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The effect of design parameters on energy characteristics of Darrieus rotor

Abstract. In the last 10-15 years the use of wind energy is growing. There are more than 20,000 wind power turbines with a total capacity of more than a few megawatts in the world. Kazakhstan has significant wind power resources. Resources of the Jungar gate and Shelek complex in Almaty region are the best known in this respect. Their capabilities for use in electricity generation of air flow are unique.
This article describes the main types of wind turbines and the benefits of Darrieus rotor over other wind turbines. The article provides the basic calculations to determine the effect of the wind turbine Darrieus design characteristics on its energy efficiency. This article shows the dependence of the maximum utilization coefficient of wind energy vertical axis windwheels from the number of blades with constant filling factor σ, from the number of blades with their constant width, from blades elongation λ. Design characteristics for 1 kW rotor were identified based on these results. Also, wind turbine scheme, that can provide thermal protection by warm air natural ventilation in the rotating elements of wind turbine which arises due to centrifugal forces, is shown.

Key words: Darrieus rotor, rotation shaft, windturbine, the fill factor, thermal protection, ideal rotor.

Introduction

In the last 10-15 years the use of wind energy is quick stepping to new peaks. There are more than 20,000 wind electric set so far in the world, the total capacity of which is more than a few megawatts.

The possibility of electric power generation is defined by the construction of wind turbines. All the wind turbines consist of blades that rotate axis connected to a generator, which generates a current.

The size and capacity of wind turbines are fluctuating widely. There are three main types of wind turbines: with horizontal axis, with vertical axis and channel.

Currently the horizontal axis or so called propeller type turbines are mainly used in the world. They compose more than 90% of the total number of wind farms, and some thousand companies are engaged in their serial production.

The vertical axis wind turbines were not developed for almost 40 years because of the improper conclusion on low rate of wind energy operation of vertical axis wind turbines. And only at the end of the last century, firstly Canadian and then American and British specialists have proved experimentally that these conclusions do not apply to the Darrieus rotor of blade lift [1].

This paper specifies that the propeller type wind turbines can significantly reduce the generated electricity with frequent changes in wind direction. When the wind direction is changed rapidly the wind wheel must accurately track these changes, but it is almost impossible to effectively orient the wind wheel when changing the wind direction due to delay in orientation mechanisms action.

Recently the majority of foreign companies began to give priority to the new type of wind turbine with vertical axis of Darrieus rotor (see Fig. 1). The turbine operates due to the occurrence of the lift on cover blades equidistant from a common axis of rotation.

The advantage of vertical axis wind turbines is the possibility of placing the generator on the turbine base. This eliminates the strong, most likely multi level angle drive of torque simplifying the requirements for the installation of equipment (exclude limitations on size and weight) and for the maintenance conditions (lack of shocks and vibrations). It facilitates the transmission of electricity generated.

Figure 1 – Darrieus wind turbine

The operation of Darrieus rotor does not depend on flow direction. Consequently, the turbine at its base unit does not require positioner. Darrieus rotor is characterized by a high specific speed at low flow rates and high flow energy efficiency, and the area swept by rotor wings can be quite large.

The most technologically advanced is the H-rotor Darrieus. This type is of high-speed installation, coefficient of efficiency reaches 0.45. Rotor H-Darrieus differs by low noise level and total lack of infrasound. The wind turbine of this type has a simple structure and high reliability.

The experimental study of energy characteristics of Darrieus rotor has showed their significant dependence on the thickness of the blade profile. The same dependence on the profile thickness is observed for the traction force generated by flapping wings [4].

The experimental study results show significant dependence of the flow energy efficiency on the geometric parameters of the wind wheel. In this regard, it is important for constructor to know the maximum energy capability of the wind wheel, which can be "squeezed" out of it by designing. The concept of an ideal wind wheel is introduced in order to estimate the maximum energy capability. It refers to a virtual wind wheel running without loss. It is believed that the Darrieus rotor and propeller type wind wheel have the same maximum values of wind flow energy efficiency [5]. However, the experimental study conducted in recent years [6] has showed that the Darrieus rotor may have a higher energy characteristic than the propeller type wind wheel.

Harsh winters so common to Nordic countries, create a very serious problem – blades icing. And it is fraught with just a few troubles, says the Swedish meteorologist Stefan Söderberg, Research Officer of Weathertech Company in Uppsala: "When the ice crust is formed on blades, their aerodynamic characteristics are significantly deteriorated. As a result the wind turbine capacity is lost. This is at first. Secondly, a nice crust unbalances wind wheel, which leads to an increased wear of the bearing parts and the wind generator as a whole. Besides that because of the freezing of super-cooled rain or wet snow the aerodynamics of the blade is worsen, and sometimes you have to disconnect the wind turbine if the ice layer thickness exceeds a critical value. The same situation is observed in Finland, and in the north of Germany and in Switzerland and Russia. Finally, we cannot ignore the dangers connected with the fact that the pieces of the ice from the ends of the rotating blades can break away and scatter over long distances. Appelbo wind turbine in Sweden, for example, reported on 7-week turbine stop in winter 2002-2003. The Swedish statistical database of accidents contains in total about 1337 such records occurred between 1998 and 2003 - as a result, in general, downtime-161 523 hours. 92 accidents (7 percent) were due to the cold climate and as a result of 8022 hours (5 percent) - loss of production. Reports on low temperature downtime in a cold climate were 669 hours (8 percent), although due to the cases of icing were 7353 (92 percent). Downtime is reported due to icing in Finland in the period from 1996 to 2001 were 1208/495/196/581/739 and 4230 hours for the 19/21/29/38/61 and 61 turbines, respectively [7].

Calculation of the effects of the design parameters

Recently the extensive studies have been conducted to identify and simulate methods of preventing icing. The variety of methods developed by experts in alternative energy resource and air flying machine to solve this problem is offered all over the world. Most of these methods have been taken from the aircraft industry and can be divided into two categories: active and passive. Passive methods are based on the physical properties of the blade for preventing ice accumulation, while active methods based on external system applied to the blade. Two types of systems can be used to prevent icing - in particular this is purging against icing and preventing icing. The first removes the ice from the surface after its formation, whereas the latter prevents early ice formation [8].

The methods of active protection for operation demand energy supply, and include thermal, chemical and pneumatic methods and act as the systems for purging of ice or anti-ice [9].

The development of a safe method of protection the operating wind electric set from adverse weather conditions is important. In this regard, the development of wind turbine with anti-icing system using natural ventilation flow turbine elements with warm air, not allowing wet snowflakes sticking on the surface of the machine and formation of ice, is proposed in this paper[10]. This paper deals with the development of thermal protection method of operating wind turbines and preservation of its operating capacity under the most severe climatic conditions in winter.

Therefore the task is to develop a design of the wind turbine Darrieus with thermal protection and to determine geometric parameters of the turbine of 1 kW capacity for the further development of semi-commercial sample of wind turbine of H-rotor type having an anti-icing system.

When designing a wind turbine constructor needs to know the influence of the main parameters on the performance of the rotor. Currently the main source of information for the design of wind wheels with Darrieus rotor is an experiment. The most complete and comprehensive experimental results are published in the works [2.11].

Thus, the calculations of the influence of design parameters on the energy characteristics of the rotor Darrieus have been done.

1) *The effect of blade elongation.* The blade elongation is one of the main rotor Darrieus design parameters that determines its aerodynamic characteristics. The aerodynamic loads level on blade, including torque significantly depends on the values of elongation. The nature of this dependence for a single blade is almost the same as for the wing. When elongating $\lambda<1$, the value of the aerodynamic load varies linearly from λ, and with the increase of the elongation these loads approach their asymptotic values at $\lambda> 5$.

2) *The effect of the number of blades.* Another important design parameter is the number of blades of the rotor Darrieus. In order to assess the effect of the number of blades on the rotor energy characteristics special investigation on the rotor models with different number of blades are held.

According to Fig.2 it is necessary to use blades with elongation of more than 6 to ensure acceptable wind energy efficiency.

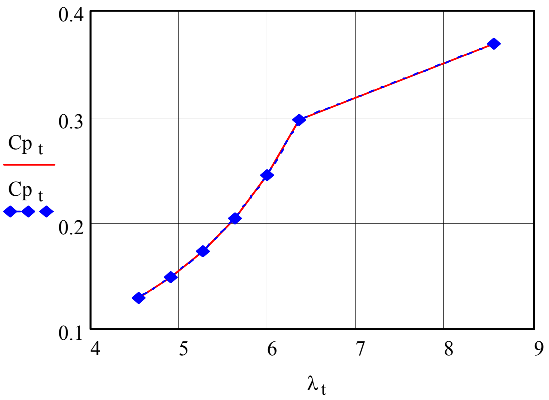

Figure 2 – The dependence of C_p on blade elongation (n = 2, b/D = 0.167, R = 1.65 m, *l* = altern.)

The experiment shows that the high energy characteristics have single-blade rotor. Although in this case, torque experiences a large ripple in time that causes dynamic problems. Increasing the number of rotor blades smoothes out torque characteristics, but it leads to a decrease in energy efficiency. This is especially appears, when increasing the number of blades to reduce their chord to preserve the constancy of the fill factor σ. In increasing the number of blades the preservation of the chord length is more effective. Fig. 3 shows the results of calculations on the study of the effect of the number of blades at constant fill factor. It is evident that with the increase of number of blades the wind energy efficiency is reduced. Fig. 4 shows that at constant width of blades the efficiency of C_P drops considerably less than at constant filling with the increase of the number of blades.

3) *The effect of blade thickness.* The effect of relative profile thickness of the blade on the amount of the maximum value of C_P coefficient at a different Re numbers is shown in [12]. The greatest effect is achieved for the blades with relative thickness of $0.15<\overline{c}<20$. The main feature of this effect is associated with a sharp drop of C_P for thin blades. It should be noted that the same dependence

character on relative thickness of the profile is observed for the traction force generated by flapping wings [4].

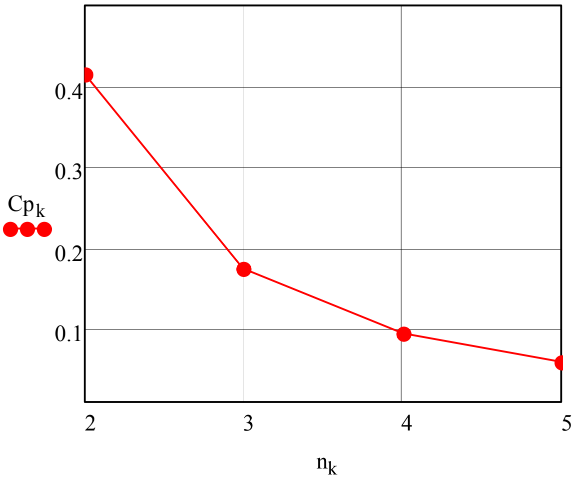

Figure 3 – The results of calculations on the study of the effect of the number of blades at constant fill factor. (σ=const, *l*=3.3 м)

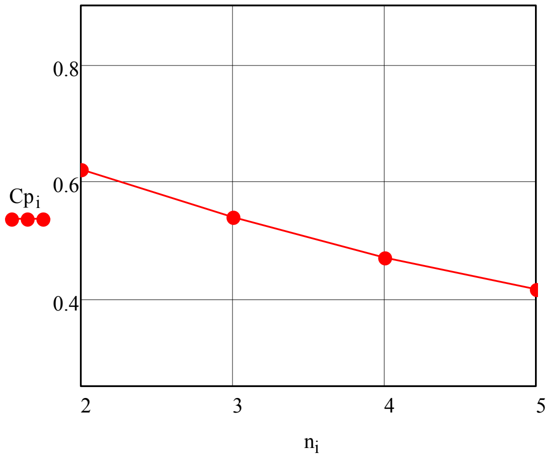

Figure 4 – The dependence of C_p on number of blades at their constant width (b=const, D=3.3 m,*l*=3.3 m)

4) *The effect of fill factor*. The fill factor is connected with two rotor design parameters: number of blades n_b and ratio of blade chord to rotor diameter b/D. It should be noted that when increasing the fill factor σ the value of rapidity z decreases, wherein C_P reaches its maximum value.

Having analyzed all the above mentioned data, the geometry of airfoil NASA-0021was determined.

In order to have a Darrieus rotor with straight blades of 1 kW power, with an average wind speed U, equal to 7 m/s, let's find a streamlined surface of rotor by formula:

$$S = \frac{2\,N_b}{C_P \rho U^3}$$

here N_b – capacity, W; C_P – wind energy efficiency, assumed equal 0,4; ρ – 1,29 kg/m^3 – air density.

The streamlined area of rotor of1kW capacity must be 11.3 m^2. If to take equal the rotor diameter D and the height of blade *l*, then D = *l*≈3,36m. During experimentally proved blade elongation λ=l/b=6-8 chord length of blade can range b=3,36/(6-8)=0,56-0,42 m and chord on average will be b=0,55m.

Since the maximum value of the coefficient C_P at different Re numbers is achieved for blades with a relative thickness of $0.15<\overline{c}<20$, let's take the relative thickness equal to 0,18. On this basis, the maximum thickness of blade, as a part of the length of chord must be 0.09m. And fill factor, in turn, will be equal to

$$\sigma = \frac{n_b b}{D} = 0.33.$$

It is important to note that the fill factor σ satisfies the conditions under which C_P reaches its maximum value.

Using the application packages for mathematical calculations we can obtain the area and perimeter of the cross section. For our rotor the wing perimeter is F=1,04m and the ratio of chord b is approximately equal to 2,1. The cross section area f_1=0.0154 m^2.

Figure 5 shows the preliminary design of machine with anti-icing system. Internal hydraulics and the movement of warm air through internal channels are described in detail in works [10,13,14].

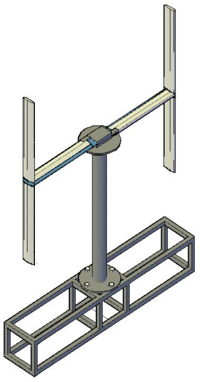

Figure 5 – Preliminary design of machine with anti-icing system

Conclusion

Now we are starting to design the wind power plant of carousel type with anti-icing system on the basis of above studies.

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