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Research lift coefficient on the distance between the revolving cylinders a turbulent stream

In this paper the possibilities of using a system of revolved cylinders as part of a wind turbine are considered. 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. This can be used to create multi-bladed wind turbines of a new generation based on the Magnus effect. The aerodynamic characteristics of the cylinders with diameters 10 cm in diameter, that is the rotary motion, is determined by the maximum value with the coefficient of lifting force and the frontal impedance coefficient. These results are useful for us in practice, as these results can be used in smaller wind speed engines. In the local economy, the use of local wind power is a convenient, affordable, and environmentally friendly, with a minimal wind speed engine focused on reducing the deficit of electricity, which is one of the key issues in rural areas.

Keywords: rotary cylinders, magnus effect, wind turbines, coefficient of lift.

Introduction

One of the most important features of the modern world is the increased attention of the world community to the problems of rational and efficient use of energy, implementation of energy saving technologies and renewable energy. The increasing demand of mankind for energy resources leads to the need to search for alternative sources of energy supply and their wider use.

Currently, energy and its sources are the most urgent problem not only in the Republic of Kazakhstan, but also around the world. Increasingly, at the highest national and international levels, issues of meeting the ever-increasing needs for all types of energy, increasing its cost, depletion of natural resources, harmful effects on the environment, the dangers of global warming, etc. are being discussed.

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.

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.

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. 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. 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, as shown in the figure 1. 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.

To study the process of converting the wind energy of the air stream into electrical energy in the laboratory, we created a special experimental industrial model of a wind turbine from systems of rotating cylinders with a porous surface, on which it is possible to determine and evaluate the use of wind flow energy. A wind generator with blades in the form of rotating porous cylinders belongs to wind power plants using the Magnus effect.

Discussion of the results of measurements

When a rotating cylinder is flowed by an air flow, the air particles of the incoming flow, flowing around the cylinder from the actions of the flow around the surface of the rotating cylinder, change their trajectory in the direction of rotation of the cylinder. The entrainment of incoming flow particles by the rotational flow and the bending of the incoming flow line depend on the type of surface and the speed of rotation. A cylinder with a porous surface is more attracted by the incoming flow when rotating than a cylinder with a smooth surface.

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 reaches 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. The 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.

When the body flows, for example, on the wing of an airplane, depending on its guiding angle, there is a lifting force that directs in one direction or another. There are also bodies that do not affect lift. This mostly depends on their shape. In this work, a rotating moving cylinder located perpendicular to the air jet is considered as the body under study.

At a constant speed, giving the rotating cylinder a different angular velocity, an air stream was sent. As the number of rotations increases, the value of the Weights will change. This gives a different kind of flow depending on the rotating cylinder than the stationary cylinder. The flow rate will be higher than under the influence of the viscosity of the rotating cylinder. Therefore, there is a horizontally oriented force that affects the wall, that is, the lifting force. When the air flow spreads in the horizontal direction of the body, creating a rotational movement, the lifting force of the cylinders appears. Lift is measured using aerodynamic Weights that are balanced. In this case, the front and rear lifting forces of rotating moving cylinders are measured separately, the total lifting force is taken as their sum: $F_{к.к} = F_1 + F_2$.

We conducted a comprehensive study to identify the dependency of the aerodynamic properties: the drag coefficient $C_x = \dfrac{\Delta F}{\rho \cdot \dfrac{\upsilon^2}{2} \cdot S}$ and the lift coefficient $C_y = \dfrac{F}{\rho \cdot \dfrac{\upsilon^2}{2} \cdot S}$ on the geometric parameters (that is in our case: diameter of the cylinder, the distance between the cylinders) and mode parameters which are: flow rate, the Reynolds number $\mathrm{Re} = \dfrac{\upsilon \cdot d}{\nu}$ and rotation velocity of cylinders. 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. 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 this work, we study the dependence of the change in lift force on changes in the air flow rate and the number of cylinder rotations that occur when the air flow of rotating moving cylinders leaks in the horizontal direction. If one of the listed variables changes during the experiments, the second one remains stable. For example, if the air flow rate changes, the number of cylinder rotations is kept stable.

During the experiment, it was found that when the speed of the air flow flowing in the horizontal direction of rotating moving cylinders is exceeded, the drag force and lift force increases.

Figure 1 shows the dependence on the change in the flow rate of the true value of the lifting force of rotating moving cylinders located at a certain angle. When the dependence is shown, the lines of dependence of the values obtained when the cylinders are positioned to each other and at an angle are shown.

The true value of the lift is determined by the formula: $F_y = \dfrac{2}{1+\cos\alpha} F$.

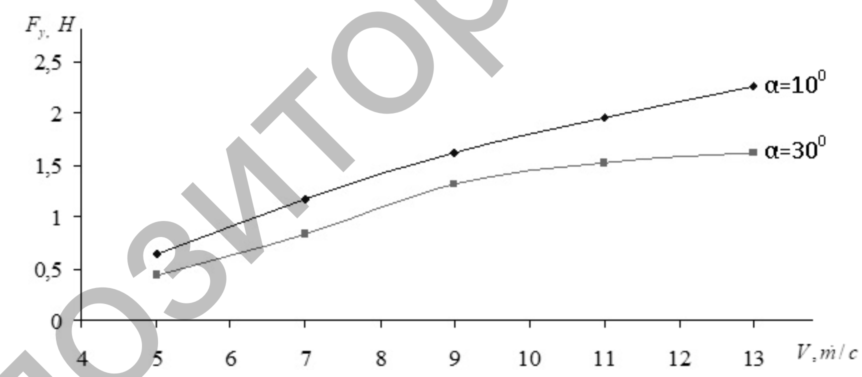

Figure 1.Cylinders with a constant amount of rotation dependence of the true lift value on the flow rate

The Figure 1 shows that the true value of the lifting force of two rotating moving cylinders is directly proportional to the speed of the air flow, i.e., when the speed increases, the true value of the lifting force increases. The reason for the increase in the true value of the lift force, the cylinders interact with the associated air flow formed on their surface during rotational movement. The accompanying flow causes the lift of the air flow, directing it in the direction of rotation of the cylinders. The higher the flow rate, the greater its impact on the accompanying flow. Therefore, when the air flow rate increases, the actual value of the lift force of the cylinders under study increases.

When studying the aerodynamic characteristics of paired cylinders of rotational motion depending on the change in the distance between the cylinders, the following cases of rotational motion of the cylinders were considered:

a) both cylinders rotate against the direction of the air flow in the same direction;

b) the cylinder below rotates in the direction opposite to the direction of the air flow, in the direction of the flow of the cylinder located above it,

c) the lower cylinder rotates in the direction of the air, and the upper cylinder rotates in the opposite direction of the air.

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. 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.

Figure 2 — dependence of the lift coefficient of paired cylinders rotating in the opposite direction on the change in distance.

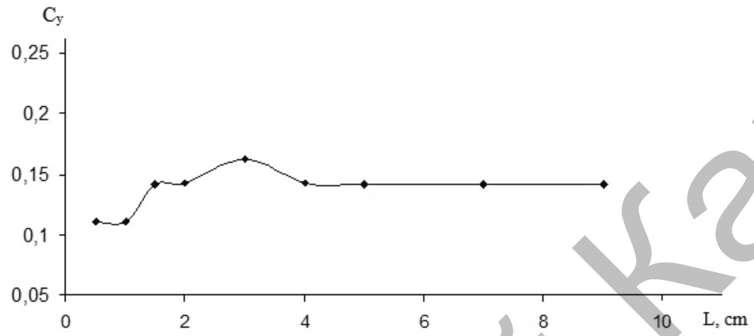

Figure 2. Graph of the dependence of the distance between the cylinders of the lift coefficient of paired cylinders in the opposite direction, the speed of which is 9 m/s, on the change in the ratio between the cylinders of the lift coefficient of paired cylinders in the opposite direction

As can be seen from the relationship, the lifting force coefficient of the rotating cylinder increases up to a certain distance and takes the largest value at this distance. Paying attention to the values of the lift coefficient as a function, these values are about 4–5 times less than the values of the lift coefficient of twin cylinders rotating in the same direction. Since when air leaks from cylinders rotating in the opposite direction, a low pressure zone appears in the middle of the two cylinders, the cylinders try to get closer to each other, that is, they try to eliminate each other's lift. Under the influence of this, the force of paired cylinders rotating in two directions becomes very small and decreases to zero.

The experimental dependencies of the aerodynamic characteristics given on the distance *L* between the cylinders are shown in Figure 3. 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.

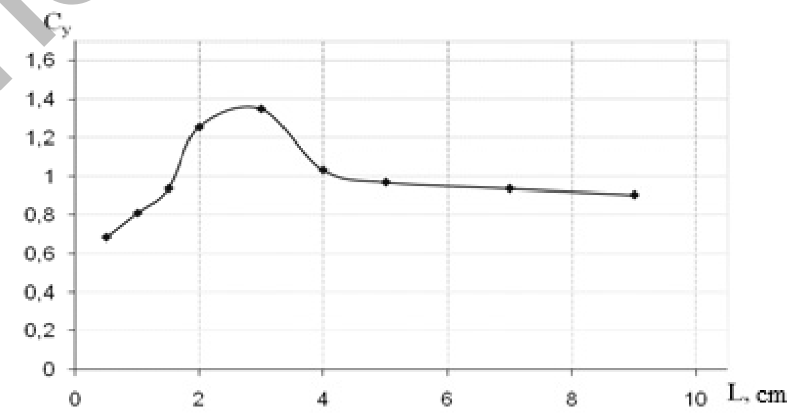

Figure 3. Dependency of the lift coefficient on the distance between the revolving cylinders

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.

Conclusion

1. The aerodynamic characteristics of the twin cylinders, namely the coefficients of drag and lift forces, depend on the geometry (the cylinders diameters, the distance between them) and mode parameters (flow rate, Reynolds number and the rotation speed of the cylinders).

2. For cylinders with diameters of 10 cm, 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.

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Турбулентті ағынның айналмалы цилиндрлер арасындағы көтеру күшінің коэффициентін зерттеу

Мақалада айналмалы цилиндрлер жүйесін жел қозғалтқышының элементі ретінде пайдалану мүмкіндіктері қарастырылған. Аэродинамикалық күштер цилиндр мен екі цилиндрлік жүйенің айналасындағы көлденең ағынмен өлшенген. Көлденең ағу кезіндегі цилиндрлер арасындағы оңтайлы қашықтықты анықтау әдісі әзірленген. Сәйкесінше, жел турбинасының тиімділігін арттыру және Магнус эффектісі әсерінің жоғарылауына ықпал ететін жағдайлар экспериментaлды түрде анықталған. Диаметрі 10 см айналатын цилиндрлердің көтергіш күші коэффициентінің аэродинамикалық сипаттамалары анықталған. Бұл нәтижелер тәжірибеде пайдалы болып табылады, өйткені оларды жел жылдамдығында жұмыс істейтін жел қозғалтқыштарында пайдалануға болады. Экономикада жел энергиясын қолдану электр энергиясының тапшылығын қысқартуға бағытталған ыңғайлы, қолжетімді және экологиялық таза тәсіл болып табылады.

Кілт сөздер: айналмалы цилиндрлер, Магнус эффектісі, жел турбиналары, көтеру күші коэффициенті.

Н.К. Танашева, А.Н. Дюсембаева, Н.Н. Шуюшбаева

Исследование коэффициента подъемной силы между вращающимися цилиндрами турбулентного потока

В статье рассмотрены возможности использования системы вращающихся цилиндров в качестве элемента ветродвигателя. Были измерены аэродинамические силы при поперечном обтекании цилиндра и системы из двух цилиндров. Разработан метод определения оптимального расстояния между цилиндрами при их поперечном обтекании. Экспериментально найдены условия, при которых эффект Магнуса способствует максимальному увеличению подъемной силы и, соответственно, возрастанию эффективности работы ветротурбины. Определены аэродинамические характеристики коэффициента подъемной силы вращающихся цилиндров диаметром 10 см. Эти результаты являются полезными на практике, так как их можно использовать в ветродвигателях, работающих на малой скорости ветра. В экономике применение энергии ветра является удобным, доступным и экологически чистым способом, направленным на сокращение дефицита электроэнергии.

Ключевые слова: вращающиеся цилиндры, эффект Магнуса, ветротурбины, коэффициент подъёмной силы.

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