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GASES AND LIQUIDS

Effect of a Rough Surface on the Aerodynamic Characteristics of a Two-Bladed Wind-Powered Engine with Cylindrical Blades

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Abstract—We have reported the results of experiments on determining the drag coefficient and the thrust coefficient of a two-bladed wind-powered engine based on the Magnus effect with rotating rough cylinders in the range of air flow velocity of 4–10 m/s (Re = 26800–90000) for a constant rotation number of a cylindrical blade about its own axis. The results show that an increase in the Reynolds number reduces the drag coefficient and the thrust coefficient. The extent of the influence of the relative roughness on the aerodynamic characteristics of the two-bladed wind-powered engine has been experimentally established.

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INTRODUCTION

The interest in alternative energy sources in the world has become topical in recent years. The conservation of fuel and power resources and the reduction of their negative effect on the environment, as well as electric energy supply to distant regions, requires the development of renewable energy sources. Wind-power engineering is one of the most rapidly developing types of renewable energy sources in the world.

In the conception of Kazakhstan's transition to sustainable development for 2007–2024, it is envisaged that the fraction of alternative energy sources must reach 5% in the country's total energy balance by 2024 [1].

Therefore, wind-power engineering is not only treated as an environmentally clean energy source, but also supports the social and economic development of the country, ensures its energy safety, and reduces the dependence of electric power on fuel prices.

The effective application of wind-powered engines is especially attractive because it does not disturb the natural energy balance on the planet and simultaneously employs nonpolluting, ecologically clean power production technology. A wind-powered engine based on rotating cylinders is of special interest, since it can even operate at a low wind velocity. To increase its efficiency, methods of optimizing the aerodynamic characteristics of its elements (a system of rotating cylinders of variable cross section) should be developed. Consequently, this problem is topical both theoretically and for practical applications.

The results of testing a model of a wind-powered unit with the Magnus effect, i.e., with rotating cylinders instead of traditional blades, and of aerodynamic parameters of individual cylinders were reported in [2, 3]. In [4, 5], the aerodynamic characteristics of the flow past a two-bladed windmill in a turbulent flow with cylindrical rotors having a smooth surface were analyzed.

In [6, 7], the aerodynamic forces acting on a rotating single cylinder with a rough porous surface in the air flow were investigated in detail.

According to an analysis of available results of investigation, the problem of the experimental study of the effect of the rough surface of cylindrical blades on the aerodynamic characteristics of a two-bladed windmill was formulated based on the Magnus effect.

The application of the Magnus effect for a rotating cylinder in a flow has been known for a long time; however, the possibility of its practical application as a driving force of new-generation wind-powered engines for low velocities of the flow has only been systematically explored in recent years.

The goal of this study is to analyze the effect of surface roughness on the aerodynamic characteristics of a two-bladed windmill with cylindrical blades, which operates at low wind velocities based on the Magnus effect.

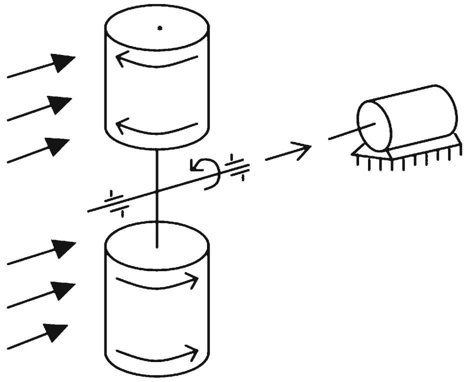

Fig. 1. Diagram of the rotation of windmill cylinders.

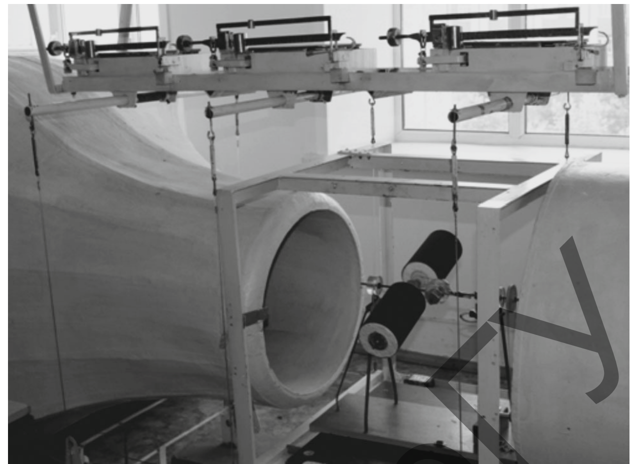

Fig. 2. Model of a wind-powered engine with two rotating elements located in the working part of the wind tunnel.

1. EXPERIMENTAL TECHNIQUE

An experimental model of a two-bladed windmill operating based on the Magnus effect was assembled at the Akylbaev Research Laboratory for aerodynamic measurements at the Engineering Thermal Physics department and was subsequently tested in a transverse air flow at different wind velocities. The model was installed in the working part of the T-1-M wind tunnel, which was fixed to the frame of a three-component aerodynamic balance using thin metal tension wires. The three-component aerodynamic balance makes it possible to measure the drag force with a fairly high degree of accuracy. The thrust of the main balance shaft of the windmill was measured using a spring dynamometer.

Figure 1 shows the diagram of the rotation of the windmill cylinders in opposite directions.

The experiments were carried out with a windmill that has two rotating cylindrical blades with a rough surface that has a diameter of 100 mm and a length of 200 mm. The velocity of the incoming flow and the rotational frequency of the cylinders remained unchanged.

Figure 2 shows the model of a windmill with rotating elements that have rough surfaces, which are installed in the working part of the wind tunnel.

During the experiments, the relative roughness varied in the range of 0.002–0.02; the dimensionless criterion of the velocity and flow regime varied in the range of 20000–105000.

The relative roughness is defined by the formula

$$\bar{k} = \frac{k}{d},$$

where k is the average height of protrusions on the rough surface of the cylinders and d is the diameter of the cylinder.

The distribution of roughness over the cylinder surface was uniform. The surface density of the granularity of the rough medium was 100–120 grains/cm^2.

2. RESULTS

The drag coefficients and the thrust coefficients were calculated based on the results of measuring the aerodynamic forces and their dependences on the Reynolds number were plotted.

Figure 3 shows the dependence of the drag coefficient of a windmill on the Reynolds number for a relative roughness of 0.005–0.02.

It can be seen that the drag coefficient decreases upon an increase in the Reynolds number for all values of relative roughness. The difference in the variations of the drag coefficient is insignificant. This is because, for a high velocity of the air flow, the eddy region behind the cylinder is separated from the walls of the rotating cylinders due to the head energy of the flow. In this case, the increase in the drag to the flow past the cylinders becomes smaller because the drag coefficient is directly proportional to the head-on force, but is inversely proportional to the squared wind velocity.

Figure 4 shows the dependence on the Reynolds numbers for the thrust coefficient of a windmill with blades in the form of rotating cylinders with rough surfaces. It can be seen that the thrust coefficients of the windmill with cylindrical blades that have a rough surface decreases with increasing Reynolds number.

In the next experiments, we determined the extent of the influence of the change in the relative roughness on the drag coefficient and the thrust coefficient. The results are shown in Figs. 5 and 6.

It can be seen that, with increasing relative roughness, the thrust coefficient and the drag coefficients increase. The curves depicted in the figures were obtained upon a change in the flow velocity from 4 to 10 m/s.

This is because, when air flows past the rotating cylinders with a rough surface, the boundary layer formed on the cylinder surface becomes thicker following an increase in the relative roughness.

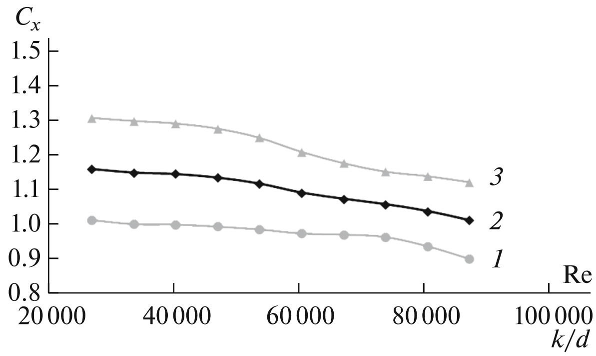

Fig. 3. Dependences of drag coefficients of windmill on the change in Reynolds numbers. *k/d*: (*1*) 0.005 (*2*) 0.01; (*3*) 0.02.

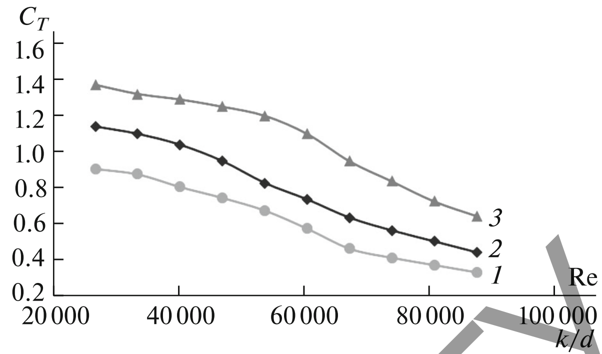

Fig. 4. Dependences of the thrust coefficient of windmill on the change in Reynolds numbers. *k/d*: (*1*) 0.005; (*2*) 0.01; (*3*) 0.02.

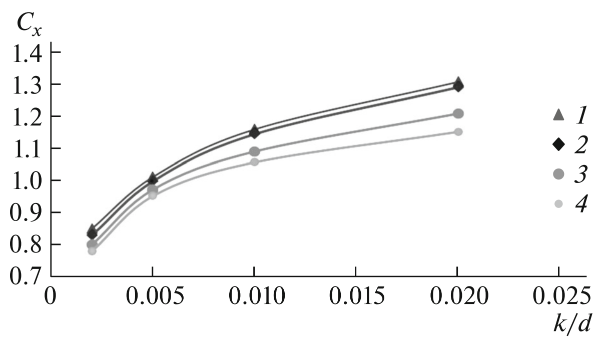

Fig. 5. Dependences of drag coefficients of windmill on the change in the relative roughness. *U*, m/s: (*1*) 4; (*2*) 6; (*3*) 8; (*4*) 10.

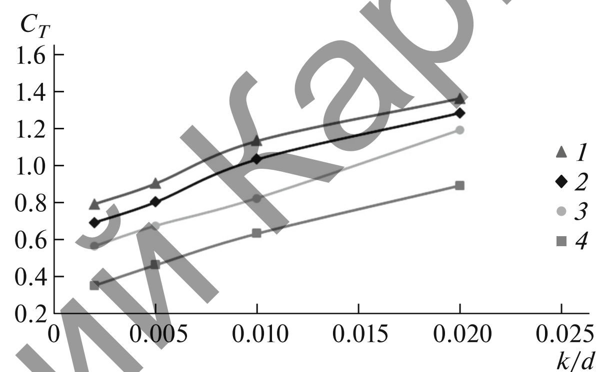

Fig. 6. Dependences of the thrust coefficients of windmill on relative roughness. *U*, m/s: (*1*) 4; (*2*) 6; (*3*) 8; (*4*) 10.

Rotating cylinders entrain air particles located near their surfaces. These particles move over the surfaces of the cylinders in the direction of the rotation of the cylinders, which produces a rotating air flow.

In the air flow past a rotating cylinder, particles of air in the oncoming flow past the cylinder change their trajectories in the direction of the rotation of the cylinder. The entrainment of particles of the incoming flow by the rotating flow and the bend in the streamline of the incoming flow depend on the type of the surface and on the rotation velocity. A cylinder with a rough surface entrains the incoming flow more intensely than a cylinder with a smooth surface.

CONCLUSIONS

Our experiments show that the drag; the thrust force; and, accordingly, their coefficients increase with the relative roughness. This is because the rough surface of a rotating cylinder embraces a larger part of the incoming flow compared to the smooth surface, which forms broad boundary layers. With increasing relative roughness from $\bar{k}$ = 0.002–0.02, the drag coefficient increases by 1.5 times, while the thrust coefficient increases threefold.

It has been established that a rough surface improves the aerodynamic characteristics of a two-bladed wind-powered engine with cylindrical rotors. It is possible to increase the efficiency of the windmill by increasing the relative roughness of the cylindrical blade surface.

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