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RAPID MANUFACTURING BY POLYJET TECHNOLOGY OF CUSTOMIZED TURBINES FOR RENEWABLE ENERGY GENERATION

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Abstract

In Romania, the small hydro power scheme (mini-, micro- and pico- hydro power) represents a potential renewable energy source for electrical energy. Nevertheless, this small hydro potential must be used efficiently. The paper proposes an innovative e-method of integrating design with manufacturing, for a small Pelton turbine. The first part presents the application of Rapid Product Development (RPD) with focus on Product Design (PD) of a new, very small customized hydropower turbine. This turbine, with an output of less than 5 kW, can be a good option for use in experimental research stands and for the electrification of rural communities. In the second part, applications of Additive Layer Manufacturing (ALM) technology, with focus on customized small hydro turbine, are presented. An experimental Pelton turbine was manufactured, using an additive manufacturing technology known as Polymer Jetting (PolyJet). The research was conducted at the Industrial Innovative Technologies Laboratory, within the Advanced Manufacturing Technologies and Systems (AMTS) research department. The paper shows how additive manufacturing technologies (AMT) can be used to build complex customized parts, such as new small Pelton turbines (for the pico hydro scheme), used in experimental research stands. It gives guidelines for designers wishing to follow a similar route.

Key words: Pelton turbine, PolyJet technology, manufacturing, rapid product development, renewable energy

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1. Introduction

Approaches regarding the small hydro scheme are focused mainly on turbine design and optimization. Mini-, micro- and pico- hydro power are now recognized as key technologies in bringing renewable electricity to rural populations. Also, the small hydropower stations offer a feasible solution for reducing greenhouse gas emissions (Jaliu et al., 2009). Within the range of small hydro power, mini-hydro typically refers to schemes below 1 MW, micro-hydro below 100 kW and pico-hydro below 5 kW (Kamaruzzaman and Juhari, 2009). Williams and Simpson (2008) focussed on the design and analysis of pico-hydro power turbine, using Ansys CFX software. The bucket of the Pelton turbine was analyzed.

Jaliu et al. (2010) have shown that the first step in designing the electro-mechanical equipment for hydro power turbine depends on selecting the best turbine for the particular hydro site, the available water flow and stream head and the generator's desired running speed. As a main feature, the majority of mentioned investigations deals with optimal design and analysis of hydro turbine.

Rapid Product Development (RPD) is an interdisciplinary methodology that combines all influences of an engineering process for iterative product development. An up-to-date review regarding RPD has been performed by Bullinger et al. (2000), Ferreira et al. (2006). The identification and implementation of designer requirements in the early stages of RPD are significant issues for successful product development, reducing time and costs

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(Engelbrektsson and Soderman, 2004) and improving quality. These leads to focusing on the integration of product design with faster manufacturing process activities. One possible methodology to achieve this goal is through the use of Rapid X technologies. The Rapid X concept groups some specific terms, such as: Rapid Prototyping (RP), Rapid Tooling (RT), Rapid Manufacturing (RM), Rapid Nanotechnology (RN) etc.

Rapid prototyping technology involves automated fabrication of physically complex shapes directly from a 3D CAD model, using a layer-by-layer deposition principle.

Rapid manufacturing is based on rapid prototyping processes and methods and consist in fast production of final products, in small series. Also, the terms of Additive Manufacturing (AM) or Direct Digital Manufacturing (DDM) are used as an extension of rapid prototyping to real parts (Wohlers, 2010). The Society of Manufacturing Engineers definition of DDM is "The process of going directly from an electronic, digital representation of a part to the final product via additive manufacturing"(Grimm, 2006).

Nowadays, there are a lot of RP/RM technologies. The oldest are layered object manufacturing and stereolithography. More recent RM technologies (Wohlers, 2010) include selective laser sintering (SLS), fused deposition modeling (FDM), inkjet technologies, Polymer Jetting (PolyJet), selective laser melting (SLM), direct metal laser sintering (DMLS), direct metal deposition (DMD), electron beam melting (EBM) and laser engineered net shaping (LENS). Different approaches regarding RM applications for turbines exist in a more or less advanced stage.

The evolution of materials used within RP/RM process and the tray size of the RP/RM machine are determinant factors in the additive manufacturing of turbines. The case study presented in (Quail et al., 2009) focused on manufacturing of complex impeller blade using RM technology such as 3D printing, FDM and a RT technology, called room temperature vulcanizing (RTV). The results of this study have shown that FDM/RTV is a good prototype production method for testing. Wu et al. (2009) studied the fabrication of an integral ceramic mould for investment casting of hollow aircraft turbine blade, based on stereolithography. Berce et al. (2008) focused their efforts on the manufacturing of the active elements for injection molding tools, using selective laser sintering technology. The case study was targeted at a lid component of a grass-cutting machine. All the researches on RM field have shown that this technique can manufacture, in a short time, very complex final products for prototype testing and small series.

The purpose of the research and development work presented in this paper was to propose and elaborate a practical methodology, in order to integrate additive manufacturing technologies in a new rapid product development cycle, for hydro turbines. The developed methodology provides information for designers and manufacturers, in order to integrate innovative technologies that are best suited for the renewable energy generation equipments production and to reduce the product development time and reduce manufacturing costs. The research has been carried out through two case studies.

The RM applications for Pelton turbine were developed within the Industrial Innovative Technologies Laboratory (IITL), Manufacturing Engineering Department from Transilvania University of Braşov. The IITL is one of the research laboratories within PLADETINO (Platform for Innovative Technological Development).

The interdisciplinary platform PLADETINO (Ivan, 2009) is integrated in a research and multidisciplinary training unitary structure of Transilvania University of Brasov and is the foundation of the AMTS (Advanced Manufacturing Technologies and Systems) research department.

2. Rapid product development focused on Pelton turbine

A new RPD process for a Pelton turbine is proposed (Fig. 1). The Pelton turbine dimensional characteristics were calculated based on hydrodynamic considerations, using TURBNPRO software. The arrangement of the Pelton turbine runner is shown in Fig. 2.

The design process consists of alternative stages: parametric design of turbine, computational fluid dynamics (CFD) optimization and Finite Element Method (FEM) analysis. CFD is a computer-based tool for simulating the behavior of systems involving fluid flow, heat transfer and other related physical processes.

FEM allows stress, thermal and dynamic analysis to be performed and produces design data quickly, easily and cheaply. Regarding the manufacturing of the Pelton runner, there are classic manufacturing methods and the authors also propose new manufacturing methods. The Pelton runner classic manufacturing methods are: welded runner bucket (WRB) technology and bolted runner bucket (BRB) technology.

The WRB technology consists in two steps. Firstly, the root area of the runner is computer numerical control (CNC) milled, and then bucket heads welded of it. The BRB technology consists also in two steps. First the buckets are CNC milled and then assembled on the wheel with bolts. Two new Pelton runner manufacturing methods, based on additive manufacturing technologies, are proposed.

The first method consists of additive manufacturing of the Pelton blades, followed by classic assembly, using bolts, on the wheel. The second proposed method consists of rapid manufacturing of a monoblock runner turbine.

Depending on the rapid manufacturing method, materials like durable plastic or metals could be used. An original Pelton runner was manufactured, with PolyJet technology, using this method. Using

SolidWorks software, parametrical CAD models for a Pelton runner was designed by the main author, one CAD model for each proposed manufacturing method. The first CAD model consists of Pelton blades attached to the wheel, with bolts (Fig. 3), according to the first proposed method. The second CAD model consists of a monoblock runner (Fig. 4). The virtual mounting (on the shaft) scheme is shown in Fig. 5. This kind of Pelton runner cannot be manufactured by classical manufacturing techniques, like CNC machining, but only using innovative technologies, like additive manufacturing.

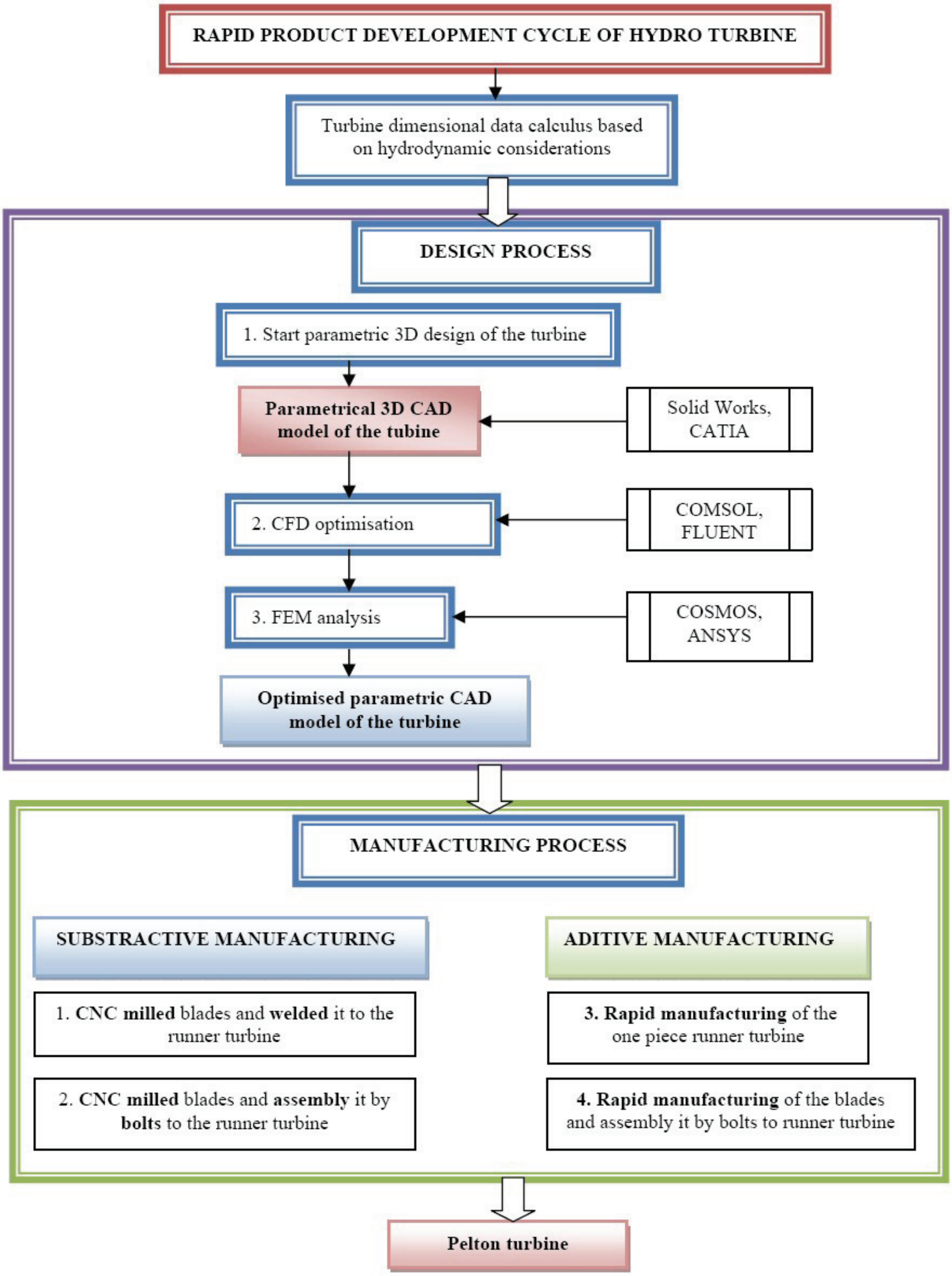

Fig. 1. Flow chart RPD cycle of Pelton turbine

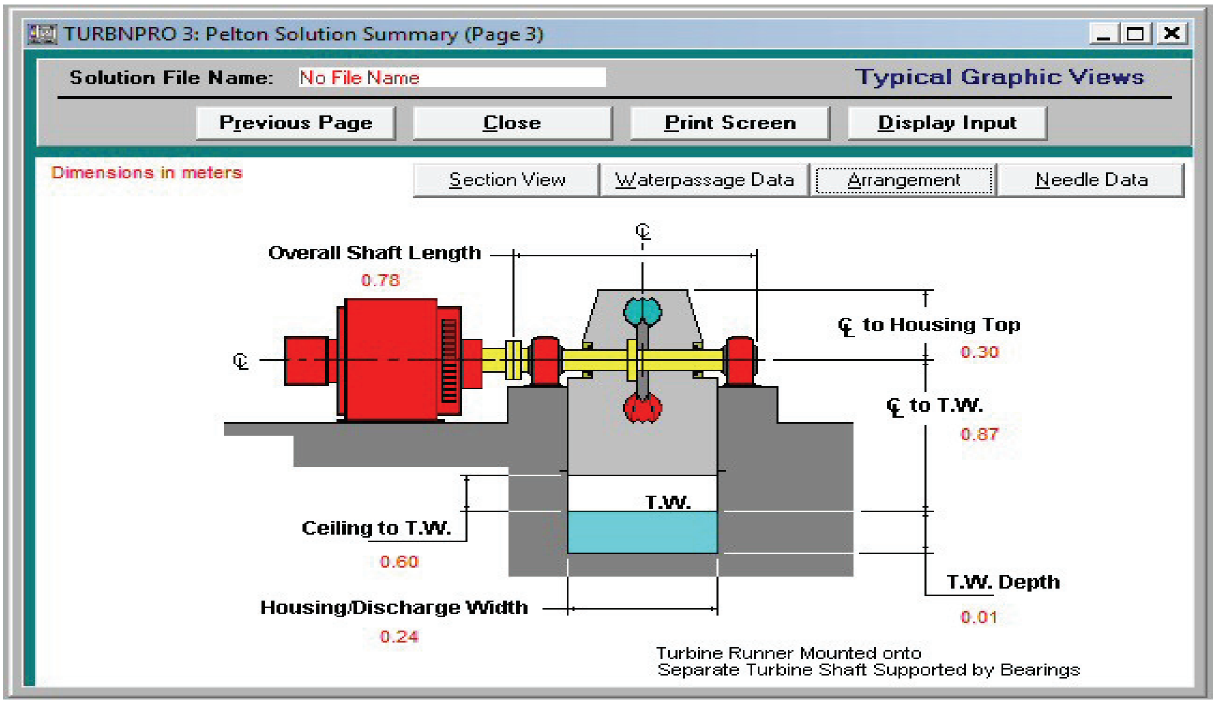

Fig. 2. The arrangement of Pelton's turbine runner using TURBNPRO software

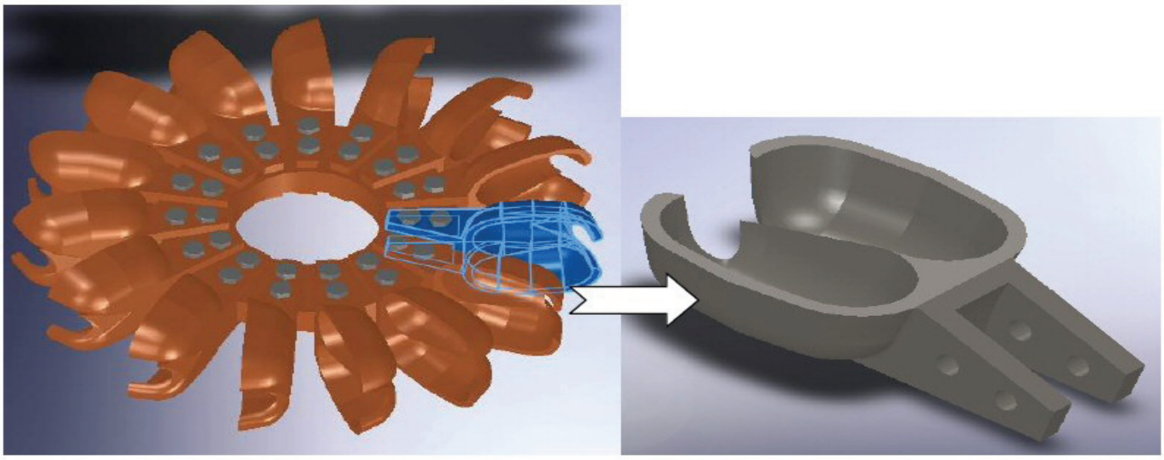

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Fig. 3. Case study 1: a) The assembled Pelton runner designed in SolidWorks; b) The bucket

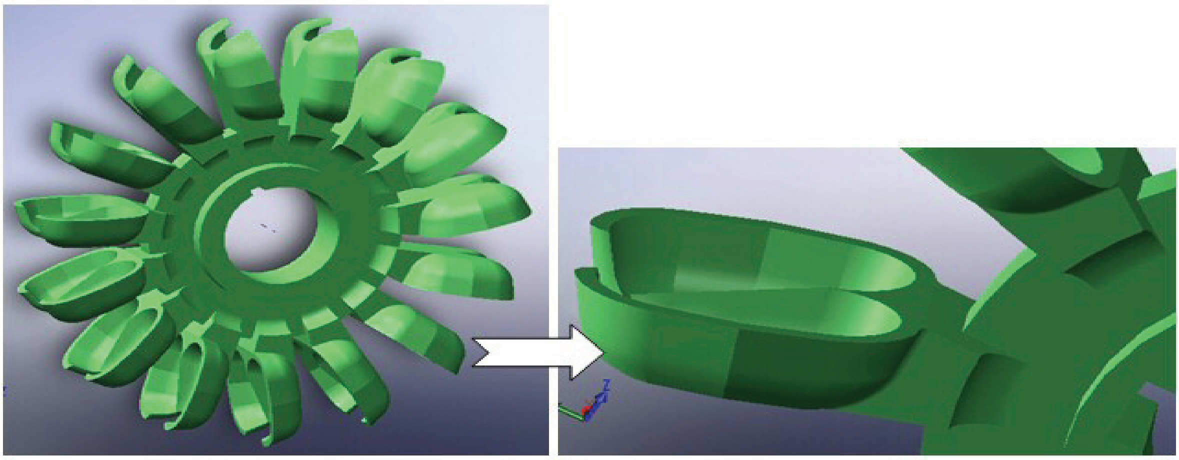

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Fig. 4. Case study 2: One part runner designed in SolidWorks

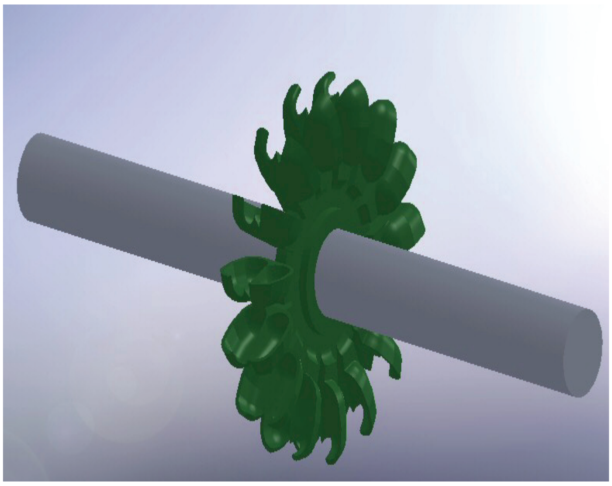

Fig. 5. Pelton virtual mounting scheme

3. Additive manufacturing of Pelton turbine runner. Case study

Based on the optimal design solution founded in the last paragraph, a monoblock Pelton runner was additive manufactured by PolyJet technology, on an EDEN 350 machine (Fig. 6).

The 3D printing process consists in the following three steps: pre-processing, processing and post-processing. In the first stage the Pelton runner 3D model was exported from SolidWorks in a very accurate STL (STereoLithography or Standard Triangulation Language) file. In this case, the original surface of solid was replaced with a mesh of 732728 triangulated surface segments (Fig. 7).

This STL file was imported into Objet Studio software in order to simulate the additive manufacturing process, estimate the material consumption and building time and find and optimal orientation.

Three main aspects are influenced by the manufacturing orientation: the surface quality, the consumption of support material and the build time.

Fig. 6. EDEN 350 rapid manufacturing machine from Transilvania University of Brasov

Fig. 7. STL model

The minimum manufacturing time was determined for the optimal runner position shown in the Fig. 8. In the processing step, the printer head moves back and forth along the X-axis and deposits thin (16 micron) layers of photopolymer onto the build tray. Immediately after building each layer, UV bulbs, placed alongside the jetting bridge, emit UV light, curing and hardening each layer.

The building tray moves down and the jet heads continue building, layer by layer, until the model is complete. Two different acrylic photopolymer materials are used: one for the model (FullCure 720), and another gel-like material for support (FullCure 705). When the printing process was completed, the part was left to consolidate for one hour. The rough Pelton model (after processing stage) is shown in the Fig. 9.

In this stage the rough buckets are filled with a combination of support and model materials, Fig. 9b. The post processing step is very simple and consists in removing of the part from the machine table, followed of support material cleaning using a water jet recycling station (Fig. 10). The surface quality of the runner is very good (comparable with injection molded parts).

4. Results and discussion

Pico-hydro is an ideal power source for experimental stands and also for improving rural energy services. Pico turbines are simple to install and operate. They can also provide an adequate source of electric power (light bulbs, radios, televisions and other appliances) for rural homesteads, 24 hours per day, from slow flowing streams. In contrast to traditional processes, rapid manufacturing is a fast and easy method capable of producing highly optimized geometries at no extra cost. Thus, RM can produce very small hydro (pico-hydro) schemes, with an output of less than 5 kW.

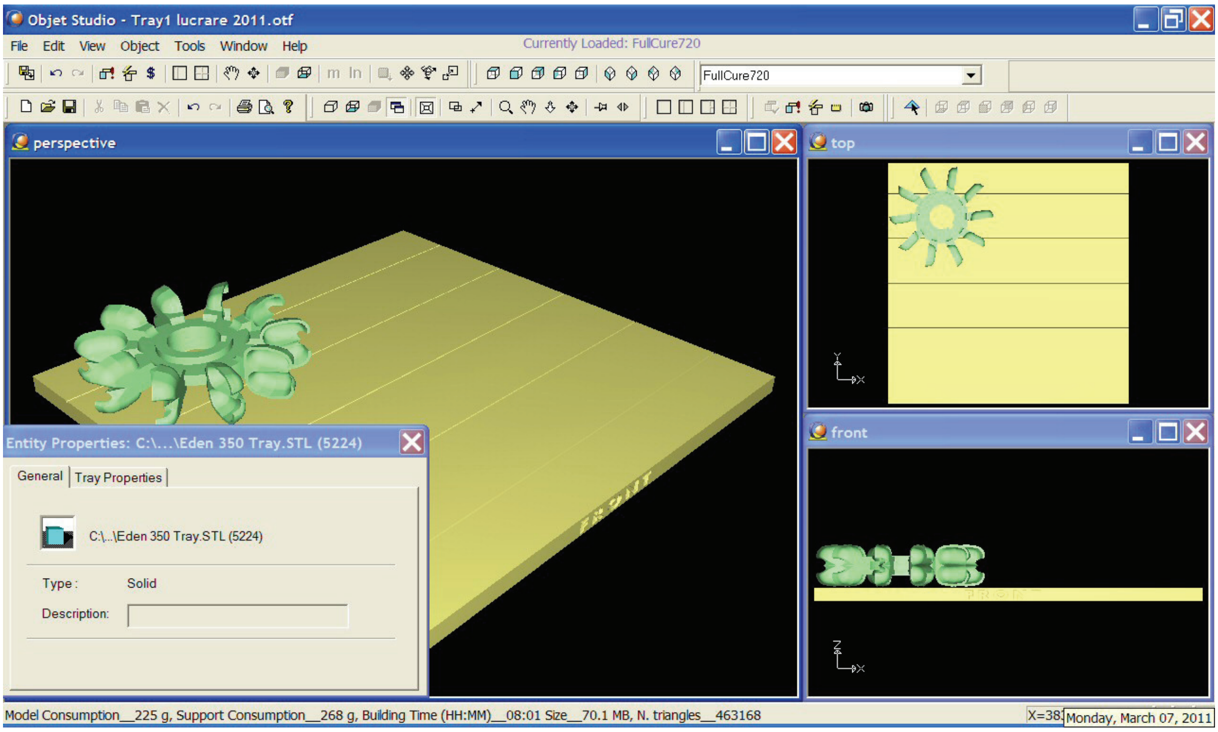

Fig. 8. The virtual manufacturing simulation of Pelton runner

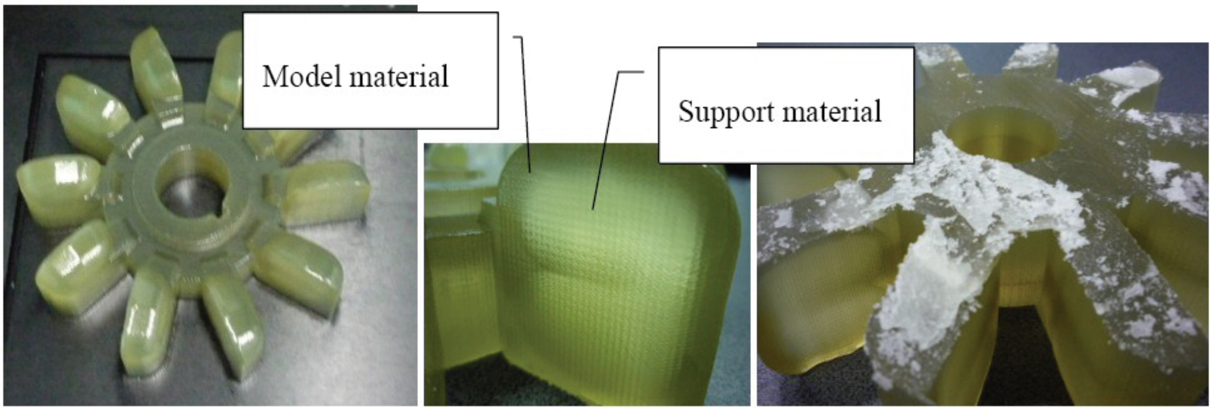

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Fig. 9. a) The Pelton runner on the build tray b) Pelton bucket c) Part bottom, with support material

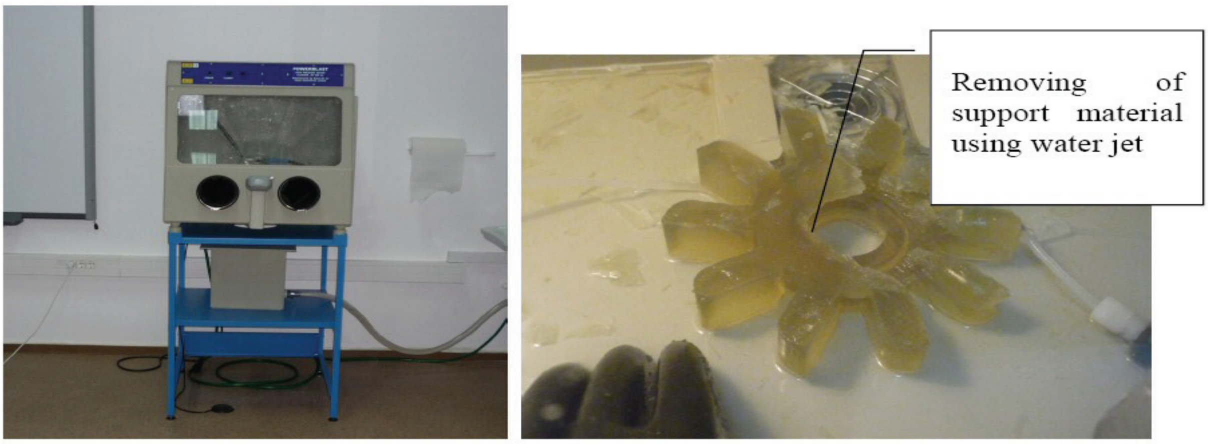

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Fig. 10. a) Water jet recycle station, Transilvania University of Brasov; b) Pelton postprocesing method

A parametric 3D model of the turbine is useful in order to develop a CAD family of turbines. Using a hybrid modeling (combination between surface and solid modeling) the complex shapes used in turbine design can be obtained. An original customized Pelton runner (Fig. 11) was designed and rapid manufactured with PolyJet technology, from transparent plastic material.

Additive manufacturing technology can reduce significantly the manufacturing time of complex products like hydro turbines. The presented Pelton runner, with an external diameter of 150 mm, was manufactured in about 9 hours.

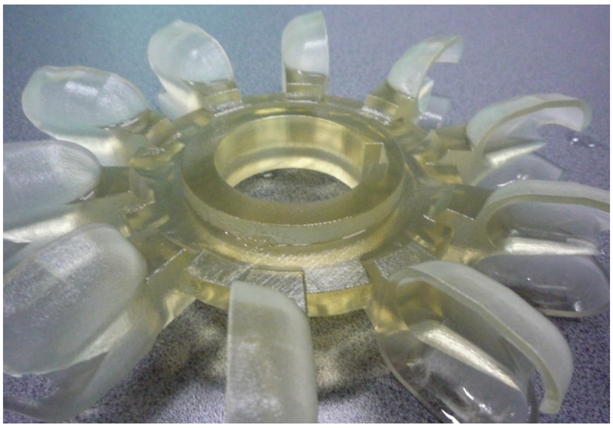

Fig. 11. Pelton runner manufactured by PolyJet technology at Transilvania University of Brasov

Also, using AM technology, complex shapes that cannot be manufacturing by classical technology like as casting, forging and milling, can be obtained. RM technique enabled the production of complex blade profiles that were dimensionally accurate and structurally robust enough for testing. The geometrical accuracy of the turbine, obtained using the EDEN 350 machine, is approximately 0.1 mm (16 micron layer material deposition). The average values for the surface roughness of the Pelton rotor obtained with PolyJet technology are Ra = 1.04 micron and Rz = 5.6 micron (Udroiu and Mihail, 2009). Thus, the PolyJet technology ensures smooth, accurate and highly detailed models.

On the other hand, customized turbines build by RM techniques can be used for experimental flow analysis within the bucket and experimental flow visualization studies, in order to obtain an optimum design.

This research is the first one in Romania about rapid manufacturing (PolyJet) of Pelton rotors from plastic. A Pelton turbines family, manufactured by RM technology, will be tested and remote monitored in an experimental stand. Solutions for the remote monitoring of the manufacturing process are currently being developed and, for the future, partial remote control is also planned. These will bring the manufacturing process to a new level. All the results will be used to develop customized turbines for use in the Romanian mountain areas. This paper gives guidelines for designers and manufactures wishing to follow a similar route for designing and fast manufacturing of other turbines. The case study did lead also to a better understanding of rapid manufacturing technology and its application scenarios. The experience gained will be very useful for the development of a tele-management software application that is planned to be started next year. The application will include production management and remote customer relations and will be dedicated to RM centers.

5. Conclusions

Pico-hydro is an ideal power source for experimental educational and research stands and for improving rural energy services. This study presents a new rapid development process for small customized hydro turbines. Using SolidWorks, a parametrical 3D model of the Pelton runner was designed in two variants: bolted runner buckets and monoblock runner turbine. A new customized Pelton turbine was proposed, designed and manufactured by PolyJet technology. This application of additive manufacturing is answering the market needs with custom innovative solutions for renewable energy generation. The ongoing research in the telemanufacturing field will bring further improvements to the manufacturing process.

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