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GEOMETRICAL OUTLINE OF THE AERODYNAMIC PROFILE OF WIND TURBINE BLADES

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Abstract: *The calculation of the blade profile has been made by determining the geometrical outline of the aerodynamic profile, defined analytically through the combination of two mathematical functions, the skeleton and the thickness functions. The model presented has been illustrated in seven calculation sections, which have configurated the final shape of the blade, taking into account the running of the aerodynamic profile which has been placed in air draught, based on a calculation algorithm.*
Key words: *wind turbine, blade, aerodynamic profiles*

1. INTRODUCTION

The turbine variant which has been analyzed is addressed to a harness domain of 4-5 m/s, and the maximum revolution imposed by the electrical generator is n = 250 rpm, ω = 26,2 rad/s, uR = 40 m/s (maximum – to minimize noise).

2. MATERIAL AND METHODS

The geometrical outline of the aerodynamic profile of the blade is made analytically, by combining two mathematical functions (see Dubău, 2007 and Bej, 2003): the skeleton function and the thickness function. The aerodynamic profiles which have been chosen are those from the NACA series with four figures: NACA 4424 (at the hub) and 4415 (at the margin), (see Gyulai, 2000 and 2003). The axis Oy falls perpendicularly on the chord in the board of attack, while the thickness function is given by the following expression:

$$\frac{y_d(x)}{l} = \frac{d_m}{l} \cdot \left[1{,}4845\sqrt{\frac{x}{l}} - 0{,}63\frac{x}{l} - 1{,}758\left(\frac{x}{l}\right)^2 + 1{,}4215\left(\frac{x}{l}\right)^3 - 0{,}5075\left(\frac{x}{l}\right)^4 \right] \quad (1)$$

The curvature radii of the boards of attack and run-off, which are both rounded, are determined using the relations: (A – attack, F – run-off)

$$\frac{r_A}{l} = 1{,}1019 \cdot \left(\frac{d_m}{l}\right)^2 \quad (2)$$

$$\frac{r_F}{l} = 1{,}105 \cdot \left(\frac{d_m}{l}\right)^2 \quad (3)$$

The skeleton function is defined using the relations below; the skeleton is made of two parabola arcs, which are connected in x_{f_m} / l.

$$\frac{y_f}{l} = \frac{f_m / l}{\left(x_{f_m} / l\right)^2} \left[2\frac{x_{f_m}}{l} \cdot \frac{x}{l} - \left(\frac{x}{l}\right)^2 \right] \quad (4)$$

for $$0 \le \frac{x}{l} \le \frac{x_{f_m}}{l} \quad (5)$$

$$\frac{y_f}{l} = \frac{f_m / l}{\left(1 - x_{f_m} / l\right)^2} \left[\left(1 - 2\frac{x_{f_m}}{l}\right) + 2\frac{x_{f_m}}{l} \cdot \frac{x}{l} - \left(\frac{x}{l}\right)^2 \right] \quad (6)$$

for $$\frac{x_{f_m}}{l} \le \frac{x}{l} \le 1 \cdot \quad (7)$$

The functioning of the aerodynamic profile, which is placed in a draught, primarily depends on the position of the profile against the draught speed, through the angle of incidence value. Based on it, we have represented the following drawings, regarding the geometrical outline of the blade.

The algorithm of calculation for the determination of the geometrical outlines implies the following steps:

- defining the calculation variants for each radius (r), correlated with the profile chord (l) and the relative thickness of profile (d/l)
- the profile chord has been divided into ten equal intervals, noted with (0,1 0,2 … 1) · l
- for each partition noted with x, we have determined the thickness function y_d / l (±), the curvature radius of the board of attack r_A /l, and of the board of run-off respectively, as well as the skeleton function y_f /l
- the front side and back side calculation of the profile has been determined according to the thickness and skeleton of the profile
- the calculation for each partition is illustrated in a grid where the relative values are presented (in relations to the profile chord – l) and another grid which has been turned into length units expressed in mm, in order to ease the performance of the profile drawings

These data will be utilized for the energy balances of the assembly H2500, which will be determined through a mathematical model used for the assessment of the system curves of energetic revaluation.

The configuration of the turbine blade is represented below in Figure 1. Section positions have been defined according to radius position, the blade chord profile of each section calculated in part (L) and blade thickness (D) respectively, with corresponding values of each string. Data are included in Tables 1 and 2.

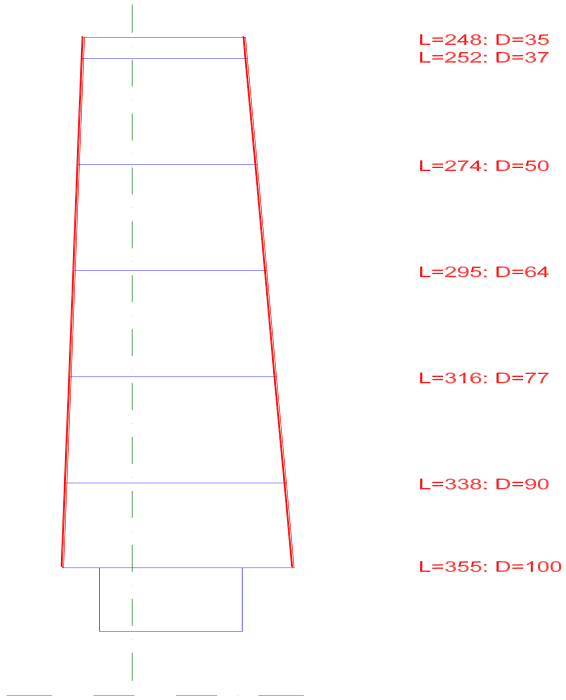

Fig. 1. Configuration of the turbine blade

Variant 1.1. r = 0,3 ; l = 355 ; d/l = 0,282										
x =	0,1·l	0,2·l	0,3·l	0,4·l	0,5·l	0,6·l	0,7·l	081·l	0,9·l	l
$\frac{y_d}{l}$ (+)	0,1100	0,1348	0,1410	0,1364	0,1244	0,1072	0,0861	0,0616	0,0340	0,0030
$\frac{y_d}{l}$ (–)	-0,1100	-0,1348	-0,1410	-0,1364	-0,1244	-0,1072	-0,0861	-0,0616	-0,0340	-0,0030
r_a / l	0,0876									
r_f / l	0,0084									
$\frac{y_f}{l}$	0,0175	0,03	0,0375	0,04	0,0389	0,0356	0,0300	0,0222	0,0122	0
extrados	0,1275	0,1648	0,1785	0,1764	0,1633	0,1428	0,1161	0,0839	0,0462	0,0030
intrados	-0,0925	-0,1048	-0,1035	-0,0964	-0,0855	-0,0717	-0,0561	-0,0394	-0,0218	-0,0030

Tab. 1. Calculation of the blade regarding relative thickness of profile (d/l)

Variant 1.1. r = 0,3 ; l = 355 ; d = 100										
x =	0,1·l	0,2·l	0,3·l	0,4·l	0,5·l	0,6·l	0,7·l	081·l	0,9·l	l
x	35,5	71	106,5	142	177,5	213	248,5	284	319,5	355
y_d (+)	39,07	47,87	50,07	48,41	44,17	38,07	30,57	21,88	12,08	1,05
y_d (–)	-39,07	-47,87	-50,07	-48,41	-44,17	-38,07	-30,57	-21,88	-12,08	-1,05
r_a	31,11									
r_f	2,96									
y_f	6,21	10,65	13,31	14,20	13,81	12,62	10,65	7,89	4,34	0,00
Extra-dos	45,28	58,52	63,38	62,61	57,97	50,69	41,22	29,77	16,42	1,05
Intra-dos	-32,85	-37,22	-36,76	-34,21	-30,36	-25,45	-19,92	-13,99	-7,74	-1,05

Tab. 2. Calculation of the blade regarding thickness of profile

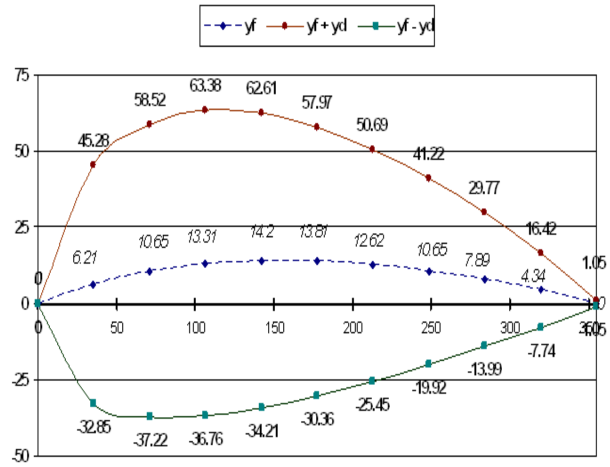

Fig. 2. Graph of blade section at r = 0,3

3. CONCLUSIONS

1. The calculation of the blade profile has been made by determining the geometrical outline of the aerodynamic profile, as we can see in Figure 2, defined analytically through the combination of two mathematical functions, the skeleton and the thickness functions.
2. The model presented has been illustrated in seven calculation sections, which have configurated the final shape of the blade, taking into account the running of the aerodynamic profile which has been placed in air draught, based on a calculation algorithm.
3. The turbine variant which has been analyzed is addressed to a harness domain of 4-5 m/s, and the maximum revolution imposed by the electrical generator is n = 250 rpm, ω = 26,2 rad/s, u_R = 40 m/s (maximum – to minimize noise).

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