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# STUDY OF AERODYNAMIC CHARACTERISTICS OF THE MODEL OF A WIND TURBINE WITH ROTATING CYLINDERS

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*The paper discusses problems of alternative energy sources uses, particularly wind energy utilization. The results of an experimental study of the aerodynamics of wind turbines using Magnus effect are considered. To carry out testing, a model of a three-blade wind turbine with rotating cylinders of various cross-sections was made. Aerodynamic testing of the wind turbine model at various airflow conditions was performed. Dependencies of drag force, tractive force and rotation frequency of the wind wheel on the flow rate at different yaw angles of the flow were found. It is shown that the use of rough-surfaced rotating cylinders of various cross-sections makes it possible to use an additional moving force resulting from the Magnus effect.*

***Keywords**:* wind turbine, aerodynamics, Magnus effect, rotating cylinder, drag force, traction force, angle of attack.

## Introduction

One of the most important features of the modern world is the increased attention of the international community to the problems of expediency and efficiency of energy utilization, the implementation of energy-saving technologies and search for renewable energy resources. The increasing demand of the humanity for energy resources necessitates search and increased use of alternative sources of energy supply. Therefore, the development of methods and technologies using renewable sources are important and relevant not only in Kazakhstan, but also throughout the world [1-3].

Issues of meeting the ever-increasing demands for all types of energy, the natural resources depletion, the harmful environmental impact, the danger of global warming, etc. are increasingly discussed at highest national and international levels. In Kazakhstan, these issues become even more urgent in view of preparation for the world exhibition of science and technology achievements "World Expo-2017", the main topics of which are "Energy of the future" and "Ecologically clean energy" [4].

The potential of renewable energy resources such as hydro-energy, wind and solar energy is very significant in Kazakhstan. It should be noted that wind energy does not pollute the environment and it is possible to produce clean, inexhaustible energy in local areas or sites remote from centralized electric networks using the wind. Despite all the advantages, in Kazakhstan the share of wind energy conversion is only 0.4% of the total production of electricity. On the one hand, this is due to the fact that the major part of Kazakhstan are the areas with low annual average wind speeds in which the use of industrially-produced wind turbines is economically unsound. In this regard, construction of wind power plants, effectively operating in low average wind speeds, is highly relevant and meets the basic priorities of the development of science and technology in Kazakhstan.

The paper presents the results of experimental research of aerodynamic characteristics of a three-blade wind turbine with rotating cylinders of various cross-sections at different airflow conditions.

## 1. The application of Magnus effect in wind turbines

The developed plant makes use of the Magnus effect, i.e. the physical phenomenon that results when fluid flows past a rotating body. The main point of this phenomenon is in the fact that in the flow past a rotating body there arises a force acting on the body and directed perpendicularly to the flow as a result of combined effects of the Bernoulli effect and the formation of a boundary layer in the medium around the streamlined object [5]. The rotating object makes a turbulent motion in the environment around it. On the one side of the object, the vortex direction agrees with the direction of the streaming flow and, respectively, the medium motion rate increases on this side. On the other side of the object, the direction of the vortex is opposite to the flow direction and the medium motion rate decreases. Because of the rate difference there is a pressure difference causing a lateral force on that side of a rotating body where the direction of rotation and flow direction are opposite to the side where the directions are the same [5-8].

It is the Magnus effect that causes curved motion of a rotating sphere. It is established that the effect of force action of air flow on the rotating cylinder is almost 10 times greater than that on the sail of the same streamlined surface [5, 6]. This phenomenon of the origination of great force action on the rotating cylinder is used in some aircraft. In the invention of Bolotov A.V. et al., the Magnus effect made it possible to increase the capacity of wind engines with rotary turbines. [9] The papers of Japanese scientist N. Murakami [10, 11] show that the Magnus effect makes for effective electric power generation at wind speeds over a wide range of the incident airflow rate. A scientist from Novosibirsk Professor N.M. Bychkov developed a wind turbine, each rotor of which is made of non-rotating root and rotating end portions, and a disk at the end [12].

It is not possible to describe all devices and wind turbines using the Magnus effect in a single paper. However, studies show that origination of an incremental lift due to the Magnus effect reduces induced drag, providing higher efficiency relative to traditional bladed wind machines.

## 2. Test technique in a wind tunnel T-M-1.

The authors made experiments to study the effect of the rate and direction of air flow on aerodynamic characteristics of a three-bladed wind turbine model with blades in the form of rough-surfaced rotating cylinders of various cross-sections. Wind tunnel experiments were based on the principle of reversibility of motion positing that displacement of a body relative to air can be replaced by the motion of the air incident to a motionless body [5, 6, 13]. The testing was conducted on a big open-jet wind tunnel T-1-M, Fig. 1b. Details of the characteristics of the working section of T-1-M are described in [6]. An air flow with a uniform rate field ranging from 3m/s to 25m/s is formed in the working part of the wind tunnel T-M-1.

For aerodynamic testing, a model of a wind turbine with rotating cylinders of variable cross-sections was developed and made, Fig. 1. A wind wheel is designed as a system of three rotating impermeable rough-surfaced cylinders with horizontal axes of rotation. The authors had previously found that the use of cylindrical blades of porous material with end discs at the tops could increase the efficiency of wind energy conversion into mechanical energy of wind-wheel rotation by (15-20)% [8].

The aerodynamic testing showed that the porous surface of the cylinder makes for active trapping of the air. In order to reduce excessive flow turbulence due to the partial migration of the air current into the pores, and accordingly, reduction in aerodynamic drag, in the test model the cylinder surface was covered with impermeable rough layer.

The wind wheel diameter was D=0.4 m, the length of each cylinder was $L_c$=0.15 m, the cylinder base diameter was $d_{c1}$=0.08 m and the neck diameter of the cylinder was $d_{c2}$=0.05 m [14]. The shaft speed of the wind turbine was (40-60) r/min, the axial rotation frequency of cylinders was (500-900) r/min, and the minimum threshold of operating wind speed was equal to 3 m /s.

Fig.1. The model of the wind turbine with rotating cylinders of various cross-sections:
a) a general view; b) in the working section of the wind tunnel.

To measure the components of the aerodynamic forces and moments acting on the model, a three-component aerodynamic balance of mechanical type was used. Through special-purposed tailings, the mechanical aerodynamic balance was attached to a rigid cubic frame, within which the model of the wind turbine was placed. The flow of air coming on the frontal part of the cylinder exerted forcing, so that the balance indicator deviated from equilibrium. Independence of measurements of the aerodynamic balance in mutually perpendicular directions made it possible to measure the value of the lift force $F_l$ and drag force $F_d$ at various flow regimes. Using a special-purposed device the wind turbine model was turned by predetermined angle $\alpha$ relative to the direction of air flow, thus providing flow past the model at different angles of attack (yaw angles of the flow). The traction force $F_t$ at different rates and directions of air flow was measured using dynamometers. Measurements of aerodynamic forces were repeated at least 5 times, the measurement error did not exceed (4-5) %.

To measure the angular rate of the rotating cylindrical blades, a contact-contactless digital phototach AT-8 was used, which provided measuring frequency in the 0.1 r/min to 10,000 rev/min range.

## 3. Discussion of tests results

Figures 2 and 3 show the curves obtained by measuring dependencies of drag forces on the rate of flow at different yaw angles. The yaw angle of the flow α is the angle between the direction of the air flow rate and the direction perpendicular to the plane of the wind wheel.

Fig. 2 shows that the drag force increases with growing air flow rate, however, the greater is the yaw angle of the flow, the less are the values of drag forces.

Figure 3 shows that within the range of yaw angles of the flow $\alpha=(0\div15)$ degrees the drag force of the wind turbine remains substantially constant; in the 15 degrees to 40 degrees range the drag force reduces, and then within the range (45-60) degrees an increase in drag force is observed. This change in the drag force value is due to the fact that with increase in deviation of the flow direction from perpendicular to the plane of the wind wheel the mid-section area reduces. When the angle of attack is over than 60 degrees, all flow rates grow due to the flow past the wind wheel at the backside.

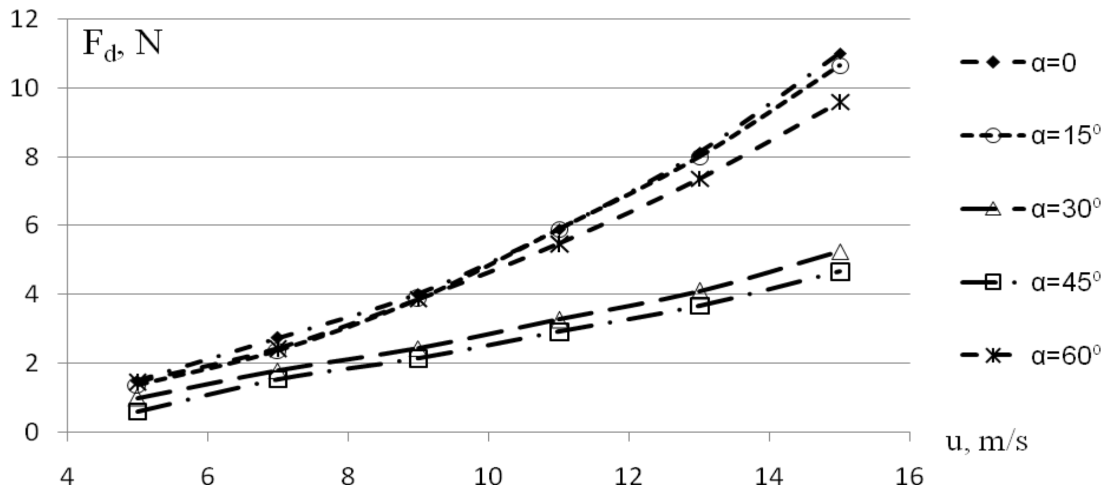


Fig.2. Dependence of the drag force on the flow rate at different yaw angles of the flow α

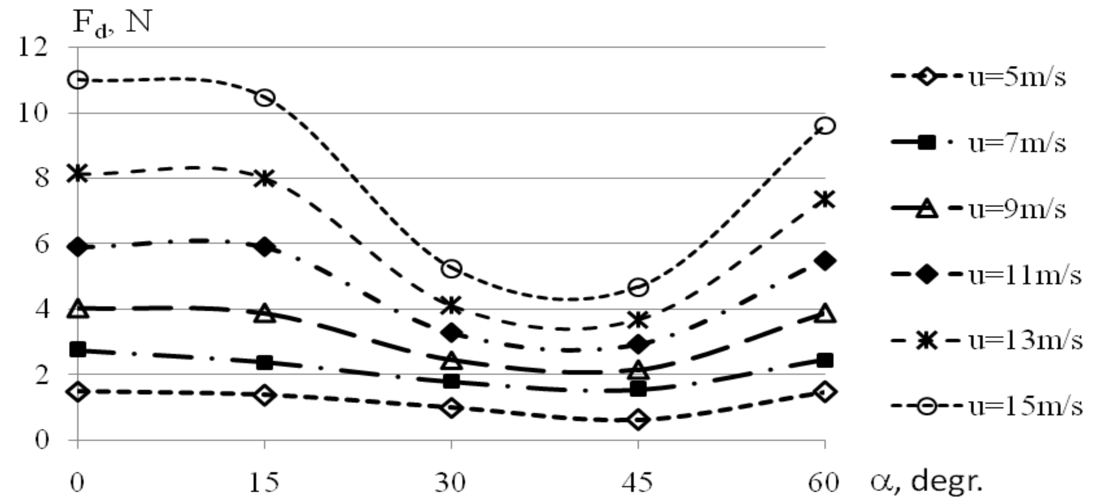


Fig.3. Dependence of the drag force on the yaw angle of the flow α at different flow rates.

Fig. 4 shows the results of experiments on the effect of flow direction on the rotation rate of the streamlined wind wheel with rotating cylindrical blades of variable cross-sections. From these graphs it follows that with an increase in the yaw angle of the flow the rotation frequency of the wind wheel of a three-bladed wind turbine model decreases, which can be explained by the decrease in the total pressure on the wind wheel due to reduced mid-section area, and consequently, lowered rotation rate of the wind wheel. The tractive force generated by the wind turbine is considered a useful effect in the conversion of wind energy.

Figures 5 and 6 show dependences of the tractive force of the wind turbine model with cylindrical rotating blades on the air flow rate at different yaw angles of the flow. Fig. 5 shows that with the rise in the air flow rate the value of the tractive force of the wind turbine model grows. At the yaw angle of 0 degrees when the air flow rate is 15 m/s, the maximum tractive force of 612.6 H is achieved. However, with increasing yaw angle of the flow the value of the tractive force of the three-bladed wind turbine model decreases, Fig.6. With the increase in air flow rate, the value of the tractive force of the three-bladed wind turbine model increases, this is also due to an increase in the pressure force on the wind wheel. This is explained by the fact that with rise in the flow rate, pressure force on the wind wheel increases, and when the yaw angle of the flow increases it decreases with reduction in the mid-section area.

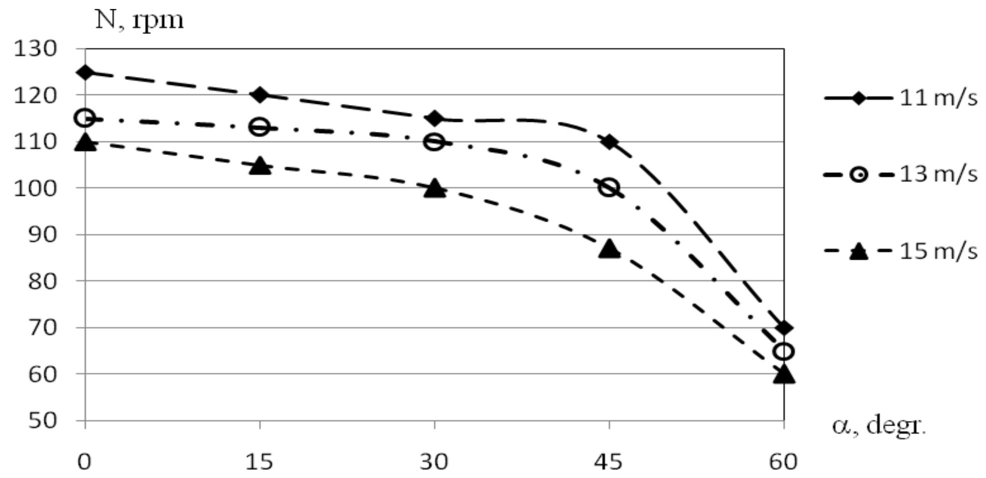


Fig.4. Dependence of rotation frequency on the yaw angle of the flow α at three different flow rates

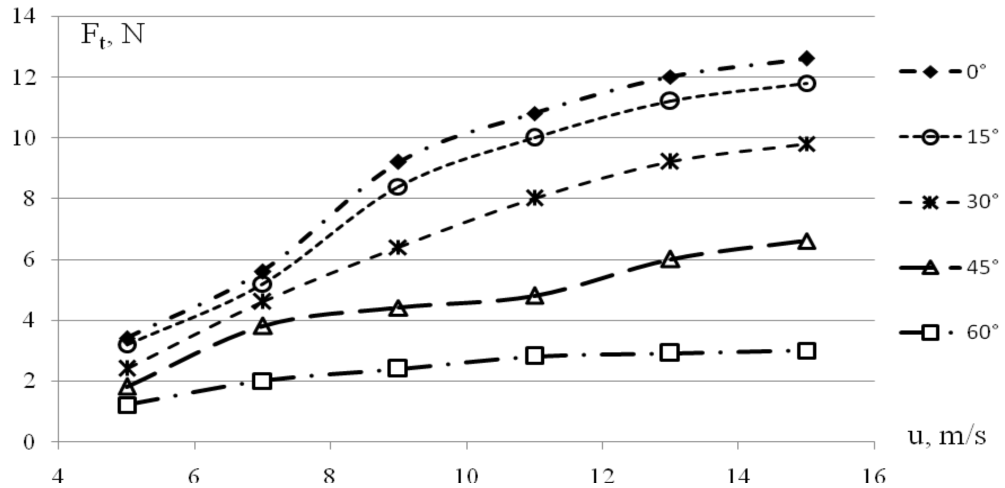


Fig.5. Dependence of the tractive force of wind turbine model at different yaw angles of the flow

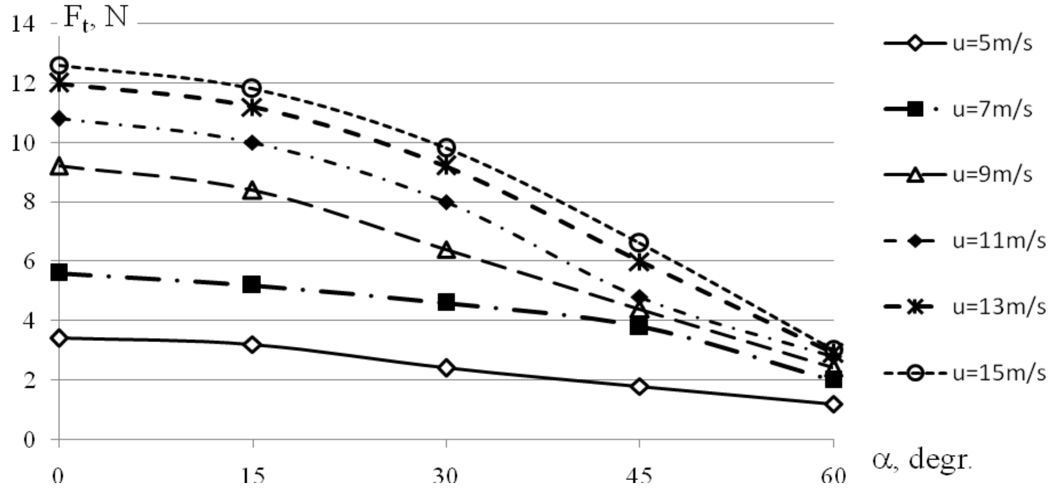


Fig.6. Dependence of the tractive force of the wind turbine model on the yaw angle of the flow at different flow rates

## Conclusion

The present level of technological development and high technology makes for the use of a rotating cylinder to generate arising incremental lift force directed across the flow. As a result of the aerodynamic testing of a wind turbine model with blades in the form of three rotating cylinders of variable cross-sections, dependences of drag and tractive forces on the flow rate at different yaw angles of the flow were found. The frequency of rotation of the wind wheel of the model at different flow conditions was studied.It had been previously found that by using porous cylinders with end discs at the tops it's possible to increase efficiency of wind energy conversion into mechanical rotation energy of a wind wheel (15-20)% [8]. In the experiments cylindrical rough- surfaced blades were used. Aerodynamic testing showed that the model of the wind turbine also carried out active trapping of the air flow due to the rotating cylindrical rough-surfaced elements. Obviously, that was caused by the additional force arising due to the Magnus effect.

A further analysis of the aerodynamic characteristics of three-blade models with rotating cylinders of porous material and coated with an impermeable rough-surfaced layer at different flow conditions will be carried out. Various cross-sections of the cylinders provide the rotating elements optimal aerodynamic drag and sufficiently high tractive force within a wide range of rates. However, when a yaw angle of the flow is above 45 degrees the value of the tractive force sharply drops. In practice, it is desirable to use a special-purposed device to keep the angle of attack from rise over 45°. The quoted results valid for the above mentioned model of the wind turbine at the indicated conditions of aerodynamic testing are quite applicable and can be used in practice.

## REFERENCES

1 Abdrakhmanov R.S., Yakimov V.V. The effectiveness of the use of wind energy resources at low wind speeds. *Proceedings of the Russian Academy of Sciences. Energy* 2010, No.5, pp. 54-57. [in Russian]

2 Karatayev M., Clarke M. A review of current energy systems and green energy potential in Kazakhstan. *Renewable and Sustainable Energy Reviews*, Vol. 55, March 2016, pp. 491–504.

3 Marinushkin B., Trofimov A. To the general scheme of development of wind power engineering in Kazakhstan. Available at: http://www.windenergy.kz/rus/articles/1/page/1/28

4 Mukasheva A., Sharapatova G.S. Problems of the use of renewable energy sources in the Republic of Kazakhstan (in the framework of EXPO 2017). *Eurasian Law Journal*, 2013, No. 4 (59), pp. 96 - 99.

5 Schlichting H. Boundary layer theory. Moscow, Nauka, 1974, 712 p. [in Russian]

6 Kussaiynov K., Sakipova S.E. *Boundary layer theory*. Textbook. Karagandy, 2002, 220p. [in Kazakh]

7 Kusaiynov K., Sakipova S.E., Nikitina L.A. Aerodynamics of the transversally streamlined rotated

8 barrel. Methods of aerophysical research. *Proc. of the 12th international conference. ICMAR-2004*. - Novosibirsk, 2004, pp. 195 – 198.

9 Kussaiynov K., Sakipova S.E., Tanasheva N.K. et al. *A wind turbine based on the Magnus effect*. RK innovative patent of invention No. 30462. Published: 15.10.2015, 3 p.

10 Bolotov S.A. *A rotary vortex wind power plant. Power supply and energy saving in agriculture*. Moscow, 2003, Part 4, pp. 177 - 185.

11 Nobuhiro Murakami A.c. RU № 2330988. A *wind power generator based on the Magnus effect ITO Dzun*; Published: 27.03.2012. Bull. No. 25, 4, p.

12 Bychkov N.M .; A.C. RU № 2118699. *A wind turbine and the method of its operation*. Published: 18.06.1996. Bull. No. 45, 3, p.

13 Gorshenin D.S. *A guide to practical training in the aerodynamic laboratory*. Moscow, Mechanical Engineering. 1997, 224, p.

14 Sakipova S.E., Kambarova Zh., Turgunov M.M., Kussaiynov Ye.K. Study of the aerodynamic characteristics of a three-blade wind turbine with rotating cylinders of various cross-sections in the flow of air. *Proc. of the 9th Intern. Conf. «Chaos and structures in nonlinear systems. Theory and experiment »,* Karaganda, 2015, pp. 319 - 323.

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