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AERODYNAMICS OF THE REVOLVED CYLINDERS SYSTEM IN A CROSS TURBULENT STREAM

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In this paper the possibilities of using a system of revolved cylinders as part of a wind turbine are considered. Experimental device and measurement technique were described. The aerodynamic forces in the cross-flow of a cylinder and a system of two cylinders have been measured. A method for determining the optimal distance between the cylinders in their cross-flow has been developed. We experimentally determined the conditions under which the Magnus effect contributes to the largest increase of a lift force and, correspondingly, to the increase of the wind turbine efficiency.

Keywords: aerodynamic force, lift force, revolved cylinders, in the cross-flow of a cylinder, Magnus effect, rotational frequency, wind turbine, wind tunnel

Introduction

At the present time, “non-traditional” techniques of heat and electrical energy generation are becoming more important. This is due to a number of factors, such as the continuous increase in the energy consumption rate, a sharp increase in prices for basic energy products, such as gas, oil, coal, and the deterioration of the environment condition. The use of wind power as a non-traditional renewable energy source is of great interest. In this paper, the problems of the development of a wind turbine that operates in a wide range of wind speeds are considered. Such a wind turbine is needed because in Central Kazakhstan the average speed of natural wind is (3-4) m/s. This is much less than the speed for which industrial wind turbines operating at a wind speed of 5 m/s and above are designed.

The analytical review of this topic shows that a wind turbine with revolved cylinders which can operate at low wind speeds is of special interest. The close analogs are two variants of the elements of wind turbines which operate at speeds less than 5 m/s: a sail-type wind turbine developed at the Academician Lavrentyev Hydrodynamics Institute of the RAS SB, and a turbine with the use of a cylindrical revolved rotor, i.e. a rotary screw [1, 2].

A circular cylinder is a frequent element of almost all aerodynamic devices, heat exchangers and power equipment. In the cross-flow of a cylinder with a fluid stream, the streamline pattern depends strongly on the Reynolds number, the degree of the stream turbulence, etc. The peculiarities of the cylinder cross-flow have been studied in some detail in the work of J.S. Akylbayev [3]. The aerodynamic characteristics of the cylinders revolving around their main axis are much less studied [4]. The present level of high technology development allows the use of a revolved cylinder as a special element for getting an additional lift force directed across the stream.

In the rotary motion of the cylinder in the upper air flow, the flow rate and the surface speed are the same, they add up and flow acceleration and increase in speed appear.

At the bottom of the cylinder, the flow rate and the surface speed have opposite directions, they are deducted, there is deceleration and decrease in speed. The appearance of such a difference in speed leads to a transverse pressure difference and the appearance of a transverse lift force, called the Magnus effect, fig.1.

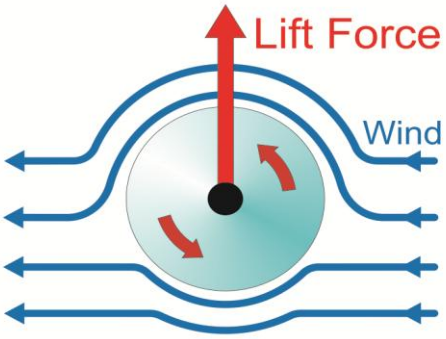

Fig.1. The scheme of the rotating cylinder in the cross-flow.

We have used this phenomenon to create a wind turbine. The novelty of the study is that, in contrast to the existing simple helical wind turbines, the blades of which reflect the air flow for small angles, in our wind turbine the cylindrical elements much more efficiently capture the wind flow through the rotation of the cylinders themselves. Due to this fact, the high efficiency of the wind turbine at low wind speeds is ensured.

Phenomenon of the Magnus effect

Each of you observed this phenomenon while watching a football match or tennis games. We all know that a soccer ball aimed at the goalposts with a twist moves along a curved locus, a tennis ball flying swiftly over the net with a twist also deflects from the rectilinear locus. At the bottom of these two examples we can see that on bodies flying with rotation in the air flow affects lateral force deflecting from the rectilinear locus, first described in 1853 by a German physicist Heinrich Magnus and named the Magnus effect in his honor. We used this phenomenon in our project to construct a wind turbine. But instead of a ball we have a rotating cylinder which creates a great force of the Magnus effect. In 1924 a German engineer A. Flettner first tested this phenomenon as a rotary engine instead of sails on the ship “Bukau” One of the first wind turbines which used the effect of rotating cylinders was a wind ship of A. Flettner, [5]. Flettner’s wind ship or the Flettner rotor has amazing characteristics that cannot be explained by simple notions of wind pressure, suffice it to say that the use of force on the rotating cylinder should be 10-15 times larger than on a sail with the same visible surface.

Fig. 2. Screw in the air stream (left) and scheme of reflect flow air (right)

At the present time hydrodynamics not only may explain well this seemingly mysterious phenomenon but it also became a planned guide at the discovering of large forceful actions of rotating cylinder. The novelty of the study is that, in contrast to the existing simple helical wind turbines, the blades of which reflect the air flow for small angles fig.2, in our wind turbine the cylindrical elements much more efficiently capture the wind flow through the rotation of the cylinders themselves. Due to this fact, the high efficiency of the wind turbine at low wind speeds is ensured fig.3.

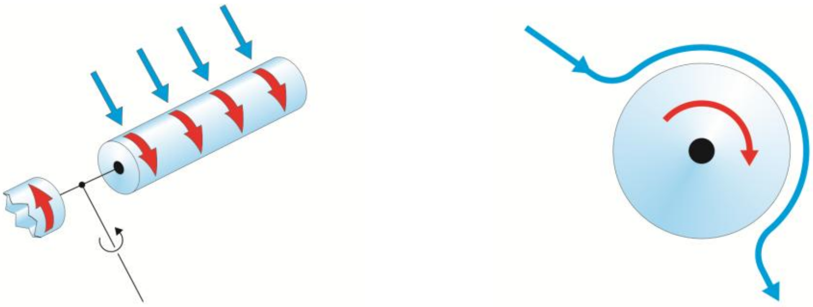

Fig.3. Flow around a rotating cylinder (left) and scheme of capturing the flow of air (right)

Experimental device and measurement technique.

The experiments have been conducted on the T-1-M wind tunnel with the diameter of the open working section D = 500 mm, fig.4. The speed of the approach flow varies in the range of 2.5-25 m/s, the diameters of the cylinders D = 50-150 mm, the length of the cylinders l = 300 mm, the variaton range of the rotational frequency of the cylinders is 100-1500 rpm.

Fig. 4. The working part of the wind tunnel with a single (left) and with two (right) cylinders

The diameter of the cylinder could be changed with the help of bulking layers with a rough surface. The cylinders were rotated with the help of drive belting received from the variable speed electric motor. The rotation speed of the cylinder is fixed with the help of a tachometer, the accuracy of a three-component aerodynamic balance during the measurement of the lift force is 8-10%. The experiments have been conducted with both single cylinders and a system consisting of two cylinders. The experiments investigated the effect of the frequency and direction of the cylinders rotation on the magnitude of the lift and drag forces. The measurements have been conducted at different speeds of the approach air flow in the presence of various degrees of the cylinders surface roughness.

Discussion of the results of measurements

After measuring, the dependency of the lift force on the rotational frequency of the cylinders with smooth and rough surfaces with a diameter of 50 mm in the flow at a speed of U = 8 m/s and

12 m/s have been obtained. We have found that, with the increase in the rotation speed of the cylinder, the lift force increases more than twice and reach its maximum at a rotation speed of about 1300 rpm. The presence of the granular roughness leads to an increase in the lift force by 30% compared to the cylinder with a smooth surface with equal flow conditions.

With the increase in the diameter of the cylinder, the lift force increases, for example, at a flow rate of 18 m/s the increase in the diameter from 50 to 150 mm leads to an increase in the lift force of more than 2.5 times. T

he magnitude of the lift force increases depending on the rotation speed of the cylinder, and this increase occurs only up to a certain maximum magnitude. A further increase in the rotational frequency does not lead to an increase in the lift force. The degree of the cylinder roughness does not lead to a significant change in the nature of the dependencies and affects only the numerical values of the drag coefficient, as in the case of the lift force. The following series of experiments have been conducted with cylinders of constant and variable cross-sections in the form of a conoid.

As a result of experimental investigations there are dependences of the aerodynamic characteristics: a drag coefficient

$$C_x = \frac{\Delta F}{\rho \cdot \frac{\upsilon^2}{2} \cdot S},$$

where C_x - a drag coefficient; ΔF – drag force, N; ρ – air density, kg/m^3; υ – air flow rate, m/s; S – frontal area, m^2, a lift coefficient

$$C_y = \frac{F}{\rho \cdot \frac{\upsilon^2}{2} \cdot S},$$

where C_y – a lift coefficient; F – lift force, N; on geometric parameters (the cylinder's diameter, the distances between the cylinders) and operating (flow rate, the cylinder's rotation velocity and the Reynolds number equal to

$$\mathrm{Re} = \frac{\upsilon \cdot d}{\nu},$$

where are next parameters: *Re* – the value of the Reynolds number; υ – air flow rate, m/s; *d* – the diameter of the cylinders, m; ν – kinematic viscosity of air, m^2/s

Below are the graphs of the dependencies given in figures 5 - 8. The experimental dependencies obtained show that, with an increase in the flow rate, the lift force increases; with an increase in the Reynolds number, the drag coefficient reduces.

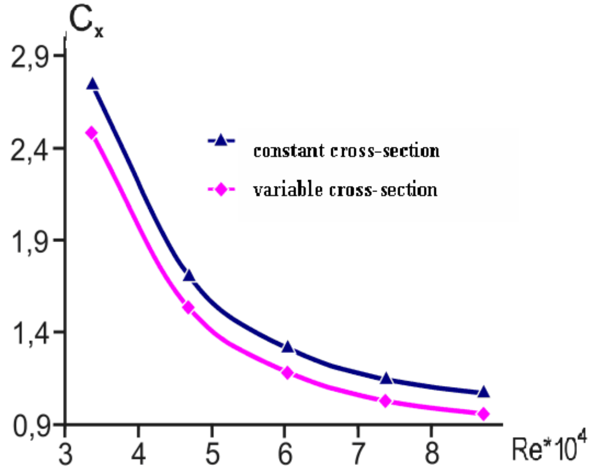

Fig. 5. Dependency of the drag coefficient on the Reynolds number

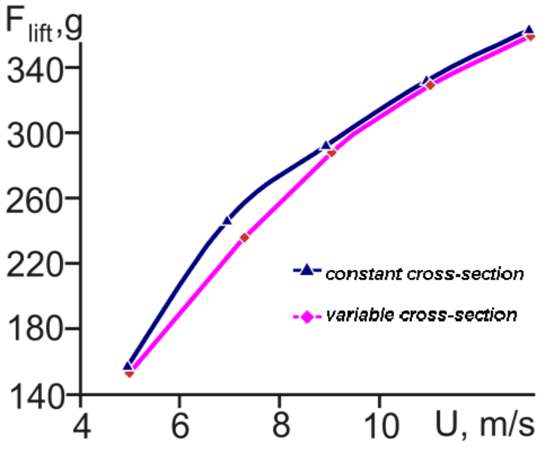

Fig.6. Dependency of the lift force on the flow rate

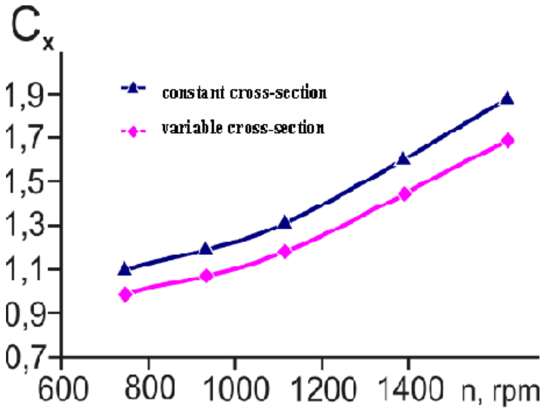

Fig.7. Dependency of the drag coefficient on the angular rotation speed of the cylinder

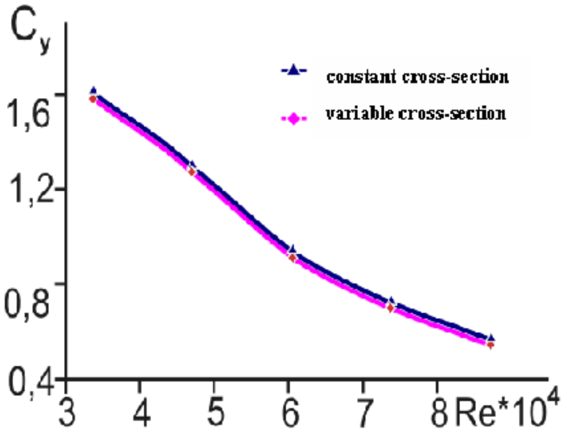

Fig.8. Dependency of the lift coefficient on the Reynolds number

It is also established that, with an increase in the angular rotation speed, the drag coefficient increases; with an increase of the Reynolds number, the lift coefficient reduces. In subsequent experiments, we have investigated the aerodynamic characteristics of a system of two cylinders with different distances between them L. As part of the study of the aerodynamic characteristics with two revolving cylinders, two cases of the rotation of the cylinder have been considered: the cylinders revolve in the same direction with the air flow, and the cylinders revolve in opposite directions. These series of experiments show that the cylinders of variable cross-section have a less aerodynamic drag and sufficiently high magnitudes of the lift force.

It is seen that, with an increase in the distance between the revolving cylinders, the lift coefficient increases and reaches its maximum at a distance of 3 cm. With a further increase in this distance, the lift coefficient reduces. Upon reaching the distance of about 6 cm, the interference of the revolving cylinders with each other virtually disappears.

The data obtained have been compared to the lift force of a symmetric airfoil, the chord of which is equal to the diameter of the cylinder, and the length of the airfoil is equal to the length of the revolving cylinder. Comparing the data obtained for the aerodynamic forces of the revolved cylinder, we can conclude that the lift and drag forces of the revolving cylinder are much larger than those of the airfoil of the same size.

Conclusions

1. The aerodynamic characteristics of the twin cylinders, namely the coefficients of drag and lift forces, depend on the geometry (the cylinders diameters and the distance between them) and mode parameters (flow rate, Reynolds number and the rotation speed of the cylinders).
2. For cylinders with diameters of 10cm, the distance from which an interaction between the cylinders almost disappears has been defined (>3 cm).
3. Rotating cylinder of variable cross-section can be used as a part of a wind turbine that works more efficiently (by 8-10 %) than that with the constant cross - section.
4. Unlike the existing methods, this approach is based on the active capture of airflow by rotating cylindrical elements. The section variability provides an optimal aerodynamic resistance and reasonably high traction for rotating elements. This can be used to create multi-bladed wind turbines of a new generation based on the Magnus effect.

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