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STUDY OF AERODYNAMICS OF A TWO-BLADED WIND TURBINE WITH POROUS-SURFACED CYLINDRICAL BLADES

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The article discusses the study results of the aerodynamic characteristics of a two-bladed wind turbine with rotating cylinders under various airflow conditions. A two-bladed wind turbine model with porous-surfaced cylindrical blades of constant cross section was developed and made. The characteristics of the experimental model and the measurement technique are briefly described. The results of aerodynamic tests of the wind turbine model under different airflow conditions are presented. Dependences of the lifting force, drag force and traction force on airflow rate are obtained. Determinate variations in the aerodynamic forces of the model of a two-bladed wind turbine with porous-surfaced cylindrical blades with increasing incident airflow rate correspond to the physical airflow pattern.

Keywords: wind turbine, aerodynamics, rotating cylinder, drag force, traction force, porous surface.

Introduction

Kazakhstan has a significant renewable energy potential, the development of which can provide significant environmental, economic and social benefits. The national strategy is aimed at bringing the share of renewable energy sources in electricity production to 50% by 2050. The most promising and affordable renewable energy source is the wind. However, despite the considerable resource base of renewable energy sources and ambitious goals on a national scale for their development, the contribution of renewable energy to total electricity production is within 1% [1, 3]. The application of renewable energy conversion technologies in a resource-rich country such as Kazakhstan is still a big problem. Among the many factors hindering the expansion of the use of renewable energy sources, the main ones are insufficient base of effective energy technologies and developments providing stable systems of alternative energy generation irrespective of weather conditions. For example, owing to objective factors, the performance coefficient of wind-driven power plants (WPP) does not exceed 20%. This is due to the fact that WPP can convert wind energy in a certain speed range; at wind speeds of less than 2-3 m/s they stand idle, and at very high storm winds they are disconnected. Therefore, the problem of developing low-power WPP to convert wind energy both at low and high speeds is still relevant.

The article discusses the results of an experimental study of the aerodynamic characteristics of a two-bladed wind turbine with rotating cylinders under various flow conditions.

1. Statement of the problem

Renewable wind energy has been used by mankind for a long time both for individual use and on a macroscopic scale in the created wind farms. In recent years, to convert renewable wind energy into electric power, wind turbines are being developed and manufactured, where besides classical wing blades, various forms of blades are used: flat, cylindrical, cone-shaped, etc. [4-12]. There is growing interest in developing and creating efficient wind generators with cylindrical blades in order to achieve efficient flow with minimal aerodynamic drag. Cylindrical blades of constant and variable cross section with flat and spherical ends, with smooth, rough and porous surfaces with flat and spherical ends, with smooth, rough and porous surfaces have been manufactured.

In [9-11], the results of experimental investigations to study the aerodynamic characteristics of a single rotating cylinder with a porous surface in transverse air flow in the speed range from 5 to

13 m/s are presented. The dependence of the coefficients of aerodynamic characteristics on the surface porosity degree of the rotating cylinder is established.

A comparative analysis showed that an increase in the surface porosity degree of the cylinder leads to a significant change in the aerodynamic characteristics compared to their values for a smooth surface. Moreover, the greater the degree of porosity, the greater the value of the coefficient of aerodynamic drag and that of a lifting force. This is due to the fact that when the air flow moves around the rotating cylinder with a porous surface; the boundary layer expands more intensively than in case of a smooth surface.

In [12], the measurement results of the traction force of a wind turbine with rotating cylindrical blades with smooth and porous surfaces are discussed at different angles of rake of the incoming air. It has been established that the traction force decreases with an increase in the angle of rake of the flow. In this paper, the results of study of the aerodynamic characteristics of a two-bladed wind turbine with a porous surface of rotating cylindrical blades under various airflow rates are discussed.

1. The experimental plant and measurement technique.

To carry out the tests, a model of a two-bladed wind turbine with a horizontal axis of rotation of the wind wheel was made. Rotating cylinders of constant cross section with flat ends were used as blades, Fig. 1. The diameter of the wind wheel D=0.4 m, the length of each cylindrical blade L_c=0.20 m, the diameter of the cross section of the cylinder d_c=0.1 m.

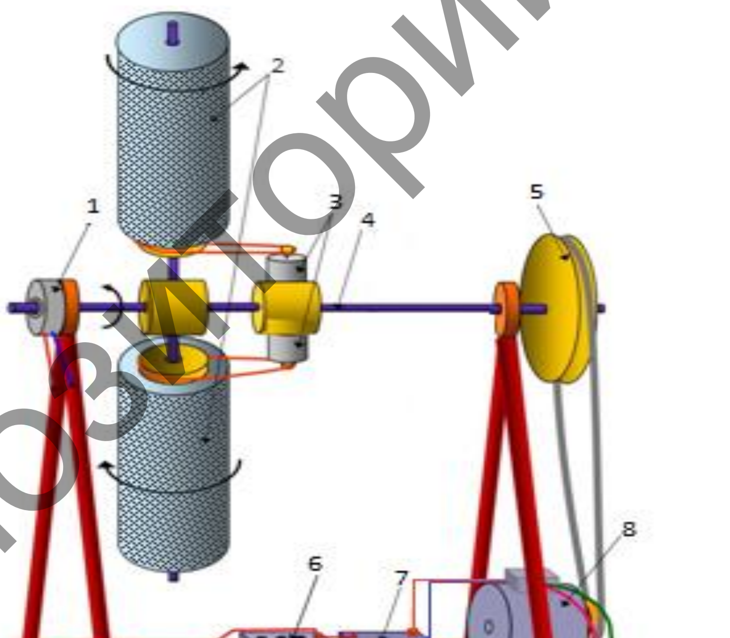

Fig.1. A model of a two-bladed wind turbine with cylindrical blades:
1– a collector device; 2 – rotating cylindrical blades; 3 – an electric motor; 4 – a horizontal shaft; 5 – a sheave wheel; 6 – a storage battery; 7 – a voltage regulator; 8 – an electric generator; 9 – an electric power consumer (ammeter).

Fig.2. A model of a two-bladed wind turbine in the working section of a wind tunnel.

In the experiments, the porous surface was modeled using a metal grid with cells of a preset size that was stretched to the surface of a cylindrical blade. The detailed description of the procedure for modeling and calculating porosity degree P_{por} through the grid cell dimensions $d_{g.c.}$ is available in [10]. In the case under consideration, the degree of porosity is:

$$P_{por} = \frac{\mathrm{dg.c./dc}}{\mathrm{Lc}} = 0.002\ \mathrm{m}^{-1}.$$

The rotational speed of the two-bladed wind turbine shaft was (40-60) rpm, the rotational speed of cylindrical elements was (500-900) rpm, and the minimum threshold of working wind speed was 3 m /s. To measure the angular rate of rotating cylindrical blades, the experimenters used a contact/noncontact digital phototach AT-8, which allows measuring in the range from 0.1 rpm to 10,000 rpm.

During the tests, the dependence of aerodynamic forces on the speed of the incoming air flow in the range from 4 m/s to 15 m/s was studied. The measurement procedure using aerodynamic weights is given in [4-5]. The traction force F_{tract} was determined using dynamometers. The error in measuring the aerodynamic forces and their moments was (3-4) %.

3. Results of the experiments and their discussion

It has been experimentally established that the values of the lifting force and the drag force increase proportionally with the increase in the airflow rate. Fig. 3a, b shows the change in the aerodynamic coefficients of a two-bladed wind turbine model with the porous surface of the rotating cylinders with increasing airflow rate. Values of aerodynamic coefficients are calculated by standard formulas [3, 11]. Experiments show that when the rate of the air flow increases, the value of the drag coefficient C_x decreases practically in accordance with the logarithmic law, Fig. 3a.

Fig. 4 shows the change in traction force $F_{tract.}$ with increasing airflow rate. As can be seen from the graph, the values of the traction force also increase almost in direct proportion to the increase in the airflow rate. A similar dependence is observed in the change in the number of revolutions of the wind wheel with increasing airflow rate, Fig. 5.

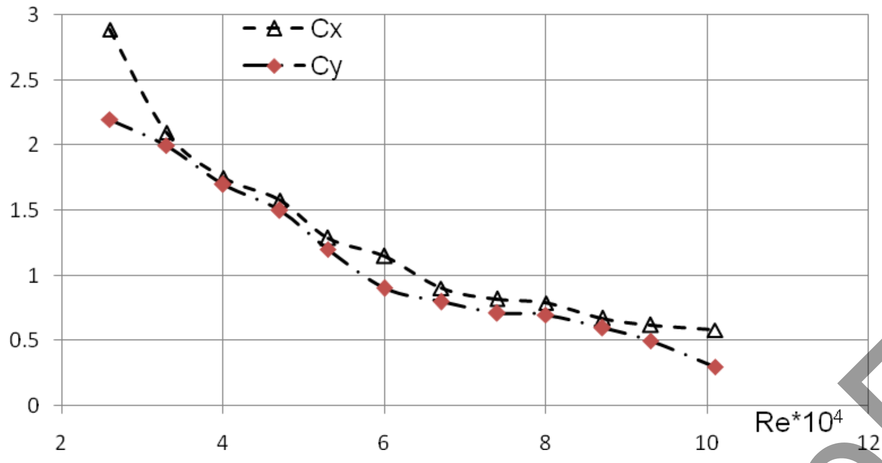

Fig.3. Dependence of the drag coefficient C_x and the lift force coefficient C_y of two-bladed wind turbine model with porous surface of the rotating cylinders on the Reynolds number.

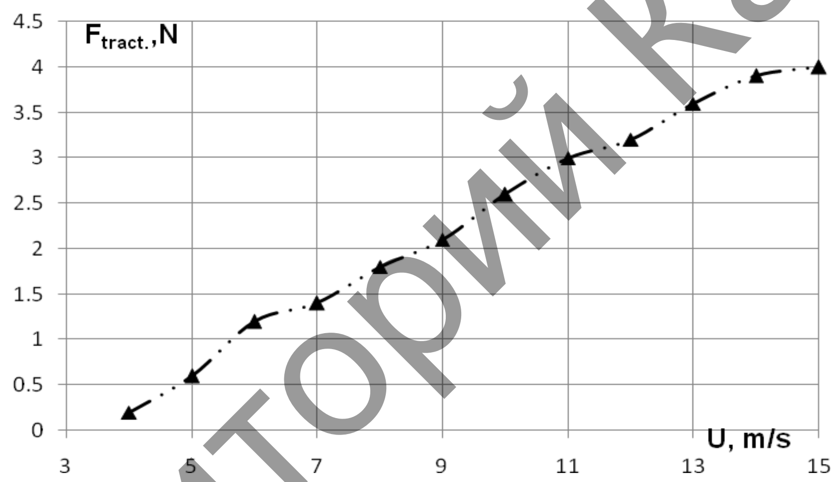

Fig.4. Dependence of the traction force of two-bladed wind turbine model with porous surface of the rotating cylinders on the rate of air flow.

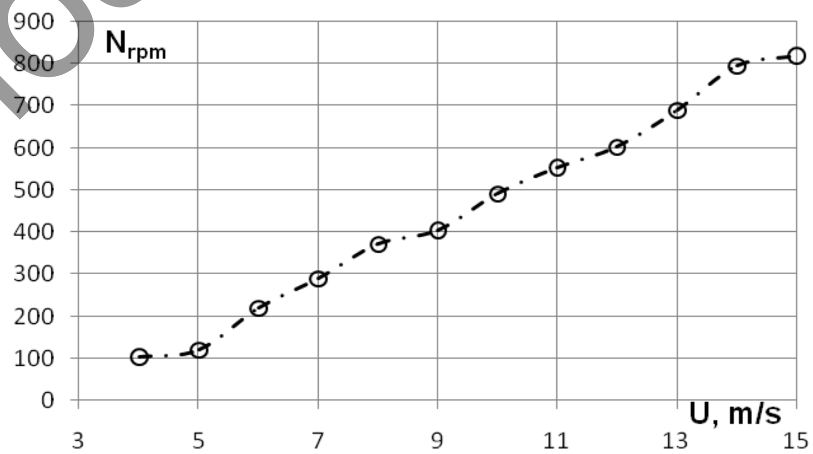

Fig.5. Dependence of the rotational speed of the wind wheel of two-bladed wind turbine model with porous surface of the rotating cylinders on the airflow rate.

Conclusion

Thus, the authors experimentally studied regularities of the change in the aerodynamic forces of the model of a two-bladed wind turbine with porous-surfaced cylinders of constant cross section with a change in the rate of the incoming air flow in the range from 5 to 13 m/s. The obtained dependences qualitatively confirmed the physical picture of the flow past a single rotating cylinder with a porous surface.

At this intermediate stage, the dependence of the aerodynamic coefficients on the porosity degree of the surface of the cylindrical blades has not been studied. Also, no special measurements have been made regarding the Magnus effect on the aerodynamics of a two-bladed wind turbine when the airflow rate changes. These regularities are planned to be investigated in further studies. Nevertheless, in the conducted experiments the technique of modeling the porosity degree of surfaces and measuring the rotational speed of the wind wheel with a change in the rate of the incoming air flow has been worked out. The obtained findings will be used for a comparative analysis with similar data for a wind turbine with smooth and rough surfaces of cylindrical blades to identify the most optimal flow parameters.

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