THE INFLUENCE OF THE INTERACTION OF WIND FLOW AND THE WIND TURBINE BLADE ON THE POWER OUTPUT

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Abstract- The process of the wind turbines work is based on the transformation of the wind motional energy into the mechanical energy of the windwheel rotation. This transformation is carried out in the process of influence of the aerodynamic forces on the wind turbine blades. The main way to calculate the wind turbine power is to compare the energy of the wind flow in front of and behind the wind-driven generator. However, to determine values affecting the power it is necessary to analyze the direct force interaction of the wind flow and the wind turbine blades. Some values, affecting the power, characterize the wind turbine stability too, which is an important factor for the safety of the wind turbine. The article describes the basics of the windwheel aerodynamics and the connection of values affecting the wind turbine stability and power.

Index Terms- Aerodynamic force, Lift force coefficient, Effective incidence, Aerodynamic drag, Wind turbine power.

I. AERODYNAMIC FORCES ANALYSIS

Consider velocity and force vectors generated in an element of the windwheel blade.
Figure 1 shows: the relative velocity vector components, the forces arising from the wind flow and the blade interaction, as well as the angles necessary to calculate the forces [1]:

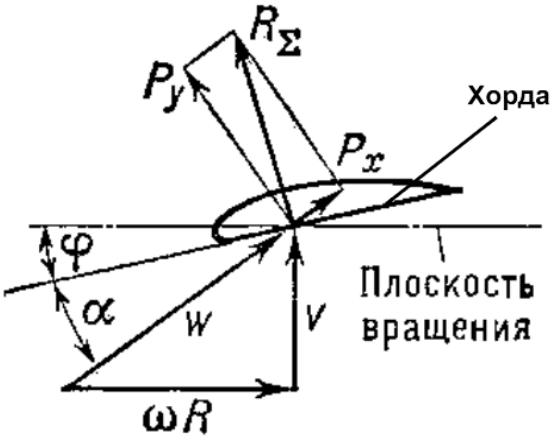


Figure 1 – The cross-sections of the blade

R - the radius of the blade;
V - wind velocity;
ωR - linear speed of the blade;
W - relative speed;
α - effective incidence;
φ - blade pitch angle;
P_x - aerodynamic drag force vector;
P_y - lift force vector;
R_Σ - aerodynamic force.

According to Newton's second law, the value of the composite force R_Σ depends on the projection of forces P_y and P_x on the rotation plane x and on the normal plane y (Figure 2):

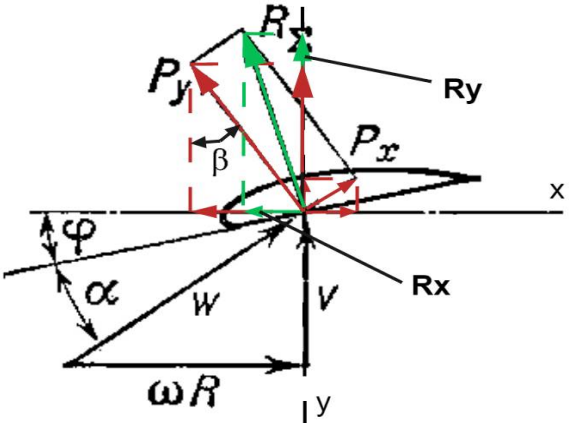


Figure 2 – Projection of forces

$\beta = \alpha + \varphi$ - projection angle.

Here force R_Σ in scalar form:

OX: $dF_x = P_y \sin\beta - P_x \cos\beta$ (1)

OY: $dF_y = P_y \cos\beta + P_x \sin\beta$ (2)

dF_x - axial force;

dF_y - circular strengthening.

Let us see what the relationship between aerodynamic force and the basic values characterizing a moving body [2].
The aerodynamic force is the resultant of the frictional force τ and the pressure force of the particulates p of the environment (the wind flow), distributed on the body surface Σ (blade element):

$$P_x = -\int_\Sigma \left(p\cos(p,x) + \tau\cos(\tau,x) \right) d\Sigma \quad (3)$$

$$P_y = \int_\Sigma \left(p\cos(p,y) + \tau\cos(\tau,y) \right) d\Sigma \quad (4)$$

Transform integrals into nondimensional form. Express $p - p_\infty$ and τ in terms of tension coefficients $\overline{p}$ and $\overline{\tau}$ according to the known formulas [3]:

$$p - p_\infty = \bar{p}\frac{p_\infty W^2}{2}, \tau = \bar{\tau}\frac{p_\infty W^2}{2} \qquad (5)$$

To transform $d\Sigma$ into nondimensional form it is necessary to divide $d\Sigma$ by the blade element surface area S equal to the length of the element dr multiplied by the width b.

Eventually the formula for the aerodynamic force becomes:

$$P_x = \frac{\rho W^2}{2} \cdot bdr \cdot \int_\Sigma \left(\bar{p}\cos(p,x) + \bar{\tau}\cos(\tau,x)\right)\frac{d\Sigma}{b \cdot dr} \qquad (6)$$

$$P_y = \frac{\rho W^2}{2} \cdot bdr \cdot \int_\Sigma \left(\bar{p}\cos(p,y) + \bar{\tau}\cos(\tau,y)\right)\frac{d\Sigma}{b \cdot dr} \qquad (7)$$

The integrals in these formulas represent a nondimensional value and characterize drag and lift force coefficients.

Let us call integrals c_x and c_y. Add negative sign in the formula of the drag force to the c_x coefficient, which will allow convenience in the further calculations.

Replace the lift force P_y and the aerodynamic drag P_x in the formulas (1) and (2):

$$dF_x = \frac{\rho W^2}{2} bdr \cdot \left(c_y \sin\beta - c_x \cos\beta\right) \qquad (8)$$

$$dF_y = \frac{\rho W^2}{2} bdr \cdot \left(c_x \sin\beta + c_y \cos\beta\right) \qquad (9)$$

ρ - density of the air 1.225 kg/m³.

To get total axial force and circular strengthening of the whole windwheel it is necessary to integrate the equations (8) and (9) [4]:

$$F_x = \int_{r_0}^{R}\left(\frac{dF_x}{dr}\right) \cdot dr \qquad (10)$$

$$F_y = \int_{r_0}^{R}\left(\frac{dF_y}{dr}\right) \cdot dr \qquad (11)$$

Where:

r_0 - the radius of dwell track of the windwheel that is not involved in the creation of these forces;

R - the radius of the windwheel.

The moment about the axis of the windwheel of the aerodynamic forces affecting the blade element is equal to:

$$dM = dF_x r \qquad (12)$$

To get total angular momentum of the whole windwheel it is necessary to integrate the equation (12):

$$M = \int_{r_0}^{R}\left(\frac{dM}{dr}\right) \cdot dr \qquad (13)$$

II. THE DEPENDENCE OF THE LIFT FORCE AND DRAG COEFFICIENTS ON THE INCIDENCE

The lift force and drag coefficients are important factors in determining the methods of the wind turbines control.

The relationship between c_y and α at low incidence is expressed as a linear equation [5]:

$$c_y = a_0 \cdot \left(\alpha - \alpha_{пик}\right) \qquad (14)$$

Where:

a_0 - slope of the line c_y $\left(a_0 = \frac{dc_y}{d\alpha}\right)$;

$\alpha_{пик}$ - angle at which the lift force is equal to zero.

Drag coefficient c_x depends on the incidence angle and characteristics of the dynamical similitude.

Figure 3 shows the dependency graph of the drag and lift force coefficient on the incidence.

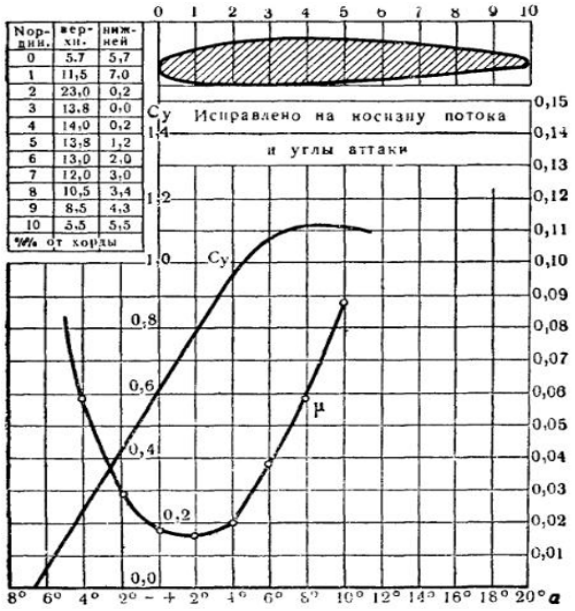


Figure 3 – The dependency of the drag and lift force coefficient on the incidence

III. THE FORMULA TO CALCULATE THE POWER BY MEANS OF AERODYNAMIC MOMENT

In the previous sections force interaction of the wind flow and the blade of the wind turbine was determined.

To calculate the power N by the means of aerodynamic moment it is necessary to multiply total angular momentum M (13) by the angular velocity of the blade:

$$N = n \cdot \frac{\rho W^2}{2} \cdot \omega R \cdot \left(c_y \sin\beta - c_x \cos\beta\right) \cdot \int_{r_0}^{R} b(r) \cdot dr \qquad (15)$$

n - the number of blades.

Relative speed W can be calculated according to the following formula:

$$W = \sqrt{V^2 + (\omega R)^2} \quad (16)$$

The function describing the shape of the blade:

$$b(r) = 0.15 \cdot \sqrt{4 - r} \quad (17)$$

1 Calculated predictions of power

Calculated predictions are implemented for the stationary case at constant values of the wind velocity V =10 mps, angle of incidence φ =5° and high speed $Z = \frac{\omega R}{V}$ = 3, to compare the influence of the lift force and drag coefficients on power. The data of the lift force and drag coefficients were taken on the basis of experimental data of the study guide for higher agricultural institutions by Ye. M. Fateev "Wind engines and wind turbines" [5]. The results differ from power calculations of the real power plants, as this calculation is designed for the stationary case (Table 1).

Blade characteristics: $r_0 = 0.2$, $R = 4$.

The example of calculation:

According to the formula of high speed:

$$\omega R = 10 \cdot 3 = 30 \quad (18)$$

Power calculation:

$$N = 3 \times \frac{1225 \times (10^2 + 30^2)}{2} \times 30 \times (0.654 \times \sin 5°30' - 0.016 \times \cos 5°30') \times$$
$$\times 2 \times \int_{0.2}^{4} 0.15\sqrt{4 - r}\,dr \approx 3609.97 \quad (19)$$

Table 1 – The results of power calculations

C_y	C_x	α	V, mps	Z	n	R, m	N, W
0.654	0.016	0°30′	10	3	3	4	3609.97
0.696	0.016	0°54′					4152.35
0.788	0.017	2°06′					6467.40
0.942	0.025	3°55′					9359.10
1.066	0.047	6°08′					12936.52

CONCLUSION

On the grounds of the conducted study there was analyzed the method to convert the motional energy of the wind flow into the mechanical energy of the windwheel. The lift force and drag coefficients, characterizing the interaction of the wind flow and the wind turbine blades, were set.

Based on the analysis of the windwheel aerodynamics the formula for power calculation was obtained. This formula is designed for the stationary case.

Calculation results show that a slight change of the incidence angle influences the lift force and drag coefficients, which in turn have quite a strong influence on the power change of the wind turbine.

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