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Determine the Correlation between Wicked Gates Angles and Servomotors Strokes for Asymmetric Hydrofoil

The paper describe the results obtained from theoretical calculus of the kinematics of the wicked gates for the correlation: $a_o=f(\alpha)$; $a_{or}=a_o/D_o(\alpha)$; $S=f(\alpha)$ and propose analytical formulas for $a_o=f(\alpha)$ correlation, applicable to 16, 24 wicked gates blade number and asymmetrical hydrofoils; also, numerical results compared with graphical values are presented.

Keywords: *Wicked gates, kinematics, asymmetric hydrofoil*

1. Introduction

Wicked gate represent a specific component of hydraulic turbines. The wicked gate's blade is calculated to ensure a uniform flow from the hydrodynamic point of view [1], [2]. The function of the blades is to guide the water flow into the runner and to modify the direction and speed of the water, through one or several servomotors. Figure 1 presents an overview of a Kaplan hydraulic turbine, drawn with SolidWorks software.

During the wicked gates design it is necessary to determine the correlations $a_o=f(\alpha)$ and $a_o=f(S)$, were a_o is the wicked gate opening, α is the positioning angle of the blade and S is the servomotor's stroke. These correlations can be obtained graphically with CAD software like SolidWorks, Inventor or Catia. The paper introduce a new software named „Kinematics AD", an original instrument created in Python language during the development of the thesis [3], which gives to the designer the following results:

- the parameters of the wicked gates blades, figure 2,;
- the correlation $a_o=f(\alpha)$ for any number of blades Z_o and wicked gate characteristic diameter D_o, for symmetrical and asymmetrical hydrofoils;
- the correlation $a_o=f(S)$;
- the graphically results and export these in image format;
- export of the numerical results to Microsoft Excel.

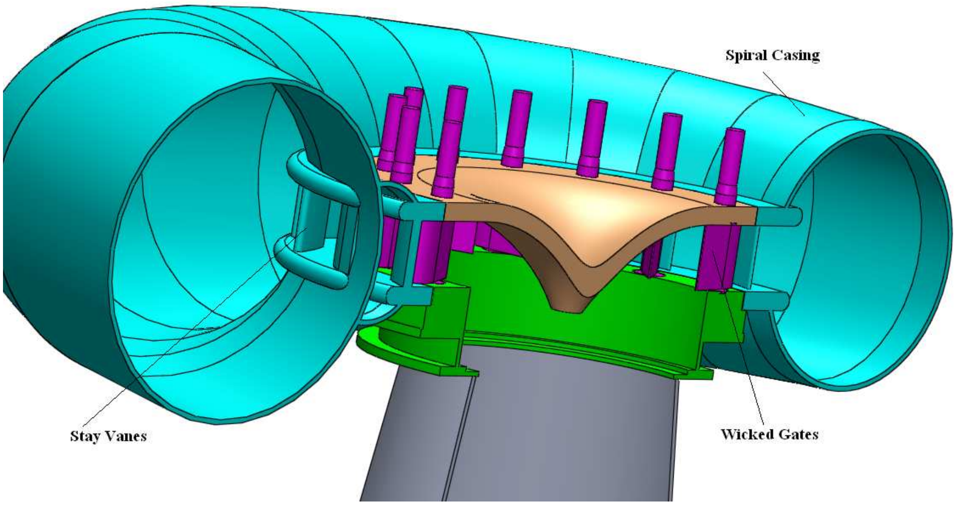

Figure 1. Overview of a Kaplan hydraulic turbine

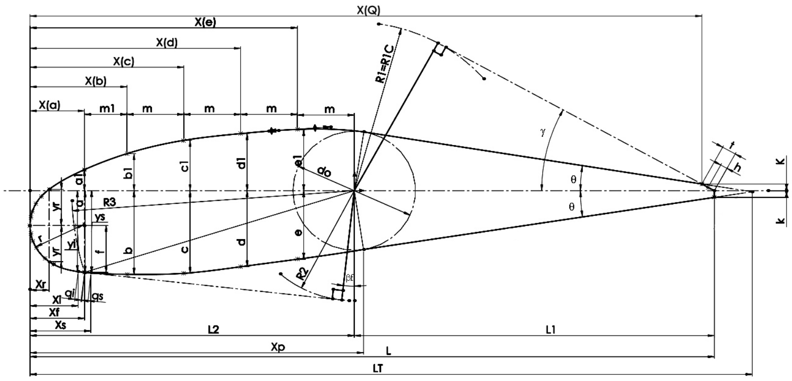

Figure 2. The theoretical asymmetrical contour of the hydrofoil

2. Relative correlation $a_{or}=a_o/D_o(\alpha)$

The relative correlation $a_{or}=a_o/D_o(\alpha)$ was obtained with SolidWorks software, for 2 cases: wicked gates with 16 and 24 asymmetrical blade number, following the goal to obtain analytical formula for $a_o=f(\alpha)$ correlation. We will consider the relative adimensional value of the wicked gates opening, described by relation (1).

$$a_{or} = \frac{a_o}{D_o} \tag{1}$$

We assume that $a_{or}=f(\alpha)$ correlation is a unique function, for a given number of blade number. The steps required to determine, graphically in SolidWorks, the correlation $a_{or}=f(\alpha)$ of the wicked gates are:

- o the placement of the blade on the characteristic diameter D_o, figure 2;
- o the calculus of the complete closing position of the wicked gates, figure 3;
- o the rotation of the gates at the imposed angle α, figure 4;
- o the determine of the wicked gates opening a_o, for each imposed angle α, figure 4;
- o the calculus of the value a_{or}.

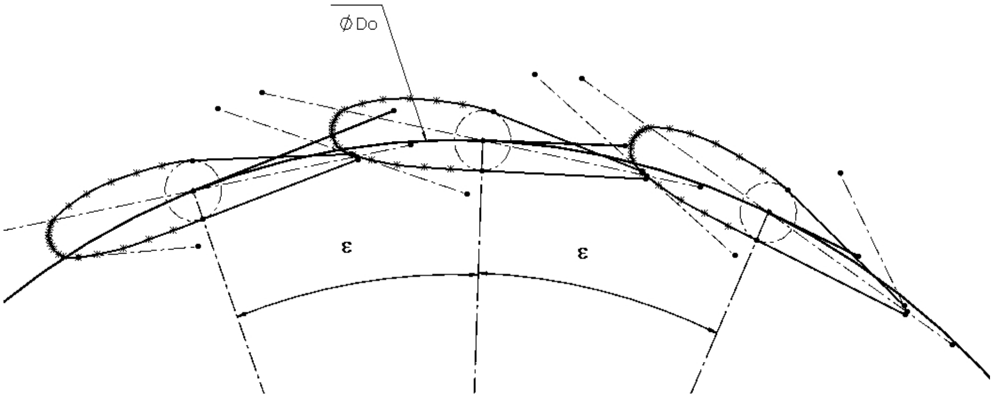

Figure 3. The closing position of the wicked gates

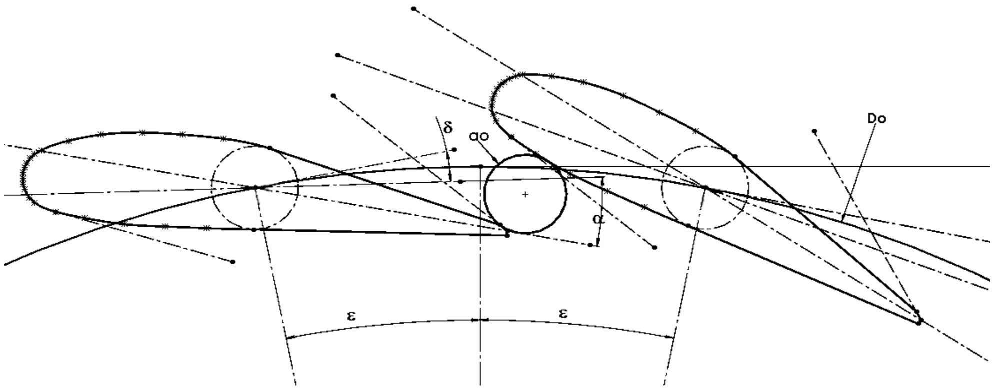

Figure 4. The position of the wicked gates for angle α

The final results, obtained with SolidWorks, are presented numerically in table 1 and graphically in figure 5 [3]. The values a_{or} were multiplied with 1000 coefficient by the numerical reasons. The values form table 1 were interpolated by polynomial function and the following formulas was generated:

- o for 16 blade and asymmetrical hydrofoils of wicked gates :

$$a_o = (-0.00016487 \cdot \alpha^3 - 0.00131397 \cdot \alpha^2 + 2.98881093 \cdot \alpha + 0.14447518) \cdot \frac{D_o}{1000} \qquad (2)$$

- for 24 blade and asymmetrical hydrofoils of wicked gates:

$$a_o = (-0.00009913 \cdot \alpha^3 - 0.00207517 \cdot \alpha^2 + 2.09527267 \cdot \alpha - 0.08532881) \cdot \frac{D_o}{1000} \qquad (3)$$

Table 1.

The correlation $a_{or}=f(\alpha)$ obtained with SolidWorks

α [°]	1000 x a_{or}		α [°]	1000 x a_{or}	
	16 blade	24 blade		16 blade	24 blade
0	0	0	38	102.84	71.26
2	6.04	4.13	40	107.06	74.22
4	12.08	8.27	42	111.13	77.06
6	18.09	12.4	44	115.04	79.78
8	24.04	16.51	45	118.80	82.36
10	29.91	20.58	46	122.33	84.81
12	35.67	24.6	48	125.64	87.13
14	41.34	28.55	50	-	89.3
16	46.93	32.44	52	-	91.34
18	52.45	36.27	54	-	93.23
20	57.91	40.05	56	-	94.98
22	63.32	43.79	58	-	96.58
24	68.68	47.48	60	-	98.03
26	73.96	51.14	62	-	99.33
28	79.15	54.74	64	-	100.49
30	84.23	58.26	65	-	101.58
32	89.15	61.68	66	-	102.56
34	93.89	64.98	68	-	103.38
36	98.45	68.18			

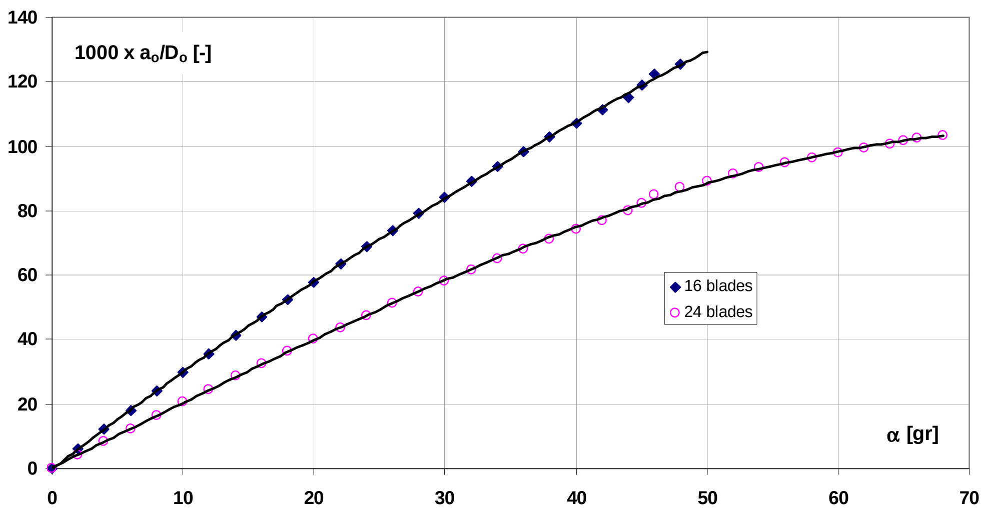

Figure 5. The correlation a_{or} = f (α) for 16 and 24 blades number

3. The correlation a_o=f(α) for asymmetric profiles obtained from the „Kinematics AD” software

For the asymmetric profiles, D_o = 2650 mm and Z_o = 16 and 24, in table 2 and in figure 6 there have been compared the results obtained with the „Kinematics AD” and SolidWorks software [3].

Table 2.

The correlation a_o=f(α) obtained with „Kinematics AD” and SolidWorks software

α [^{o}]	SolidWorks 16 blades	SolidWorks 24 blades	„ Kinematics AD” 16 blades	„ Kinematics AD” 24 blades	α [^{o}]	SolidWorks 16 blades	SolidWorks 24 blades	„ Kinematics AD” 16 blades	„ Kinematics AD” 24 blades
0	0	0	0	0	37	266.54	184.38	265.025	183.892
1	8.30	5.32	7.07	5.293	38	272.35	188.41	270.884	187.965
2	16.21	10.85	15.023	10.705	39	278.06	192.37	276.641	191.96
3	24.10	16.37	22.895	16.069	40	283.66	196.26	282.292	195.875
4	31.98	21.88	30.864	21.482	41	289.15	200.08	287.834	199.709
5	39.84	27.37	38.83	26.817	42	294.53	203.81	293.263	203.462
6	47.69	32.83	46.683	32.257	43	299.78	207.48	298.545	207.131
7	55.50	38.28	54.601	37.615	44	304.92	211.06	303.708	210.716
8	63.30	43.71	62.523	43.005	45	309.93	214.56	308.74	214.216
9	71.07	49.11	70.309	48.396	46	314.82	217.98	313.619	217.629
10	78.80	54.49	78.099	53.728	47	319.59	221.32	318.374	220.955
11	86.50	59.84	85.87	59.077	48	324.22	224.57	322.963	224.193
12	94.17	65.16	93.579	64.385	49	328.72	227.74	327.428	227.341

Table 2.

The correlation $a_o=f(\alpha)$ obtained with „Kinematics AD” and SolidWorks software

α [°]	SolidWorks		„ Kinematics AD”		α [°]	SolidWorks		„ Kinematics AD”	
	16 blades	24 blades	16 blades	24 blades		16 blades	24 blades	16 blades	24 blades
13	101.80	70.45	101.196	69.651	50	333.08	230.81	331.735	230.399
14	109.39	75.71	108.773	74.907	51		233.80	335.912	233.365
15	116.93	80.94	116.302	80.131	52		236.70	339.938	236.239
16	124.43	86.13	123.777	85.292	53		239.50	343.833	239.02
17	131.88	91.29	131.184	90.428	54		242.21	347.589	241.708
18	139.27	96.40	138.502	95.533	55		244.82	351.204	244.3
19	146.62	101.48	145.764	100.602	56		247.33	354.692	246.797
20	153.90	106.52	152.969	105.605	57		249.75	358.03	249.198
21	161.13	111.52	160.115	110.573	58		252.06	361.248	251.501
22	168.29	116.47	167.2	115.503	59		254.28	364.304	253.707
23	175.39	121.38	174.226	120.395	60		256.38	367.239	255.814
24	182.43	126.23	181.161	125.247	61		258.39	370.007	257.823
25	189.39	131.04	188.036	130.04	62		260.28	372.639	259.731
26	196.28	135.80	194.848	134.792	63		262.07	375.108	261.54
27	203.09	140.51	201.597	139.503	64		263.74	377.417	263.248
28	209.83	145.17	208.282	144.174	65		265.31	379.569	264.854
29	216.49	149.76	214.899	148.803	66		266.76	381.545	266.358
30	223.06	154.31	221.445	153.389	67		268.09	383.351	267.761
31	229.55	158.79	227.919	157.917	68		269.31	384.995	269.06
32	235.95	163.21	234.31	162.401	69		270.42	386.474	270.257
33	242.26	167.58	240.619	166.84	70		271.40	387.783	271.366
34	248.48	171.88	246.85	171.214	71		272.26	388.945	272.394
35	254.60	176.11	252.997	175.515	72		272.99	389.949	273.419
36	260.62	180.28	259.056	179.741					

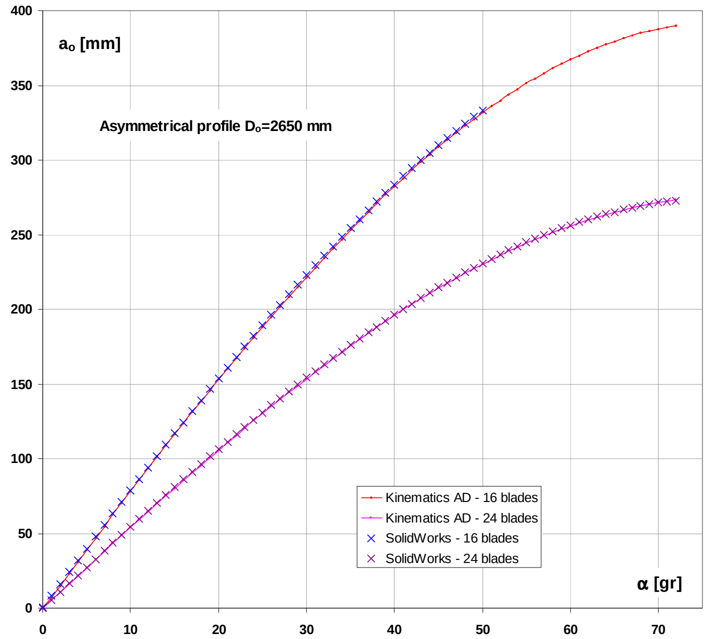

Figure 6. Curves comparison $a_o=f(\alpha)$ generated by SolidWorks and „Kinematics AD" for asymmetrical profile, D_o=2650 mm şi Z_o=16, 24 blades

4. The S=f(a_o) correlation resulted from „ Kinematics AD" software

To verify the „Kinematics AD" software for asymmetric profiles were compared the results with those obtained graphically for two data sets:

- **1st Data set** : D_o=4500 mm, Z_o=24, D_c=3090 mm, D_y=2730 mm, L_m=520 mm, L_b=415, α_R=35°, $a_{o\ max\ maj}$=375 mm;
- **2nd Data set** : D_o=4500 mm, Z_o=24, D_c=3090 mm, D_y=2650 mm, L_m=523 mm, L_b=415, α_R=35°, $a_{o\ max\ maj}$=450 mm.

The results are presented graphically in figure 7 and table 3 [3].

Table 3.

The correlation S=f (a_o) obtained with „Kinematics AD" software

α [gr]	a_o [mm]	1st Data set S [mm]	2st Data set S [mm]	α [gr]	a_o [mm]	1st Data set S [mm]	2st Data set S [mm]
0	0	0	0	37	307.121	396.199	382.35
1	8.665	20.89	19.988	38	314.214	404.239	390.078
2	17.663	39.242	37.64	39	321.2	412.217	397.744
3	26.687	55.863	53.671	40	328.077	420.131	405.348

Table 3.

The correlation S=f (a_o) obtained with „Kinematics AD" software

α [gr]	a_o [mm]	1st Data set S [mm]	2st Data set S [mm]	α [gr]	a_o [mm]	1st Data set S [mm]	2st Data set S [mm]
4	35.538	71.209	68.497	41	334.827	427.979	412.887
5	44.492	85.57	82.385	42	341.441	435.76	420.359
6	53.433	99.142	95.519	43	347.917	443.47	427.761
7	62.236	112.069	108.031	44	354.253	451.107	435.091
8	71.119	124.454	120.023	45	360.448	458.666	442.346
9	79.965	136.381	131.57	46	366.5	466.145	449.521
10	88.719	147.912	142.734	47	372.406	473.539	456.614
11	97.517	159.101	153.565	48	378.165	480.844	463.621
12	106.246	169.989	164.104	49	383.775	488.055	470.535
13	114.916	180.611	174.384	50	389.234	495.168	477.354
14	123.605	190.998	184.433	51	394.541	502.176	484.072
15	132.206	201.174	194.276	52	399.694	509.074	490.684
16	140.763	211.16	203.934	53	404.692	515.857	497.185
17	149.32	220.977	213.425	54	409.533	522.518	503.567
18	157.782	230.639	222.764	55	414.216	529.051	509.827
19	166.201	240.16	231.964	56	418.738	535.449	515.956
20	174.603	249.553	241.038	57	423.099	541.705	521.949
21	182.92	258.829	249.996	58	427.298	547.811	527.798
22	191.175	267.996	258.847	59	431.333	553.76	533.497
23	199.4	277.064	267.599	60	435.203	559.544	539.038
24	207.563	286.039	276.259	61	438.906	565.156	544.413
25	215.632	294.927	284.833	62	442.442	570.585	549.616
26	223.659	303.735	293.327	63	445.81	575.825	554.637
27	231.637	312.467	301.745	64	449.008	580.866	559.467
28	239.525	321.126	310.091	65	452.036	585.698	564.1
29	247.334	329.716	318.369	66	454.892	590.312	568.525
30	255.083	338.241	326.58	67	457.576	594.699	572.734
31	262.768	346.702	334.728	68	460.087	598.848	576.716
32	270.38	355.101	342.815	69	462.424	602.748	580.463
33	277.885	363.44	350.841	70	464.587	606.389	583.963
34	285.315	371.719	358.807	71	466.574	609.759	587.207
35	292.667	379.939	366.714	72	468.386	612.847	590.183
36	299.937	388.099	374.562				

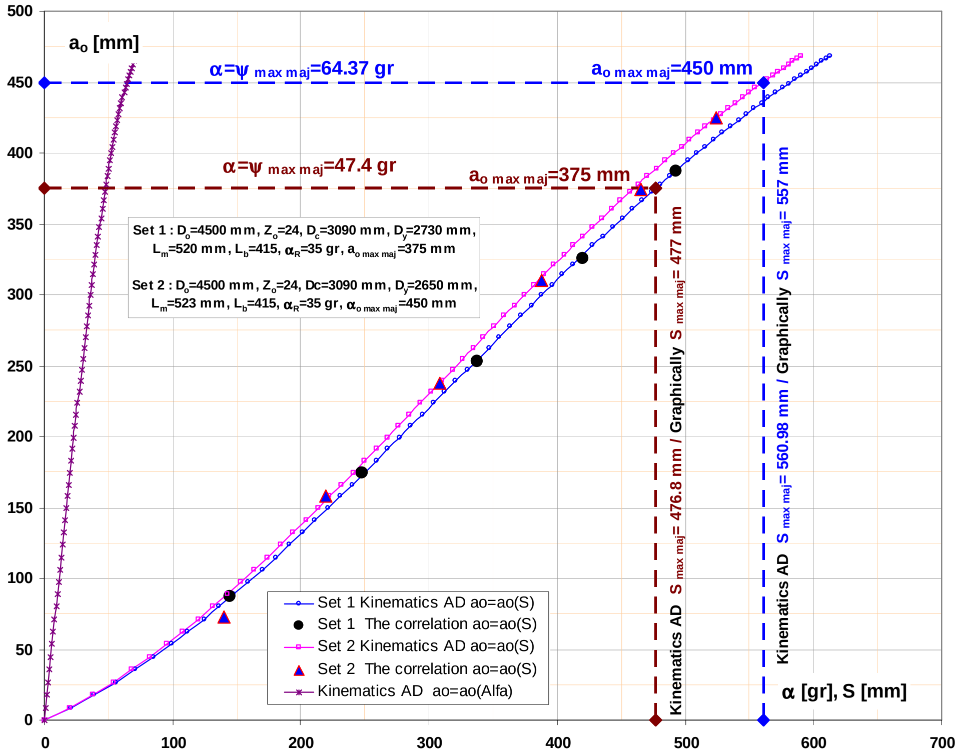

Figure 7. Comparison of the servomotor curves resulted from „Kinematics AD” and graphical for the asymmetric profiles and two data sets

4. The „Kinematics AD” software

The „Kinematics AD” software was created in Python language using the wxPython extension and requires the following the input data:

- the characteristic diameter of the wicked gate D_o [mm];
- the bolt diameter which fix the forks on the adjustment ring D_c [mm];
- the bolt diameter of the servomotor D_y [mm];
- the crank length L_b [mm];
- the rod length L_c [mm];
- the maximum opening of the wicked gate $a_{o\ max\ maj}$ [mm];
- the rigid angle between the profile chord and the crank α_R [grade].

The „Kinematics AD” interface for asymmetrical hydrofoil is shown in figure 8, which include:

- the Windows controls for input data;

o buttons for hydrofoil graphical representations and Microsoft Excel exportation;
o table with the parameters of the wicked gates hydrofoil;
o table with hydrofoil coordinates X, Y_{ex}, Y_{in};
o table with the correlations a_o=f(α) and a_o=f(S).

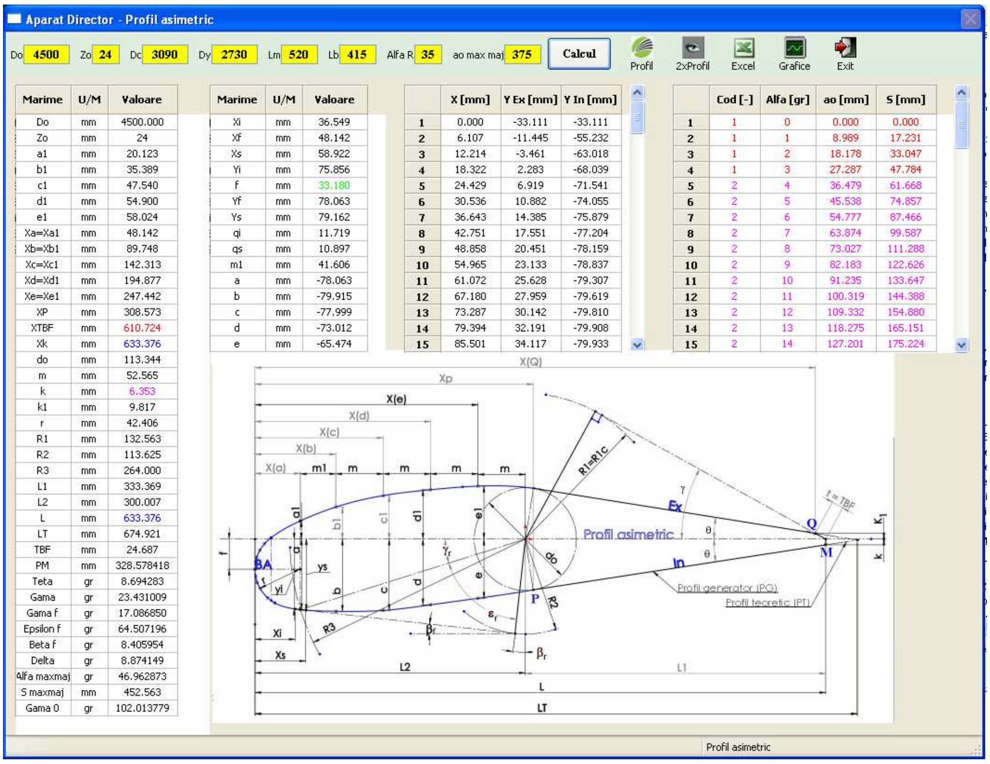

Figure 8. The „Kinematics AD” interface for asymmetrical hydrofoil

The figure 9 show the wicked gate opening a_o for the positioning angle of the blade α and the figure 10 show the graphical representations of the a_o=f(α) and a_o=f(S) correlations.

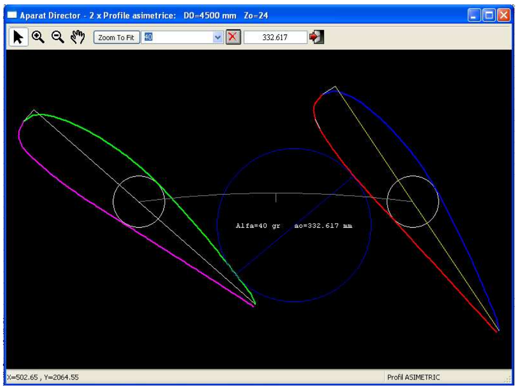

Figure 9. The wicked gate opening a_o for the positioning angle of the blade α

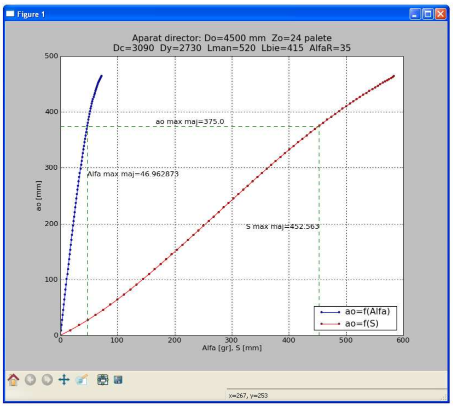

Figure 10. The representations of the a_o=f(α) and a_o=f(S) correlations

5. Conclusion

The paper present results for the wicked gates kinematics a_o=f(α) and a_o=f(S), calculated graphically with SolidWorks and numerically with „Kinematics AD" software, which was developed based on a mathematical algorithm for symmetric and asymmetric standardized hydrofoils. The results provided by the „Kinematics AD" software were compared with experimental curves and SolidWorks graphic results. Comparisons of these curves validate the „Kinematics AD" software and provide the designer with a computerized calculation tool of these correlations. The advantages of such a tool are obvious: quick computing time, accuracy of the calculations and optimization solution by going through several sets of input data.

References

[1] Alnaga A., Kueny J.L, *Optimal Design of Hydraulic Turbine Distributor*, National Polytechnic Institute of Grenoble, France, Issue 2, Vol. 3, 2008.

[2] Balint D., Muntean S., Romeo Susan-Resiga, Bernad S., *Swirling flow optimization in the spiral case and distributor of Kaplan hydraulic turbines*, Workshop on Vortex Dominated Flows–Achievements and Open Problems Timisoara, Romania, June 10-11, 2005.

[3] Daia D., *Theoretical and experimental research regarding the study and design of the spiral case, stay vane and wicked gate as components of the hydraulic turbines*, PhD Thesis, "Eftimie Murgu" University of Reşiţa, 2013.

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