THE IMPACT THAT THE DEGREE OF REACTION OF THE WIND TURBINE HAS ON THE POWER VALUE C_{Pmax}

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Abstract

In order to study the impact that the degree of reaction of the wind turbine has on the power value, several working variants have been used with the help of a programme made up according to an algorithm, with a view to identifying optimum conditions to maximize the power harnessed from the wind.

Key words: turbine, degree of reaction, power value, wind speed

INTRODUCTION

In order to describe the type of machine in terms of transferred energy structure, we operate with the concept of *machine's degree of reaction*, which is defined as the relation between the static drop of pressure and the total drop of pressure. Through the degree of reaction value it is established to what extent the turbine contributes to the energy exchange. Thus, we intend to accomplish an elevated degree of reaction, around the value of 0,8-0,9, where the theoretical power value can reach 0,8.

MATERIAL AND METHOD

The algorithm ensures the calculation of the kinematical values along the scope of the blade. The speed in the inlet section v1 is considered as constant all along the blade and normal at the tangent direction ($\alpha_1 = 90^o$). The tangential speed (of transport) is calculated for each section of calculation given through the current coordinate r with the relation $u_r = u_R(r/R)$ For each section of calculation r, we calculate all the elements of the speed triangles from inlet section (1), outlet section (3), and for asymptotic conditions (α), through the usual trigonometric relations.

The studied power values are maximum theoretical values. It is obvious that the elevated degrees of reaction are very effective in obtaining elevated power values. Further variables that influence the power value are λ_0, k_{V_3}

The domains for the turbines have been structured according to the type of turbine - λ_0, v1- the harness speed of the turbine, u_R - the peripheral speed, correlated with the maximum revolution imposed by the generator. Using this information, by analyzing different variants of distribution along the distances of the kinematical values from the triangle of speeds, we present the results related to these kinematical conditions imposed by the constraints of the design calculations.

RESULTS AND DISSCUSIONS

The calculation has been made for a wind speed within the range of interest of the turbine that is under study. This speed has a direct impact on the theoretical power which can be harnessed from the wind, depending also, on the area exposed to the wind.

The domains for the designed turbine, which have been used for establishing the number of analyzed variants must meet the following conditions:

- Type of turbine $\lambda_0 = 2...3$
- Wind speed of calculation 12 m/s

The variants which have been studied are materialized in the table below:

$v_1 = 12$	$k_{V_3} = 0,8$	$\lambda_0 = 2$	$\overline{R} = 0,2$; 0,4; 0,6; 0,8
		$\lambda_0 = 3$	

Legend for identifying the degree of reaction:

Semnificație variante: x_1-x_2-x_3-x_4		
$x_1 \rightarrow \lambda_0$	= 2	1
	= 3	2
$x_2 \rightarrow v_1$	= 12	
$x_3 \rightarrow k_{V_3}$	= 0,8	1
$x_4 \rightarrow \overline{R}$	= 0,8	1
	= 0,6	3
	= 0,4	4
	= 0,2	5

The results are presented in the following grid $C_{Pmax} = f(\overline{R}$, constant value)

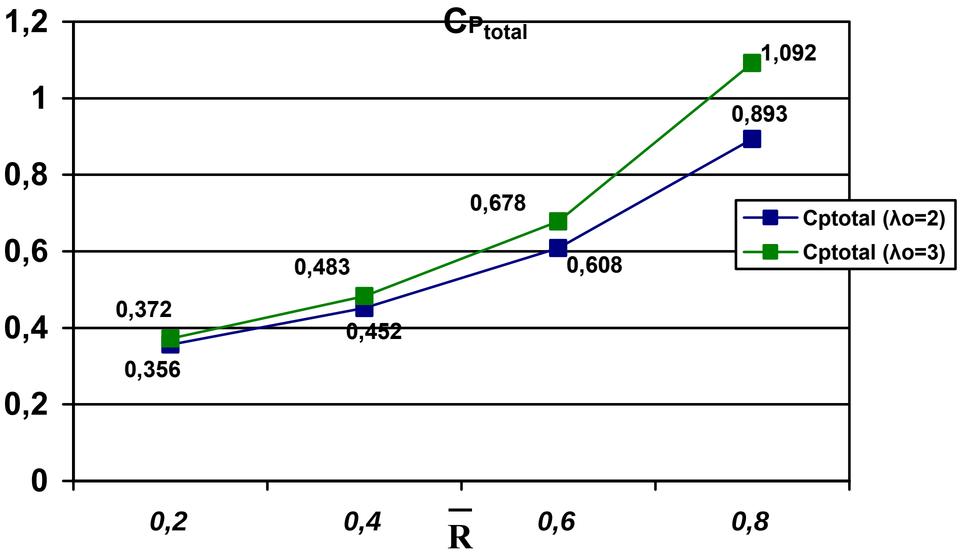

Fig.1 C_{Pmax} according to the degree of reaction

We can notice an increasing variation of the value C_{Pmax} according to the degree of reaction, differentiated for the two types of turbine ($\lambda_0 = 2$, $\lambda_0 = 3$)

In order to make comparisons, the programme has also been used for the Betz theory, for the next two variants:

$v_1 = 12$	$k_{V_3} = 0,33$	$\lambda_0 = 2$ $\lambda_0 = 3$	$\overline{R} = 0,375$

Legend:

- Variant 1 Betz theory - $\lambda_0 = 2$
- Variant 2 Betz theory - $\lambda_0 = 3$

It is then presented the kinematical calculation in table form for the small degrees of reaction ($\overline{R} = 0,375$). Through these variants we have in view the relation between $C_{P\max}$ and $\overline{R}$ when the values are constant.

Table 1

Variant 1 Betz theory

Varianta 1 tip. Betz $\lambda_0 = 2$; $\alpha_1 = 90^o$; $v_1 = 12$ m/s ; $u_R = 24$ m/s ; $k_{V_2} = 0{,}333$; $v_{ax3} \cong$ m/s ; $v_{axT} \cong$ m/s ; $k_{v_T} =$; $\overline{R} = 0{,}375$; $k_{V_3} = 0{,}666$							
r [m]	r_b = 0,3	0,5	0,75	1	1,25	1,5	R = 1,55
Δr	0,1	0,225	0,25	0,25	0,25	0,15	0,025
v_1	12	12	12	12	12	12	12
$v_{ax2} = k_{v2} \cdot v_1$	3,96	3,96	3,96	3,96	3,96	3,96	3,96
$v_{ax3} = k_{v3} \cdot v_1$	7,992	7,992	7,992	7,992	7,992	7,992	7,992
$v_{axT} = \frac{v_1 + v_{ax3}}{2}$	9,996	9,996	9,996	9,996	9,996	9,996	9,996
$\overline{R}$	0,375	0,375	0,375	0,375	0,375	0,375	0,375
$\Delta Q = v_{axT} \cdot \Delta S$; $\Delta S = 2\pi r \Delta r$	1,884	7,066	11,776	15,702	19,627	14,132	2,434
$Q = \sum \Delta Q$	72,620						
$u_r = u_R \frac{r}{R}$	4,645	7,742	11,613	15,484	19,355	23,226	24
$\lambda_r = \frac{u_r}{v_1}$	0,387	0,645	0,968	1,290	1,613	1,935	2
$k_t = -(1-\overline{R}) + \sqrt{(1-\overline{R})^2 + \frac{1-k_{V_3}^2}{\lambda_r^2}}$	1,401	0,689	0,367	0,226	0,153	0,109	0,103
$v_{u3} = k_t \cdot \lambda_r \cdot v_1$	6,507	5,337	4,266	3,505	2,952	2,538	2,468
$w_1 = \sqrt{u_r^2 + v_1^2}$	12,868	14,281	16,699	19,590	22,773	26,143	26,833
$w_3 = \sqrt{(u_r + v_{u3})^2 + v_{ax3}^2}$	13,720	15,327	17,777	20,602	23,695	26,975	27,648
$w_\infty = \sqrt{\left(u_r + \frac{v_{u3}}{2}\right)^2 + v_{axT}^2}$	12,740	14,432	16,996	19,925	23,105	26,456	27,142
$v_3 = \sqrt{v_{ax3}^2 + v_{u3}^2}$	10,306	9,610	9,059	8,727	8,520	8,385	8,364
$\beta_1 = \arcsin \frac{v_1}{w_1}$	68,839	57,171	45,939	37,776	31,799	27,324	26,565
$\beta_3 = \arcsin \frac{v_{ax3}}{w_3}$	35,626	31,428	26,716	22,825	19,712	17,234	16,802
$\beta_\infty = \arcsin \frac{v_{axT}}{w_\infty}$	51,684	43,837	36,024	30,111	25,635	22,200	21,610

$\alpha_3 = \text{arctg}\dfrac{v_{u3}}{v_{ax3}} + 90°$	129,15	123,73	118,09	113,68	110,27	107,62	107,16
$\Delta p_{st} = \rho\dfrac{w_3^2 - w_1^2}{2}$; ρ=1,225	13,886	18,980	22,759	24,932	26,245	27,080	27,209
$\Delta p_d = \rho\dfrac{v_1^2 - v_3^2}{2}$;	23,143	31,633	37,931	41,553	43,742	45,133	45,348
$\Delta p_t = \Delta p_{st} + \Delta p_d$	37,028	50,614	60,689	66,485	69,986	72,212	72,557
$\overline{R} = \dfrac{\Delta p_{st}}{\Delta p_t}$ (verificare)	0,375	0,375	0,375	0,375	0,375	0,375	0,375
$\Delta P_t = \Delta p_t \cdot \Delta Q$	69,77	357,62	714,69	1043,93	1373,63	1020,47	176,59
$(P_t)_{total} = \sum \Delta P_t$	4756,698						
$\Delta P_{t_{mediu}} = \dfrac{(P_t)_{total}}{Q}$	65,501						
$C_{Pr} = \dfrac{\Delta P_t}{\rho\dfrac{v_1^3}{2}\Delta S}$	0,350	0,478	0,573	0,628	0,661	0,682	0,685
$C_{Ptotal} = \dfrac{(P_t)_{total}}{\rho\dfrac{v_1^3}{2}\pi R^2}$; R=1,55	0,595						
$C_y\dfrac{l}{t} = \dfrac{2v_{u3}}{w_\infty}$	1,022	0,740	0,502	0,352	0,256	0,192	0,182
$(C_y \cdot l)_{necesar} = \dfrac{4\pi}{z}\cdot\dfrac{v_{u3}}{w_\infty}\cdot r$; r – variabil (0,3 → 1,55)	321	387	394	368	334	301	295

Table 2

Variant 2 Betz theory

Varianta 2 tip. Betz $\lambda_0 = 3$; $\alpha_1 = 90^o$; $v_1 = 12$ m/s ; $u_R = 36$ m/s ; $k_{V_2} = 0,333$;

$v_{ax3} \cong$ m/s ; $v_{axT} \cong$ m/s ; k_{v_T} = ; $\overline{R} = 0,375$; $k_{V_3} = 0,666$

r [m]	$r_b = 0,3$	0,5	0,75	1	1,25	1,5	R = 1,55
Δr	0,1	0,225	0,25	0,25	0,25	0,15	0,025
v_1	12	12	12	12	12	12	12
$v_{ax2} = k_{v2} \cdot v_1$	3,96	3,96	3,96	3,96	3,96	3,96	3,96
$v_{ax3} = k_{v3} \cdot v_1$	7,992	7,992	7,992	7,992	7,992	7,992	7,992
$v_{axT} = \frac{v_1 + v_{ax3}}{2}$	9,996	9,996	9,996	9,996	9,996	9,996	9,996
$\overline{R}$	0,375	0,375	0,375	0,375	0,375	0,375	0,375
$\Delta Q = v_{axT} \cdot \Delta S$; $\Delta S = 2\pi r \Delta r$	1,884	7,066	11,776	15,702	19,627	14,132	2,434
$Q = \sum \Delta Q$	72,620						
$u_r = u_R \frac{r}{R}$	6,968	11,613	17,419	23,226	29,032	34,839	36
$\lambda_r = \frac{u_r}{v_1}$	0,581	0,968	1,452	1,935	2,419	2,903	3
$k_t = -(1-\overline{R}) + \sqrt{(1-\overline{R})^2 + \frac{1-k_{V}^2}{\lambda_r^2}}$	0,804	0,367	0,184	0,109	0,072	0,051	0,048
$v_{u3} = k_t \cdot \lambda_r \cdot v_1$	5,600	4,266	3,207	2,538	2,088	1,768	1,715
$w_1 = \sqrt{u_r^2 + v_1^2}$	13,876	16,699	21,153	26,143	31,415	36,847	37,947
$w_3 = \sqrt{(u_r + v_{u3})^2 + v_{ax3}^2}$	14,893	17,777	22,121	26,975	32,130	37,469	38,553
$w_\infty = \sqrt{\left(u_r + \frac{v_{u3}}{2}\right)^2 + v_{axT}^2}$	13,976	16,996	21,489	26,456	31,694	37,095	38,189
$v_3 = \sqrt{v_{ax3}^2 + v_{u3}^2}$	9,759	9,059	8,612	8,385	8,260	8,185	8,174
$\beta_1 = \arcsin \frac{v_1}{w_1}$	59,859	45,939	34,563	27,324	22,457	19,006	18,435
$\beta_3 = \arcsin \frac{v_{ax3}}{w_3}$	32,453	26,716	21,179	17,234	14,403	12,316	11,964

$\beta_\infty = \arcsin\frac{v_{axT}}{w_\infty}$	45,662	36,024	27,720	22,200	18,385	15,633	15,174
$\alpha_3 = \operatorname{arctg}\frac{v_{u3}}{v_{ax3}} + 90°$	125,02	118,09	111,87	107,62	104,64	102,48	102,11
$\Delta p_{st} = \rho\frac{w_3^2 - w_1^2}{2}$; ρ=1,225	17,924	22,759	25,666	27,080	27,845	28,298	28,366
$\Delta p_d = \rho\frac{v_1^2 - v_3^2}{2}$;	29,873	37,931	42,777	45,133	46,408	47,163	47,276
$\Delta p_t = \Delta p_{st} + \Delta p_d$	47,796	60,689	68,443	72,212	74,253	75,461	75,642
$\overline{R} = \frac{\Delta p_{st}}{\Delta p_t}$ (verificare)	0,375	0,375	0,375	0,375	0,375	0,375	0,375
$\Delta P_t = \Delta p_t \cdot \Delta Q$	90,06	428,82	806,01	1133,86	1457,38	1066,38	184,09
$(P_t)_{total} = \sum \Delta P_t$	5166,594						
$\Delta P_{t_{mediu}} = \frac{(P_t)_{total}}{Q}$	71,145						
$C_{Pr} = \frac{\Delta P_t}{\rho\frac{v_1^3}{2}\Delta S}$	0,451	0,573	0,646	0,682	0,701	0,713	0,714
$C_{Ptotal} = \frac{(P_t)_{total}}{\rho\frac{v_1^3}{2}\pi R^2}$; R=1,55	0,647						
$C_y\frac{l}{t} = \frac{2v_{u3}}{w_\infty}$	0,801	0,502	0,299	0,192	0,132	0,095	0,090
$(C_y \cdot l)_{necesar} = \frac{4\pi}{z}\cdot\frac{v_{u3}}{w_\infty}\cdot r$; r – variabil (0,3 → 1,55)	252	263	234	201	172	150	146

CONCLUSIONS

As a result of this calculation, we notice the values for C_{Pmax} in the two situations:

- Variant 1 Betz theory - $\lambda_0 = 2$, obtained for $C_{Pmax} = 0{,}595$
- Variant 2 Betz theory - $\lambda_0 = 3$, obtained for $C_{Pmax} = 0{,}647$

These values have been calculated in order to conduct an analysis regarding the identification of the influence that the degree of reaction has upon the power value C_{Pmax}

The achieved results have been marked in the chart $C_{Ptotal} = f(\overline{R})$. It can be noticed that these results can be correlated, having as a result the main conclusion that through an increased degree of reaction, the power value can be increased.

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