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EFFECTIVE DARRIEUS *H*-ROTOR WITH OPTIMAL PITCH ANGLES OF BLADES

Purpose. *To create the computational method to determine optimal pitch angles of straight blades for the Darrieus rotor.*

Methodology. *Method to determine optimal pitch angles to increase the efficiency of the Darrieus H-rotor.*

Findings. *Torque and power characteristics of Darriues H-rotor versus tip speed ratio and pitch angles.*

Originality. *Optimal pitch angles for all the work conditions of the rotor were obtained.*

Practical value. *It was shown that the controlling of the blades deflection can provide to create and increase the starting torque and also to enlarge the rotor efficiency.*

Key words: *aerodynamics, controlled pitch angles, Darrieus rotor, wind turbine.*

Introduction. It is well known that the Darrieus rotor is rather efficient among vertical axis wind turbines. But it is not self starting at low wind speed and there is a problem of having excessive runaway in strong wind. This paper conducts with the controlled ways of providing the Darrieus rotor with the self starting, cutting of the runaway and further increase of its efficiency.

Definition of objective. Two principal views of blades control (passive and active) are distinguished. At passive blades control each turbine blade has turn possibility due to crosspiece and, depending on a site of this axis on chord blade, aerodynamic (or inertial) forces will try to turn the blade towards the reduction of angle of attack. If putting any elastic catchers of blade turn on crosspiece a possibility arises to passively regulate an angle of attack of blade depending on turbine rotation speed. The detailed review of such devices is presented in [1], as well as results of tests, models and the natural samples. An active pitch control presumes optimal individual angles of attack for every blade. There is presented vector chart (Fig.1) for determining the local angle α of attack for a blade and incident wind speed U with the wind speed upstream U_∞ and with the rotational one ωR [2].

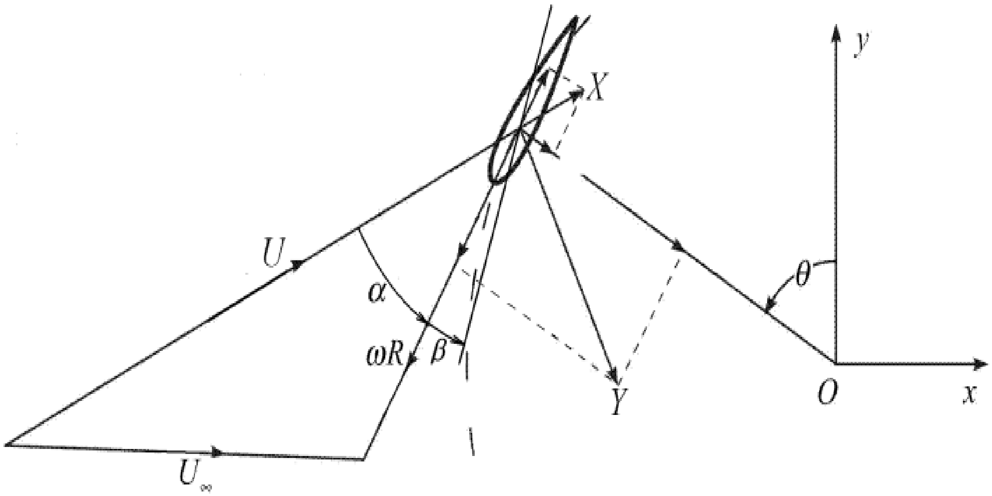

Fig.1. **Vector chart of velocities and forces acting the blade. θ is the azimuth angle of the blade, ω is the angular velocity of the rotor, *R* is the rotor radius, β is the pitch angle**

It may be written from the vector triangle of speed (Fig.1):

$$U^2 = U_\infty^2 + (\omega R)^2 + 2U_\infty \omega R\cos\theta, \qquad \frac{U_\infty}{\sin\alpha} = \frac{U}{\sin\theta}.$$

Introducing dimensionless values for the incident wind speed U and the rotational one ωR respectively:

$$\overline{U} = \frac{U}{U_\infty}, \qquad \lambda = \frac{\omega R}{U_\infty},$$

we have the more compact formulae:

$$\left.\begin{aligned} \overline{U}^2 &= \lambda^2 + 2\lambda\cos\theta + 1, \\ \sin\alpha &= \frac{1}{\overline{U}}\sin\theta. \end{aligned}\right\} \tag{1}$$

Dependence of the local angle α of attack for the non-deflected blade versus the tip speed ratio (TSR) λ is calculated and the azimuth angle θ using the formulae (1) is presented in (Fig.2):

As it is seen from this diagram the angles of attack have not always the optimal values and they ought to be properly reduced.

Torque of the blade versus azimuth angle θ:

$$\mathrm{M}(\theta) = (Y\sin\alpha - X\cos\alpha)R. \tag{2}$$

Taking into account the pitch angle β (Fig.1) the formula (2) is transformed to the form:

$$\mathrm{M}(\theta) = \left[Y\sin(\alpha+\beta) - X\cos(\alpha+\beta)\right]R.$$

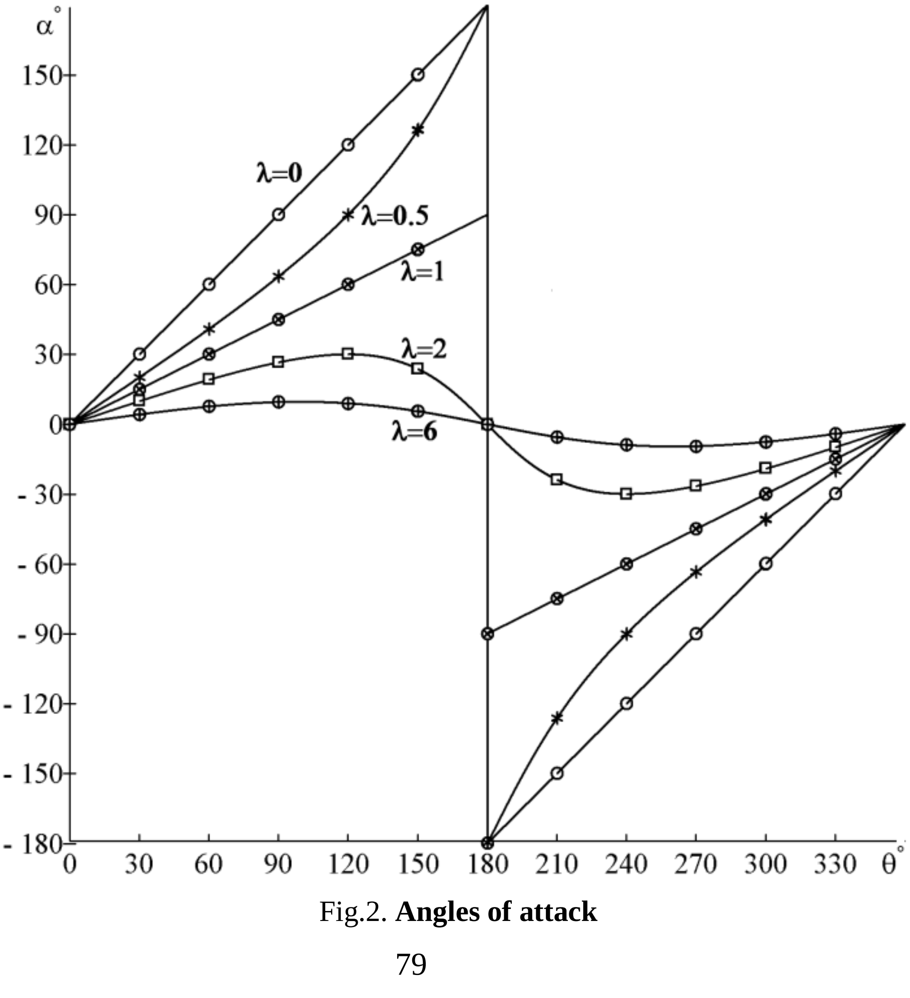

Fig.2. **Angles of attack**

Moving to the dimensionless form we obtain the torque coefficient for the blade:

$$\mathrm{C}_M(\theta)=\left[C_Y\sin(\alpha+\beta)-C_X\cos(\alpha+\beta)\right]\overline{R}\big/\overline{U}^2,$$

where $\overline{R}=R/L_{REF}$ is the dimensionless radius;

L_{REF} is the characteristic dimension (usually it is the rotor diameter *D*).

Thus averaged torque and power coefficients for the rotor are respectively:

$$\left.\begin{aligned}C_T&=\frac{i}{2\pi}\int_0^{2\pi}\mathrm{C}_M(\theta)d\theta,\\ C_P&=C_T\lambda,\end{aligned}\right\}$$

where *i* is the number of blades.

It is necessary to find pitch angles β to enhance the efficiency C_P over the whole range of service wind speed with:

$$\left.\begin{aligned}&\max_\beta \mathrm{C}_P,\\ &0<\lambda<\lambda_{\max},0<\theta<2\pi.\end{aligned}\right\}$$

Trapezium method is used to determine the torque coefficient C_T and the power one C_P.

The dependence of the optimal pitch angles β_{opt} throughout the full range of azimuth angles θ of blades position for various values of TSR λ is presented in (Fig.3) for the NACA 0018 airfoil.

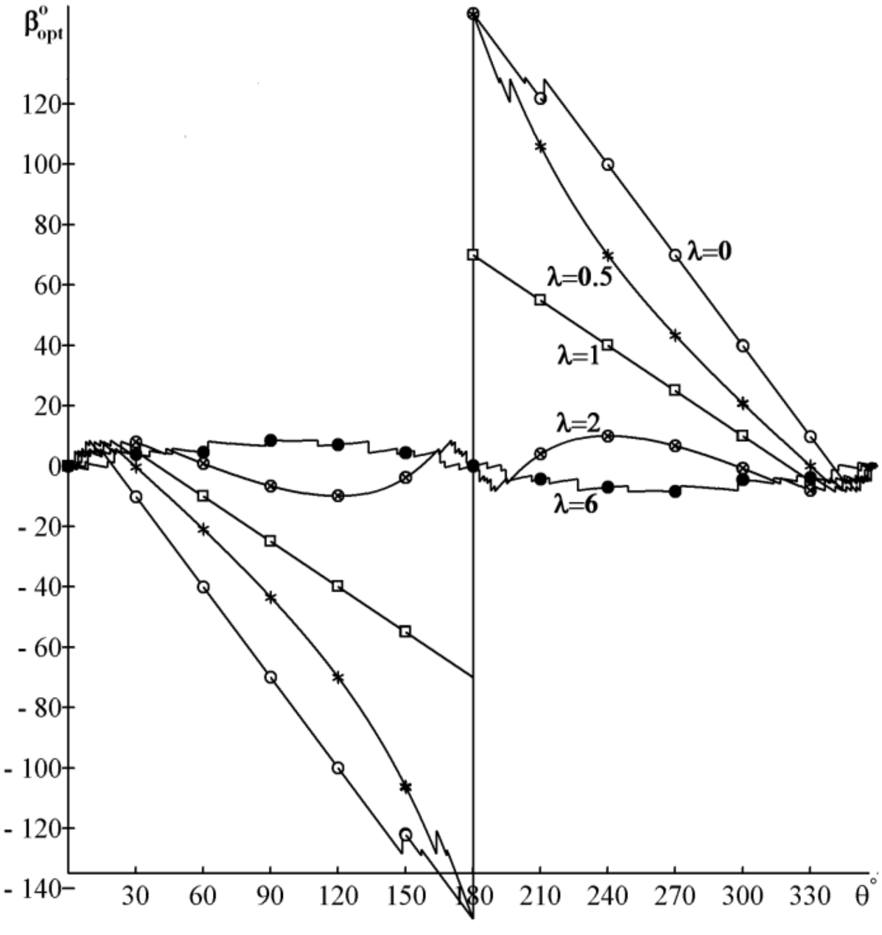

Fig.3. **Optimal pitch angles**

Naturally we have obtained the values of the actual angles of attack $(\alpha+\beta)$ in the range where the airflow is without separation.

At low values of tip speed ratio λ the blade oscillations with the big angular amplitude of β are more effective, and at higher values λ the oscillations with the small angular amplitude of β are efficient. It agrees with the test results in wind tunnels [3-5].

In (Fig.4) and (Fig.5) the curves of torque and power coefficients versus TSR λ for the fixed and the controlled pitch angles β are presented.

It must be noted from the picture (Fig.4) that controlling the pitch angles generates the starting torque which was absent before. The phenomenon of the torque coefficient curve falling at the beginning of motion (Fig.4) may be explained with the impairing of blades work due to very low values of the incident wind speed in the range of azimuth angles from 90 to 270 degrees where the wind speed is greater than the rotational one.

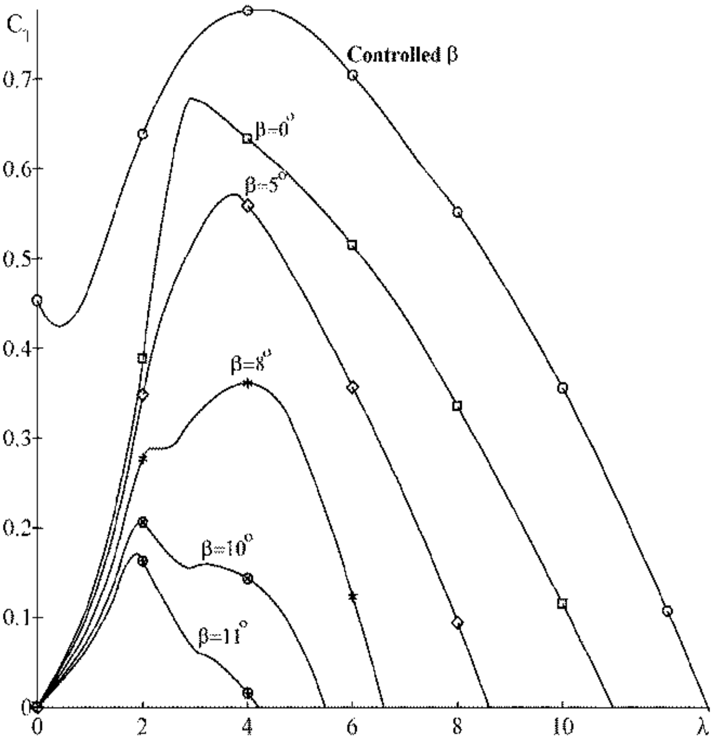

Fig.4. **Torque coefficient**

As it is seen from the curves the best non-controlled pitch angle equals to zero. Thus we may conclude that if we fix the blades it is very important to make it accurately. A case when we control the pitch angles only by TSR has not shown in (Fig.4) and (Fig.5) because of it is practically coincided with the curve for the case of $\beta=0$. Thus we may resume that there is no sense to control pitch angles only by TSR.

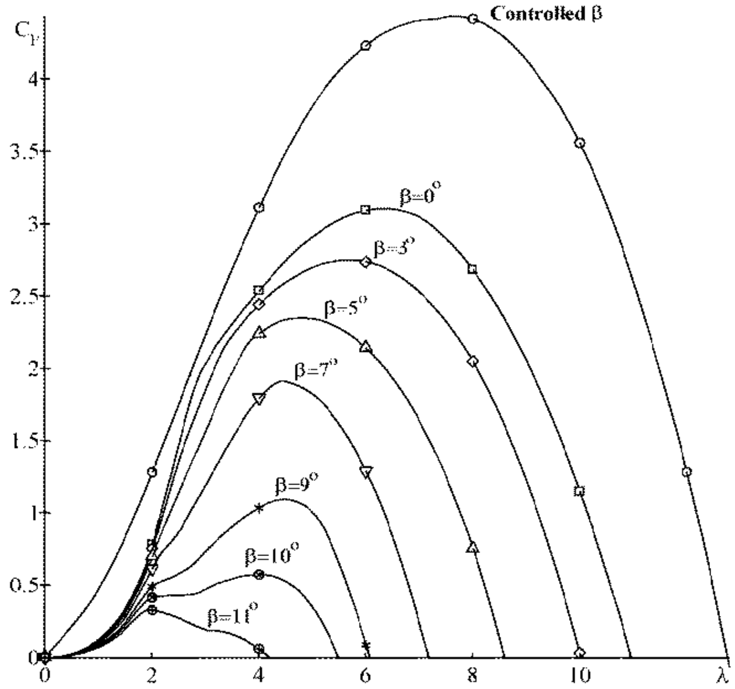

Fig.5. **Power coefficient**

Expressions for calculate the rotor torque and power coefficients via TSR λ and pitch angles β of the blades for the whole range of azimuth location θ of blades have been obtained.

The suitable computer aided algorithm was produced to determine the optimal values of pitch angles β_{opt} throughout the full range of azimuth angles θ of blades position for various values of tip speed ratio λ.

Controlling the blades deflection provides:

– to create and increase the starting torque coefficient C_T (which was absolutely absent earlier) at low wind speed that leads to decreasing of the cut in wind speed;

– to enlarge the rotor efficiency C_P at exploitation range of wind speeds (up to 40% of increasing for the value of TSR $\lambda = 6$);

– to impair the work of rotor with zero rotation with the zero torque coefficient C_T to avoid its damage at excessive strong wind;

– to increase the cut off (autorotational) value of TSR λ.

Thus controlling of pitch angles widens the work range of the rotor TSR. Controlling of the pitch angles may be successfully used in tidal and water wave energies where it takes place alternating to and from the coast stream direction apart from the rotation of the rotor itself. The values of the optimal pitch angles diminish with the increasing of the TSR.

Conclusions. Further investigations must be made taking into account the interference between the rotor blades and damping with the rotation ω of the blades.

It is probable controlling of the pitch angles of blades may essentially diminish:

– the appearance of vortices and turbulence in the downstream airflow, that would improve efficiency of the leeward side blades;

– the aerodynamic load on the rotor shaft.

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ЭФФЕКТИВНЫЙ *H*-РОТОР ДАРЬЕ С ОПТИМАЛЬНЫМИ УГЛАМИ ОТКЛОНЕНИЯ ЛОПАСТЕЙ

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Цель. Создать численный метод для определения оптимальных углов отклонения прямых лопастей Н-ротора Дарье.

Методика. Метод определения оптимальных углов отклонения для увеличения эффективности Н-ротора Дарье.

Результаты. Характеристики крутящего момента и мощности Н-ротора Дарье в зависимости от быстроходности и углов отклонения лопастей.

Научная новизна. Получены оптимальные углы отклонения для всех режимов работы ротора.

Практическая значимость. Было показано, что управление отклонением лопастей может обеспечить создание и увеличение пускового момента и также повысить эффективность работы ротора.

Ключевые слова: *аэродинамика, управление отклонением, ротор Дарье, ветровая турбина.*

ЕФЕКТИВНИЙ *H*-РОТОР ДАР'Є З ОПТИМАЛЬНИМИ КУТАМИ ВІДХИЛЕННЯ ЛОПАСТЕЙ

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Мета. Створити числовий метод для визначення оптимальних кутів відхилення прямих лопастей ротора Дар'є.

Методика. Метод визначення оптимальних кутів відхилення для покращення ефективності *H*-ротора Дар'є.

Результати. Характеристики крутного моменту і потужності *H*-ротора Дар'є в залежності від швидкохідності та кутів відхилення лопастей.

Наукова новизна. Отримано оптимальні кути відхилення для усіх режимів роботи ротора.

Практична значимість. Було показано, що керування відхиленням лопастей може забезпечити створення і збільшення пускового моменту та підвищити ефективність роботи ротора.

Ключові слова: *аеродинаміка, керування відхиленням, ротор Дар'є, вітрова турбіна.*