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Experimental study of aerodynamic coefficients of a combined blade

Magnus wind turbines have a number of advantages in the form of electricity generation at low wind values, ranging from 3-4 m/s. However, at high speeds around the existing blades of wind turbines, there is a phenomenon of separation of vortices, which entails the destruction of the structure, as well as an increase in drag. Based on this, an urgent issue is the regulation of the flow around cylindrical bodies, along with a decrease in drag force. The novelty of the work is the elimination of vortices, as well as their control, by adding a fixed blade to the cylinder. Authors of the article for this purpose created a mock-up of the cylinder blade with a fixed blade. A number of experimental studies were carried out to determine the aerodynamic forces and coefficients depending on the angle of inclination with respect to the incoming flow at U = 5 m/s. It was found that at an angle of inclination of 0° and 180°, the combined blade has a maximum lifting force of 2.7 N and 2.75 N, respectively. It is determined that at these angles, the drag force is the lowest and is 1.26 N and 1.08 N.

Keywords: Wind turbine, Magnus, combined blade, cylinder, lifting force, drag force, flow velocity, tilt angle.

Introduction

It is well known that the tasks of studying transversely streamlined cylindrical bodies are relevant for wide industries ranging from thermal power engineering and aerodynamics to cosmonautics. However, despite all the simplicity of geometric visualization, the flow around a round rotating cylinder is complex, and largely depends on the flow mode.

The classical aerodynamic problem of the flow around the cylinder modules is the object of the study of aerohydrogas dynamics. Of these, the study of the flow around a rotating vertical cylinder is of great interest.

Many scientists and researchers in the field of aerodynamics have devoted their work to studying the flow pattern around the cylinderat high Reynolds numbers [3–5].

In the study [6], the authors experimentally and numerically investigated the flow characteristics around a rotating circular cylinder, the diameter of which is 20 mm. Parameters such as the time-averaged velocity, turbulence intensity, drag coefficient and flow structure at the Reynolds number $5900 \leq Re \leq 11800$ and the rotation coefficient $0 \leq \alpha \leq 0.525$ were investigated. Using the SST turbulence model, a numerical simulation of the flow was carried out. The authors found that due to the rotational movement of the cylinder, a change in profiles is observed the average and fluctuation velocities, and the area of velocity reduction has become smaller due to arise in the Reynolds number. It is established that symmetry of the flow breaking is observed with an increase in the rotation coefficient.

The authors of the work [7] investigated the problem of the flow around a round cylinder, with a constant angular velocity, fixed in a homogeneous flow. An interesting result is that, as the rotation speed increases, the vortex loss is suppressed. It is also determined that rotation weakens the secondary instability and rises the critical Reynolds number for the occurrence of this instability.

At high Reynolds numbers starting from $5\ 10^4$, with the transverse flow around the cylinders with an increase in the flow velocity, the separation of vortices is observed, and the formation of a trace behind the cylinder, the so-called Pocket track. Mechanical vibrations caused by the disruption of vortices can lead to vibration, acoustic noise and, if the frequency of the separation of vortices coincides with the natural frequency of the structure, to its destruction.

Based on this, the task of regulating the flow of cylindrical bodies, along with reducing the drag force, is relevant.

The purpose of this work is experimental study of aerodynamic coefficients of a combined blade in the form of a cylinder and a fixed plate, depending on the angle of inclination relative to the incoming flow.

Research objectives:

– creation of a laboratory layout of a combined blade;

– study of the influence of the angle of inclination on the values of aerodynamic forces;

– investigation of the influence of the angle of inclination on the values of the aerodynamic coefficients of lift and drag force.

The use of the plate as a means of preventing the formation and separation of the boundary layer behind the rotating cylinder is a novelty of the work. The studied object of research is a combined blade that can be used as the power element of Magnus wind turbines, with a vertical axis of rotation.

Experimental methodology

The authors of the work created a combined blade in the form of a cylinder with a fixed blade with a vertical axis of rotation to solve the problem of separation of the boundary layer as well as its prevention.

Aerodynamic experiments were completed in the laboratory “Aerodynamic Measurements” at the scientific center “Alternative Energy” at the E.A. Buketov Karaganda University. The object under study is installed in the working area of the T-1-M wind tunnel (Fig. 1).

Figure 1. Experimental layout of a cylinder with a fixed blade

As can be seen from Figure 1, the experimental layout consists of a cylinder and a fixed blade attached to disc-shaped bases on both sides, fixed between them. To start the cylinders in rotational motion, an electric drive is used, fixed on the upper part of the base.

The geometric dimensions of the sample are given in Table below.

T a b l e

Parameters	Values
Cylinder diameter	4 cm
Cylinder length	9 cm
Width of the fixed blade	3 cm
Fixed blade length	10.5 cm

Figure 2 shows the layout of the fixed blade relative to the flow.

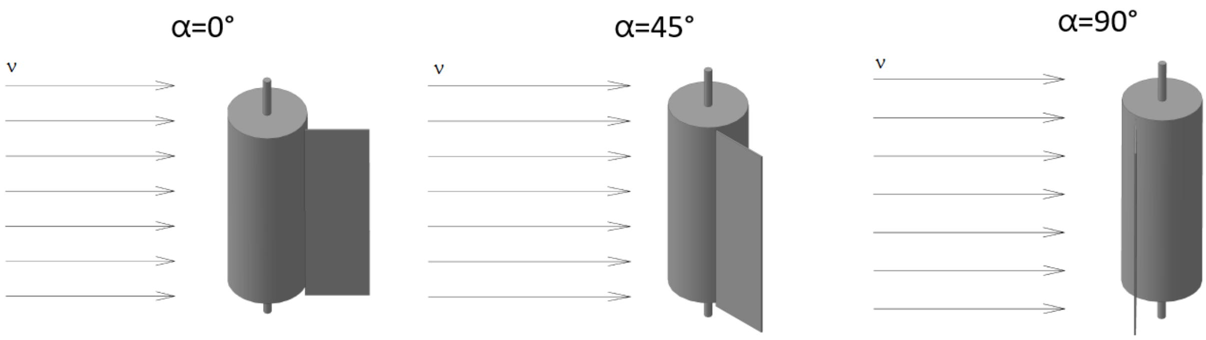

Figure 2. Location of the stationary blade of the rotating cylinder

Results and Discussion

When the flow velocity changes from 3 to 15 m/s, the angle of inclination of the fixed blade on the aerodynamic forces of the entire blade layout is studied.

In the course of experimental studies, graphs of the dependence of aerodynamic forces and their coefficients depending on the angle were obtained (Fig. 3–6).

Figure 3 below shows the results of measurements of the drag force depending on the angle of inclination at a wind speed of 5 m/s.

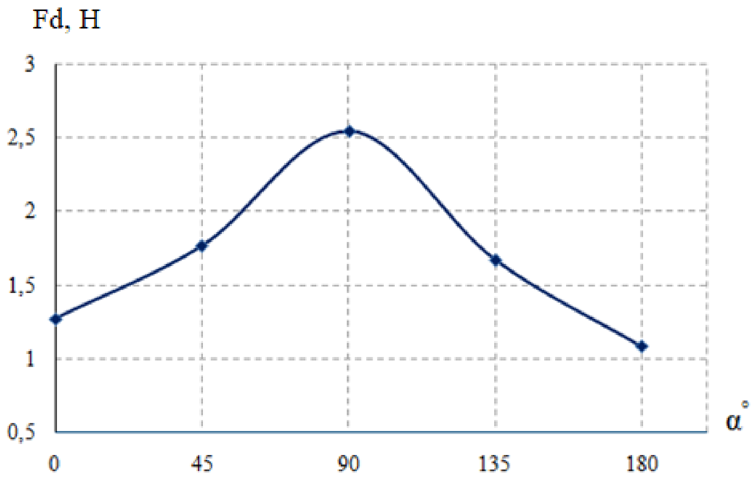

Figure 3. The results of measurements of the drag force from the angle of inclination at a flow rate of 5 m/s

As can be seen from the graph, the minimum value of the drag force of 1.25 N is observed at an angle of 0 degrees, after which, with an increase in the angle of inclination to 90 degrees, the force value increases to 2.5 N, which is the maximum value of the drag force.

As can be seen from the graph, the minimum value of the drag force of 1.25 N is observed at an angle of 0 degrees, after which, with an increase in the angle of inclination to 90 degrees, the force value increases to 2.5 N, which is the maximum value of the drag force. The reason for this is an increase in the mid-section of the entire blade in relation to the flow, which subsequently slows down the flow by forming pressure on the front part. In the future, with an increase in the angle to 180 degrees, there is a monotonous decrease in the value of the drag force to a minimum of 1.1 N. The explanation for this is the favorable flow around the blade without obstacles.

Figure 4 below shows the results of measurements of the lifting force values depending on the pitch of the fixed blade at a speed of 5 m/s.

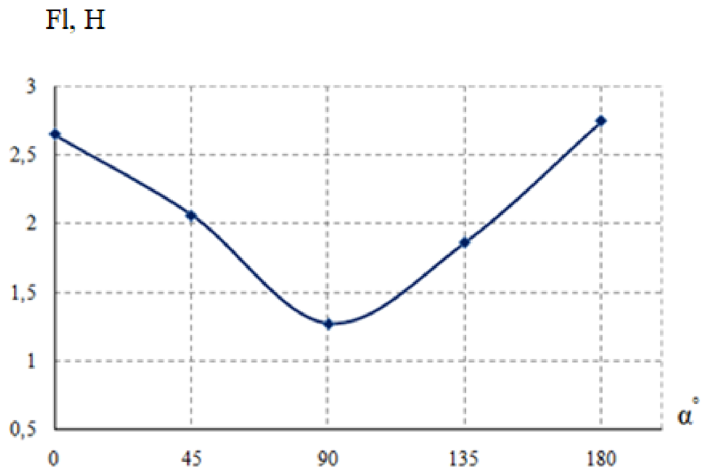

Figure 4. The results of lifting force measurements depending on the angle of inclination at a flow rate of 5 m/s

As can be seen from Figure 4, the value of the maximum lifting force of 2.7 N is observed at a speed of 0 degrees, after which it decreases linearly with an increase in the angle of inclination to 90 degrees.

According to the Kutta-Joukowski theorem [8] (the lifting force theorem of a body), where the lifting force is equal to the product of the density and velocity of the liquid, the circulation of the flow velocity and the length of the blade, which occurs at right angles against the direction of circulation, i.e. with non-symmetrical flow with an increase in the mid-section of the combined blade relative to the flow, there will be an increase in lifting force with an increase in the angle of attack to a critical value (90°). As can be seen from graphs 4 and 5, after 90° there is a sharp decrease in lifting force, due to the occurrence of flow disruption with an increase in the force of frontal resistance.

The calculated aerodynamic coefficients depending on the angle of inclination at different flow rates are shown in Figures 5 and 6. The aerodynamic coefficients are calculated using the formulas in the work [9].

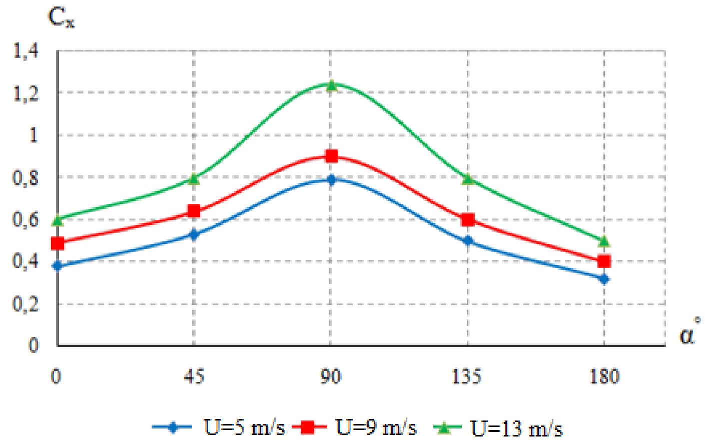

Figure 5. Change in the drag coefficient a depending on the angle of inclination at different flow rates

From Figure 5, it is established that with an increase in the angle of inclination to 90 degrees, there is an increase in the drag coefficient to 1.2 at 13 m/s, subsequently, with an increase in the angle to 180, there is a decrease in the coefficient value of 0.5.

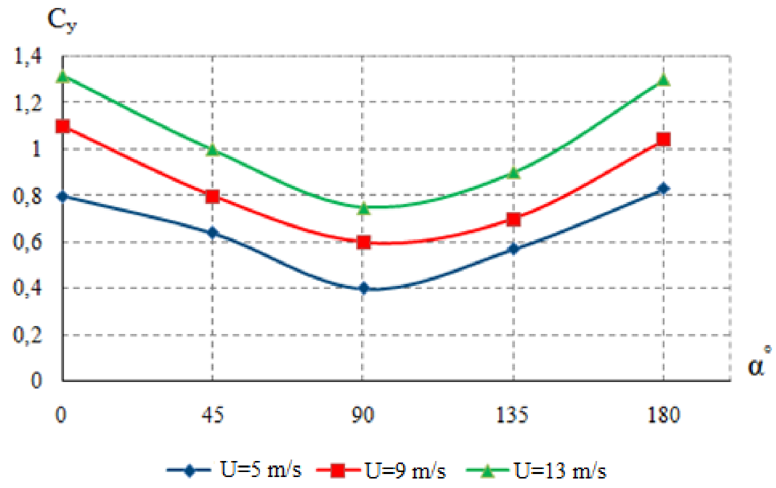

Figure 6. Change in the lift coefficient a depending on the angle of inclination at different flow rates

From Figure 6, it is determined with an increase in the angle of inclination from 0 to 90 degrees, there is a decrease in the coefficient of lift from 1.3 to 0.75 at 13 m/s, subsequently, with an increase in the angle from 90 to 180, there is an increase in the coefficient value to 1.32. The nature of the changes in the dependency lines presented in Graphs 5 and 6 do not contradict the previous experimental [10] and numerical [11] results.

Conclusions

In the course of conducting experimental studies, the authors of the work obtained the following results:

– A model of a combined blade with a diameter of 4 cm and a length of 9 cm of the cylinder, and a fixed blade with a length of 10.5 cm and a width of 3 cm has been developed and created;

– The graph of the dependence of the drag force on the angle of inclination of the fixed blade to the flow is obtained, during which the maximum drag is 2.5 N at an angle of 90 °;

– From the lifting force measurement results, it is determined that the maximum values of 2.7 N and 2.75 N are obtained at tilt angles of 0 ° and 180 °;

– From the calculated results of drag force values, it is determined that at an angle of 90 ° and U = 13 m/s, the maximum value is 1.2;

– It was determined that the maximum values of the lift coefficients 1.32 and 1.3 were obtained at an angle of 90 ° and U = 13 m/s;

– The drop in the value of the lifting force after increasing the angle of attack from 90 to 180 is a consequence of the occurrence of the physical phenomenon of disruption of vortices, which is also the reason for the increase in the drag force;

– It is determined that the angles of inclination of 0 ° and 180 ° are favorable angles for the location of a fixed blade, followed by obtaining maximum lift and minimum drag force.

The experimental results obtained by the authors will be useful in developing a layout of a wind turbine with a vertical axis of rotation containing combined blades.

Acknowledgments

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Құрамалы қалақшаның аэродинамикалық сипаттамаларын зерттеу

Магнус эффектісіне негізделген жел энергетикалық қондырғысы 3-4 м/с–тан басталатын жел жылдамдығының төмен мәндерінде электр энергиясын өндіру түрінде бірқатар артықшылықтарға ие және желдің бағытын аз талап етеді. Алайда, жел энергетикалық қондырғыларында, яғни цилиндрлердің қолданыстағы қалақтарының айналасында үлкен жылдамдықта құйындылардың үзілуінен күрделі физикалық құбылыс пайда болады, бұл қондырғының құрылымын бұзуға, сондай-ақ маңдайлық кедергі күшінің жоғарылауына әкеледі, осылайша қондырғының тиімділігін төмендетеді. Ауа ағынының көлденең бағытына қарай ағатын цилиндрлер айналмалы қозғалысқа келтірілгенде цилиндрлердің бетінде ілеспелі ағын пайда болады. Осыдан цилиндрлік денелердің айналуын реттеу, сонымен қатар маңдайлық кедергі күшінің төмендеуі және көтеру күшінің жоғарылауы (Магнус күші) өзекті мәселе болып саналады. Жұмыстың ғылыми-зерттеу жаңалығы — цилиндрге бекітілген қалақшаны қосу арқылы құйындыларды жою, сонымен қатар оларды басқару. Осы мақсатта жұмыс авторлары қозғалмайтын қалақшасы бар цилиндр түріндегі қалақ үлгісін жасады. Т-1-М аэродинамикалық құбырын қолдана отырып, U=5 м/с-та көтерілу ағынына қатысты көлбеу бұрышқа тәуелді аэродинамикалық күштер мен коэффициенттерді анықтау үшін бірқатар эксперименттік зерттеулер жүргізілді. 0º және 180º көлбеу бұрышында құрамалы қалақшаның (бекітілген қалақшасы бар цилиндр) сәйкесінше 2,7 Н және 2,75 Н максималды көтеру күші бар екені анықталды. Бұл бұрыштарда кедергі күші ең аз және 1,26 Н мен 1,08 Н құрайтыны айқындалды.

Кілт сөздер: жел энергетикалық қондырғы, Магнус, құрамалы қалақша, цилиндр, көтеру күші, маңдайлық кедергі күші, ағын жылдамдығы, көлбеу бұрышы.

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Исследования аэродинамических характеристик комбинированной лопасти

Ветроэнергетические установки на основе эффекта Магнуса обладают целым рядом преимуществ в виде выработки электроэнергии при низких значениях ветрах, начиная от 3–4 м/с, и менее требовательны к направлению ветра. Однако при больших скоростях вокруг существующих лопастей ветроэнергетических установок-цилиндров возникает сложное физическое явление — отрыв вихрей, которое влечет собою разрушение конструкции самой установки, а также рост лобового сопротивления, снижая тем самым эффективность работы установки. Исходя из этого, актуальным вопросом является регулирование обтекания цилиндрических тел, наряду с уменьшением силы лобового сопротивления и увеличением подъемной силы (силы Магнуса). Новизной работы является устранение вихрей, а также управление ими путем добавления неподвижной лопасти к цилиндру. Авторы работы для этой цели создали макет лопасти в виде цилиндра с неподвижной лопастью. Провели ряд экспериментальных исследований по определению аэродинамических сил и коэффициентов в зависимости от угла наклона по отношению к набегающему потоку при U = 5 м/с, используя аэродинамическую трубу Т–1–М. Установлено, что при углах наклона 0 и 180º комбинированная лопасть (цилиндр с неподвижной лопастью) обладает максимальным значением подъемной силы 2,7 и 2,75 Н соответственно. Определено, что при данных углах сила лобового сопротивления самая минимальная и составляет 1,26 и 1,08 Н.

Ключевые слова: ветроэнергетическая установка, Магнус, комбинированная лопасть, цилиндр, подъемная сила, сила лобового сопротивления, скорость потока, угол наклона.

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