.Zh.: Conceptualization, Writing - Original Draft; Dyusembayeva A.N.: Data Curation, Tanasheva N.K.: Methodology, Supervision; Bakhtybekova A.R.: Writing - Review & Editing; Kutumova Zh.B.: Resources, Mukhamedrakhim A.R.: Investigation. The final manuscript was read and approved by all authors.

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