UDC 533.601; 621.548

THE EFFECT OF POROSITY ON THE AERODYNAMIC CHARACTERISTICS OF A ROTATING CYLINDER

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The paper presents the results of experimental studies on determination of the drag and lift force of a rotating cylinder with a porous surface within the airflow velocity range from 5 to 13 m/s (Re = 40,000-105,000) at a constant rotation of the cylinder around its axis. There are also presented the results of studies of drag and lift force of a single rotating cylinder within the range of the cylinder revolutions number around its axis from 400 to 1,400 rev/min at a constant air flow rate. It is shown that the drag coefficient and the lift force coefficient depend on the Reynolds number and the cylinder revolutions number. The dependence of the coefficients of aerodynamic characteristics on the degree of porosity of the surface of the rotating cylinder is established.

Keywords: Magnus effect, porous surface, Re numbers, rotating cylinder.

INTRODUCTION

To save fuel and energy resources, to reduce the negative impact on the environment, as well as to supply power to regions, requires the development of harnessing of renewable resources. The Republic of Kazakhstan has huge a potential of renewable energy sources. For example, in most parts of the territory of the Republic of Kazakhstan an average annual wind speed is 3-5 m/s, therefore the urgent task is to develop a windmill. Of particular interest is the windmill based on rotating cylinders of constant and variable cross-sections that can efficiently operate even at low wind speeds. To optimize the efficiency of the windmill, it is necessary to study the aerodynamic characteristics of the component of a windmill that is of the rotating cylinder. Therefore, this task is relevant both for science and practical use.

Aerodynamic characteristics of cross-flowed fixed single cylinders in an infinite stream has been fairly well studied by S.I. Isataev in his work [1]. Effect of cross-section area reduction ratio of flow on the flow pattern of an infinite cylinder on aerodynamic and hydraulic drag are investigated and systematized in the work of Akylbaev Zh.S. [2,3]. Aerodynamics of short cylinders, quite often found in power units and installations, is investigated using experimental and theoretical methods in the work of Zhangunov O.N. [4].

However, nowadays there are extremely scarce works on the study of aerodynamics of the complicated flow around a single rotating cylinder and a system of the ones which are components of developed by us windmill, the rotating cylinders accompanied by a turbulent flow of the group of interacting vortices. The known works of Bychkov N.M. [5, 6] are concerned with determining of aerodynamic parameters of single rotating cylinders in the airflow.

On the basis of the analysis of existing studies we proposed an experimental investigation of the effects of porosity on the aerodynamic characteristics of a rotating cylinder as component of a windmill, using the Magnus effect.

Application of Magnus effect at rotating a cylinder in a flow has been known since ancient times [4], but the possibility of practical use as a driving force for a new generation of windmills for small flow rates has been systematically studied only in recent years.

The objective of the work is to study the effect of surface porosity on the aerodynamic characteristics of a single rotating cylinder as the main component of a windmill operating at low wind speeds using the Magnus effect.

RESEARCH METHODOLOGY

The experimental plant was a closed type wind tunnel with an open working section with metal frame hanging on a three-component aerodynamic balance. The diameter of the working section was 0.5 m, its length was 0.8 m.

Investigations were carried out within the air flow speed range from 5 to 13 m/s (Re = 40,000-105,000) at a constant revolutions number of the cylinder around its axis. The drag force and lift force of the rotating cylinder was measured with the three-component aerodynamic balance. The three-component aerodynamic balance makes it possible to measure the drag force and the lift force with a sufficiently high degree of accuracy.

The arrangement of the main components of the plant in the working section of the wind tunnel is shown in Fig.1.

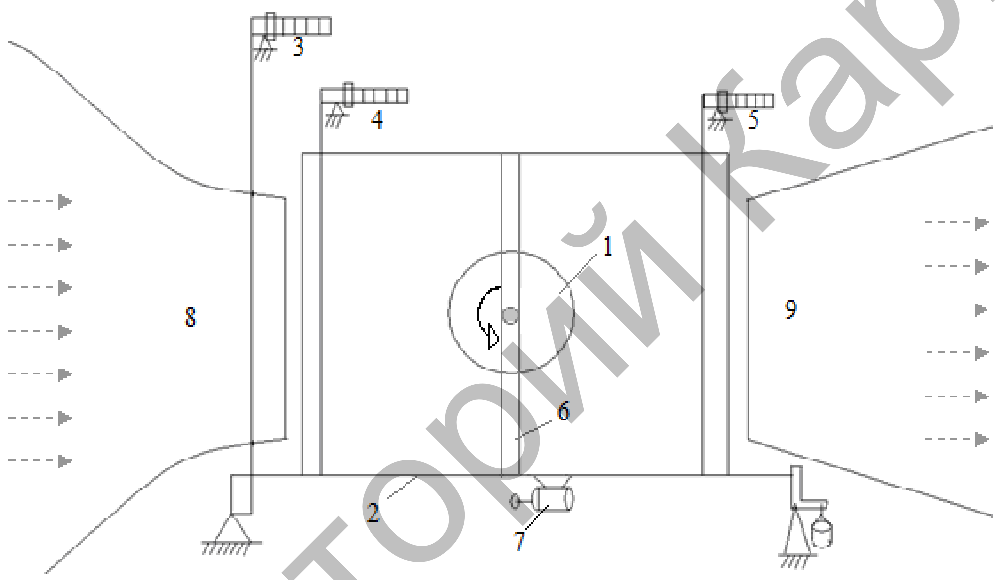

Fig.1. Scheme of the experimental plant for the study of aerodynamic characteristics of the cylinder

Here in Figure 1: 1 – the cylinder under investigation; 2 – a frame for fixing the model with aerodynamic balance; 3 – drag balance; 4, 5 – lift balance; 6 – the rack for mounting cylinders; 7– the engine for rotation of cylinders; 8, 9 – the diffuser and contractor of the wind tunnel.

The experimental model was streamlined with a cross air flow, generated in the working section of the wind tunnel (Fig. 2). The cylinder was rotated by an electric motor.

The air flow approaching the frontal part of the cylinder, applies a force that is indicated on the balance.

The tests were performed with two types of rotating cylinders with a diameter of 120 mm and a length of 330 mm: those having a smooth surface and a porous surface.

Reynolds number and the coefficients of aerodynamic characteristics were calculated as follows:

The formula for determining the Reynolds number:

$$\mathrm{Re} = \frac{ud}{\nu} \qquad (1)$$

where u is the velocity of the air flow, approaching the cylinder; d is the outer diameter of the cylinder under study; ν is the kinematic viscosity of air.

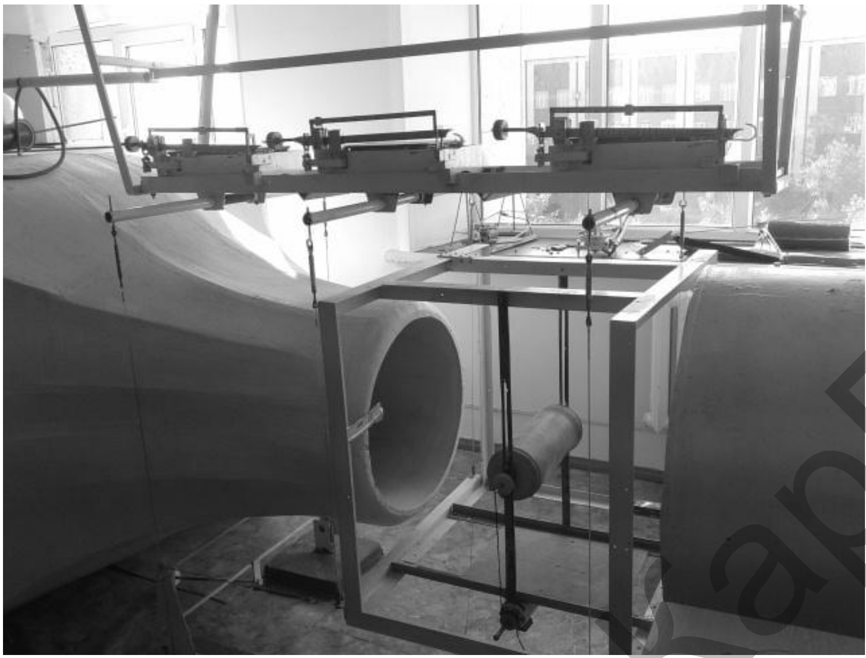

Fig.2. Photo of a cylinder under study installed in the working section of the wind tunnel T-1-M

The formula for determining the drag coefficient:

$$C_x = \frac{Fd}{\frac{\rho u^2}{2} S} \quad (2)$$

where Fd is the drag force;
u is the air flow velocity;
ρ is the air density;
S – is the area of a middle section of the cylinder under study.
The formula for determining the lift force coefficient:

$$C_y = \frac{Fd}{\frac{\rho u^2}{2} S} \quad (3)$$

where C_y is the lift force.

RESULTS OF RESEARCH OF AERODYNAMIC CHARACTERISTICS OF A ROTATING CYLINDER WITH A POROUS SURFACE

Dependence of drag coefficient C_x and lift force coefficient on Re number are shown in Fig. 3 and 4.

Fig.3 and 4 show that the drag coefficient and the coefficient of lift force of the rotating cylinder decrease with increasing of flow velocity (Re numbers).

During the experiment, in addition to study of dependency of aerodynamic characteristics coefficients we investigated the dependence of drag coefficient and lift force coefficient on the rotation frequency of the cylinder around its axis at a constant incident flow velocity.

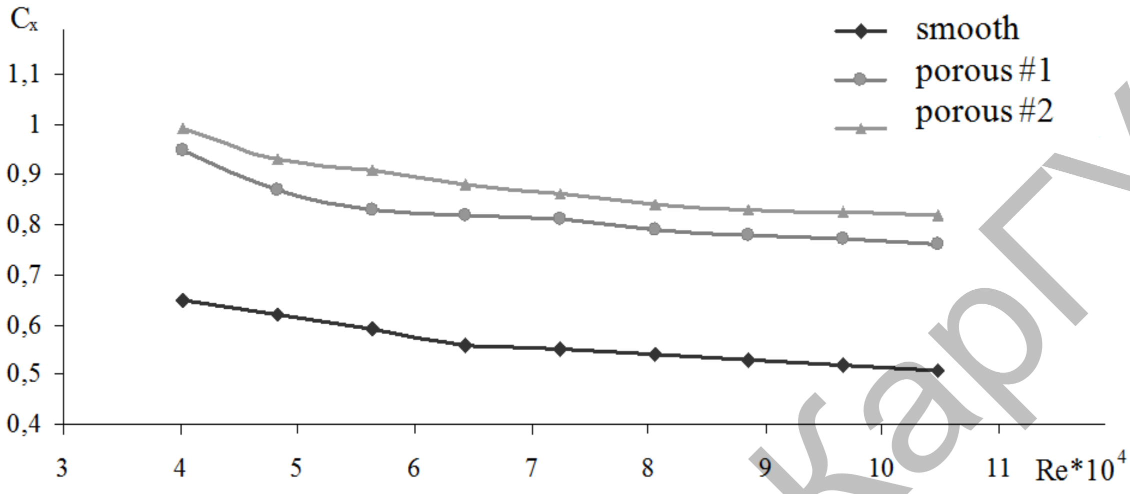

Fig.3. Dependence of C_x on the Reynolds number

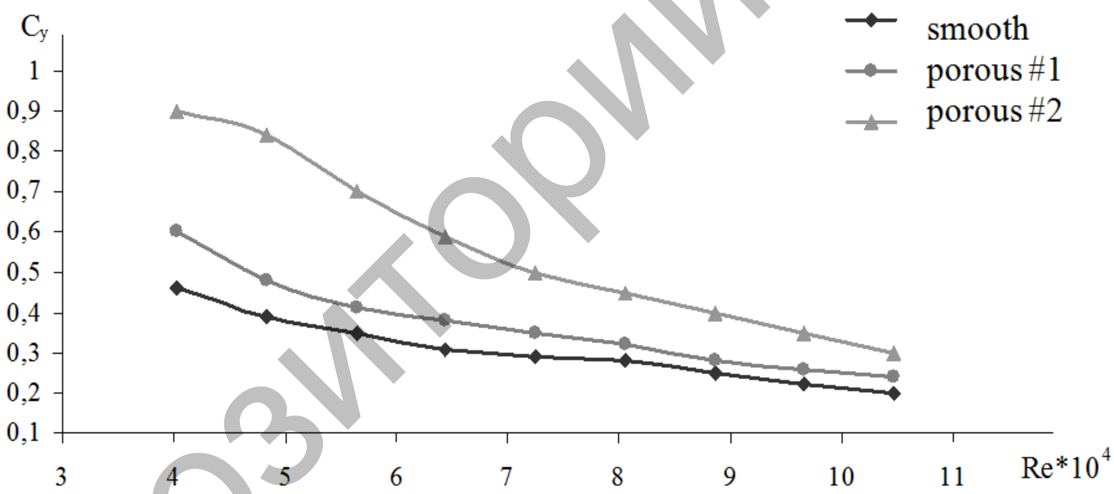

Fig.4. Dependence of the lift force coefficient on the Reynolds number

Fig.5 is a graph of dependence of drag coefficient on rotation frequency at a constant velocity of air flow approaching the cylinder. In Figure 5 you can see that an increase in the rotation frequency of the cylinder results in growth of the drag coefficient. This is due to the fact that, when a stream at a certain velocity flows around a rotating cylinder, vortex flows are formed behind the latter. These vortex flows will interact with particles of the air on the surface of the cylinder at its back and block the incident flow. With an increase in the frequency of rotation of the cylinder, the blocking force of the cylinder against the flow increases. Therefore, the drag of the rotating cylinder increases.

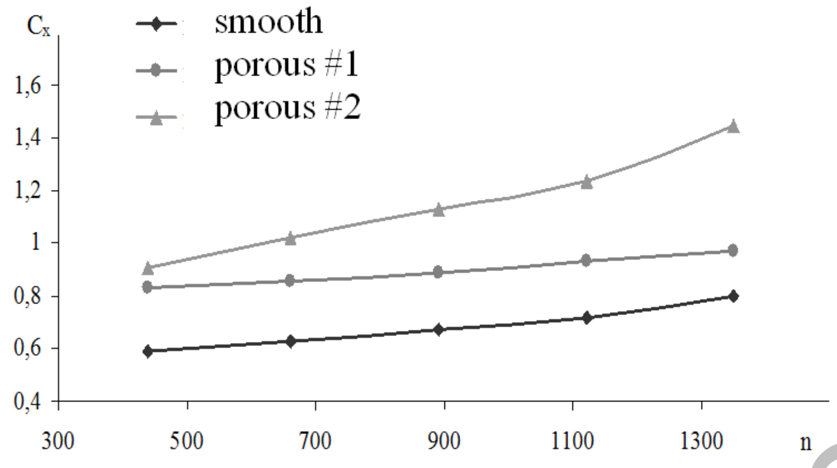

Fig.5. Dependence of the drag coefficient of the rotating cylinder on the rotation frequency

Fig.6 shows the dependence of the lift force coefficient on the frequency of rotation of the cylinder at a constant velocity of the cross-flow stream.

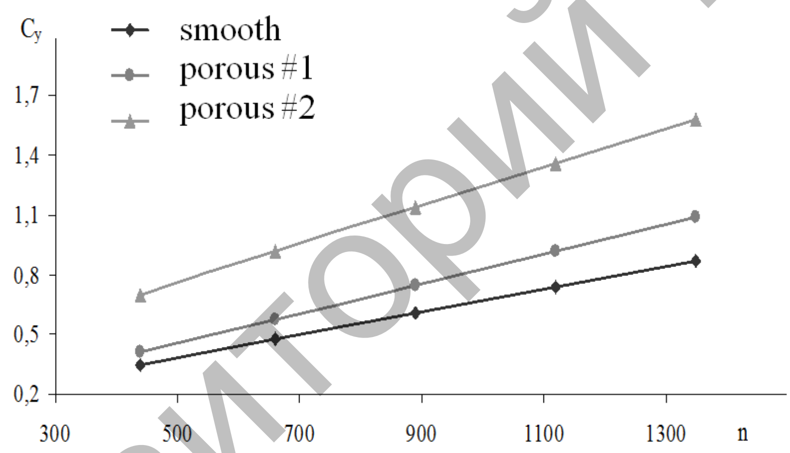

Fig.6. Dependence of the lift force coefficient of a rotating cylinder on the rotation frequency

Fig.6 shows that at a constant velocity of the air flow, the lift force coefficient of the rotating cylinder rises when the rotation frequency of the cylinder increases. This is due to the fact that when the cylinder begins to rotate, it forms a swirling motion around itself. The rotating cylinder entrains the neighboring layers of air; as a result of it, the surrounding air gets, apart from the translational movement, rotation around the cylinder as well. In those places where the velocities of the rotational motion and translational movement are added, the resulting speed exceeds the velocity of the flow, approaching the cylinder. And on the opposite side of the cylinder, the velocities are subtracted and the resulting speed is less than the velocity of the flow away from the cylinder. As a result of it, there is a difference in pressure on the cylinder surface. These differences affect the coefficients of aerodynamic characteristics of a rotating cylinder. The greater the rotation frequency of the cylinders, the more the pressure difference on the cylinder surface. Therefore, the coefficients of aerodynamic characteristics of a rotating cylinder increase.

From the above charts you can see that increase in the porosity of the cylinder surface leads to quantitative growth of coefficients of aerodynamic characteristics of a rotating cylinder. The reason is as follows: when flowing around a rotating cylinder with a porous surface with the air flow, a boundary layer is formed the on the surface of the cylinder that will expand with increase in the degree of porosity.

CONCLUSIONS

On the basis of the data research of the effect of porosity on the aerodynamic characteristics of a rotating cylinder we can draw the following conclusions:

- drag and lift force coefficients of the rotating cylinder as components of a windmill based on Magnus effect depend on the Reynolds number. Increase in the flow velocity (Re numbers), is followed by reduction in the coefficients of lift force and drag by 5-10%.
- Increase in rotation frequency of the cylinder around its axis raises the quantitative values of aerodynamic characteristics of a rotating cylinder, i. e. drag coefficient and the coefficient of lift force.
- aerodynamic characteristics of a rotating cylinder depend on the degree of porosity of the surface of the cylinder. The more the degree of porosity the quantitatively greater drag and lift force coefficients.

Thus, the results obtained can be used to develop and build windmills of small velocities based on the Magnus effect.

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Article accepted for publication 27.09.2013