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A.Zh. Tleubergenova[1], N.K. Tanasheva[1], K.M. Shaimerdenova[1],
N.K. Botpaev[1], L.L. Minkov [2], S.B. Kassiyev[1]

[1] Karaganda University of the name of academician E.A. Buketov, Karaganda, Kazakhstan;
[2] National Research Tomsk State University, Tomsk, Russia
(e-mail: shymkent.a7@mail.ru)

Investigation of Aerodynamic Characteristics of a Two-Bladed Sailing Wind Turbine

The article examines a prototype of a wind turbine with two blades. For experimental work, a mock-up of a sailing wind turbine consisting of two blades was developed. The material of the sail blades was selected according to elasticity and lightness, cheapness, roughness of the streamlined surfaces. The study shows the aerodynamic parameters acting on the blade. The air flow velocity varied from 3 to 12 m/s. The dependence of the lifting force and the frontal barrier on the air flow velocity was obtained by turning the blades of the wind turbine so that the angle of attack was α = 00, 150, 300, 450, 600. It is established that when the position of the blade's changes, the lifting force and the drag force decrease. With an increase in the angle of attack α > 00 leads to a decrease in the midsection of the wind wheel with respect to the air flow. On this basis, there is a decrease in aerodynamic forces. As the speed of the air treacle increases, the speed of rotation of the wind wheel also increases. However, during the experiment it was found that the location of the blades at different angles affects the numerical value of the rotational speed. According to the conducted experiments, several values were obtained. The analysis of the obtained values is carried out. A graph is constructed based on the dependence of the wind wheel rotation frequency on the wind speed with a change in the angle of attack. A wind turbine with blades with a variable angle of attack, which, turning, gradually become more parallel to the direction of the wind. Centrifugal forces regulate the inclination of the blades, and as a result, the speed of rotation of the wind wheel, and keep the wind generator at the nominal speed of rotation.

Keywords: lifting force, wind power plant, drag force, angle of attack, wind speed, rotational speed.

Introduction

The limited fuel reserves in the world by the end of the twentieth century led to a revival of interest in wind energy, which is almost endless.

It is important for Kazakhstan to develop environmentally friendly energy technologies to avoid environmental pollution caused by coal-fired power plants. In addition, the development of renewable energy sources diversifies the economic and energy sectors of the country, while improving the environment and human health. The climate in Kazakhstan is favorable for the construction of wind power plants due to the presence of wind corridors with a wind speed of more than 5 m/s, which is necessary for the operation of wind turbines.

The development of renewable energy in general gives Kazakhstan the opportunity to build a strong economy and meet its demand for energy consumption [1]. According to annual meteorological data, the average annual air flow velocity is 3-3.5 m/s, which varies from the terrain of the territory [2].

In this regard, the development and research of wind turbines that work efficiently and generate electricity at low wind speeds is relevant.

At low wind speeds from 2 m/s to 5 m/s, sailing wind turbines have an advantage in the form of starting the operation of the wind wheel and generating electric energy over traditional blade wind turbines.

Also, sailing wind turbines have increased efficiency compared to classical wind turbines [3] due to the so-called adjustment to the direction and strength of the wind. If conventional wind turbines have an efficiency of 30 %, then a sailing-type wind turbine gives all 80 %. Its efficiency exceeds the blade-type wind turbines by 2.3 times.

An important advantage is that the operating costs of sailing wind turbines are twice as low as those of conventional installations.

The original design of the wind wheel makes it possible to do without other weather- or wind-oriented devices [4-6].

Sailing aerodynamic surfaces are installed to the wind in such a way that they provide maximum resistance to the air flow, that is, they have high frontal or aerodynamic resistance. This position allows them to create maximum pressure on the surface and obtain, respectively, the maximum driving (aerodynamic) force [7].

To increase the strength of the sail blade, the authors of the patent for the invention [8] included wind turbines of wind intakes and wind deflectors in the design, which are made of sail fabric with the possibility of lifting and lowering it, in which part of the blade of the rotor blades from the inner rib is made whole, and the rest up to the outer rib is in the form of vertical blinds. However, the disadvantage of such a design is the bulkiness and complexity.

The novelty of the work is the addition of an adjustment mechanism to control the pitch of the blade rotation by changing the angle of attack when the wind increases.

The aim of the authors' work is to study the aerodynamic characteristics of a two-bladed sailing wind turbine. This goal is achieved by the following tasks:

- creating a layout of a two-bladed sailing wind turbine;
- conducting experiments in the T-1-M wind tunnel;
- determination of the drag force of the sail blades from the angle of attack at different wind speeds;
- determination of the lifting force of the sail blades from the angle of attack at different wind speeds;
- finding the rotation frequency of the wind power plant from the angle of attack at different wind speeds.

Experimental methodology

To create a real wind turbine design with sailing blades, a two-bladed sailing wind turbine was developed and created, where the blades are made of elastic, lightweight and durable material [9]. The material of the raincoat, having a high density, also has a large roughness of the streamlined surfaces. The elasticity and lightness of the raincoat material ensures the flexibility of the surface, which is well amenable to fluctuations in the air flow, which reduces its resistance. An estimated comparison of the resistance of a solid triangular plate of a similar area showed significantly greater resistance than that of a movable, self-regulating air flow form, triangular sail.

The wind wheel is fixed through bearings to the mast. The mast is made of 40 mm plastic pipes. The metal axis of rotation of the wind wheel and the metal frame of the blades are fixed to the bearings. The triangular shaped blade frame consists of two metal rods 22 cm and 13 cm long.

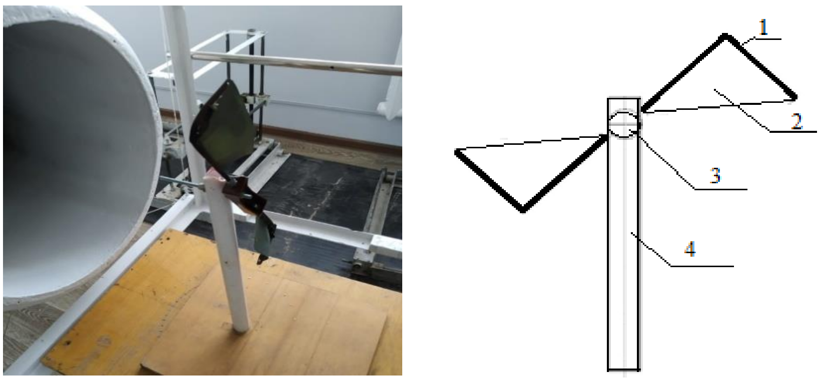
A sail cloth is fixed to the frames of the blades. The material of the sail consists of a raincoat fabric [10]. Raincoat is a fabric made of natural or synthetic material, which is impregnated with a special moisture–repellent substance. This substance protects the material from getting wet and helps to remove moisture. The material of this nature is convenient and necessary for use in rainy and snowy seasons.

Experimental studies were conducted at the Scientific Center “Alternative Energy” in the laboratory “Aerodynamic Measurements” of the Faculty of Physics and Technology of the Academician E.A. Buketov Karaganda University.

All experimental studies were carried out in the T-1-M wind tunnel. Drag forces and lift were measured on aerodynamic scales. The location of the sailing lines in the working part of the T-1-M wind tunnel is shown in Figure 1.

The flow rate was controlled using the wind tunnel control panel and varied from 3 m/s to 12 m/s.

When the wind increases, the adjustment mechanism controls the pitch of the blade rotation, changing the angle of attack. The rotation speed of the wind wheel will slow down and the wind turbine will have a stable output power and safe operation and maintenance. The wind wheel will never go beyond the permissible limits of rotation speed, even when faced with variable wind speed and strong storms.



a) b)

1 — blade frame, 2 — blade material, 3 — wind wheel rotation axis, 4 — mast.

Figure 1. Location of the sail blade in the working part of the T-1-M wind tunnel (a), schematic diagram (b)

The wind wheel (Fig.1), driven by the thrust of the sail blades, experiences the action of several forces, of which the actual thrust force and the lifting force arising on the sails are useful. Another component is the drag force of the sail.

The novelty of the prototype is that the fabric is attached to an L-shaped base.

Based on laboratory studies, the sailing aerodynamic surfaces of the prototype showed maximum resistance to air flow, i.e. high frontal or aerodynamic drag.

When studying the effect of wind on a sail, a whole set of forces arises on it, including aerodynamic force. A rarefaction region appeared on the outside of the sail, where aerodynamic forces arise, the resultant of which R (Fig. 2) is almost perpendicular to the chord of the sail — the segment connecting the edges of the sail. The value of the force, as well as the point of application of the resultant, strongly depend on the angle at which the sail (its chord) is to the wind — this angle is called the angle of attack, as well as the bending of the sail (the potbellied was 5 cm), wind strength and how much the incoming wind flow is laminar, that is, without vortices and turbulence.

If we decompose the aerodynamic force into two components — parallel X and perpendicular to the wind Y, then we can estimate how much the sail will tend along with the wind and move perpendicular to the wind. In this case, the Y component is called the lifting force (because it is this force that causes the blade to rise when the blade is horizontal), and the X component is the drag force of the sail.

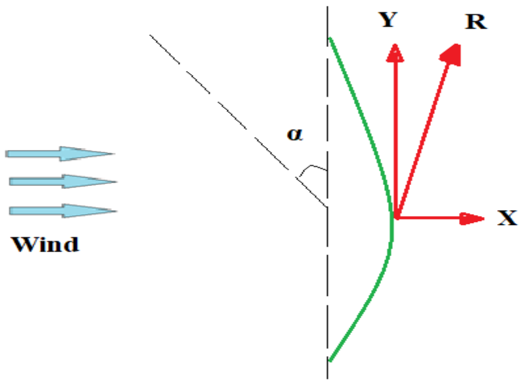


Figure 2. Distribution of forces on the surface of the sail blade

If we consider the movement of the wind engine in sharp directions to the wind, then the efficiency of the sail as a driving force depends on the same parameters as the efficiency of the blades when creating lift:

– surface area of the sail;

– the profile of its cross-section;

– the angle of the installation of the sail in relation to the incoming air flow (pennant wind) and wind speed;

– aerodynamic elongation and shape of the sail contour.

The blades of a wind turbine with a dynamically changing surface have a shape that allows you to get the maximum effect from the wind force at minimal cost. The choice of blade material also affects the aerodynamic parameters or the performance of the wind turbine.

Research results

The resulting aerodynamic force of the sail is formed by two main components: lifting force (F_y) and drag force (F_x). The lifting force (F_y) acts at right angles to the wind, and the drag force (F_x) acts downwind. As the wind speed increases, the drag force grows faster than the lifting force. Therefore, for different wind speeds, different forms of sails differ, which have optimal lift-to-drag ratios.

Figure 3 shows a graph of the dependence of the drag forces of the sail blades on the angle of attack at different wind speeds.

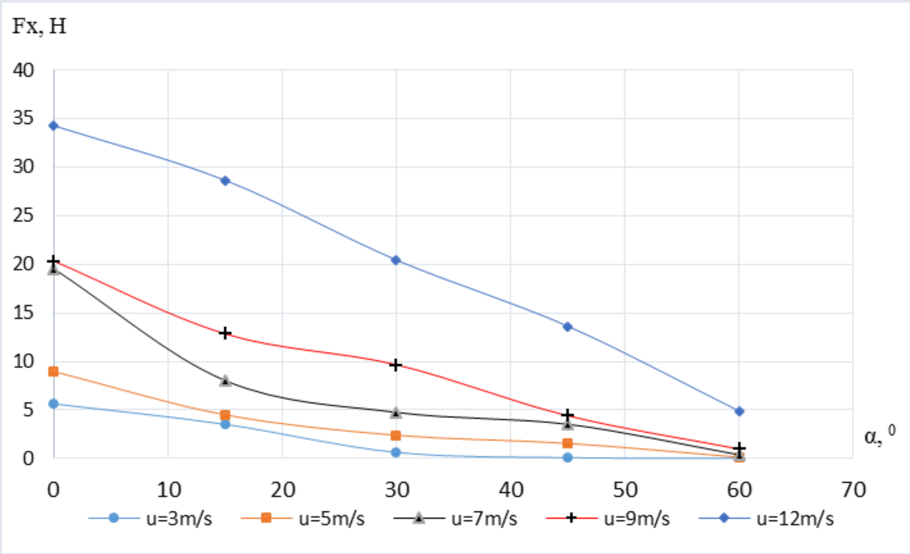


Figure 3. Graph of the dependence of the drag forces of the sail blades
on the angle of attack at different wind speeds

The dependence of lift and drag on the angle of attack is crucial in determining the effectiveness of the sail blade.

As can be seen from the graph, a change in the drag force at the angle of attack α is obtained=0^0, 15^0, 30^0, 45^0, 60^0 in different wind speeds. When analyzing the quantitative values of the drag force, it was found that at 0 degrees with an increase in wind speed, the drag force value becomes higher. The maximum value of F_x = 34 N is at α = 0^0 and 12 m/s.

Figure 4 shows a graph of the dependencies of the lifting force of the sail blades on the angle of attack at different wind speeds.

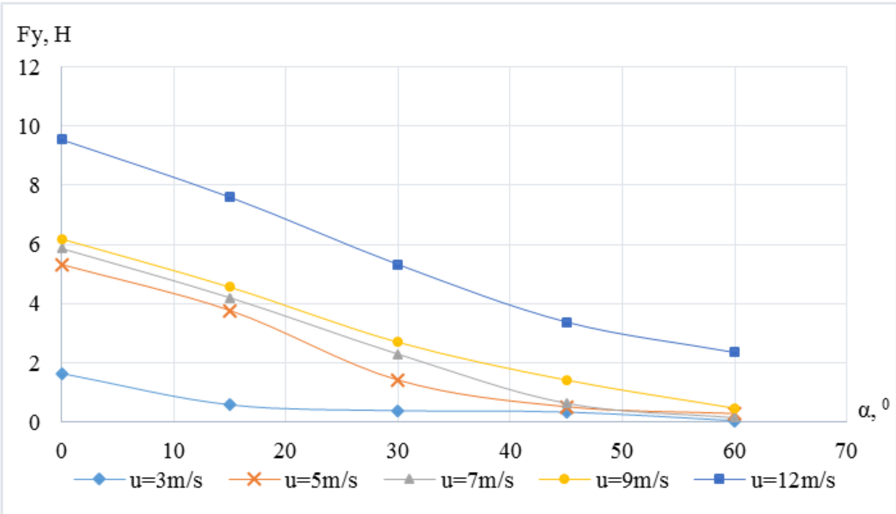


Figure 4. Graph of the dependence of the lifting force of the sail blades on the angle of attack at different wind speeds

Figure 5 shows a graph of the dependencies of the rotational speed of a prototype wind power plant on wind speed. It is shown how the value of the lifting force changes with an increase in wind speed and a change in the angle of attack. It is established that at the angle of attack α = 0 °, the maximum values of the lifting force are obtained. The measurement error is 1-2 %.

The lifting force is the result of an uneven distribution of air pressure on one side compared to the other side of the sail blade. Based on this, according to the Bernoulli principle, the sail has a lower air pressure on the front (leeward) side and more pressure on the rear (windward) side. With a minimum angle of attack, since the flow smoothly flows around the sail blades, there is a smooth transition from low pressure on the leeward part to higher pressures on the windward part.

It is necessary to pay attention that the sail blades with a high angle of attack have a very low pressure near the front, which is then followed by a sharp increase in pressure. In this case, the boundary layer cannot withstand such a rapid increase in pressure, as a result of which the flow is separated, and the flow is disrupted, which entails a decrease in the value of the lifting force.

From the obtained dependences (Fig. 3-4), the proportional dependence of the lifting force and the drag force of the blades on the angle of attack is visible.

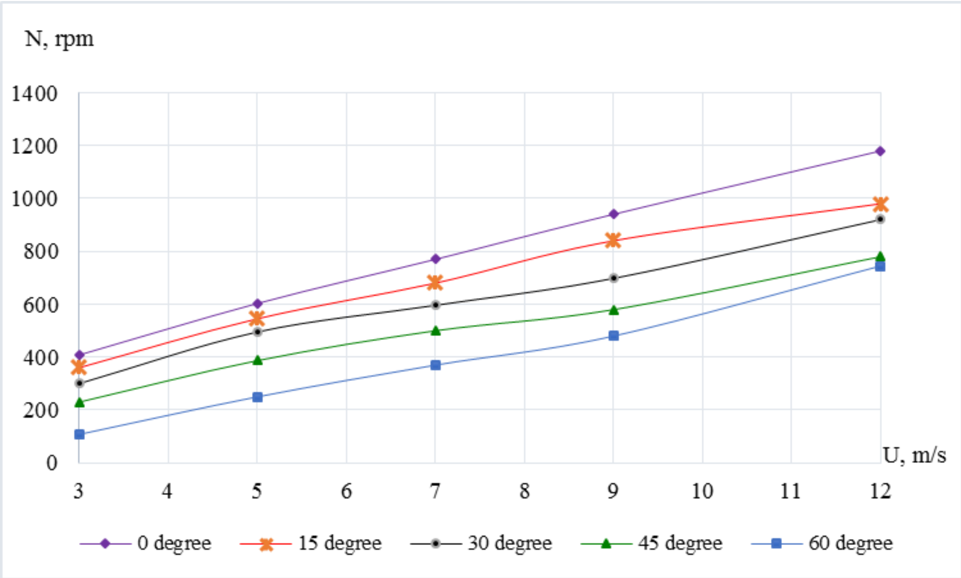


Figure 5. Dependence of the rotation frequency of the wind power plant on the angle of attack at different wind speeds

Figure 5 shows that an increase in wind speed leads to an almost linear increase in the number of revolutions of the wind wheel per minute. This is due to the fact that with an increase in the wind speed running into the wind wheel, the pressure force acting on the sail blades increases linearly. It is established that at an angle of attack of 0, the maximum aerodynamic quality of the wind wheel is realized. At a given angle of attack, maximum aerodynamic forces arise, which causes the wind wheel to rotate.

Conclusion

In the course of the study, the following optimal results were obtained:

- a graph of the dependences of the drag forces of the sailing blades on the angle of attack at different wind speeds, based on it is established that the maximum value of F_x = 34 N has at $\alpha = 0^0$ and 12 m/s. This fact is explained by the fact that with an increase in the deviation of the flow direction from the perpendicular to the plane of the blades, a restructuring of the turbulent air flow around the wind turbine occurs. In a turbulent flow, as a result of interaction with secondary flows created by the sail blades, pressure discharge zones appear, the volume of this discharge zone varies depending on the angle of attack of the air flow. As a result of the interaction of the pressure field created by the main flow and the discharge zone created by the secondary flow, we have a complex dependence, where the drag force with increasing flow velocity and angle of attack begins to decrease sharply. This is due to the turbulence of the flow, as a result of which turbulent vortices create additional aerodynamic drag;
- a graph of the dependencies of the lifting force of the sailing blades on the angle of attack at different wind speeds, based on which it is determined that at the angle of attack $\alpha = 0$ °, the maximum values of the lifting force are obtained, because at the minimum angle of attack, the flow smoothly flows around the sailing blades, there is a smooth transition from low pressure on the leeward part to higher pressures on the windward part;
- the dependence of the rotation frequency of the prototype wind power plant on the wind speed, at which it is established that, at an angle of attack of 0°, the maximum aerodynamic quality of the wind wheel is realized.

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References

1 Потенциал ветровой энергии в Казахстане [Электронный ресурс]. — Режим доступа: https://www.eurasian-research.org/publication/potential-of-wind-energy-in-kazakhstan/? lang=ru/

2 Погода в стране Казахстан. — [Электронный ресурс]. — Режим доступа: http://weatherarchive.ru/Pogoda/Kazakhstan

3 Соколов С.Е. Электрические станции и подстанции. Ветровая и солнечная энергетика: учеб. пос. / С.Е. Соколов, И.С. Соколова. — Алматы: АУЭС, 2018. — 105 с.

4 Грибач Ю.С. Ветер — альтернативный источник энергии / Ю.С. Грибач, О.О. Егорычев, Е.В. Кургузова // Силовое и энергетическое оборудование. Автономные системы. — Т. 2. Вып. 1. — 2019. — С. 40–49.

5 Грозных В.А. Проблемы надежности электроснабжения от ветроэнергетических установок / В.А. Грозных // Главный энергетик. — 2017. — № 8. — С. 67–75.

6 Лукашин П.С. Методика решения задач аэроупругости для лопасти ветроустановки с использованием СПО / П.С. Лукашин, В.Г. Мельникова, С.В. Стрижак, Г.А. Щеглов // Тр. ИСП РАН. — 2017. — Т. 29. Вып. 6. — С. 253–270. DOI: 10.15514/ ISPRAS2017-29(6)-16.

7 Власов В.К. Ветродвигатели. Теория и практика / В.К. Власов. — М.: Техносфера, 2020. — 226 с.

8 Аманов Б.И. Патент РФ № 2664037 С2. Ветроэнергетическая установка вертикального типа / Б.И. Аманов. Опубл. 2018.

9 Tleubergenova A.Zh. Study of aerodynamic parameters of the sail blade / A.Zh. Tleubergenova, N.K. Tanasheva, K.M. Shaimerdenova, L.L. Minkov, A.N. Dyusembaeva, S.Zh. Uzbergenova // Bulletin of the University of Karaganda-Physics, 2022. — Vol. 1(105). — P. 58-65.

10 Tanasheva N.K. Investigation of the aerodynamic forces of a triangular wind turbine blade for the low wind speeds / N.K. Tanasheva, A.Zh. Tleubergenova, K.M. Shaimerdenova, L.L. Minkov, S.Zh. Uzbergenova // Eurasian physical technical journal, 2021. — Vol. 4(38). — P. 59–64.

А.Ж. Тлеубергенова, Н.К. Танашева, К.М. Шаймерденова, Н.К. Ботпаев, Л.Л. Миньков, С.Б. Қасиев

Екіқалақшалы желкенді жел қондырғысының аэродинамикалық сипаттамаларын зерттеу

Мақалада екіқалақшалы желкенді жел қондырғысының тәжірибелік үлгісі зерттелген. Эксперименттік жұмыс жасау үшін желкенді екіқалақшадан тұратын жел қондырғысының макеті жасалды. Желкенді қалақшалардың материалы икемділігі мен жеңілдігі, арзандығы, тегістелген беттердің кедір-бұдырлығы бойынша таңдап алынды. Зерттеу барысында қалақшаға әсер ететін аэродинамикалық параметрлер көрсетілген. Ауа ағынының жылдамдығы 3-тен 12 м/с-қа дейін өзгерді. Шабуыл бұрышы $\alpha=0^0$, 15^0, 30^0, 45^0, 60^0 болатындай жел қондырғысының қалақшаларын бұра отырып, ауа ағынының жылдамдығына көтеру күші мен маңдайлық кедергі күшінің тәуелділігі алынды. Қалақшалар орналасу деңгейін өзгерткенде көтеру күші мен маңдайлық кедергі күшінің төмендейтіні анықталды. Шабуыл бұрышы өскен сайын $\alpha>0^0$ ауа ағынына қатысты жел доңғалағының мидель қимасының төмендеуіне алып келеді. Соның негізінде аэродинамикалық күштердің төмендеуі байқалады. Ауа ағынының жылдамдығы артқан сайын жел доңғалағының айналу жиілігі де артады. Алайда қалақшалардың әртүрлі бұрыш жасай орналасуы айналу жилігінің сандық мәніне әсер ететіндігі тәжірибе кезінде анықталды. Жасалған эксперименттер бойынша бірнеше мәндер алынды. Алынған мәндерге талдау жасалды. Шабуыл бұрышының өзгеруімен жел жылдамдығына жел доңғалағының айналу жиілігі тәуелділігі бойынша график тұрғызылды.

Кілт сөздер: көтеру күші, жел энергетикалық қондырғы, маңдайлық кедергі күші, шабуыл бұрышы, жел жылдамдығы, айналу жиілігі.

А.Ж. Тлеубергенова, Н.К. Танашева, К.М. Шаймерденова, Н.К. Ботпаев,
Л.Л. Миньков, С.Б. Касиев

Исследование аэродинамических характеристик двухлопастной парусной ветроустановки

В статье исследован опытный образец ветроустановки с двумя лопастями. Для экспериментальной работы был разработан макет парусной ветроустановки, состоящей из двух лопастей. Материал парусных лопастей подбирался по эластичности и легкости, дешевизне, шероховатости обтекаемых поверхностей. В ходе исследования показаны аэродинамические параметры, действующие на лопасть. Скорость воздушного потока варьировалась от 3 до 12 м/с. Зависимость подъемной силы и лобовой преграды от скорости воздушного потока получали путем поворота лопастей ветродвигателя так, чтобы угол атаки составлял $\alpha = 0^0$; 15^0; 30^0; 45^0 и 60^0. Установлено, что при изменении положения лопастей уменьшаются подъемная сила и сила лобового сопротивления. При увеличении угла атаки $\alpha > 0^0$ наблюдается уменьшение мидельного сечения ветроколеса по отношению к воздушному потоку. На этой основе происходит снижение аэродинамических сил. По мере увеличения скорость воздушного потока и частота вращения ветроколеса возрастают. Однако во время эксперимента установлено, что расположение лопастей под разными углами влияет на численное значение частоты вращения. По указанным выше экспериментам было получено несколько значений. Проведен анализ полученных значений. Построен график по зависимости частоты вращения ветрового колеса от скорости ветра с изменением угла атаки. Ветроустановка с лопастями с изменяемым углом атаки, которые, поворачиваясь, постепенно становится всё более параллельнным к направлению ветра. Центробежные силы регулируют наклон лопастей и, как следствие, скорость вращения ветроколеса, и держат ветрогенератор при номинальной частоте вращения.

Ключевые слова: подъемная сила, ветроэнергетическая установка, сила лобового сопротивления, угол атаки, скорость ветра, частота вращения.

References

1 Potentsial vetrovoi energii v Kazakhstane [Wind energy potential in Kazakhstan]. (n.d.). base.garant.ru. Retrieved from https://www.eurasian-research.org/publication/potential-of-wind-energy-in-kazakhstan/? lang=ru/ [in Russian].

2 Pogoda v strane Kazakhstan [Weather in the country of Kazakhstan]. (n.d.). base.garant.ru. Retrieved from: http://weatherarchive.ru/Pogoda/Kazakhstan [in Russian].

3 Sokolov, S.E. & Sokolova, I.S. (2018). Elektricheskie stantsii i podstantsii. Vetrovaia i solnechnaia energetika [Electric stations and substations. Wind and solar energy]. Almaty: AUJeS [in Russian].

4 Gribach, Yu.S., Egorychev, O.O. & Kurguzova, E.V. (2019). Veter — alternativnyi istochnik energii. Silovoe i energeticheskoe oborudovanie. Avtonomnye sistemy [Wind is an alternative source of energy. Power and power equipment. Autonomous systems]. Moscow, 2, 1, 40–49 [in Russian].

5 Groznyh, V.A. (2017). Problemy nadezhnosti elektrosnabzheniia ot vetroenergeticheskikh ustanovok [Problems of reliability of power supply from wind power installations]. Glavnyi energetic [Chief Power Engineer]. 8, 67–75 [in Russian].

6 Lukashin, P.S., Melnikova, V.G., Strijhak, S.V., & Shcheglov, G.A. (2017). Metodika resheniia zadach aerouprugosti dlia lopasti vetroustanovki s ispolzovaniem SPO [The method of solving aeroelasticity problems for wind blade using open source software]. *Trudy ISP RAN — Proceedings ISP RAS,* 29, 6, 253–270. DOI: 10.15514/ISPRAS2017-29(6)-16 [in Russian].

7 Vlasov, V.K. (2020). Vetrodvigateli. Teoriia i praktika [Wind turbines. Theory and practice]. Moscow: Tekhnosfera [in Russian].

8 Amanov, B.I. (2018). Patent Rossiiskoi Federatsii № 2664037 C2. Vetroenergeticheskaia ustanovka vertikalnogo tipa [Patent of Russian Federation No. 2664037 C2. Vertical wind turbine] [in Russian].

9 Tleubergenova, A.Zh., Tanasheva, N.K., Shaimerdenova, K.M., Minkov, L.L., Dyusembaeva, A.N., & Uzbergenova, S.Zh. (2022). Study of aerodynamic parameters of the sail blade. *Bulletin of the University of Karaganda-Physics, 1(105),* 58-65.

10 Tanasheva, N.K., Tleubergenova, A.Zh., Shaimerdenova, K.M., Minkov, L.L., & Uzbergenova, S.Zh. (2021). Investigation of the aerodynamic forces of a triangular wind turbine blade for the low wind speeds. *Eurasian Physical Technical Journal, 4(38),* 59–64.