A comparative Study Between the Costs of Polymer Based Rapid Prototyping and Steel Based Manufacture

DORIAN NEDELCU*, AUREL BARA, ADRIAN PELLAC, SORIN LAURENTIU BOGDAN
Eftimie Murgu University of Resita, Department of Mechanics and Material Engineering, 1-4 Traian Vuia Sq., 320085 Resita, Romania

The Pelton turbines convert hydraulic energy into mechanical energy, through the Pelton runner, by using high heads and small discharges. The runner has a complex geometry, described in drawings by transversal and longitudinal sections that form continuous surfaces. The SolidWorks software was used to design two Pelton runners: the R1 runner with 21 buckets and the R2 runner with 19 buckets. The runners were made of polymeric materials through the Rapid Prototyping process, using the Objet Desktop 3D printer, which is based on the Objet PolyJet technology, with a layer thickness of 28 microns [1]. The runners were used to measure the hydrodynamic characteristics of a Pelton microturbine on a test rig. The paper aims to highlight the advantages of the Rapid Prototyping process compared to the traditional technology used to manufacture Pelton runners that are intended for experimental research.

Keywords: polymer, Rapid Prototyping, Pelton, runner, manufacture, costs

The CAD model of the two Pelton runners was created using the SolidWorks software. The geometry of the V1 Pelton runner, with 21 buckets and of the V2 runner, with 19 buckets, is presented in figure 1 [2]. The buckets of the V2 Pelton runner are scaled with a 21/19 ratio on the X, Y and Z directions, maintaining the same characteristic diameter of 148 mm [2, 3].

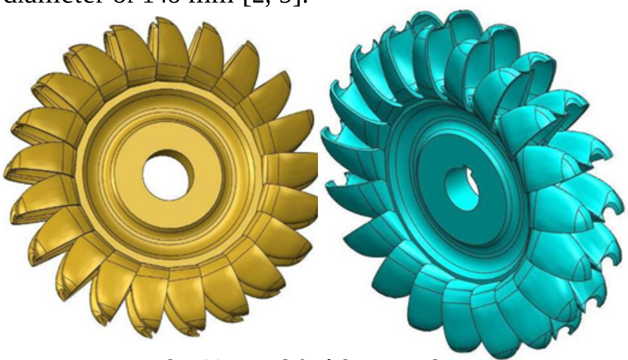

Fig. 1 The CAD model of the V1 and V2 runner

The two Pelton runners were printed on the Objet 3D Printer Multifunctional Desktop 30 in a horizontal position, with the plane of blade symmetry disposed parallel to the printer table. The geometry of the runner that was obtained after removing the support material, figure 2, revealed the high precision of the geometrical details with a small thickness and the high quality of the surfaces. Table 1 shows the printing parameters of the two runners [3].

In the Center for Numerical Simulation & Digital/Rapid Prototyping (www.csnp.roedu.ro) of the Eftimie Murgu University of Resita, research on a Pelton microturbine, manufactured through rapid prototyping and equipped with the two runners and different nozzles was performed [4], [5].

The Rapid Prototyping cost calculation

This section presents the cost of the two runners that were obtained through PolyJet Inkjet technology, based partially on the cost estimation algorithm described in [6]. The cost **Cost** can be divided into five main categories: machine purchase cost allocated to the build **P**, material cost **M**, labour cost $\mathbf{L_c}$, department fixed costs $\mathbf{R_s}$ and profit $\mathbf{P_r}$:

$$Cost = P + M + L_c + R_s + P_r$$

The machine purchase cost **P** is based on the build time of the part. We can assume a useful life of the machine and divide the purchase price equally by all years. Also, the machine builds parts only a fraction of the time during a year. Then, the purchase cost for one build can be calculated as [6]:

Parameter	U/M	Runner V1	Runner V2
The characteristic diameter	mm	148	148
The maximal dimensions	mm	182.75 x 182.68 x 41.01	186.5 x 186.5 x 45.3
Material	-	VeroWhite polymer	VeroBlue polymer
Model material	g	766	839
Support material	g	639	726
Printing time	h/min	17 h	17 h 20 min
Layer thickness (Z-axis)	μm	28	28
Layer's number	-	1464	1671

Table 1
THE PRINTING PARAMETERS OF THE TWO RUNNERS

*email: d.nedelcu@uem.ro,; Phone.: 0723299050

$$P = \frac{M_{ac} \cdot T_b}{h_d \cdot 365 \cdot Y}$$

where:

- M_{ac} is the machine acquisition cost, in Euros;
- T_b is the time needed to build a part, in hours; the build time is a function of part size, part shape, number of parts in the build, and the machine's build speed.
- 365 represent the number of days in a year;
- h_d is the average number of hours per day used by the machine to build parts during one year; in our case, the average build time for a year can be estimated at 2 h per day; if the machine was acquired for repetitive manufacturing, the average build time per day will increase and this value must be modified consequently;

Y is the useful life of the machine, in years.

The material **M** cost can be easily calculated based on the cost of the model and support material per kilogram and the model and support consuption during the build process:

$$M = c_v \cdot (M_c + S_c) = c \cdot (C_m * Q_m + C_s * Q_s)$$

where:

c_v is a coefficient for extra material volume that is lost during the build process; typical values range from 1.1 to 1.5;

$M_c = C_m * Q_m$ is the model cost, in Euros;

C_m is the model cost per kilogram;

Q_m is the model consumption, in kilograms;

$S_c = C_s * Q_s$ is the support cost, in Euros;

C_s is the support cost per kilogram;

Q_s is the support consumption, in kilograms.

Usually, the model and support material are delivered in packs of 2 and, for only one kit acquisition, the cost also includes transport.

The labour cost L_c is the time required for employees to set up the build, remove the fabricated parts, clean the

Table 2
THE RAPID PROTOTYPING COST CALCULATION

Cost component	Cost element	Symbol	U/M	Runner V1	Runner V2
Machine purchase	Machine acquisition cost	M_{ac}	Euro	40000	40000
	Useful life of the machine	Y	years	5	5
	Typical up-time percentage	h_d	hours	2	2
	Time for part build	T_b	hours	17	17.3
	Machine purchase cost	P	Euro	**186**	**190**
Material cost	Model consumable name	-	-	VeroWhite	VeroBlue
	Support consumable name	-	-	FullCure 705 Support Resin	
	Model cost / kg	C_m	Euro/kg	483	483
	Model consumption	Q_m	kg	0.766	0.839
	Model cost	M_c	Euro	370	405
	Support cost / kg	C_s	Euro/kg	243	243
	Support consumption	Q_s	kg	0.639	0.726
	Support cost	S_c	Euro	155	176
	Loss coefficient	c_v	%	1.2	1.2
	Material cost	M	Euro	**630**	**698**
Labor cost	Number of employees	N	No.	1	1
	Cost per hour	C_h	Euro/hour	10	10
	Work hours	W_h	hours	3	3
	Labor cost	L_c	Euro	**30**	**30**

Continuated table 2

The department fixed cost	The fixed percentage	$R_{s\%}$	%	15	15
	The fixed cost	R_s	Euro	**127**	**138**
Profit	The profit percentage	$P_{r\%}$	%	10	10
	The profit	P_r	Euro	**97**	**106**
-	**Final cost**	$Cost$	Euro	**1071**	**1161**

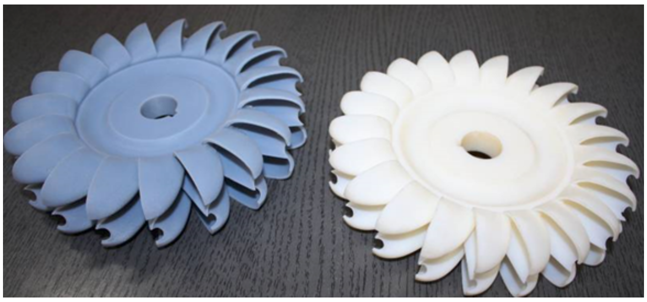

Fig. 2 The final shape of the two Pelton runners

parts, clean the machine and get the machine ready for the next build.

$$L_c = N \cdot C_h \cdot W_h$$

where:

N is the number of employees allocated to the build process;

C_h is the employee's salary per hour, in Euros/hour;

W_h is the number of hours worked by the employees, in hours.

The department fixed costs R_s take into account the energy cost, service and maintenance costs and other general costs of a department.

$$R_s = R_{s\%} \cdot (P + M + L_c)$$

The profit P_r can be calculated through the profit percentage $P_{r\%}$.

Table 2 shows the Rapid Prototyping cost calculation.

The Manufacturing cost calculation

This section presents the technology that was used for the execution and the method that was used to calculate the costs of a Pelton runner, starting from the raw material type X3CrNiMo13-4 [7].

The costs can be divided into four categories: the acquisition costs A_c, the manufacturing costs *Mc*, the fixed costs F_c and the collaboration costs C_c.

$$Cost = A_c + M_c + F_c + C_c \quad [Euro]$$

The acquisition costs A_c consist of the raw material price R_{mc} and the transport costs T_c.

$$A_c = R_{mc} + T_c \, [Euro]$$

The manufacturing costs M_c consist of:

$$M_c = L_c + U_c + H_{tc} \, [Euro]$$

where:

-L_c represents the labour costs, which consist of the price for the following technical operations:

- cutting of the material;
- turning at the requested dimensions; due to the complexity of the runner, the use of a CNC turning lathe machine is necessary for this operation;
- grinding of the internal diameter; the grinding operation will be done on a conventional grinding machine;
- execution of the keyway;
- milling rotor blades; this operation requires the use of a CNC milling machine in five axes.

The necessary time for all operations is 100 h.

- U_c represents the cost of utilities;
- H_{tc} represents the costs for the stress relieving heat treatment.

The fixed costs F_c implies the service and maintenance prices and other general costs of the company [8].

The collaboration costs refer to the price for external collaboration. In our situation, it is the price paid to balance the runner.

The final cost will be calculated as follows:

$$P = Cost + P_r$$

where P_r is the profit.

The profit will be calculated through the profit percentage:

$$P_r = P_r \% \, Cost$$

The cost calculation for the execution of the Pelton runner is presented in table 3.

To finalize the runner geometry, a minimum of 10 people are involved in the following operations: the auction of the material acquisition, the material cutting, the turning, the rectification, the milling, the locksmithing, the runner

Cost component	Cost element	Symbol	Value (Euro)
Acquisition cost (A_c)	Raw material	A_c	105
	Transport cost	T_c	60
Manufacturing cost (M_c)	Labour cost	L_c	322
	Cost of utilities	U_c	347
	Heat treatment cost	H_{tc}	250
Fixed cost		F_c	732
Collaboration cost		C_c	120
		Cost	1936
Profit	The profit percentage	P_r %	10 %
	The profit	P_r (Euro)	193.6
		Final cost (Euro)	2129.6

Table 3
THE MANUFACTORING COST CALCULATION

Table 4
THE COMPARATIVE RESULTS BETWEEN RAPID PROTOTYPING AND THE MANUFACTURING PROCESS

Parameter	U/M	Rapid Prototyping process	Manufacturing process
Material type	-	Polymer	X3CrNiMo13-4
Material cost	Euro	630 / 698	105
Build time	h	~17 / 17 h 20 min	~100
Number of employees	No.	1	Minimum 10
Final cost	Euro	1071 / 1161	2129.6

balancing, CNC programmer, the technologist, the CTC control.

Rapid Prototyping versus Manufacturing

Table 4 shows the main conclusions of this comparative study:

- the time of the process is ~ six time smaller for the Rapid Prototyping technology;
- the number of required employees is ten times bigger for the classic process compared to the Rapid Prototyping technology;
- the final cost of the Rapid Prototyping technology is half of the classic manufacturing process cost, even if the material cost is six times bigger.

Conclusions

Experimental research on hydraulic turbine runners involves the alteration of their geometries in order to find the optimal one. The two runners were used to measure the hydrodynamic characteristics of a Pelton microturbine on a test rig [5]. The runner's geometry, created through Rapid Prototyping technology, withstood all experimental tests very well, without registering any incident during the experiments, even for the maximum test speed of 3000 rpm. In the experimental research area, Rapid Prototyping technology is an alternative solution for microturbine components fabrication, offering a high precision (0.1 mm), fast and cheap manufacture of these geometries.

References

1.*** PolyJet™ Materials Data Sheet, 2014.

2.NEDELCU, D., POP, F.M., COJOCARU, V., HOPOTA, A., Rapid prototyping of a Pelton runner, A XII-a Conferinta Nationala multidiciplinara – cu participare international Profesorul Dorin PAVEL – fondatorul hidroenergeticii romanesti, Sebes, 2012, ISSN 2067-7138.

3.NEDELCU, D., AVASILOAIE, R., FLOREA, D., RAJIC, A., Applications of the Rapid Prototyping Technology to Manufacture the Pelton Runners, Eftimie Murgu University of Resita, Year XX, No. 1, 2013, ISSN 1453 – 7397.

4.NEDELCU, D., COJOCARU, V., GHICAN, A., PERIS-BENDU, F., AVASILOAIE, R., Considerations Regarding the Use of Polymers for the Rapid Prototyping of the Hydraulic Turbine Runners Designed for Experimental Research on the Model, Mat. Plast., **52**, no. 4, 2015, p. 475

5.AVASILOAIE, R., Theoretical and experimental research on microturbines for high head and low discharges, PhD thesis, Eftimie Murgu University of Resita, 2013.

6.GIBSON, I., ROSEN, D.W., STUCKER, B., Additive Manufacturing Technologies, Rapid Prototyping to Direct Digital Manufacturing, Springer, ISBN: 978-1-4419-1119-3.

7.BORDEASU, I., MICU, L.M., MITELEA, I., UTU, I.D., PIRVULESCU, L.D., SIRBU N.A., Cavitation Erosion of HVOF Metal-ceramic Composite Coatings Deposited onto Duplex Stainless Steel Substrate, Mat. Plast., **53**, no.4, 2016, p.781

8.POPESCU, T. C., DUMITRESCU, C., BORDEASU, I., Aspects Concerning the Use of Plastics in Developing Test Stands for Experimental Models of Hydraulic Turbine Blades and Rotors, Mat. Plast., **53**, no.1, 2016, p.174

Manuscript received: 6.03.2017