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THE IMPACT OF THE DEVELOPMENT ANGLE OF A HELICAL PADDLE OF A DARIUS ROTOR ON THE UNSTEADINESS OF THE TORQUE

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ABSTRACT:
In the following work on the basis of theoretical relationships (1) between the torque and the rotation angle of a Darius rotor we derive the corresponding graphs for the rotor with a paddle folded with respect to the helical line by conducting theoretical investigation of the influence of the angle of development on the unsteadiness of the torque.

KEYWORDS:
wind power, Darius rotor, unsteadiness of the torque

1. INTRODUCTION

In paper (3) we discussed the impact of paddles’ number of a Darius rotor on torque’s unsteadiness. It was concluded that the latter declines with an increase in paddles’ number N and the high speed Z at which a rotor works. An essential conclusion on the side of torque’s unsteadiness is that the Darius rotor with straight vertical paddles must be produced at least with four paddles and not more that six. A natural question is how the steadiness of the torque can be reached without any change in paddles’ number. A solution to the latter is the use of a rotor, whose paddles are folded with respect to the helical line (Fig.1.)

2. MAIN BODY

The estimation scheme of the investigated working rotor is given in Fig. 2. It consists of a shaft 1, bearings 2, messengers 3 and paddles 4. A paddle can be thought of as one comprising short paddles with length $h=h_o/(\varphi_o+1)$, which corresponds to sector 1° of the angle φ_o of paddle’s development with total length h_o. The moment $M_{11}(\varphi)$ derived from one sector is defined as follows:

at φ = (0..90)° and (270..360)°

$$(1)\quad M_{11}(\varphi) = \sqrt{C_X{}^2 + C_Y{}^2}\, bh\frac{\rho}{2}\upsilon^2(1+z^2+2z\sin\varphi)r\sin\left[arctg\frac{\cos\varphi}{z+\sin\varphi} - arccos\frac{C_Y}{\sqrt{C_Y{}^2+C_X{}^2}}\right],$$

at φ = (90..270)° and $C_Y>0$

$$(2)\quad M_{11}(\varphi) = -bhr\frac{\rho}{2}\upsilon^2\sqrt{C_x{}^2+C_Y{}^2}(1+z^2+2z\sin\varphi)\sin\left[arctg\left(-\frac{\cos\varphi}{z+\sin\varphi}\right) + arccos\frac{|C_y|}{\sqrt{C_Y{}^2+C_X{}^2}}\right],$$

at φ = (90..270)° and $C_Y<0$

$$(3)\quad M_{11}(\varphi) = -bhr\frac{\rho}{2}\upsilon^2\sqrt{C_x{}^2+C_Y{}^2}(1+z^2+2z\sin\varphi)\sin\left[-arctg\left(-\frac{\cos\varphi}{z+\sin\varphi}\right) + arccos\frac{|C_y|}{\sqrt{C_Y{}^2+C_X{}^2}}\right],$$

where *r*, *b*, *h* are the main geometric rotor's measures (Fig. 2); υ - air speed; $Z = \omega r/\upsilon$ - rotor's high speed; ω-angle's speed, ρ - air density; C_x and C_y – aerodynamic coefficients of a paddles' profile of front resistance and hoisting power respectively.
The moment of a paddle is calculated as,

$$(4)\qquad M_1(\varphi) = M_{11}(\varphi) + M_{11}(\varphi+1^o) + M_{11}(\varphi+2^o) + \ldots + M_{11}(\varphi+\varphi_o) = \sum_{i=0}^{\varphi_o} M_{11}(\varphi+i)\,,$$

where φ_o is the angle of paddle's development.

The theoretical investigation for determination of $M_1 = f(\varphi)$ at $\varphi = 0..360$ grad is done for a working rotor with dimensions- diameter D = 1m and total length h_o = 1 m. The paddles' profiles are "Espero" with a chord b = 0.15 and relative thickness δ/b = 0,2. The paddles' number starts at 1, air velocity υ = 10 m/s and high speed Z = 2..8.

The degree of unsteadiness for the investigated schemes at high speed form 2 to 8 does not depend on air velocity *v* and is determined by the formula,

$$(5)\qquad \sigma = \frac{M_{\max} - M_{\min}}{M_{avr}}\,,$$

where M_{max}, M_{min} и M_{avr} are maximal, minimal and average torque's values.

The average values of the moment are determined by the integral,

$$(6)\qquad M_{avr} = \frac{1}{2\pi}\int_{0^o}^{2\Pi^o}[M_1(\varphi)]d\varphi\,,$$

where $M_1(\varphi)$ is defined in relationship (4).

The results are presented in Fig.3 in terms of graphical relationships $M_1 = f(\varphi)$. The graphs of the torque are a harmonic curve, that's why it is evaluated with respect to four characteristics-average value, amplitude, phase, alternation frequency.

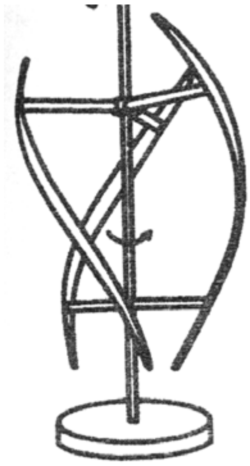

FIGURE 1. A Darius rotor with helical paddles

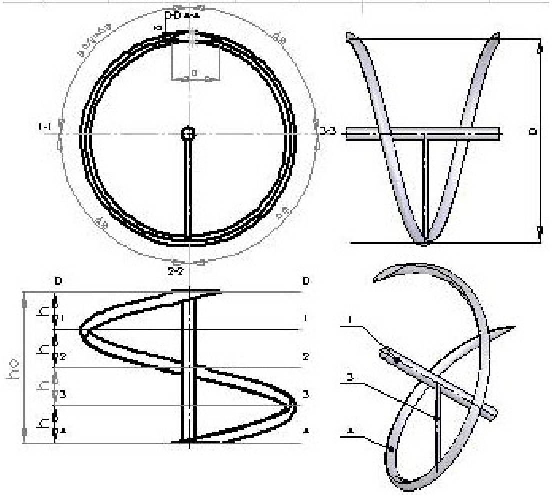

FIGURE 2. Main geometrical measures of a Darius rotor
1-shaft, 2-bearings, 3-messengers, 4-paddles

The analysis spreads on three levels. At first we discuss the impact of the angle φ_o on torque's development with a constant number of paddles N and constant high speed Z and later the effect of the paddles' number on the torque at constant φ_o and constant high speed. In the end, we investigate the impact of the high speed on the torque at constant φ_o and constant paddles' number. A basis for comparison constitutes the torque's curve at an angle φ_o of paddles' development equal to 0 grad.

The phase with which the curves of the moment begin at an angle of rotation φ = 0° is determined mainly by the paddles' number N and is affected little by a change in Z (3). In Fig. 3 we can see that the phase shift is positive and stronger at high speed Z<5. At higher high speed (6, 7, 8) it can be neglected. Similar is the shift of the moment's curves with helical paddles (φ_o =60…360 grad).

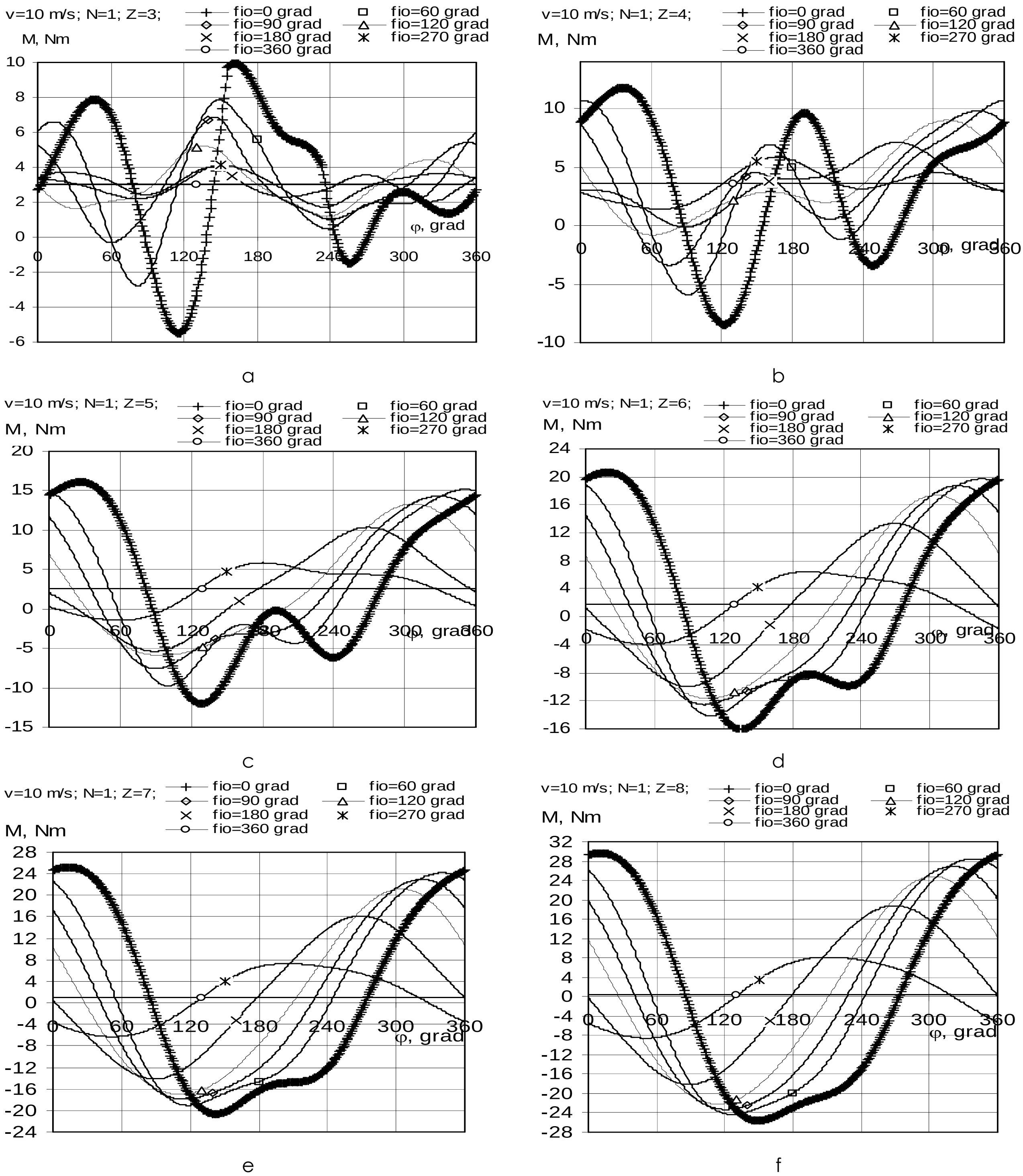

FIGURE 3

The shift of the curves of M_1 for rotors with helical paddles has a positive angle of dephasing with respect to the rotors of straight paddles, i.e. the initial part of the curves is shifted from their ascending to their descending region. Another peculiarity of the moment's characteristics is its average value. At high speed Z < 2 and Z > 9 the average values of the moment become negative, i.e the rotor does not work as an engine but as a ventilator. Due to the latter we discuss the work of a rotor within the working region of high speed values Z=2…8.

Table 1

Z	2	3	4	5	6	7	8	9
M_{avr},Nm	-2,93	3,02	3,52	2,50	1,71	1,00	0,31	-0,41

Table 1 shows the calculated average values corresponding to equation (5) of a torque and its respective high speed values. The data shows that M_{avr} first increases with a rise of Z to 4, and afterwards declines with a continuing rise in Z to 8. Besides, it does not depend on the angle of paddle's development φ_o although the graphical relationships $M_{avr} = f(\varphi)$ differ across φ_o with constant high speed (Fig. 3.) As far as the level of the torque's middle value is concerned, the optimal high speed is reached at Z=4. At this value M_{avr} has a maximum of 3, 52 Nm.

The quantity evaluation of the value of the moment's amplitude is its unsteadiness. From the graph it can be seen that at N=1 and constant value of φ_o a rise in Z results in an increase in the value of unsteadiness M_1. For instance, the unsteadiness at N=1, φ_o =120 grad and Z = 3 is σ_M = 1,34, while at Z = 8 is σ_M = 152, and at N = 1, φ_o =270 grad and Z = 3 is σ_M = 0,8, and at Z = 8 is σ_M = 54,1. The examples show that the unsteadiness of the angle φ_o of paddles' development leads to a decrease in the amplitude, respectively the unsteadiness of the torque. The biggest amplitude change is prescribed to the values of M_1 for rotors with φ_o =0 grad - σ_M = 5,1..179. This range declines with an increase in φ_o. For example, at Z = 3..4 and φ_o = 60, 90, 120, 180, 270 and 360 it is respectively σ_M = 3,5..170,1; 2,4..162,6; 1,3..152; 0,64..119,6; 0,8..54,1 and 0. On the side of the amplitude the optimal high speed is Z=3 because at it M_1 obtains negative moment values in small angle intervals of rotation only at angles of development φ_o =0, 60 and 90 grad. Also, on the side of the amplitude at Z=3 the optimal values of the angle φ_o are bigger than 120 grad because under them M_1 is positive at all angles of paddle's rotation. The optimal solution at all high speed values is φ_o =360 grad.

An important characteristic for the work of a rotor as an engine is its frequency of torque's alternation for one full rotation. Fig. 3 exhibits that for one and the same high speed (Z=3 or 4) with one paddle the frequency of torque's alternation declines with a rise in the angle φ_o. For instance, at Z = 4 and φ_o = 0, 180 and 360 grad the frequency of M_1's alternation is respectively 3, 2 and 0 for one full shaft's rotation. Rotors with Z higher than 4 exhibit constant frequency of torque's alternation with an increase in high speed values regardless of the value which φ_o obtains. As for the alternation frequency of M_1 the optimal case is obtained at φ_o =360 grad with no alternation in M_1

3. CONCLUSION

The torque's unsteadiness of a working rotor with helical paddles of N=1 depends on the high speed Z, at which a rotor and the angle of development of the paddle work.

The Darius wind rotor with helical paddles should be constructed with an optimal angle $\varphi_{\text{опт}}$ of paddles' development depending on their number N, which is determined by the relationship $\varphi_{\text{опт}} = \frac{360}{N}$.

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