2. Что важнее: высокая эффективность HEPA-фильтров или их производительность.// Бардадым В.Ю.- 2021г.- №1.- С. 15-18.- Статья.

3. Высокоэффективный электростатический фильтр – стерилизатор воздуха жилых помещений.// Варехов А.Г.- 2015г.- №1(31).- С. 6-11.- Статья.

ENHANCING MAGNUS-EFFECT WIND TURBINES WITH FIXED BLADES: AN EXPERIMENTAL STUDY

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The paper presents a study of a combined wind power plant (wind turbine) with a horizontal axis combining rotating cylindrical elements and fixed blades. The novelty of the installation lies in the use of the Magnus effect due to the rotation of the cylinders and the simultaneous introduction of a fixed plate to reduce the turbulence of the flow behind the cylinder. An experimental wind turbine model with a diameter of 50 cm has been developed, in which cylinders with a diameter of 5 cm and a length of 23 cm are driven by electric motors, and a fixed blade with a width of 3 cm and a length of 24 cm is fixed parallel to each cylinder. Aerodynamic tests of the model were carried out in a wind tunnel at flow rates of 3-12 m/s and various angles of installation of the fixed blade. The experimental results demonstrate that as the angle of inclination of the fixed blade increases, the drag force of the rotor increases, but at angles above ~ 15 °, its sharp decrease is observed. The thrust force of the rotor increases with increasing flow velocity; the optimal blade angle ensures an increase in lifting force without a significant increase in resistance. The use of a fixed blade in conjunction with a rotating cylinder leads to an increase in wind energy utilization and wind turbine efficiency at low wind speeds.

Keywords: Magnus effect, wind power plant, horizontal axis, rotating cylinder, fixed blade, aerodynamic drag, lifting force.

Traditional wind power plants with bladed rotors have low efficiency at low wind speeds (less than 5 m/s). One of the promising alternatives is the use of the Magnus effect, which uses the lifting force generated by rotating cylinders to drive a wind turbine [1]. Wind turbines of this type are capable of operating efficiently at lower flow velocities compared to classical turbines. For example, it has been shown that a wind turbine with the Magnus effect can be energetically efficient in the speed range of 2-40 m/s versus 5-25 m/s for conventional small wind turbines [2].. Such installations are of particular interest for regions with moderate wind potential, allowing them to generate electricity even in low winds. Despite the advantages of operating at low speeds, Magnus-effect wind turbines are difficult to implement and require careful design study..However, the rotating cylinders themselves have significant wind resistance when flowing around and relatively low aerodynamic efficiency.

To overcome this disadvantage, it is proposed to combine a cylindrical rotor system with an additional fixed blade. According to the results of a recent numerical study, it was revealed that adding a fixed plate (blade) to a cylindrical wind turbine can increase the lifting force by 40-55% and increase the power factor by almost 1.5–1.7 times compared with a single cylindrical blade [3,4]. This is achieved by regulating the flow and reducing the intensity of the vortices behind the rotating cylinder [5]. Thus, the use of a fixed blade in conjunction with a cylinder opens up new opportunities for improving the efficiency of wind turbines with the Magnus effect. The purpose of this work was to experimentally study the aerodynamic characteristics of a combined cylindrical wind turbine with a horizontal axis of rotation equipped with a fixed blade, as well as to evaluate the effect of the angle of installation of this blade on drag and thrust forces.

An experimental sample of a combined cylindrical wind turbine with a horizontal axis has been developed for the study (Fig. 1). The wind wheel of the installation has a diameter of 50 cm and includes three cylindrical rotors (blades). Each rotor is a cylinder with a diameter of 5 cm and a length of 23 cm, which can rotate around its longitudinal axis using an electric drive. A fixed blade (plate) with a width of 3 cm and a length of 24 cm is fixed parallel to the axis of each rotating cylinder. The fixed blade is mounted behind the cylinder relative to the direction of the incoming flow and can change the angle of inclination relative to the horizontal axis (cylinder axis).The installation structure is mounted on a horizontal shaft connected to an electric generator (Fig. 1).

Figure 1. Combined wind power plant with horizontal axis of rotation

During the operation of the installation, electric motors spin the cylinders, as a result of which, when the wind flows around each cylinder, a flow circulation occurs. According to Bernoulli's principle, on the side of the cylinder, where the direction of its rotation coincides with the direction of the incoming flow, the air velocity relative to the surface increases and the pressure decreases. On the opposite side of the cylinder, the rotation is directed against the flow, the flow velocity is lower, and the pressure is higher. As a result, due to the Magnus effect, a pressure difference is formed on opposite sides of the cylindrical blade. This pressure difference creates a lifting force that rotates the entire wind wheel around the horizontal shaft. An additional fixed blade performs the function of a flow rectifier and prevents intense air turbulence immediately behind the cylinder. The presence of such a plate contributes to a more efficient separation of the flow behind the cylinder and reduces the zone of turbulent braking.

Experimental aerodynamic studies of the installation were carried out at the Department of Engineering Thermophysics in a small-section wind tunnel. The wind turbine model was positioned in the working part of the pipe in such a way that the incoming flow flowed around it in a horizontal plane (simulating natural wind conditions). Aerodynamic forces were measured at different flow rates (V = 3, 5, 8, 10, 12 m/s) and different angles of inclination of the fixed blade relative to the axis of the cylinder (0°, 5°, 10°, 15°, 20°). The drag force (aerodynamic force against the flow direction) and thrust force (axial force tending to rotate the rotor) were determined using dynamic sensors mounted on the model mounting stand.

The aerodynamic characteristics of the model, such as the drag force and the thrust force of the wind turbine, were determined at flow rates from 3 m/s to 12 m/s (Fig. 2 and 3).

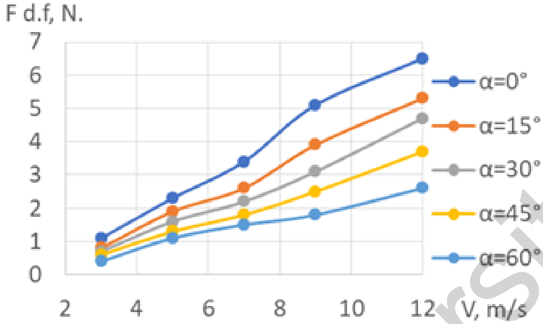

Figure 2. Dependence of the drag force on the flow velocity at different angles of the fixed blade for wind turbines with three blades

During the tests, the operability of the proposed design at low wind speeds was confirmed. It has been experimentally established that the rotation of the wind wheel begins already at V ≈ 3-5 m/s, which is consistent with the calculated expectations for installations with the Magnus effect. At an incoming flow velocity of 8-12 m/s, stable efficient operation of wind turbines is observed, which makes it possible to obtain significant values of aerodynamic forces. In Fig. 2 shows the obtained dependences of the rotor's drag force on wind speed at different angles of installation of a fixed blade (for a three-blade configuration). It can be seen that the resistance increases almost linearly with increasing flow velocity for each fixed angle. In addition, as the angle of inclination of the plate relative to the flow increases (from 0° to 20°) The drag force increases over the entire speed range. This is because at a higher angle, the fixed blade is positioned more frontally to the flow, increasing the effective resistance area. However, at angles of more than ~15°, the resistance curves reach saturation or even decrease. Probably, if the plate is excessively deflected, the flow is redistributed and the high-pressure area in front of the rotor decreases, which leads to a reduction in resistance. The maximum value of the drag force in the experiment was about 6.5 N (at V = 12 m/s, angle ~15°) for the three-bladed circuit, whereas for the two-bladed configuration it did not exceed 4.1 N.

Figure 3 below shows the results of the draft force of the layout as a function of the flow velocity.

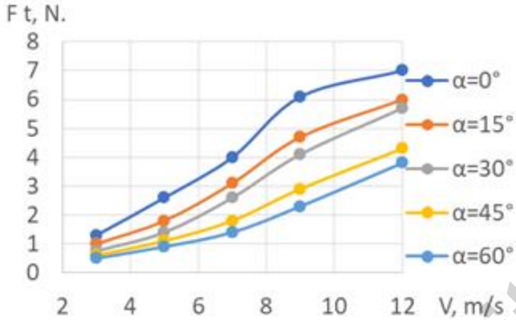

Figure 3. Dependence of the thrust force of a three-bladed wind turbine on the flow velocity at different angles of the fixed blade

As the flow velocity increases, the thrust force increases non-linearly: when moving from 3 m/s to 8 m/s, the increase is more dramatic, then the trend becomes close to linear. The presence of a fixed blade significantly affects the amount of thrust. At small angles (0-5°), the lifting force is relatively small, since the plate is practically not involved in generating lift. Increasing the angle to the optimal one (~10-15°) leads to a significant increase in thrust due to more efficient use of the Magnus effect – the plate captures the low-pressure zone behind the cylinder and converts it into additional lifting force. With a further increase in the angle (up to 20°), the thrust growth slows down or stops: probably, excessive deflection of the plate leads to a disruption of the flow and a partial loss of lifting force. The maximum value of the thrust force recorded in the tests was about 15 N (at V ≈ 12 m/s and an angle of ~15 °).

The results obtained are consistent with known theories and numerical simulation data. The increase in lifting force at the optimal angle of the fixed blade confirms the effectiveness of the combined rotor scheme. In addition, the noted decrease in resistance at large angles correlates with the conclusions of [5], which shows a decrease in the vortex wake behind the cylinder in the presence of a plate. Thus, it has been experimentally proven that adding a fixed blade to a cylindrical rotor makes it possible to improve the aerodynamic characteristics of wind turbines by increasing useful thrust and simultaneously reducing drag.

As a result of the research, a new design of a Magnus-effect wind turbine with a horizontal axis of rotation has been developed and tested, the distinctive feature of which is the combination of a rotating cylinder and a fixed blade. The operability of this wind turbine at wind speeds of 3-5 m/s and its effective operation at 8-12 m/s has been experimentally confirmed. It is shown that the use of a fixed plate makes it possible to significantly increase the lifting force of the rotor and reduce aerodynamic drag due to the regulation of the air flow behind the cylindrical blade. The optimal angle of the fixed blade (0-15°) ensures maximum thrust gain with minimal increase in drag. The data obtained are in good agreement with the results of numerical modeling and confirm the prospects of combined wind turbines with the Magnus effect for efficient energy generation at low wind speeds. In the future, it is planned to conduct research on the wind energy utilization factor and the output power of such an installation, as well as optimize the rotation parameters of the cylinders and the geometry of the fixed blades to maximize efficiency.

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References

1. Sedaghat A. Magnus the wind turbines: Prospectus and challenges in design and modelling // Renewable Energy. 2014. Vol. 62. P. 619–628.
2. Lukin A., Demidova G., Rassadkin A., et al. Small Magnus Wind Turbine: Modeling Approaches // Applied Sciences. 2022. Vol. 12, No. 4. P. 1884.
3. Bychkov N.M. Wind turbine with Magnus effect: design characteristics of a wind turbine // Thermophysics and Aeromechanics. 2008. Vol. 15, No. 2. P. 341–348.
4. Marzuki O.F., Mohd Rafie A.S., Romli F.I., Ahmad K.A. An experimental investigation on the effect of surface roughness on the performance of Magnus wind turbine // ARPN Journal of Engineering and Applied Sciences. 2015. Vol. 10, No. 20. P. 9725–9730.
5. Dyusembaeva A.K., Tanasheva N.Zh., Sarzhanova I.E., et al. Improvement of a Magnus VAWT based on numerical simulation using a fixed blade // CFD Letters. 2025. Vol. 17, No. 7. P. 98–112.