TECHNICAL SOLUTIONS TO DESIGN AN EQUIPMENT FOR ICE PARTS RAPID PROTOTYPING

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Abstract: The paper presents some detailed technical solutions to design an equipment for ice parts Rapid Prototyping. The authors designed two alternative solutions of the equipment applying a methodology developed within the TCM Department of the POLITEHNICA University of Bucharest. Both alternative solutions are based on the operation principle of selective freezing with liquid nitrogen of water sprayed on the working surface according to section image conveyed by computer by slicing a CAD model. The article focuses on the methods of solving several issues of conception, design and achievement of the high complexity equipment.

Keywords: *Rapid Prototyping, ice, equipment, design*

1. Introduction

Rapid Prototyping procedures has gained wider applicability recently, as a modern manufacturing technique, due to short time machining of a large type of parts by using this method. As it is well known, there are currently applied with good results several rapid prototyping techniques, such as [7]: Stereolithography - SLA, Selective Laser Sintering – SLS, Solid Ground Curing – SGC, 3D Printing, Fused Deposition Modelling – FDM, Laminated Object Manufacturing – LOM and Ink-Jet Printing.

Each of these methods had both advantages and drawbacks, yet what all have in common is the fact that the part is achieved by material deposition not removal, as it is the case with classical technologies.

Not withstanding all the latest improvements of the recent years, all these rapid prototyping methods have a major drawback in common that is the very high cost of parts achieved, due mainly to high cost of equipment and consumables.

One way to cut down the rapid prototyping costs is to use less expensive raw materials. Therefore, rapid achievement of ice prototyping is based on using very cheap material, namely water. At this moment, world wide achievements in this domain are but at an early stage of experimental research [2, 3, 4, 5, 6].

This article presents the principal aspects of the extended research work carried out by the authors, ending up with the achievement at final stage of an equipment for ice parts rapid prototyping.

Considering the current research carried out to the present moment, the authors are entitled to state that the achievement of this equipment would bring about special effects, both in scientific terms, and practical applications. Among the most important domains of application for the ice parts rapid prototyping that are currently applied with special outcome, it should be mentioned here of the achievement of the fusible casting moulds [1, 8] and medical bio-models.

2. The principle of ice prototypes production

Most of the rapid prototyping techniques are still very expensive; in addition, some of them generate dust and smoke emissions, thus endangering the operators' health. One of them is the method „Rapid Freeze Prototyping – RFP", which is a remarkable technique [5, 6], featuring high technical characteristics,

This method helps to obtain the intended technical characteristics, as well as higher operation speed, without generating noxious agents, while the working material – water, is much less expensive than any material used for the other rapid prototyping techniques [6].

Based on the RFP technology, a three-D model can be obtained of ice by using the CAD model, through selective deposition of water and water freezing layer by layer, in conformity with the principle technical diagram shown below in figure 1.

In this case, according to figure 1, water is sprayed on a table and freezed by simultaneous spraying of liquid nitrogen. The part formation takes place in a tank with constant low temperature maintained through thermostat control system. After deposition of the first layer, the nozzle is lifted, or the table is lowered with the thickness of the deposition layer. At the end of the indicated period when total water freezing takes place, the process is resumed with the deposition of a new water layer on top of the first.

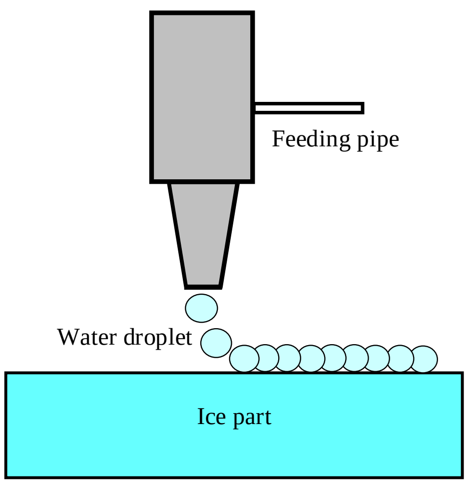

Figure 1: *Principle of Rapid freeze prototyping [2]*

When the entire part is ready, the part thus obtained can be used immediately, or it may be kept in a refrigerator for a distant use.

3. Conceptual design of the ice parts rapid prototyping equipment

The conceptual design of the RFP equipment has been achieved based on a methodology that had been developed during several years by the TCM Department of POLITEHNICA University. This methodology has been applied with special results, both in didactic events, and in graduation diploma studies of the master degree, as well as in projects that are being in progress.

This methodology started to be applied when the need has been identified and defined to rapidly obtain cheap prototypes. Based on a questionnaire, the client's demands regarding the rapid prototyping equipment have been examined and grouped according to ten primary requirements and sequenced in hierarchy.

The next step was the analysis of competing products, that is, in principal, the rapid prototyping equipment corresponding to the most relevant techniques, as mentioned in Introduction to this article. The authors followed this procedure to ensure competitive design of this type of equipment, in comparison with the most advanced existing international technologies; the equipment technical specifications have been determined accordingly.

The next step was to prepare the functional design, by determining the general function of the equipment that is ice prototyping in a wide range of standard dimensions. The general function was then submitted to a general examination procedure, resulting in the first place the principal functions, and then the complementary and supplementary functions.

Considering the principal functions, a list was set up of the critical functions, which determine the commercial success of the product which correspond to the size and demands with relatively high importance: ensure the movement on the three axes, conveying of information from computer to equipment, water spraying on strictly controllable sectors, simultaneous spraying of liquid nitrogen to induce freezing and maintaining a negative temperature in the part processing area.

To determine the partial solutions at conceptual level, an external research was prepared mainly consisting in the study of several patents, consulting several experts in this domain, and interviewing top users.

Following the sorting of concepts, two of them were retained, which are shown in figures 2 and 3.

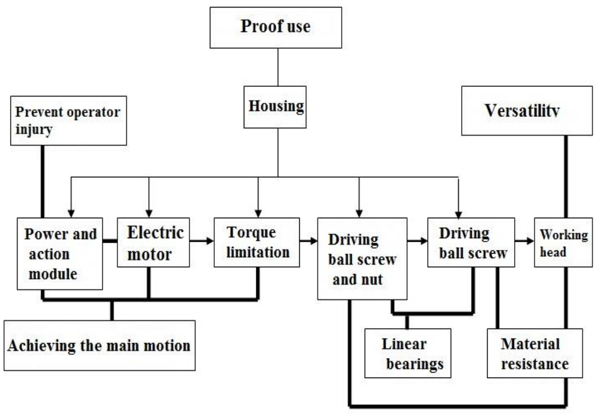

Figure 2: *Concept no. 1*

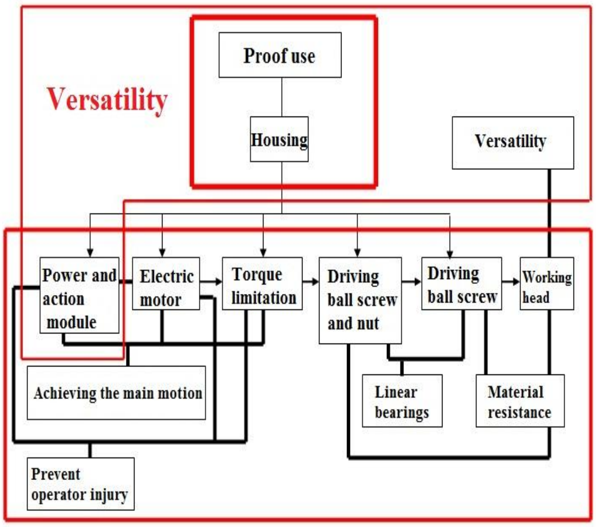

Figure 3: *Concept no. 2*

Applying the multi-criteria method of analysis, Analytically Hierarchy Process (AHP) – we selected concept no. 1, to be further examined at the detailed design phase.

4. Detailed design of the ice parts rapid prototyping equipment

At this stage, the detailed design was prepared of the product, considering both the total assembly and its component parts, to provide the prototype documentation.

In the framework of the constructive design of the total assembly, the product architecture was prepared, the configuration of parts and subassemblies, as well as their preliminary dimensioning, based on their functional role.

Design was carried out, while taking into consideration a series of criteria in accordance with the technical service life cycle of the product, such as its functionality, usefulness, ergonomy, labour protection, ecology, aesthetics, manufacturing, product disposal and minimal cost.

For the selected product concept, the product architecture was determined in several stages, as follows.

To better observe the interfaces between the product blocks, an approximate constructive product plan was first created comprising five large blocks – the system of transmissions, actuation, the item corpus, the water circulation system and the liquid nitrogen circulation system. Next, we developed the detailed constructive plan of the part, as indicated in figure 4 and we identified the fundamental and incidental interactions.

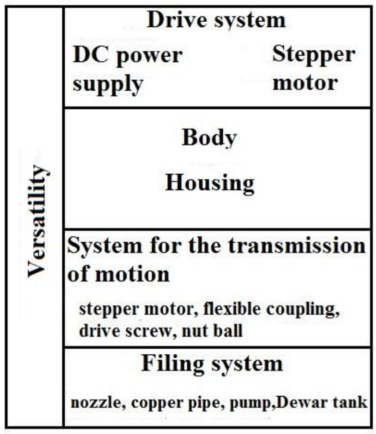

Figure 4: *Detailed constructive plan of the product*

Based on this approach, the authors prepared the final block diagram, stating the constructive solutions for the principal interactions (figure 5).

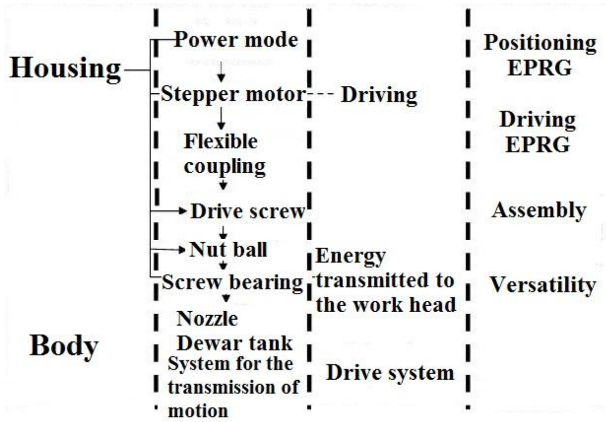

Figure 5: *Final block diagram*

Based on the above mentioned, two alternative solutions were prepared of the rapid prototyping equipment.

In the first solution, the horizontal movement is performed by the working head, while the vertical displacement by the mass of the equipment. In the second alternative solution, the displacements on the three axes are provided by the working head.

Figures 6, 7, 8 and 9 show the constructive solutions adopted under the first alternative solution.

The shape of the working head is shown in figure 6. The water is pumped by the cylinder and piston unit upon disconnecting of power magnet, then water is injected through nozzle, when the power magnet is actuated through computer control. Injected water comes in contact with the cold environment produced by liquid nitrogen and freezes, getting thus attached to the deposition ice layers. This shape of the working head leads to the significant decrease of the ice layer deposition time, as compared to the working head with water dropping on the working surface.

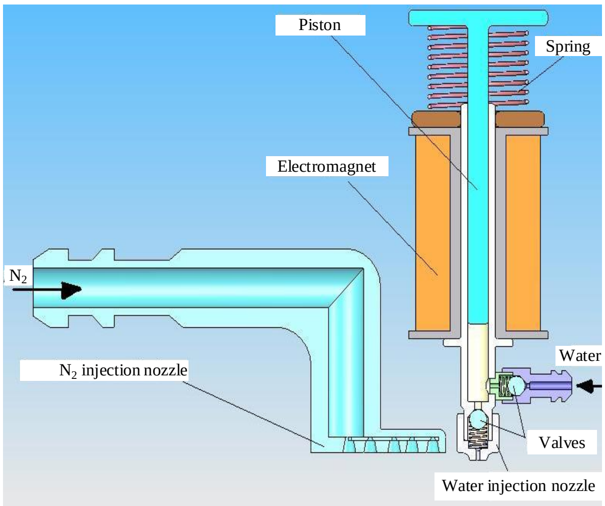

Figure 6: *Construction of the working head*

Figure 7 shows the working head movement principle. Movement is conveyed through motor V-belt gear assisted by planetary rotary speed reducer. The movement of the working head is achieved by linear transducer (with photodiodes) and calibrated ruler. The intention was to improve the positioning precision in the case of higher working speed.

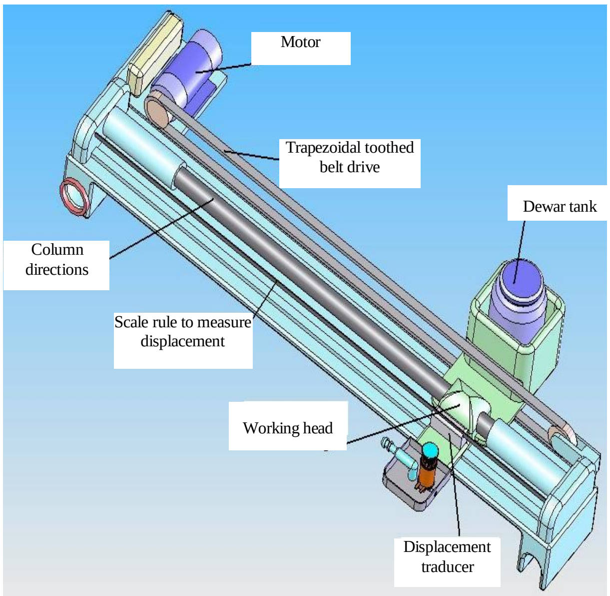

Figure 7: *Working nozzle movement principle*

The less sophisticated shape was selected for the chamber of ice part prototyping and constant temperature maintenance, to minimize the cost of paying off the prototyping equipment and the ice part prototypes, respectively (figure 8).

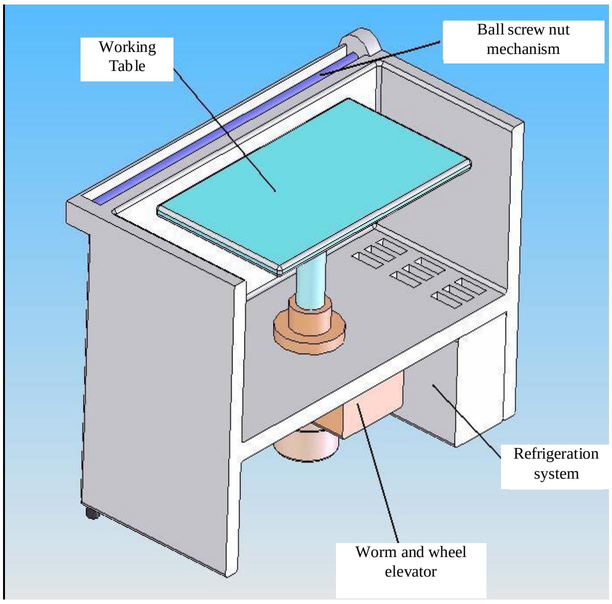

Figure 8: *Ice part prototyping and temperature maintenance chamber*

Figure 9 shows a general view of the first alternative solution of ice parts rapid prototyping equipment.

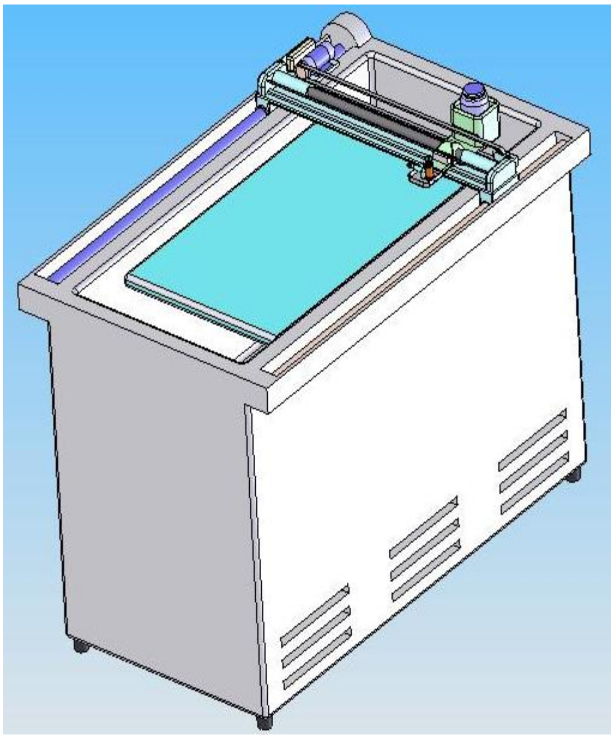

Figure 9: *General view of RFP equipment first alternative solution*

The constructive solution for the second alternative was designed to provide the movement of working nozzle along the three axes. Figure 10 shows the general view of the RFP equipment in the second alternative solution.

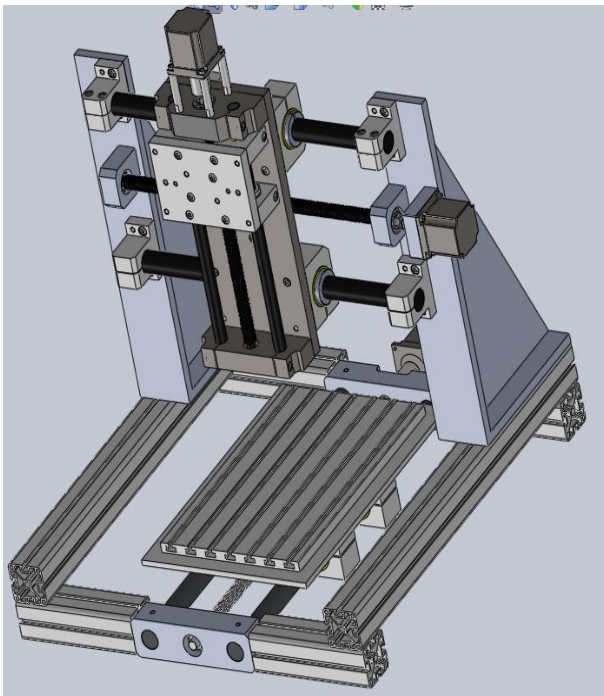

Figure 10: *General view of RFP equipment second alternative solution*

The principal constructive elements of the unit have been selected, or, from case to case, designed, as described below.

For the selection of motors, we examined several alternatives from the products of manufacturers available on the specialised market, considering DC motors in miniature variant, with or without reducer. The authors considered linear motors, servomotors and step by step motors.

Linear motors have the advantage of high precision and reliability, high feeding speed and acceleration and relatively high cost with respect to the cost objectives envisaged for the RFP equipment. Other shortcoming of this item is that it needs a source of compressed air to make it possible to maintain the distance between rotor and stator, which makes the equipment a rather complicated construction.

Servo motors are direct motors which require position actuators (encoders), which increase significantly the cost of equipment. They are however less expensive than linear motors, but show lower repeatability performance.

Step by step motors rotate at a specified angular step and require no position actuator. They are not expensive and require no sophisticated electronic control units. Other advantage is their rotation by 1/2 to 1/32 of the normal step, thus increasing the positioning precision, yet at the expense of smaller feed speed. The principal disadvantage of these types of motors is the so-called phenomenon of electro-magnetic skidding at high speed, that is the motor skips over rotation steps. This would result in low feeding speed, which is a minor disadvantage, considering the smaller CNC operation travel (150x200X350mm) in the case of this construction of the authors. To prevent electro-magnetic skidding of motors, the feed speed had been limited to 500 mm/min. maximum, which means smaller equipment output, still better quality of the machined surface.

Considering the above-mentioned, the authors selected step by step three-motors manufactured by NEMA.

Also, due attention was paid to transmission screws: we selected ball screws produced by ISEL GmbH, made of special hardened steel CIF at 60HRC, which ensures high wear resistance and core elasticity.

The screw thread flank is obtained through rolling, which leads to high precision of positioning of the nut, with respect to the leading screw. The ball nut also from the producer ISEL GmbH made of steel 16MnCr5 hardened and nitrated in gas atmosphere, which provides low wear percentage of the rolling flank.

The authors selected a free software equipment that can be purchased via Internet, with the result that the cost of this component part of the RFP equipment is zero.

The performances of this software are comparable with those of genuine software equipment, its technical characteristics being totally compatible with the design RFP equipment of the authors.

This software makes the translation from machine code ‘’G-code’’ into one decodable by the equipment controller, thus enabling the execution of rapid working feed movements, rotary speed and other auxiliary movements. This code conversion is made by the so-called ‘’Postprocessor’’ specific to the RFP equipment jointly working with the electronic controller.

Generally, this software is used with industrial PCs integrated in the equipment construction, but in the case of the equipment conceived by the authors, this software will be installed on a laptop controlling the equipment.

Two software items, Mach3 and K-CAM, have been examined, the second being selected, since Mach3 requires a stronger computer for its optimum operation and in addition, it was noticed that this software evinces a delay between the computerised control and the real control response from the equipment engines.

The electronic controller provides the connection between software and hardware, being compulsory for the control function of the RFP equipment, which is feasible in two alternative solutions:

1. The G code is hardware-integrated in controller, which requires more complex electronics and is more expensive. (microprocessors and ROM memory).
2. Code G is software-generated and requires lower costs.

The power supply for the switch unit is high output, which is specific for these types of power supply systems and is available for acquisition at Conex Electronic Bucharest.

For water supply, the authors found the solution of customizing a pump used for car wash, namely front screen wash. This type of pump is computer controlled in accordance with the slicing section of the CAD model, water being pushed towards the spraying system above the part.

The equipment is endowed with a liquid nitrogen storage and circulation unit comprising Dewar tank, insulated pipes, valves, electric fuse for the tank pressurisation, etc. By the heating of the electric fuse fixed on the pipe for nitrogen extraction from the tank, part of the liquid nitrogen gets evaporated and pressurises the tank. Thus, the nitrogen is forced up the discharge pipe and reaches the working zone through opening a valve actuated in correlation with the way in which water is sprayed.

The prototype of second alternative solution was produced, tested and standardised in the Dr. Kocher Center inside the POLITEHNICA University of Bucharest.

5. Conclusions

Based on the above-mentioned descriptions and definitions made by the authors, several conclusions can be stated, as follows:

1. The authors proposed a solution of rapid prototyping cost reduction consisting in the utilization of less expensive raw material in the process. Ice parts rapid prototyping involves the utilisation of a very cost-efficient material, which is water.

2. Conceptual design of RFP equipment is based on the methodology developed during several years of research by the authors within the TCM Department of POLITEHNICA University of Bucharest.

3. Two alternative solutions were prepared of the RFP equipment. The first solution contains horizontal movement by aid of working head, and vertical movement by aid of the equipment table. In the second alternative solutions, the movement on the three axes are performed by the working head.

4. Both solutions are based on the same operation principle of selective freezing using liquid nitrogen, of the sprayed water on the working surface, in conformity with the slicing section of the CAD model.

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