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General Equation of the Moment of a Concave Wing

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Abstract: *The article defines the general basic moment equation for a concave winged rotor with a vertical axis of rotation. The changing equation in the integral form is found depending on its position in the intervals.*

Keywords: *Rotor, concave wing, radius of curvature, angle of rotation, wind pressure, integral, operating intervals, active wing, semi-active wing.*

The use of concave fins in the vertical axis rotors of wind turbines increases their efficiency. The intake of wind pressure with a concave shoulder can increase the forehead resistance (lobovaya soprativleniya) up to 1.43. In addition, if the width of the working surface of the wing is projected at a distance d from the rotor axis, the interval of the working period of the wings increases. In this article, we present the general equation of the driving moment of this structure.

A brief description of the design is as follows: a vertically mounted rotor blade operates in the range of 0 to 1800 degrees, and in this range, the working blades are located in five different positions relative to the wind direction vector. In its central part, there is an open surface that passes the current. The wing surface is mounted on a vertical truss consisting of horizontal beams, and its width is located between the distance d from the central axis and the distance ℓ, which does not block the wind flow even in the width of the distance from the shaft axis to the distance d (Figures 1-2).

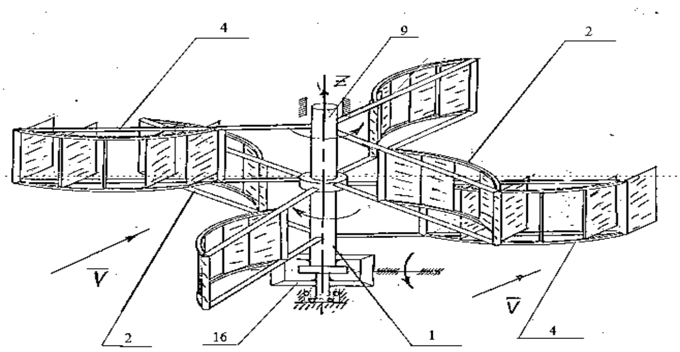

Figure 1: General view of the rotor. Application for the invention: LAP 20200106/1

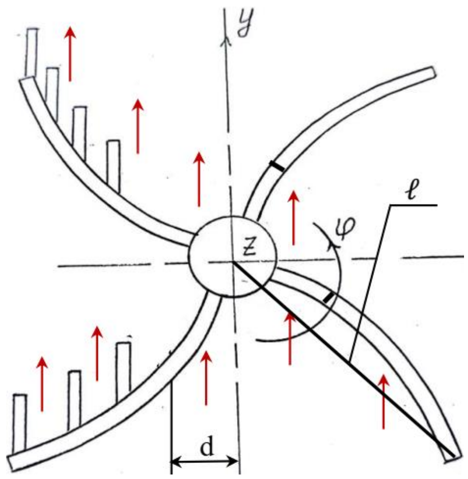

Figure 2: Horizontal view of the rotor and its blades

Suppose point S is acting on wind pressure. When this point of the wing rotates around the center O, its linear velocity value is the radius vector |OS| = r and its angular speed is proportional to ω, and its direction is perpendicular to the radius vector (Fig. 3):

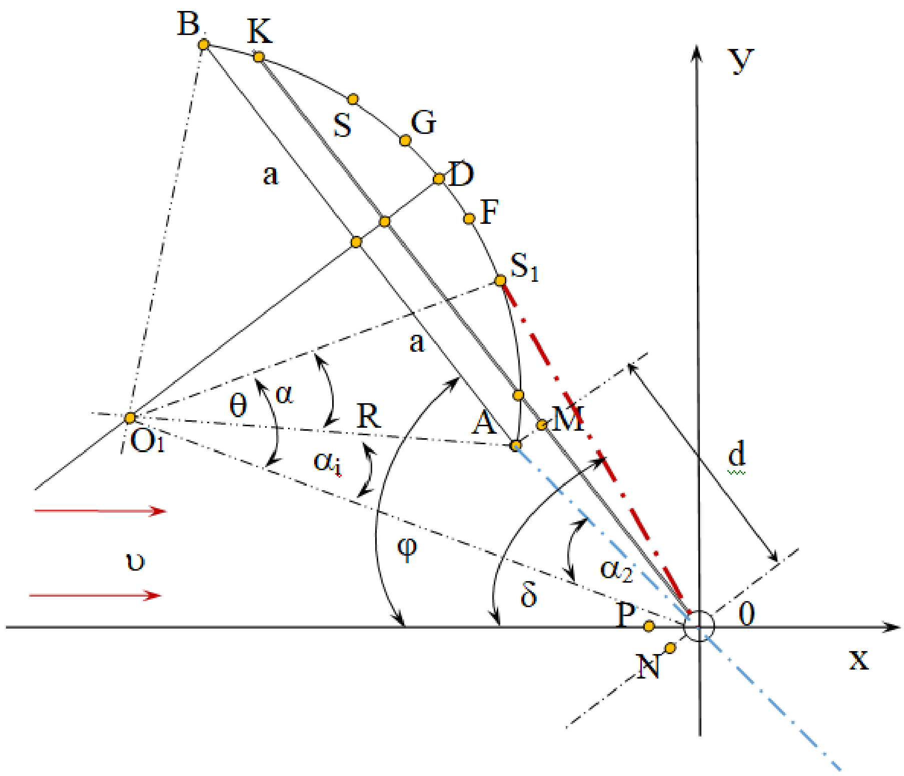

Figure 3. General of the driving torque equation to determine the appearance

$$\upsilon_S = \omega \cdot r_S \qquad (1)$$

Then the relative speed is the difference between the wind speed and the linear speed of the point

$V = \upsilon \cdot \sin\delta - \omega \cdot r$ - the relative speed of the wing tip speed to the wind speed,

From the above and the known expressions for wind pressure, we derive the elementary torque equation:

$$dM = \frac{1}{2} \cdot r \cdot (\upsilon \cdot \sin\delta - \omega \cdot r)^2 \cdot \rho \cdot h \cdot dr$$

Here, $dQ = \frac{1}{2} \cdot (\upsilon \cdot \sin\delta - \omega \cdot r)^2 \cdot \rho \cdot h \cdot dr$ elemental power,

$p = \frac{1}{2} \cdot V^2 \cdot \rho$ - wind pressure on the wing surface

$ds = h \cdot dr$ – elementary surface of the wing

In equation (2) δ is the angle formed by the radius vector with the 0X coordinate axis (this is the quantity that determines the angle between the linear velocity vectors of the point S of the wind vector), υ-wind speed, ρ-air density, h - the height of the rotor wing (the wing diagram is depicted in a horizontal projection it is not shown in the figure).

Then, the final equation looks like:

$$M = \frac{1}{2} \cdot c \cdot \rho \cdot h \cdot [\int (\upsilon \cdot \sin\delta - \omega \cdot r)^2 \, r \cdot dr \qquad (3)$$

and (3) we write in the form Here c is the drag coefficient of the front of the wing, it is the Reynolds number for concave surfaces, ρ is the air density, h is the height of the wing, δ is the

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angle formed by the *Ox* axis of the radius vector transferred to an arbitrary point of the wing (Fig. 2).

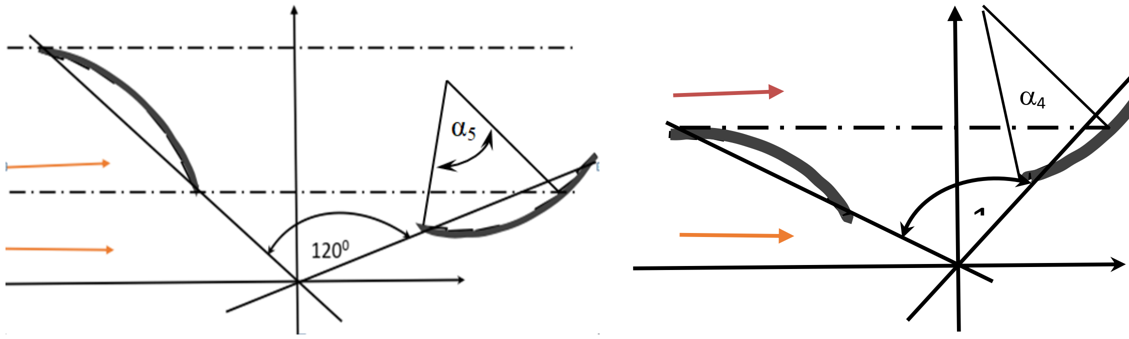

Figure 4. Partially to show active wings moving behind active wings.

In the schematic view of the wing structure presented in Figure 3, the arcs AF and GB are considered working surfaces, and the arc GF consists of an open part that passes the wind flow, taking into account the characteristic spans of the wing presented in table 1 (Figure 4)

Table 1. Defined intervals of cases

Situations	*From*	*To*	*Working wings*
1	*0*	$arc\ ctg\,\frac{1}{\sqrt{3}}\cdot\left(\frac{2}{k}+1\right)$	*1A, 2A*
2	$arc\ ctg\,\frac{1}{\sqrt{3}}\cdot\left(\frac{2}{k}+1\right)$	$\pi/6$	*1A, 2A*α_5
3	$\pi/6$	$arc\ sin(k\cdot sin\delta)$	*1A, 2A*α_4
4	$arc\ sin(k\cdot sin\delta)$	$\pi/3$	*1A, 2A*
5	$\pi/3$	$2\pi/3$	*1A*

In the table, the indicated symbols are 1A -1 active wing, *2A*α_5 – the driving moments of the 2nd active wing blocked from the point α_5 of the 2nd active wing arc is blocked, *2A*α_4 is blocked from the point of blocking the α_4 part of the 2nd active wing arc.

We express equation (5) as follows:

For active wing:

$$M_1=\frac{1}{2}\cdot c\cdot\rho\cdot h\cdot\left[\int_{\alpha_A}^{\alpha_F}(\upsilon\cdot\sin\delta-\omega\cdot r)^2\, r\cdot dr+k\cdot\int_{\alpha_G}^{\alpha_B}(\upsilon\cdot\sin\delta-\omega\cdot r)^2\, r\cdot dr\right] \quad (4)$$

Here, the AF range of the wing works when the twist angle k is up to $\varphi\le arc\ ctg\,\frac{1}{\sqrt{3}}\cdot\left(\frac{2}{k}+1\right)$, that is, $k=0$

For a partially active wing intercepted from point A of the wing:

$$M_{2A}=\frac{1}{2}\cdot c\cdot\rho\cdot h\cdot\left[k1\cdot\int_{\alpha_A}^{\alpha_F}(\upsilon\cdot\sin\delta_1-\omega\cdot r)^2\, r\cdot dr+ k2\cdot\int_{\alpha_G}^{\alpha_B}(\upsilon\cdot\sin\delta_1-\omega\cdot r)^2\, r\cdot dr+k3\cdot\int_{\alpha_5}^{\alpha_B}(\upsilon\cdot\sin\delta_1-\omega\cdot r)^2\, r\cdot dr\right] \quad (5)$$

Here, $\alpha\le\frac{\pi}{4}$ да $k1=0$; $\frac{\pi}{4}\le\alpha\le\frac{\pi}{4}+\frac{\pi}{20}$ да $k1=0$, $k2=0$, $k3=0$;

$\frac{\pi}{4}+\frac{\pi}{20} \leq \alpha \leq \frac{\pi}{2}$ да k1=0, k2=0

For a partially active wing intercepted by the B-point of the wing:

$$M_{2A}=\frac{1}{2}\cdot c\cdot \rho\cdot h\cdot\left[k4\cdot \int_{\alpha_A}^{\alpha_F}(\upsilon\cdot \sin\delta_1-\omega\cdot r)^2\cdot r\cdot dr\right.$$
$$+k5\cdot \int_{\alpha_G}^{\alpha_B}(\upsilon\cdot \sin\delta_1-\omega\cdot r)^2\cdot r\cdot dr+k6\cdot \int_{\alpha_4}^{\alpha_F}(\upsilon\cdot \sin\delta_1-\omega\cdot r)^2\cdot r\cdot dr$$
$$+k7\cdot \int_{\alpha_4}^{\alpha_B}(\upsilon\cdot \sin\delta_1-\omega\cdot r)^2\cdot r\cdot dr \qquad (6)$$

Here, $\alpha \leq \frac{\pi}{4}$ да k4=0; k5=0, k7=0; $\frac{\pi}{4} \leq \alpha \leq \frac{\pi}{4}+\frac{\pi}{20}$ да k5=0, k6=0, k7=0; $\frac{\pi}{4}+\frac{\pi}{20} \leq \alpha \leq \frac{\pi}{2}$ да k5=0, k6=0. $\delta_1=\delta+\frac{2\pi}{3}$

Here φ is the radius of the wing between ℓ = NB and *OX* axis. It is taken as $\varphi_2=\varphi+120$ for the second wing, that is, equations 5 and 6.

Here OM=d is an open surface, the radius of the wing is NB=ℓ, the coefficient of openness $k=\frac{d}{l}$ is known.

In order to obtain the necessary results from equations (4), (5), (6), the equation of the wing arc and the radius vector, the expression of the angle δ formed by the radius vector r with the *OX* axis, the characteristic points A, F, G, B for the curvature of the wing (integral limits) it is necessary to determine expressions of angular coordinates of α.

Based on Figure 3, we present the expressions of auxiliary values:

$R = |O_1A| = |O_1B| = |O_1D|$ - radius of curvature of the wing

$|AB|= 2 R \sin\alpha = 2 a$ - watar length

$\ell = |OM| + |AB| = d + 2a$ - wing radius

$k = d / \ell$ $d = k * \ell$ - the opening ratio of the wing

$b= |DE| = R - R\cos\alpha_1$ - segment height (7)

$O_1C = (R \sin\alpha) / \alpha_1$, - The distance from the center of a circle to the geometric center of its segment.

$|CD| = R - |O_1C| = R \cdot [1 - (\sin\alpha_1/ \alpha_1)]$

$|EC| = h - |CD| = R(1-\cos\alpha_1) - R[1-(\sin\alpha_1/\alpha_1)] = R[(\sin\alpha_1/\alpha_1) - \cos\alpha_1)]$

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