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Computer-aided design of vertical-axis wind turbines with a combined rotor

Work represents the parameters that must be considered during the vertical axis wind turbine design process and describes the functions of computer-aided design system developed for such turbines with combined rotors.

Vertical-axial wind turbines are divided into two classes: Darrieus and Savonius rotors.

According to the principle of operation, Darrieus rotors operate due to the torque from the lifting force created by the blades. Because of this, the rotor can produce sufficiently large capacities compared to the rotors, which are using the blades drag forces difference. The vector sum of the incoming flow velocity and the circumferential velocity from the blade rotation creates an angle of attack with respect to the blade chord. In Darrieus rotors, blades circumferential speed exceeds the speed of the incoming flow. Since the blade must create a lifting force when moving in both directions, its profile's shape is chosen symmetrical. Based on all this, Darrieus rotors for lack of rotation torque does not create and therefore are unable to start on their own. Usually, at the moment of starting at low speeds, this rotor has a small, and sometimes even negative, torque (located in the "dead zone") [1-4]. On the other hand, there is a particular problem with hurricane winds when a reliable brake is needed to stop the rotor. If the rotor is not fixed from above, then a sufficiently large load in the form of bending moment may appear.

The parameters, characterizing the turbine's work and affect its work's effectiveness, are as follows:

- rotor blades number;
- the rotor swept area;
- the blades relative thickness;
- rapidity;
- fill factor;
- the rotor's extension;
- blades plant angle.

Rotor blades number N. On the one hand, the increase in the blades number should lead to improved torque uniformity and increase the efficiency of the rotor, but at the same time their mutual influence increases, which reduces the efficiency of each blade [1]. Increasing the blades number can also make it easier to run at lower wind speeds. Usually the Darrieus rotors have 3 or 4 blades.

Measured area of the rotor - the product of the rotor diameter by its height H:

$$A_S = 2RH, \tag{1}$$

where R – the rotor's radius.

It is natural to assume, that with the increase in captured area produced power increases proportionally, although the efficiency can be practically unchanged.

The relative thickness of the blades. To create a large lifting force, profiles with a greater relative thickness $\acute{c}$ from 12 to 25% are used. Usually, thin blades work well at high (more than 5) rapidity, and thick - with small (less than 4).

Rapidity – this is the ratio of the blade rotational speed to the speed U_{∞}ofundisturbed flowing stream:

$$\lambda = \frac{\omega R}{U_{\infty}^{2}}, \quad (2)$$

where ω - angular velocity of rotor rotation.

Generally, the rapidity varies in a wide range: 2 … 8.

Filling factor - this is the ratio of the blades total chord to the rotor's diameter:

$$\sigma = \frac{Nb}{2R}, \quad (3)$$

where b – the blade's chord.

Rotor's elongation – is the ratio of the turbine height H to its diameter:

$$AR = \frac{H}{2R}. \quad (4)$$

With increasing elongation, the rotor's efficiency is slightly increasing.

Blades mounting angle. Since the blades circular speeds are large, the plant angle is zero and rarely exceeds 10 degrees.

Varieties of the Darrieus rotor are rotors:

- H-rotors;
-with blades, curved in a circle;
-with helical blades.

Darrieus and Savonius rotors have the following basic geometrical parameters.

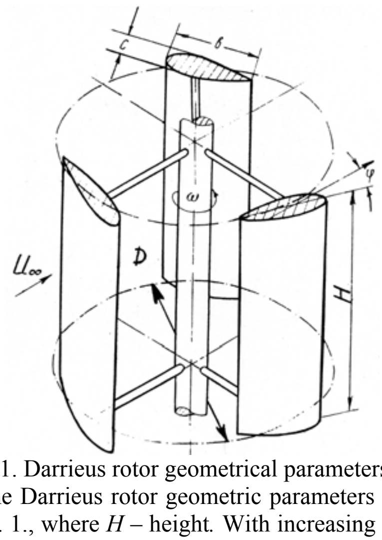

Fig. 1. Darrieus rotor geometrical parameters

Let's consider the Darrieus rotor geometric parameters on the example of a three-bladed rotor in fig. 1., where H – height. With increasing the rotor's height H, it almost linearly increases the useful power on the shaft of the wind turbine; D – diameter. With rotor's diameter increase, almost quadratically increases the useful power on the wind turbin'se shaft; *b* – blade's chord; *c* – blades thickness. Increase in relative thickness σ leads to an increase in the aerodynamic drag of the profile. On the other hand, it provides large angles of attack at which the flow failure begins. Within the relative thickness of 12 to 15%, the maximum lift coefficient c_y can be obtained; φ – blades plant angle. Increasing the angle of the blades up to 5-10 degrees can improve to an improvement in the Darrieus rotor characteristics within the operating speed values.

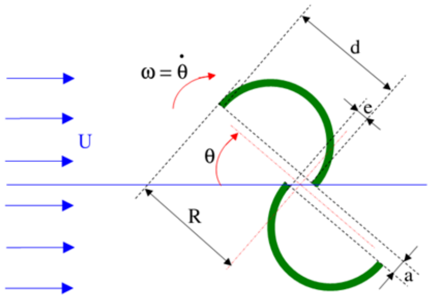

Fig. 2. Savonius rotor geometrical parameters

We present the geometric parameters of the Savonius rotor in fig. 2, where *H* – height. With increasing the rotor height *H* it almost linearly increases the useful power on the shaft of the wind turbine; *D* = *2R* – diameter. With increasing the rotor diameter, the useful power increases almost with a quadratic dependence; *d* – blade chord; *e* – blades overlap. Optimum relative overlap *e/d* in the range from 0 to 0.35; *a* – the gap between the blades. The optimum relative gap *a/d* is in the range from0 to 0.2.

The composition of the combined rotor includes: the mutual arrangement of the main and accelerating rotors, the type of main and accelerated rotors, the number of main and accelerated rotors, the number of blades of main and accelerated rotors; the profile shape of the main rotor blades, the type of material for elements manufacturing.

Savonius rotors can be placed coaxially inside the Darreus rotor. The advantage of such a scheme is that the combined rotor is compact and takes up less constructive height. However, with such configuration, the internal Savonius rotor is in the "aerodynamic shadow" of the external Darrieus rotor, which is undesirable for the start-up and operation of the combined rotor at low wind speeds. In this case, the Savonius rotor also reduces the efficiency of the main rotor.

Savonius rotors can also be located coaxially outside of the Darrieus rotor. Since the combined rotor is orthogonal, in this situation, the negative interaction of the rotors is minimal and each rotor works efficiently.

As the main rotor of the combined rotor VAWT it is expedient to use the Darrieus rotor due to its high wind power utilization factor. Structurally the Darrieus rotors can have straight (H-rotors), screw-shaped and arch-shaped blades. Since the acceleration rotor must be effective at low air velocity, the Savonius rotors are well proven. Forms of cross sections of these rotors can be both parts of the circle arc, and special form (Bach, Benesh, Ugrinsky).

For a combined rotor, it is expedient to use one Darrieus rotor to the geometric parameters optimal for the required power.

Savonius rotor is more efficient with two or three blades, but such rotor, as indicated above, has uneven rotation. Therefore, it is more appropriate to have at least two such rotors with phase shifted blades.

With a reduction in the number of Darrieus rotor blades the total working area of the blades is reduced, which leads to a decrease in the power factor and an increase in uneven rotation. With an increase in the number of blades, the fill factor of the rotor increases, but simultaneously increases the negative interaction of blades. Depending on the length of the chord, there may be optimal to use three or four-bladed Darrieus rotor.

Similar considerations can also be applied when selecting the number of blades of the Savonius rotor. With an increase in the number of blades of the Darya rotor to four, the rotor power factor is significantly reduced, and therefore it is expedient to use two- or three-stage rotors with two or three blades, separated by phase.

Computer-aided design system for VAWTs with combined rotors must consider all described above structural, geometric and performance parameters in order to obtain optimal power generation, and optimal geometric parameters and mass of rotor that will lead to decrease of production costs.

Developed CAD system was used to design the combined rotor for VAWT that can be used in areas with low wind speeds. Structural and geometrical parameters of combined rotor are given in table 1.

The main VAWT technical characteristics are given in table. 2.

Experimental sample of designed rotor is shown in fig.3.

Table 1

Combined rotor main geometrical parameters

Parameter	Value
Main rotor type	Darrieus
Accelerating rotor type	Savonius
Number of main rotors	1
Number of accelerating rotors	1
Number of main rotor blades	3
Number of accelerating rotor blades	3
Main rotor height	2 m
Main rotor diameter	2,4 m
Accelerating rotor height	0,4 m
Accelerating rotor diameter	0,4 m

Table 2

Wind power plant main technical characteristics

Characteristic	Value
Rated power	2 кW
Maximum power	2,2 кW
Generator's maximum output voltage	~60 V
Working wind speed	10-14 m/s
Starting wind speed	4 m/s
Wind speed operating range	4-30 m/s

Fig. 3. Experimental sample of designed VAWT rotor

Conclusions

Developed CAD system allows to design VAWTs with combined rotors optimal for local area wind conditions that allow to get maximum power output. It also allows to perform materials selection in order to reduce rotors overall mass and costs and provide required mechanical strength.

References

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