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EXPERIMENTAL INVESTIGATION OF WIND ENERGY PLANT WITH HELICOIDAL ROTOR

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Abstract**—*****The article is devoted to design and investigation of a helicoidal wind rotor in the wind tunnel, which is a modification of the Darrieus rotor – the most promising rotor type for vertical axis wind turbines. The graphs of power and rotation of the investigated wind generator depending on the incoming air flow speed are obtained. Investigation of the helicoidal rotor in a large wind tunnel has shown that the helicoidal rotor type has a high potential for use in vertical axis wind turbines. The high cut in speed of the incoming air flow is caused by the phenomenon of "sticking" of the axial generator with steel cores, as well as by the absence of an additional starting Savonius rotor, which could create the initial torque moment at rhe low speed of the incoming air flow.Iit is necessary to enlarge diameter of the generator and to reduce the air gap between the magnets and the stator to increase electric power.*

Index Terms—Wind power; wind generator; Darrieus rotor; helicoidal rotor.

I. INTRODUCTION

Today, wind power is one of the main areas for electricity generation in the world. This is primarily due to the high cost of organic fuels and the problem of protecting the environment.

For the most territories of Ukraine, wind rotors with vertical axis of rotation, which unlike wind rotors with horizontal axis of rotation, are safe for people and can be installed near houses in rural areas or on the roofs of multi-storey buildings. The main examples of vertical axis wind rotor designs are the wind rotor with the Savonius rotor or the Darrieus rotor [1]. Thus, the study of different types and shapes of wind rotors is important both scientifically and practically.

Savonius' rotor includes two or more blades in the shape of a semicircle. The pressure acting on the "open" part of the circle significantly exceeds that acting on the opposite side. The rotor has a small starting torque, so it does not require initial forced unwinding. However, the Savonius rotor cannot operate at high speeds because its surfaces cannot move faster than the incoming air flow.

The Darrieus rotor has a symmetrical structure consisting of two or more aerodynamic wings fixed on radial beams. The rotation is due to the wing-shaped blade. With the air flow, a lift is created, due to which the moment of rotation of the axis arises. The lifting force acts on each wing, the value of which depends on the angle between the velocity vectors and the instantaneous velocity of the wing (Fig. 1). The maximum value of the lift reaches the orthogonality of these vectors. Given that the instantaneous velocity vector of the wing cyclically changes during the rotation of the rotor, the torque developing force of the rotor is also variable.

The advantages of the Darrieus rotor can be attributed to the high tip speed ratio and high wind energy utilization. In addition, this rotor can run at high speeds of incoming air flow. The Darrieus rotors are no worse, and sometimes even better, in horizontal axis wind turbines [2].

It has its drawbacks as well, and the main one is self-starting issues. The self-start improves when three or more blades are used, but in this case, the rotor pre-acceleration is required. Also, the srcond disadvantage of the Darrieus rotor is the low mechanical strength and high noise at work.

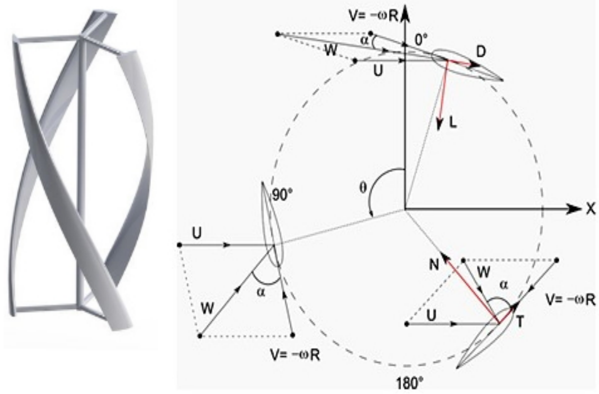

Fig. 1. Darrieus Rotor

http://jrnl.nau.edu.ua/index.php/ESU, http://ecs.in.ua

One of the modifications of the Darrieus rotor is a helicoidal rotor in which the blades are twisted along the bearing axis, which greatly increases the service life of the whole structure, as it provides a uniform load on the bearings and mast on all sides. As a result, the life of the mechanism is significantly increased, the rotor rotation is smoother, and the noise level is reduced. But at the same time, due to the complicated production technology, the cost of manufacturing this rotor increases.

II. THE WIND POWER PLANT STRUCTURE

The main components of a wind farm are a rotor and a generator. In Figure 2 it is shown a 3D model of a helicoidal rotor with four blades, on the basis of which the prototype was made. The rotor consists of a steel traverse circle, upper and lower aluminum traverses, and blades made of composite materials. Node attachment of the blade to the beam allows you to set the angle of attack within small limits. The rotor must additionally be tightened and balanced to ensure rigidity of the structure and to prevent "spacing" at high rotational speed.

An axial flux synchronous generator with permanent super magnets was used for the experimental study of this rotor (Fig. 3). The synchronous three-phase generator in normal construction was composed of three armatures: two moving ones, named rotors and the fixed armature, named stator, concentrically located inside these moving rotors. Every rotor is a disk with 24 super magnets. A cast iron brake disk was used as the rotor one. Every coil of the stator has a low carbon steel core for the windings. Eighteen coils were housed with epoxy resin. The wind rotor is concentrically fixed to the generator rotor.

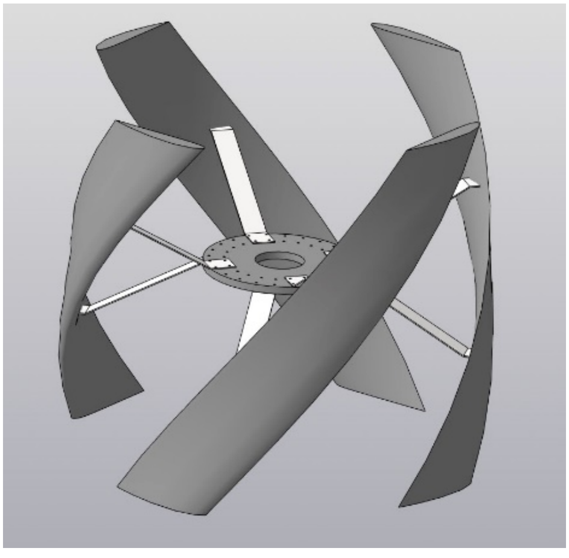

Fig. 2. 3D model of helicoidal rotor

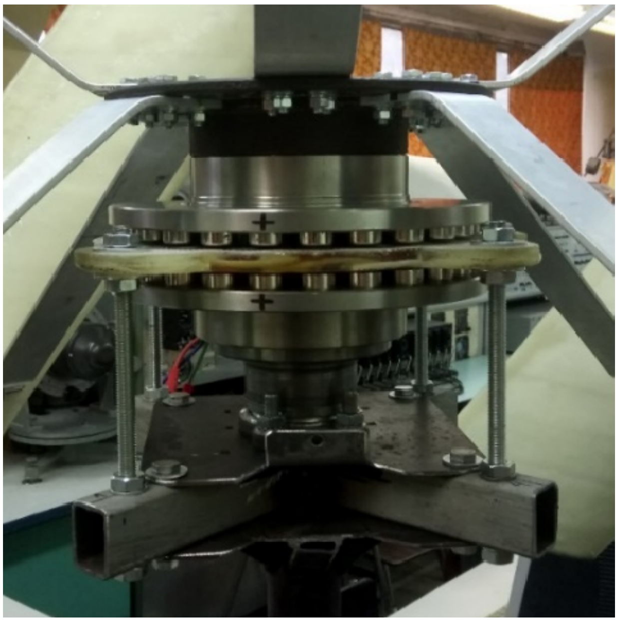

Fig. 3. Axial generator

III. INVESTIGATION OF WIND POWER PLANT IN WIND TUNNEL

In order to determine the characteristics of wind rotors, a test sample of the rotor in the wind tunnel was conducted. In Figure 4 it is shown a pilot plant, consisting of a rack, the base of which is bolted to the turntable of the wind tunnel. Additionally, the rack is secured with stretch marks, which are also bolted to the turntable. On the top of the rack there is a generator with a helicoidal rotor.

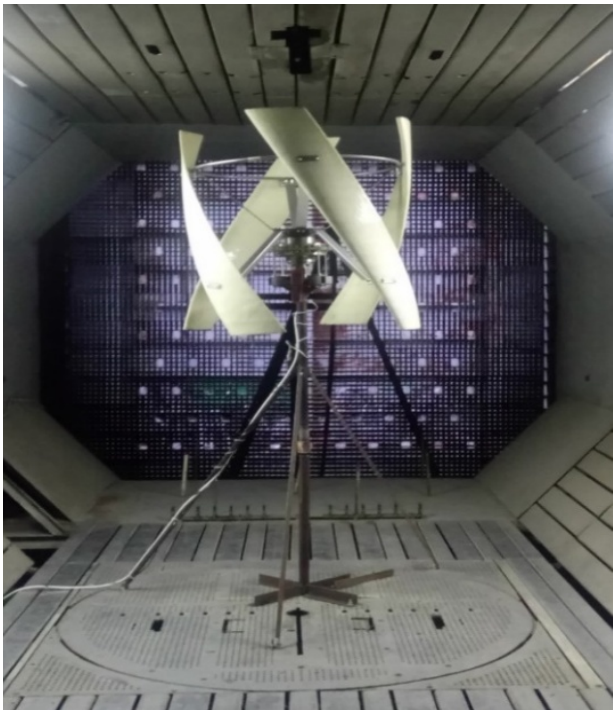

Fig. 4. Experimental plant

Rotor parameters:
- height – 1 m;
- diameter – 1 m;
- number of blades – 4;
- blade chord – 0.25 m;
- the blade profile is asymmetrical.

The research agenda consist of the following key steps:

1) Determination of incoming air flow velocity at the moment of rotor displacement at different generator loads.

2) Obtaining of static characteristics of wind rotors at different generator loads.

3) Results processing and calculation of wind rotor efficiency.

A measuring stand was developed for research, the structural diagram of which is shown in Fig. 5. From the test installation, a three-phase electrical cable from the generator and a USB cable from the tachometer are output to the room of the wind tunnel operator.

The measuring stand consists of the following elements:

– three-phase diode bridge to rectify the alternating current of the generator;

– 400 Ohm rheostat. Used to set the generator load;

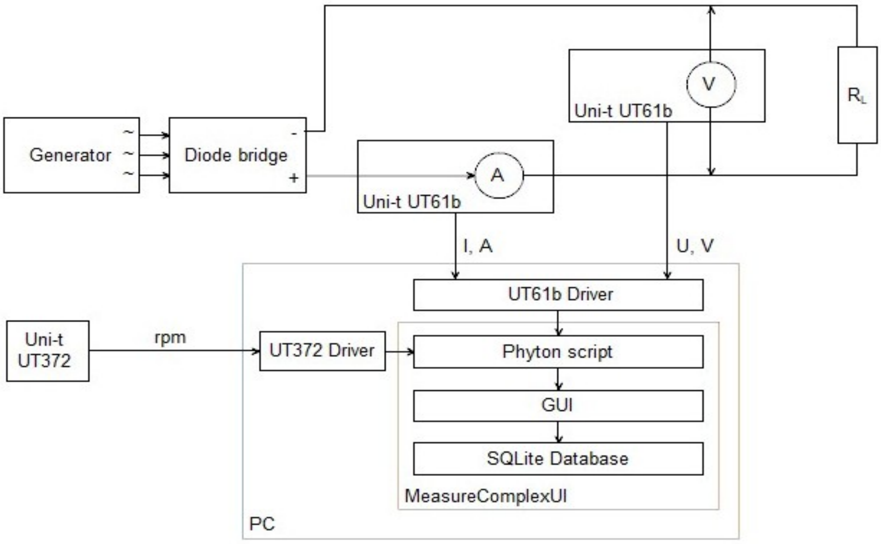

Fig. 5. Structural diagram of the measuring stand

– two Uni-t UT61b digital multimeters. One multimeter is set to voltmeter mode and the other to ammeter mode. Additionally, to set the rheostat to the exact load value, the first multimeter can switch to resistance measuring mode. These multimeters have the function of transmitting the measured value via the Serial Port. A UART to USB converter is used to connect a laptop that is not equipped with a COM port;

– digital tachometer Uni-t UT372, which is attached directly to the rack of the pilot plant. The rotational speed is transmitted to the computer via USB;

– notebook with installed drivers and special MeasureStandUI software and SQLite database.

IV. Investigation Results

After processing of the received information in the database of the measuring stand the following results were obtained.

The required speed of the incoming air flow for the rotor to move the unloaded generator is 9 m/s, and for a load of 20 Ohms – 11.5 m/s. Such values are due to the generator cores through which additional "sticking" of the rotor occurs. The test rotor is not self-starting, so it must be additionally equipped with a Savonius rotor for initial unwinding.

The starting torque of the rotor was determined by the dynamometer that was connected to the blade of the rotor. For the case of the generator with the cores obtained value of the moment of displacement for the test installation is 1 Nm.

The dependence of the steady rotation of the rotor on the incoming air flow velocity is shown in Fig. 6. The maximum rotation frequency that can be fixed is 430 rpm at a incoming air flow speed of 15 m/s in the no-load case. The rotor construction withstood such a speed without any problems, so you can expect that this type of rotor is capable to run at higher rotational speeds.

The dependence of the generator electrical power rotation frequency is shown in Fig. 7. This generator can reach 100 watts of electrical power at about 300 rpm with a load of 8 ohms. Based on the obtained graphs, reducing the load to, for example, 2 ohms, it will allow to achieve to much more power at the same revolutions per minute.

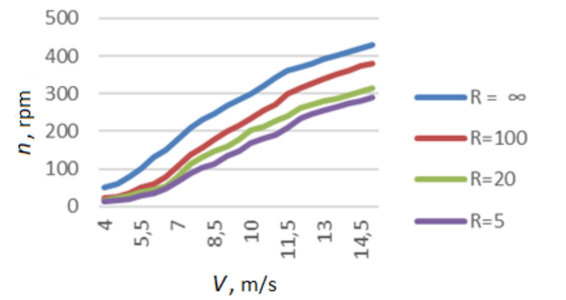

Fig. 6. Graph of revolutions depending on wind speed at different values of generator load

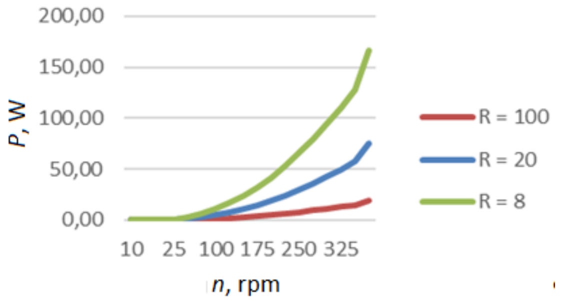

Fig. 7. Graph of the electric power of the generator

Calculations have shown that the efficiency of wind rotors at different incoming air flow velocities lies in the range of 4–11%. The swept area of the blades affected by the incoming air flow $S = 1$ m^2 and the density of air ρ = 1.23 kg/m^3 were taken into account. It should be noted that in this case the efficiency calculation is primarily influenced by the developed axial generator, which has a small diameter and the air gap between the magnets and stator is of 2–3 mm. Also, since the actual efficiency of the generator is not known, the value was assumed to be 0.85.

V. Conclusion

Investigation of the helicoidal rotor in a large wind tunnel has shown that the helicoidal rotor type has a high potential for use in vertical axis wind turbines. The main advantages of this type of rotor are the ability to spin to high revolutions, reliability and smooth rotation due to the fact that the lift force of the blades creates torque constantly, regardless of the wind direction.

The high cut in speed of the incoming air flow is caused by the phenomenon of "sticking" of the axial generator with steel cores, as well as by the absence of an additional starting Savonius rotor, which could create the initial torque moment at rhe low speed of the incoming air flow. After starting, the rotor can easily accelerate to high rpm, gaining more power. Because of that the Savonius rotor can create the negative torque at high revolutions, there is a prospect of using a special combined rotor design in which the Savonius rotor opens at low revolutions and closes at high ones.

A more sophisticated axial generator will increase electric power. For this purpose it is necessary to enlarge diameter of the generator and to reduce the air gap between the magnets and the stator.

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В. М. Синєглазов, Є. В. Даскал, А. А. Зіганшин. Експериментальне дослідження вітроенергетичної установки з гелікоїдною турбіною

Статтю присвячено розробці та дослідженню в аеродинамічній трубі гелікоїдного ротора, що є модифікацією ротора Дар'є – найбільш перспективного типу ротора вертикально-осьових вітрогенераторів. Отримані графіки потужності та обертів досліджуваного вітрогенератора в залежності від швидкості набігаючого повітряного потоку. Дослідження гелікоїного ротора у великій аеродинамічній трубі показує, що ротор геліклоїдного типу має великий потенціал для використання у вертикально осьових вітроустановках. Велику швидкість набігаючого потоку, за якої відбувається зрушення, викликано явищем залипання генератора зі сталевими сердечниками, а також відсутністю додаткового стартового ротора Савоніуса, який може створювати початковий пусковий момент за малих швидкостей набігаючого потоку. Для збільшення електричної потужності необхідно збільшити діаметр генератора і зменшити повітряний зазор між магнітами і статором.

Ключові слова: вітроенергетика; вітрогенератор; ротор Дар'є; гелікоїдний ротор.

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В. М. Синеглазов, Е. В. Даскал. А. А. Зиганшин. Экспериментальное исследование ветроэнергетической установки с геликоидной турбиной

Статья посвящена разработке и исследованию в аэродинамической трубе геликоидного ротора, который является модификацией ротора Дарье – наиболее перспективного типа ротора вертикально-осевых ветроэнергетических установок. Получены графики мощности и оборотов исследуемого ветрогенератора в зависимости от скорости набегающего воздушного потока. Исследование геликоидного ротора в большой аэродинамической трубе показывает, что ротор геликлоидного типа имеет большой потенциал для использования в вертикально осевых ветроустановках. Большая скорость набегающего потока, при которой происходит трогание, вызвана явлением залипания генератора со стальными сердечниками, а также отсутствием дополнительного стартового ротора Савониуса, который может создавать начальный пусковой момент при малых скоростях набегающего потока. Для увеличения электрической мощности необходимо увеличить диаметр генератора и уменьшить воздушный зазор межлу магнитами и статором.

Ключевые слова: ветроэнергетика; ветрогенератор; ротор Дарье; геликоидный ротор.

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