PRACTICAL EQUATION OF TORQUE FOR A CONCAVE WING ROTOR DRIVE

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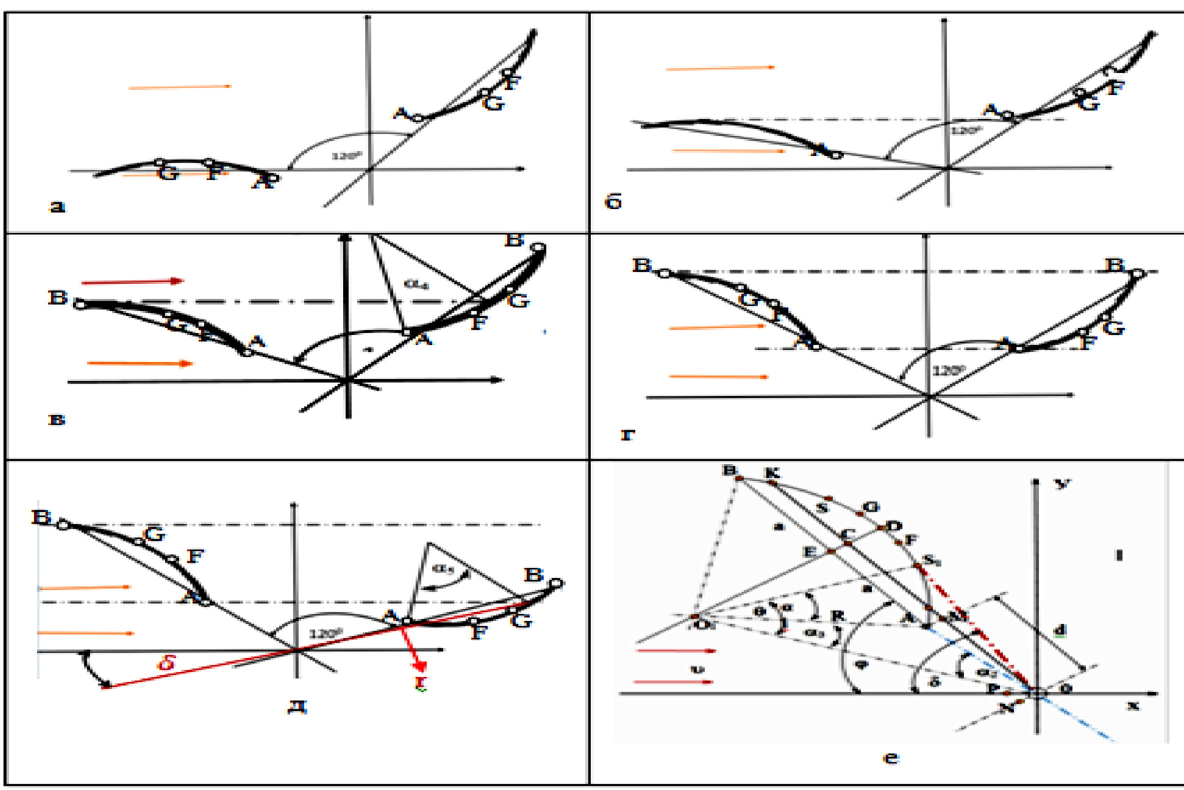
Abstract
The article presents the equations of the rotor of a wind turbine with a concave wing in such a format that it can be used in practice. It is adapted to obtain results using computer programs.

Keywords: Speed vector, rotor, wings, wind turbine, driving moment, working position, working period wings.

INTRODUCTION

In our previous articles, the basic information for deriving the real equation of the rotor torque was given. Based on them, we will determine the practical equation of the moment generated by the vertical rotor.

Based on the 1st figures, we explained the following 1st table.



1- Fig. To show the rotation of rotornig blades in the period from 00 to 1200.

The conclusion from these figures is that a change in the 1st wing turning angle φ changes the working part of the 2nd wing surface:

In case 1 (Fig. 1(a,b)), the AF part of wing 1 works.The GB part, which passes the flow due to the curvature of the wing, remains a passive part of the wing (Fig. 1(b)).

In case 2 (Fig. 1(в,г)), the entire AB surface of the wing works, while the entire AB part of the 1st wing works, the 2nd wing curvature angle starts from α40 to 900, i.e., the surface up to point B works.

In case 3 (Fig. 1(в,г)), if the entire AB part of the 1st wing works, the surface of the 2nd wing up to α5 works.

The entry and exit limits for these states are tabulated, showing whether the lower (from point A) or upper (from point B) section of the wings is in operating position relative to the active and mid-open section of the wings in these states.

Table 1. Defined intervals of cases

Situations	From φ	To φ	Working wings
1	0	$\text{arc ctg}\,\frac{1}{\sqrt{3}}\cdot\left(\frac{2}{k}+1\right)$	1A, 2A
2	$\text{arc ctg}\,\frac{1}{\sqrt{3}}\cdot\left(\frac{2}{k}+1\right)$	$\pi/6$	1A, $2AB\alpha_4$
3	$\pi/6$	$\text{arc ctg}\left[\frac{2}{\sqrt{3}}\cdot\left(\frac{d}{d+2a}-\frac{1}{2}\right)\right]$	1A, $1AA\alpha_5$
4	$\text{arc ctg}\left[\frac{2}{\sqrt{3}}\cdot\left(\frac{d}{d+2a}-\frac{1}{2}\right)\right]$	$\pi/3$	1A, 2A
5	$\pi/3$	π	1A

Note: In the table, the listed characters are:

1A -1 – active wing torque; 2A – 2nd active wing;

2ABα4 – the 2nd partial active wing moment blocking the part of the 2nd wing spread to the angle α4 from the point B of the 1st wing (Fig. 1(в));

2AAα5 is the moment of the 2nd partially active wing, which works only from the point A of the 1st wing and the part of the 2nd wing spread to the angle α5 (Fig. 1(г)).

According to the working spans of the wings, we expressed the torque equation as follows:

For active wing:

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

Here, the AF part of the wing does not work in the range (case 1) when the twist angle is 0≤ φ≤ arc ctg 1/√3 .(2/k+1), that is, k=0.

For a partially active wing intercepted from point B of the wing (Figure 1(в)):

$$0\le\varphi\le arc\ ctg\,\frac{1}{\sqrt{3}}\cdot\left(\frac{2}{k}+1\right)$$

$$M_{2B\alpha4}=\frac{1}{2}\cdot c\cdot\rho\cdot h\cdot[k4\cdot\int_{\alpha_A}^{\alpha_F}(\upsilon\cdot\sin\delta_1-\omega\cdot r)^2\cdot r\cdot dr+k5\cdot\int_{\alpha_G}^{\alpha_B}(\upsilon\cdot\sin\delta_1-\omega\cdot r)^2\cdot r\cdot dr+k6\cdot\int_{\alpha_4}^{\alpha_F}(\upsilon\cdot\sin\delta_1-\omega\cdot r)^2\cdot r\cdot dr+k7\cdot\int_{\alpha_4}^{\alpha_B}(\upsilon\cdot\sin\delta_1-\omega\cdot r)^2\cdot r\cdot dr \quad (2)$$

Here, at $0\leq\alpha\leq\frac{\pi}{2}$, k4=1; k5=1, k6=0, k7=0.

$$arc\ ctg\ \frac{1}{\sqrt{3}}\cdot\left(\frac{2}{k}+1\right)\leq\varphi\leq\pi/6$$

$$M_{2B\alpha4}=\frac{1}{2}\cdot c\cdot\rho\cdot h\cdot[k4\cdot\int_{\alpha_A}^{\alpha_F}(\upsilon\cdot\sin\delta_1-\omega\cdot r)^2\cdot r\cdot dr+k5\cdot\int_{\alpha_G}^{\alpha_B}(\upsilon\cdot\sin\delta_1-\omega\cdot r)^2\cdot r\cdot dr+k6\cdot\int_{\alpha_4}^{\alpha_F}(\upsilon\cdot\sin\delta_1-\omega\cdot r)^2\cdot r\cdot dr+k7\cdot\int_{\alpha_4}^{\alpha_B}(\upsilon\cdot\sin\delta_1-\omega\cdot r)^2\cdot r\cdot dr \quad (3)$$

$0\leq\alpha\leq\frac{9\cdot\pi}{40}$, k4=0, k5=1, k6=1, k7=0; $\frac{9\cdot\pi}{40}\leq\alpha\leq\frac{11\cdot\pi}{40}$ k4=0, k5=1, k6=0, k7=0; $\frac{11\cdot\pi}{40}\leq\alpha\leq\frac{\pi}{2}$ at k5=0, k5=0, k6=0, k7=1. $\delta_1=\delta+\pi$

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

$$M_{2A\alpha5}=\frac{1}{2}\cdot c\cdot\rho\cdot h\cdot[k1\cdot\int_{\alpha_A}^{\alpha_F}(\upsilon\cdot\sin\delta_1-\omega\cdot r)^2\cdot r\cdot dr+k2\cdot\int_{\alpha_G}^{\alpha_B}(\upsilon\cdot\sin\delta_1-\omega\cdot r)^2\cdot r\cdot dr+k3\cdot\int_{\alpha_A}^{\alpha_5}(\upsilon\cdot\sin\delta_1-\omega\cdot r)^2\cdot r\cdot dr+k4\cdot\int_{\alpha_G}^{\alpha_5}(\upsilon\cdot\sin\delta_1-\omega\cdot r)^2\cdot r\cdot dr] \quad (4)$$

Here, at $\alpha\leq\frac{9\cdot\pi}{40}$, k1=0, k2=0, k3=1, k4=0; $\frac{9\cdot\pi}{40}\leq\alpha\leq\frac{11\cdot\pi}{40}$ k1=1, k2=0, k3=0, k4=0;

At $\frac{11\cdot\pi}{40}\leq\alpha\leq\frac{\pi}{2}$, k1=0, k2=0, k3=0, k4=1

Here φ is the wing radius is 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.

If we bring the angle δ according to our defined equation,

$$\delta=2\cdot arctg\sqrt{\frac{-A\pm\sqrt{A^2-\left(\frac{r^2+C}{r}\right)^2+B^2}}{\left(B+\frac{r^2+C}{r}\right)}} \quad (5)$$

it depends on the coefficients A and B,

$$A=-2\cdot|0_10|\cdot\sin(\varphi-\beta); \qquad B=-2\cdot|0_10|\cdot\cos(\varphi-\beta); \qquad C=|0_10|^2-\frac{\ell^2\cdot(1-k)^2}{2} \quad (6)$$

Then for wing 2, the value of its angle δ_1 is sin(φ-β+120^0);cos(φ-β+120^0) is calculated using expressions.

Case 2. In this case, wing 1 partially occludes wing 2, and this continues until it completely occludes it (Figure 1(г)). From the figure,

$$\ell\cdot sin\varphi=r\cdot\sin(180^0-\delta_1) \quad (7)$$

we find that: $sin\delta_1=\frac{\ell}{r}\cdot sin\varphi$, Also $cos\delta_1=\sqrt{1-sin^2\delta_1}$ (8)

Here, ℓ- wing radius, R-wing radius of curvature, h-wing height, k-wing opening coefficient and the following expressions are known:

$$\alpha_3=arc\ \cos\frac{2\cdot d^2-R^2}{|O_1O|^2-2\cdot R|O_1O|} \quad (a) \qquad C=|0_10|^2-\frac{\ell^2\cdot(1-k)^2}{2}; \quad (d)$$

$$A=-2\cdot|0_10|\cdot\sin(\varphi+120^0-\beta); \quad (b) \qquad r=\sqrt{R^2+|OO_1|^2-2\cdot R\cdot|OO_1|\cdot\cos(\alpha_3+\alpha_i)} \quad (e) \qquad (9)$$

$$B=-2\cdot|0_10|\cdot\cos(\varphi+120^0-\beta); \quad (c) \qquad r\cdot sin\delta=\frac{-A\pm\sqrt{A^2-4\cdot(r^2\cdot cos^2\delta-B\cdot r\cdot cos\delta+C)}}{2} \quad (f)$$

If we put the expressions (5), (6) and (9e) into the equation (9f), we get the equation in the form $\alpha_i=f$(A, B, C, R, $|OO_1|$, α_3). In this case it will be α_4 or α_5

The purpose of determining the angle α_i is to determine the integral limits when calculating the driving moment of the partially active state of the rotor blade, that is, the part of the blade below the angle α_4 is not in the working state. Based on the structure of the wing structure,

$0<\angle AO_1F=\alpha<40{,}5^0=\frac{9\cdot\pi}{40}$ working in the interval,

$\frac{9\cdot\pi}{40}<\angle DO_1F=\alpha<45^0$ and $\angle DO_1G=\alpha<49{,}5^0$ doesn't work in the meantime,

$49{,}5^0<\angle GO_1B=\alpha<90^0=\frac{9\cdot\pi}{40}$ taking into account that there are working surfaces, the working surface of a partially active wing now starts at the angle α_4. The value of the full angle that forms the curvature of the wing is in the range $\alpha_4 \le \alpha \le 90^0$. This situation occurs in the range of the turning angle $arc\ ctg\frac{1}{\sqrt{3}}\cdot\left(\frac{2}{k}+1\right)<\varphi\le 30^0$, that is, at 30^0, the active wing partially blocks the active wing.

Case 3: In this case, the passive wing (Figure 1(г)), which is fully blocked by the active wing, resumes the working state (Figure 1(д)). According to the figure, state 3 lasts from π /6 to 2π /6 turning angle interval of wing 1, at the end of which wing 2 goes into passive state.

Situations	1-Wing turning angle, φ	α	The angle forming the curvature of the wing, α	moment
1	$0\le\varphi\le arc\ ctg\frac{1}{\sqrt{3}}\cdot\left(\frac{2}{k}+1\right)$	$\frac{\pi}{2}$	k 0=0	M_1
		$\frac{\pi}{2}$	k4=1; k5=1, k6=0, k7=0	$M_{2B\alpha4}$
2	$arc\ ctg\frac{1}{\sqrt{3}}\cdot\left(\frac{2}{k}+1\right)\le\varphi\le\pi/6$		-	M_1
		$0\le\alpha_4\le\frac{9\cdot\pi}{40}$	k4=0, k5=1 k6=1, k7=0	$M_{2B\alpha4}$
		$\frac{9\cdot\pi}{40}\le\alpha_4<\frac{11\cdot\pi}{40}$	k4 = 0, k5 = 1, k6=0, k7=0	
		$\frac{11\cdot\pi}{40}\le\alpha_4\le\frac{\pi}{2}$	k4=0, k5=0, k6=0, k7=1	
3	$\frac{\pi}{6}\le\varphi\le arc\ ctg\left[\frac{2}{\sqrt{3}}\cdot\left(\frac{d}{d+2a}-\frac{1}{2}\right)\right]$	-	-	M_1
		$\alpha\le\frac{9\cdot\pi}{40}$	k1=0, k2=0, k3=1, k4=0	$M_{2A\alpha5}$
		$\frac{9\cdot\pi}{40}\le\alpha\le\frac{11\cdot\pi}{40}$	k1=1, k2=0, k3=0, k4=0	
		$\frac{11\cdot\pi}{40}\le\alpha\le\frac{\pi}{2}$	k1=0, k2=0, k3=0, k4=1	
4	$arc\ ctg\left[\frac{2}{\sqrt{3}}\cdot\left(\frac{d}{d+2a}-\frac{1}{2}\right)\right]\le\varphi\le\pi$		-	M_1
			k1=0, k2=0, k3=0, k4=1	$M_{2A\alpha5}$
5	$\pi/3<\varphi\le 2\pi/6$	$0\le\alpha\le\pi/2$	k1=0, k2=1, k3=0, k3=0	$M1+M_{2A}$

From the above considerations, it can be seen that each blade of the rotor goes through several states in relation to the direction of the wind vector during its working period. Since the angle between the blades is 1200, the working period of the rotor is returned in this range.

Since the rotor is two-stage, and the upper part enters the working position 600 later than the lower part, both parts of the rotor generate the same driving torque, only they are shifted by 600.

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