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NEW PERSPECTIVE VERSION OF BI-DARRIEUS WINDTURBINE

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Abstract

There are a great variety of wind turbine constructions but by their principle of operation they are divided into three main types - sail (Savonius wind power unit), propeller and airfoils (Darrie wind turbine). At present, propeller-type wind-turbines are the most widely spread. They are produced on a commercial level in many countries. Other conditions being equal, the power produced by wind power unit (WPU) is proportional to the area being swept around by a wind wheel. Therefore, Megawatt propeller-type wind turbines have blades with the length of 40 and more meters. Only aircraft works with a highly-qualified personnel and corresponding equipment can produce such long blades of a specific shape. Of high interest have become airfoil wind turbines (Darrie WPU) lately. They are of a simpler construction and have a quite high wind power utilization factor (ξ =0.45). In spite of the fact that this is a good index of WPU efficiency, the workers of al-Farabi Kazakh National University have developed a new version of a wind turbine which allows increasing 1.3-1.6 times the value of this coefficient. This apparatus is named a Bi-Darrie unit. This paper presents the description of a Bi-Darrie unit, the principle of its operation and the possibility of increasing the wind power utilization factor. Also, the results of testing an acting laboratory model in an aerodynamic tunnel and a full-length apparatus are reported. Video films are attached to the paper.

Key words*: wind turbine, the blade, wind energy utilization coefficient*

There are a lot of modifications of wind-driven electric plants the main element of which is a wind turbine which transforms natural power of wind into a constructive mechanical one. Figure 1 presents characteristic curves for some types of wind turbines being used now.

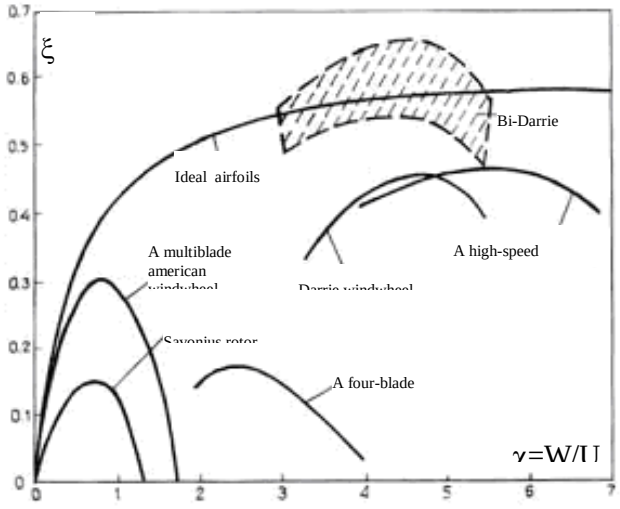


Figure1. Dependencies of wind power utilization factor ξ for different types and constructions of wind turbine on the degree of their specific speed χ.

Propeller-type wind turbines are the most widely spread owing to both the formed traditions and a well-developed technology of production of airplane propellers. Operation of a propeller-type turbine is accompanied by a high level of noise. This is due to the fact that, despite the angle of decalage, a discontinuous flow is formed

– at the wide root part of a blade an aerodynamic trail with a large-scale turbulence develops, at the head (its narrow part) there develops an aerodynamic trail with a high frequency turbulence, possibly of an ultrasonic frequency, i.e. it is noted that bats migrate from the regions with WPU to more silent places. This is one of disadvantages of a propeller-type wind turbine. However, a new type of wind turbines with a vertical axis of rotation of a Darrie system has attracted interest lately [1, 4]. They use airfoils with the lift force of the wing originating on them to develop a torque.

Darrie wind turbine has 2 diametrically opposite blades (sometimes 3 at an equal distance from one another) which are NASA airfoils symmetric with respect to a chord. Darrie apparatus has the following advantages over propeller-type wind turbines:

1) the direction of wind is of no importance owing to vertical-axial rotation of the turbine;

2) the electric generator and other equipment are placed at the earth level, that lightens the construction of a machine of great power, makes easier its maintenance and repair;

3) it has a high wind power utilization factor (ξ=0.45). These units do not yield to propeller-type turbines in their technico-economic indices (Figure 1).

It is shown that at the turbine rotation the maximum angle of attack does not exceed 12^o. Therefore, the working blades are sweaping around continuously (Figure 2), this greatly decreasing the noise produced.

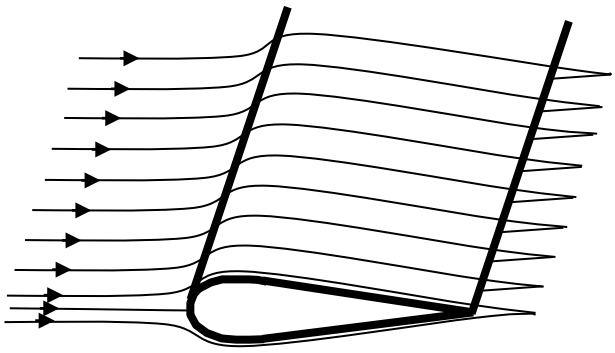


Figure 2. A scheme of a NASA-0021 air foil continuously flown around.

A Darrie turbine has a maximum value of wind power utilization factor of ξ_{max} =0.45 (Figure 1). Despite the fact that it is good index of the turbine operation efficiency, the workers of al-Farabi Kazakh National University have developed a new version of the turbine which allows increasing 1.3-1.6 times the effective value of this coefficient.

Thus, the question concerns the creation of a rotor-type wind power turbine with high specific power compared to all the other known ones. The technical result is an increased extraction of power from the wind flow at one and the same value of the area being swept around by the turbine blades.

The proposed unit consists of two coaxially located shafts with which the working blades are jointed in this or that way (see below). The turbine rotation takes place on account of the action of the lift on working blades which are positioned uniformly along the radius circle r_0 with respect to the vertical axis of rotation. Also, as in the known Darrie turbine, the working blades can be joined with the rotation shaft with the help of a shoulder or by a troposkino method. A distinguishing peculiarity of a Bi-Darrie unit is a constructive use of the principle of independence operation of shafts which are jointed to the turbine and transfer wind power to current generators.

Fundamental constructive schemes of a Bi-Darrie wind turbine are shown in Figures 3-5. The first picture presents a variant with straight working blades (1) of H-rotor. Each of the two coaxially located shafts (4) are jointed with the help of shoulders (2) with its symmetrically located pair of blades (1) which, when rotating, form a moment of forces independently acting on its “own” shaft. In this variant, the both shafts must rotate to

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one side with an equal angular velocity. A special correcting device was developed to support the angle $\alpha=90^{o}$ at the work of a Bi-Darrie unit. In the second picture, the scheme of work of a Bi-Darrie wind unit is the same as in the first case, but the blades are in the form of troposkino. And finally, the third picture presents a construction which allows the shafts to rotate in opposite directions. Stability of the wind turbine operation is achieved by symmetric position of the blades.

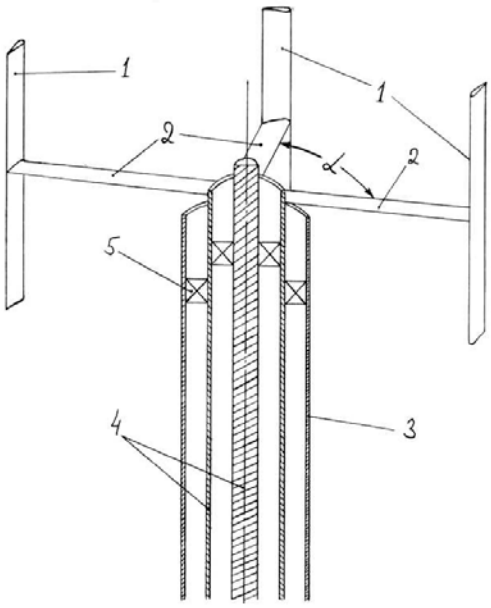


Figure 3. A principle scheme of a Bi-Darrie with straight wings (one-side rotation): 1-blades, 2-shoulders, 3-tower, 4-rotation shafts, 5-bearing, $\alpha=90^{0}$.

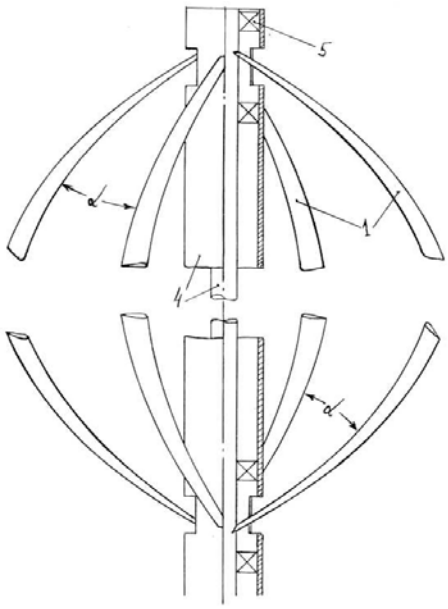


Figure 4. A principle scheme of a Bi-Darrie of a troposkino system (one-side rotation). Denotations are the same as in Figure 3, ($\alpha=90^{0}$).

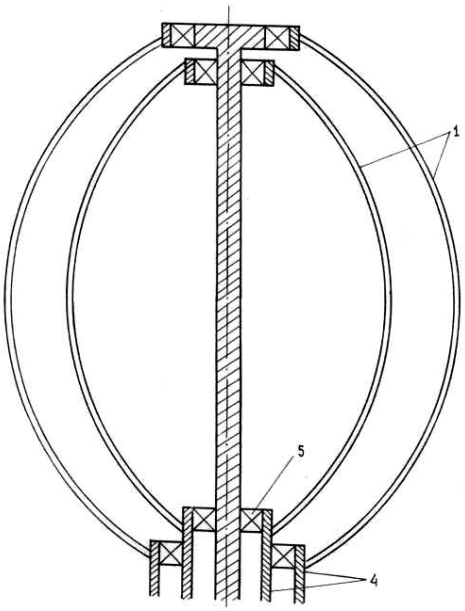


Figure 5. A principle scheme of a Bi-Darrie wind turbine construction with troposkino blades (rotation of shafts in opposite directions). Denotations are the same as in Figure 3.

Operation of a Bi-Darrie wind turbine is similar to that of a usual Darrie but it has a higher value of an effective wind power utilization factor. This is explained by the inequality of the moment of forces acting on the blade which moves along the windward and leeward sides of the air flow.

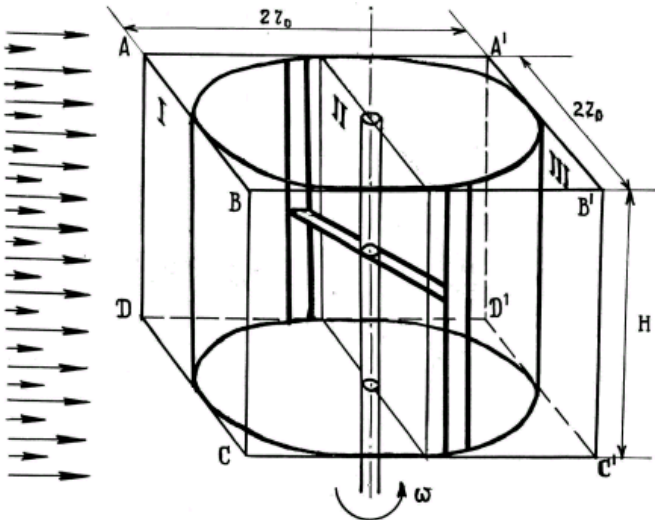


Figure 6. A schematic picture demonstrating extraction of wind power by a Darrie turbine from the windward and leeward sides.

As is known, power N_w which is transferred to the wind wheel of a Darrie unit with straight working blades is proportional to the area being swept around F, kinetic energy of wind $\rho U^3/2$ and this power utilization factor ξ. The value ξ depends on the specific speed of rotor χ=W/U, where W is the linear rotation velocity of the rotor blades. Thus, power extracted from the unit of the area being swept around is expressed by the formula:

$$\overline{N}_w = \xi F \rho \frac{U^3}{2} . \quad (1)$$

Figure 6 schematically shows area F which is the side surface of the cylinder with radius r_0 and height H.

To show the essence of the proposed solution, let us consider a rectangular parallelepiped ABCDA'B'C'D' containing surface F. The upper and lower faces of the parallelepiped go through the end planes of the cylinder and the rest four ones are two by two tangent to its side surface. The parallelepiped is oriented so that two side faces (on the left and right of the cylinder) are perpendicular to the wind flow and the second pair is parallel to it. Let us construct another plane which is perpendicular to the direction of wind and goes through the axis of the cylinder. Thus, we have three reference surfaces (I), (II), (III) the area of each of them is equal to midship section ($S=2r_0H$) of the side surface of cylinder F. As is seen in Figure 1, Darrie unit uses maximum 45% ($\xi_{max}=0,45$) of the wind power and transfers it to the shaft. Then the question is what portion of this power is extracted from the windward side of surface F being swept around (the left end of cylinder in Figure 6) and from the leeward side (the right end of F). Let us see energy flows through reference surfaces (I), (II), (III):

a) density of wind power flow through reference surface (I) is equal to

$$\overline{N}_{wI} = \rho \frac{U^3}{2}; \quad (2)$$

b) after passing the left half of cylindric surface being swept arou`nd and transferring part of its power to the blades of wind turbine, flow density of wind power decreases by value "k" and will go through reference surface (II) with specific power

$$\overline{N}_{wII} = (1-k)\rho \frac{U^3}{2}; \quad (3)$$

c) when crossing the right side surface of cylinder F, the wind will also lose the "k"-th part of its power $\overline{N}_{вII}$ and will go through reference surface (III) which is behind the wind turbine with specific density of energy flow

$$\overline{N}_{wIII} = (1-k)\rho \frac{U^3}{2} - k(1-k)\rho \frac{U^3}{2}. \quad (4)$$

On the other hand, it is known, that the total amount of specific power extracted by a Darrie wind wheel is determined by formula (1). Hence, behind the wind wheel or, which is the same the reference surface (III) density of wind power flow decreases $(1-\xi)$ times:

$$\overline{N}_{вIII} = (1-\xi)\frac{\rho U^3}{2}. \quad (5)$$

Equating (4) to (5), we have $k = 1-\sqrt{1-\xi}$.

If we take $\xi_{max} = 0.45$ we will get that 26% of the total amount wind power is extracted from the windward side and the rest 19% – from the leeward side. This fact makes it possible to extract an appreciably greater amount of wind power from one and the same surface being swept around F, if two equally sized Darrie wind turbines rotating in one direction (there may be constructions with rotation of turbines in opposite directions (Figure 5) are fixed on two aligned shafts jointed with two independent current generators.



Figure 7. An acting laboratory model of a Bi-Darrie turbine.

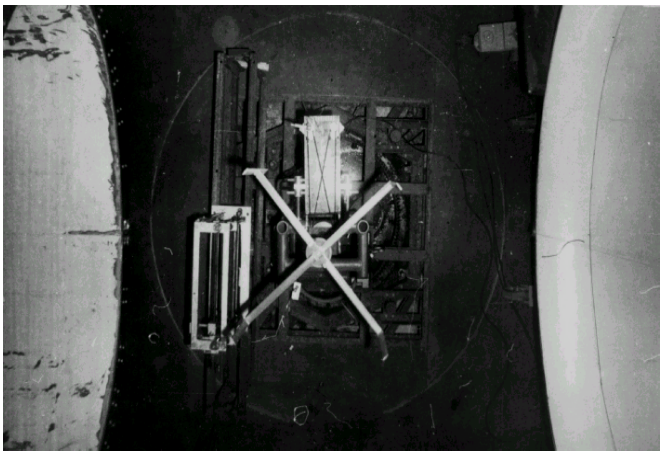


Figure 8. Location of an acting laboratory model of a Bi-Darrie turbine at the working site of an aerodynamic tunnel (top view).

The greatest effect is achieved, when using two-blade wind turbines set up at an angle of 90^{o} with respect to each other. Then, every time, passing around the windward side, the turbine blades will extract 26% of energy each from the continuously flowing undisturbed current and transfer it to their current generators via their own shafts. Naturally, from the leeward side energy is extracted from the twice weakened wind. Unlike in case of a simple Darrie, the specific power will decrease 2k times.

Thus, two Bi-Darrie wind wheels will extract 26% of energy each from the side of fresh air and only 12% each from the leeward side as $k_m(1-2k_m)=0.1248,$ index "m" indicates that κ_m corresponds to ξ_{max}. In the total, each generator transforms 38% of power into electricity that will make up the sum of 76% against 45% in case of a Darrie turbine.

A special experiment was carried out to verify the theoretical results. The research institute "Gidropribor" designed and produced an acting laboratory model of a rotor-type wind turbine which can operate in the mode of Darrie and Bi-Darrie. Four sets of tests were carried out in both modes in the aerodynamical tunnel of this institute. It is stated that the summary coefficient of wind power utilization in Bi-Darrie is 40% higher than that in Darrien [2, 3] (see the shaded region in Figure 1).

The acting model has the following sizes: the total height is 785 mm; the span on which four working blades are located is 800 mm.

The working blades and shoulders were in the form of a symmetric profile NASA-0021. The chords of blades and shoulders are similar and equal to 32 mm, the length of blades is 550 mm, the length of shoulders is 400 mm. Each pair of blades was jointed with interperpendicular shoulders. Thus, the four blades were at an angle of 90^{o} with respect to each other. The picture of a Darrie wind turbine model itself is shown in Figure 7.

Then a full-legth machine with the power of 7 kW at the wind velocity of 7-8 m/s was constructed (Figure 9). A picture of a three-blade Darrie wind unit (10kW) is shown in Figure 11 (Schuchinsk).



Figure 9. A Bi-Darrie (7kW) with rotation of shafts in opposite directions (Uralsk)

But the most perspective is the use of the so-called tuned-input oscillator the stator of which rotates in one direction and the rotor rotates in the opposite direction (Figure 10). In the sources of information known to the authors, such constructive solution and, correspondingly, the increase in wind power utilization factor are not reported.

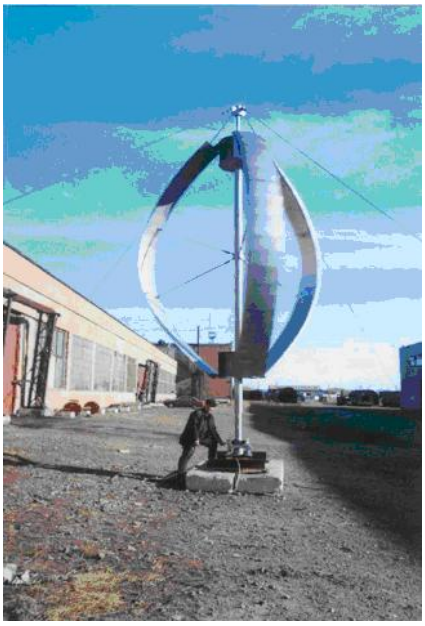


Figure 10. Three-blade Darrie wind-turbine (Shuchinsk)

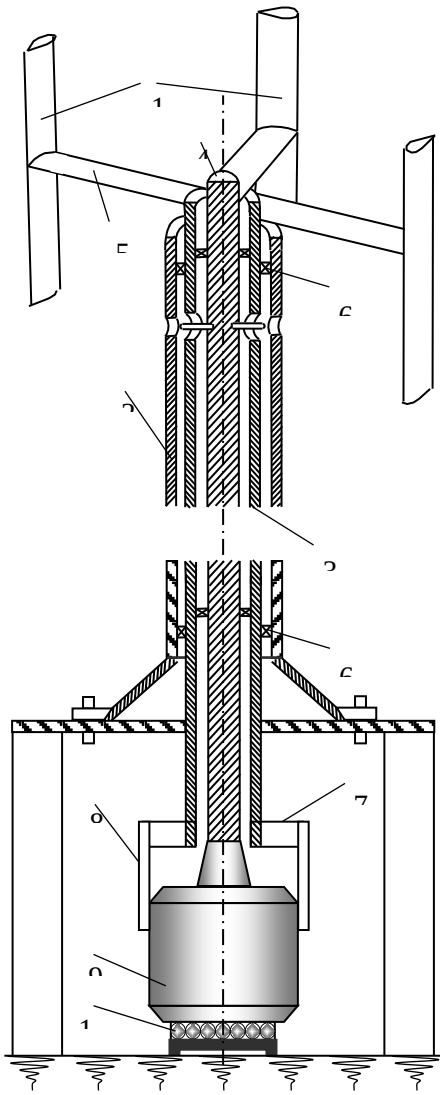


Figure 11.

1-blades, 2 –tower, 3-cylindric shaft, 4-central shaft, 5-shoulder, 6-bearing, 7-satellite gear, 8- a joint with the stator, 9-tuned-input electric oscillator, 10-bearing stand.

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