THE PELTON RUNNER DESIGN METHODOLOGY

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Abstract. The paper presents a Pelton runner design methodology and a new original software to generate the bucket geometry and the main dimensions of the Pelton components: the jet diameter, the flow needle, the housing size. This software is used to design two Pelton runners and the flow needle geometry, which will be manufactured by rapid prototyping technique, using the Objet 30 Desktop Multifunctional 3D printer included in the endowment of the Center for Numerical Simulation and Prototyping from the "Eftimie Murgu" University of Resita. The runners are different through the number of buckets and through the second runner's bucket geometry which is similar to that of the first runner, but scaled in all directions with the bucket's numbers ratio. These parts were included in an experimental stand and coupled with an electrical generator, to study the influence of the runner and the flow needle geometry on the energetically characteristics of the turbine.

1. Introduction

This methodology covers the design of Pelton runners and aims to solve the following objectives:

- optimal parameters calculation for a series of Pelton runners;
- the calculation of geometrical bucket sizes;
- transversal cross-sections through Pelton bucket;
- longitudinal cross-sections through Pelton bucket.

These objectives have been implemented in a specific application "PeltonDesign", developed in Python language, that calculates the optimal parameters of the runner, the bucket geometry, the transversal and longitudinal cross-sections, the export of all calculated parameters to Microsoft Excel and create data files to generate bucket and the runner geometry in SolidWorks.

The model diameter is selected at D=400 mm, imposed from the condition of the runner Pelton fitting in the experimental stand. Based on market demands, the following area of interest for specific speed / injector: 19.2 .... 26.4 rpm was identified.

2. The optimal parameters calculation for a series of Pelton runners

The following correlations, obtained from theoretical and experimental research, are proposed in [1]:

- the correlation between the optimal specific speed $n_{s\,opt}$ and the ratio between the nozzle diameter „d" and the characteristic runner diameter „D";

$$n_{s\,opt} = (220...252)\frac{d}{D} \qquad \text{for one injecting needle} \tag{1}$$

$$n_{s\,opt} = (220...252)\frac{d}{D}\sqrt{i} \qquad \text{for „i" injecting needle} \qquad (2)$$

o the correlation between the optimal unitary discharge Q_{11opt} and the ratio between the nozzle diameter „d" and the characteristic runner diameter „D":

$$Q_{11opt} = 3.39\,(\frac{d}{D})^2 \qquad (3)$$

o the correlation between the nozzle diameter „d" and the jet diameter „d_o":

$$d = 1.1\,d_o \qquad (4)$$

o the performance Pelton runners have the ratio „D/d_o" between the limits 10 ... 18.

Adopting the model diameter D = 400 mm, the 19.2 .... 26.4 rpm range for specific speed / injector, the coefficients 2.47 and 240 for equations (1), (2) and (3), result optimal values for a range of 4 Pelton runners presented in Table 1, plotted in Figure 1, where the buckets number of the rotor „Zp" was imposed based on the experience of Pelton design and correlated with literature [2], [3], [4].

Table 1

Optimal values for a range of 4 Pelton runners

$n_{s\,opt}$	d/D	D	d	d_o	D/d_o	$Q_{11\,opt}$	$Q_{11\,opt}$	Z_p
rpm	-	mm	mm	mm	-	m^3/s	l/s	-
19.2	0.08	400	32	29.1	13.75	0.0158	15.8	23
21.6	0.09	400	36	32.7	12.22	0.0200	20.0	21
24	0.1	400	40	36.4	11.00	0.0247	24.7	19
26.4	0.11	400	44	40.0	10.00	0.0299	29.9	17

3. The geometrical bucket sizes

Based on the experience of Pelton design and experimental measurements on model Pelton, the main dimensions of the bucket from Figure 2 were obtained according to Table 2, compared with data from the literature.

Table 2

The geometrical bucket size

Parameter	D/d_o	B/d_o	L/B	b/d_o	L/d_o	h/d_o	L_1/d_o
Ratio	12.23	3.1	0.92	1.41	2.87	0.93	1.31
Anton [1]		2.8…4	0.7 … 0.9				
Voith [1]	11.02	2.94		1.04	2.5	0.86	1.08
Escher Wyss [1]	11.78	3.14		1.26	2.48	0.88	1.44
LMZ [1]	11.02	3.36		1.16	2.85	1.06	1.36
Kjolle [5]		2.5…3.1			2.1…2.5		1.2…1.5

Based on the analysis of performance Pelton geometry runners the following data were obtained:

o the unitless trailing edge and the outer side shape, Figure 3, relative to the characteristic runner radius R=D/2; the abscissa correspond to the unitless distances between sections dX, where 0 value correspond to the characteristic runner radius R, the positive values to the L1 area and the negative values to the L2 area, Figure 2; the ordinates correspond to the half unitless distances of the trailing edge „Y=B/2" and to the outer side „Y=B/2+g" respectively;

o the Z_{si}=f(Y) function of the Pelton bucket inner side, for 5 sections S1÷S5, Figure 4, both coordinates made unitless relative to the „B_{max}" section distance;

o the Z_{se}=f(Y) function of the Pelton bucket inner side, for 5 sections S1÷S5, Figure 6, both coordinates made unitless relative to the „B_{max}+g" section distance;

o the unitless Z_{si}=f(X) and Z_{se}=f(Y) functions of the Pelton bucket inner/outer side, Figure 7, for 3 A,G, B sections, Figure 2.

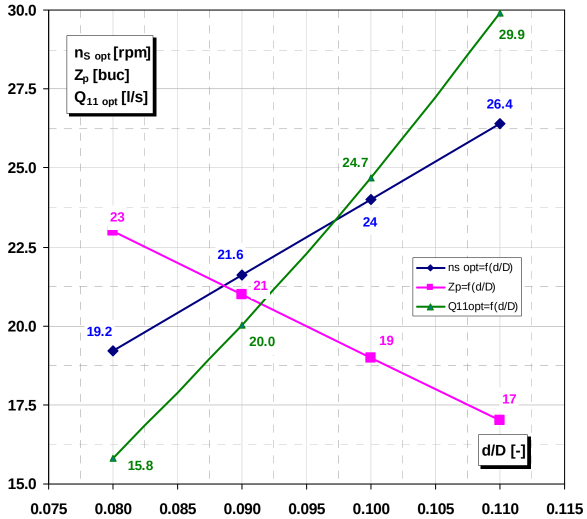

Fig. 1 The optimal $n_{s\ opt}$, Z_P, $Q_{11\ opt}$ values for 4 Pelton runners

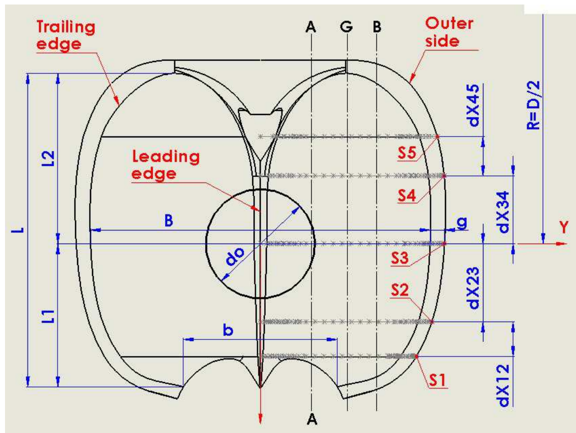

Fig. 2 The geometrical parameters of the Pelton bucket

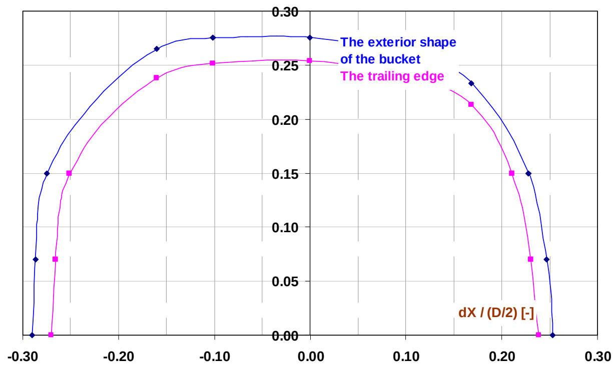

Fig. 3 The trailing edge and the outer side of the bucket

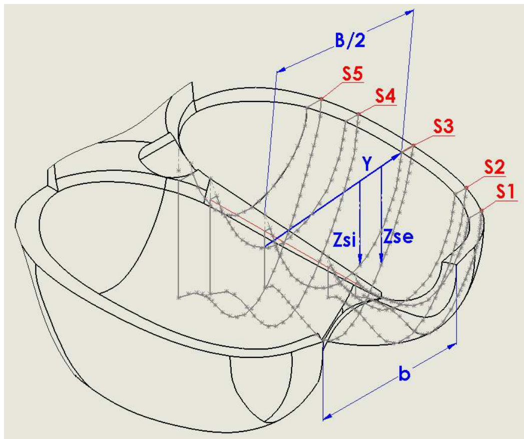

Fig. 4 The 3D view of the Pelton bucket

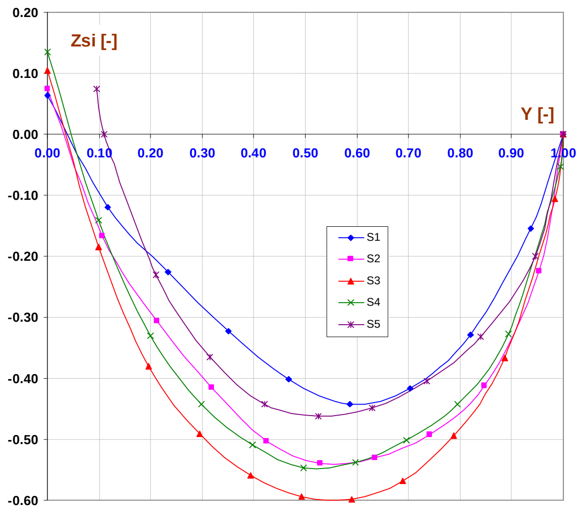

Fig. 5 The $Z_{si}=f(Y)$ function of the Pelton bucket inner side

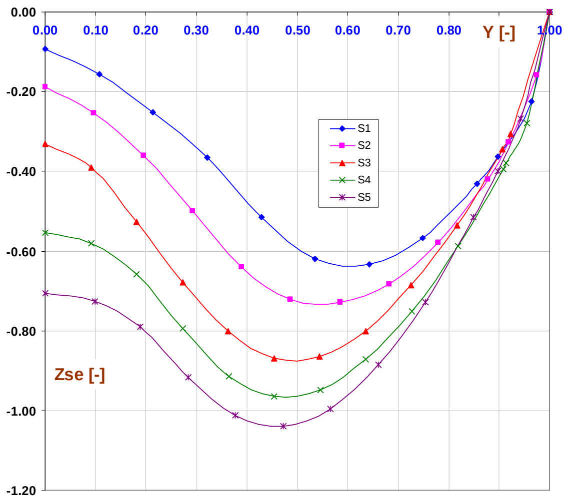

Fig. 6 The $Z_{se}=f(Y)$ function of the Pelton bucket outer side

4. The design of 2 Pelton Runners

The "PeltonDesign" software was used for the design of two Pelton runners with the same characteristic diameter D = 400 mm, first V1 with 21 bucket and second V2 with 19 buckets. The geometry of the V2 bucket has been scaled by a factor of 21/19 in the X, Y and Z direction, maintaining the same characteristic diameter D. The Z_{si} = f (Y) and the Z_{se} = f (Y) functions of the inner / outer sides are shown comparatively in Figures 8÷ 12, for the S1÷S5 sections.

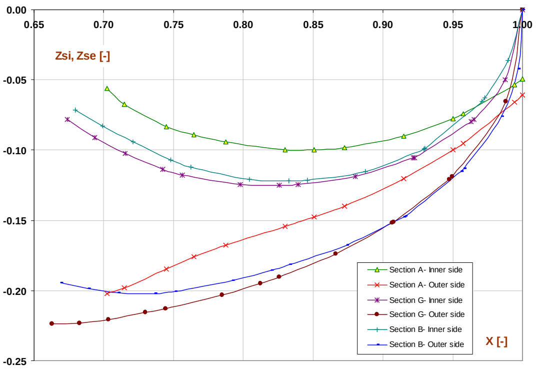

Fig. 7 The Z_{si}=f(X) and Z_{se}=f(Y) functions of the Pelton bucket inner/outer side for A, G, B sections

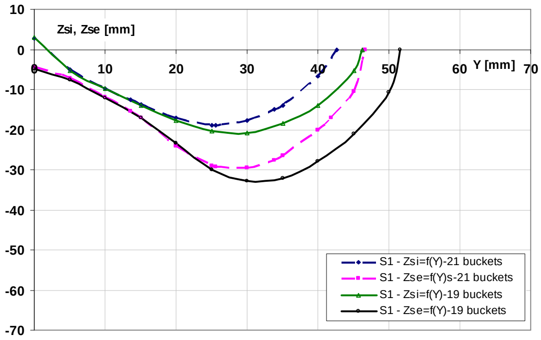

Fig. 8. The Z_{si}=f(Y) and Z_{si}=f(Y) of the Pelton bucket for S1 section

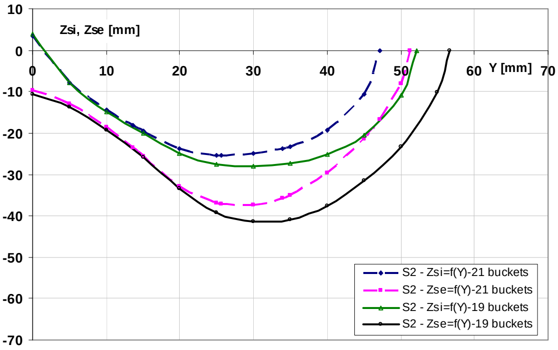

Fig. 9. The Z_{si}=f(Y) and Z_{si}=f(Y) of the Pelton bucket for S2 section

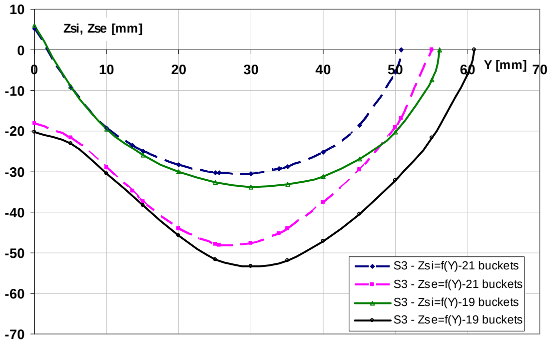

Fig. 10. The Z_{si}=f(Y) and Z_{si}=f(Y) of the Pelton bucket for S3 section

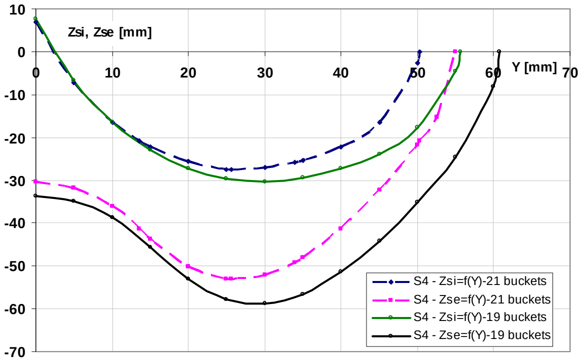

Fig. 11. The Z_{si}=f(Y) and Z_{si}=f(Y) of the Pelton bucket for S4 section

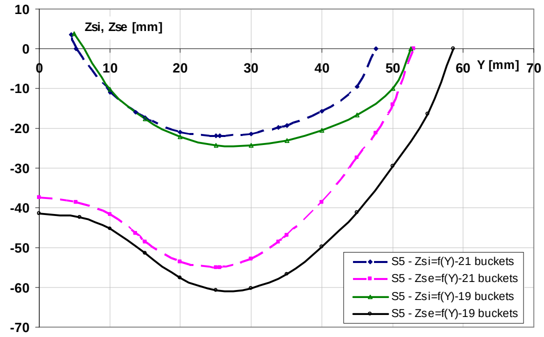

Fig. 12. The Z_{si}=f(Y) and Z_{si}=f(Y) of the Pelton bucket for S5 section

The runners data was exported from the "PeltonDesign" software to the SolidWorks to generate 3D geometry, Figures 13, 14. The two Pelton runners were manufactured by Rapid Prototyping technology, Figures 15, 16, on the Objet 30 Desktop printer included in the endowment of the Center for Numerical Simulation and Rapid Prototyping, University "Eftimie Murgu" Resita. From SolidWorks, the 3D geometry of the two runners was exported in STL format and imported into Objet Studio software, an application that manages the entire process of 3D printing process. For the runners fitting on tray printer, their geometry was scaled by a factor of 0.37, corresponding to a characteristic diameter of D=148 mm.

Fig. 13 The 3D runner geometry V1 with 21 buckets created in SolidWorks

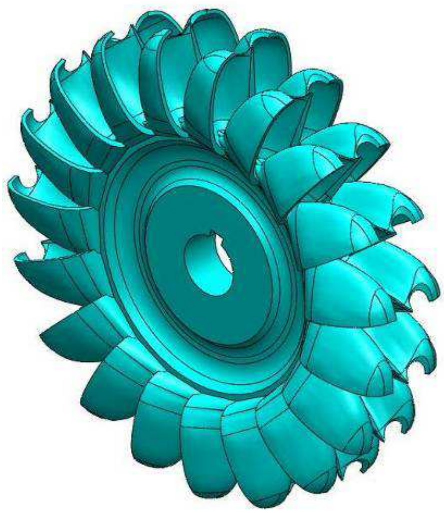

Fig. 14 The 3D runner geometry V2 with 19 buckets created in SolidWorks

Fig. 15 The runner V1 with 21 buckets manufactured by Rapid Prototyping technology

Fig. 16 The runner V2 with 19 buckets manufactured by Rapid Prototyping technology

5. The experimental stand for Pelton runners measurement

The experimental stand was designed for runners manufactured by Rapid Prototyping technology with characteristic diameter D = 148 mm. Three nozzle and needle injectors were designed, Figures 17, 18, also made by Rapid Prototyping.

Figure 19 shows the experimental stand for Pelton runners measurement. The microturbine is connected to the pressure circuit, the shaft rotor being coupled to an alternator. Shaft moment is calculated by the product of the force and its arm, and the force is measured by a force transducer.

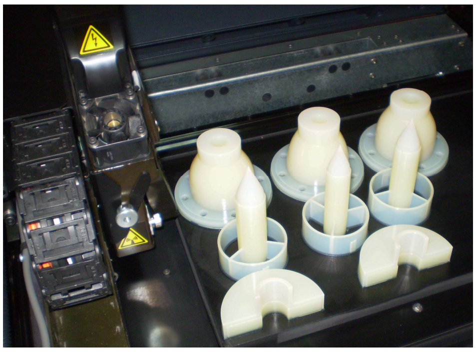

Fig. 17 The 3 nozzle and needle injectors on the printer tray

Fig. 18 The 3 nozzle and needle injectors after support material removal

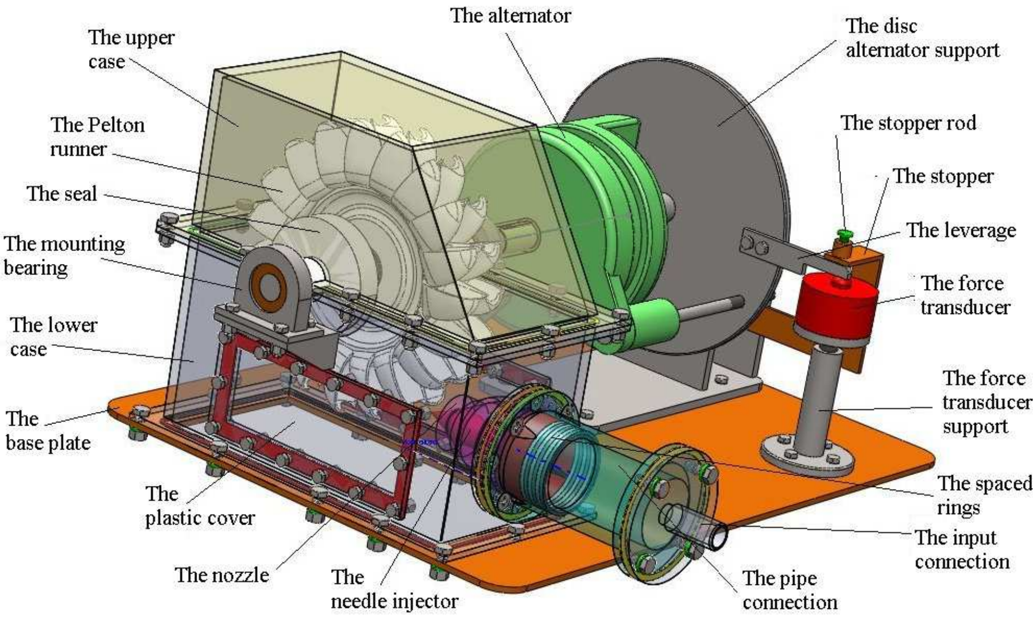

Fig. 19 The experimental stand for Pelton runners measurement with D=148 mm

6. Conclusions

The paper presents numerical and graphical results generated by the "PeltonDesign" software, two different Pelton runner geometries designed by this application and the components of an experimental stand for testing Pelton runners with characteristic diameter D=148 mm, that can be generated by Rapid Prototyping technology. Numerical results on experimental stand will be available after final component execution.

References

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