DESIGNING A RAPID PROTOTYPING EQUIPMENT USING MODULAR STRUCTURAL ELEMENTS

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Abstract: The rapid prototyping with ice is a new manufacturing technology that can generate three-dimensional objects made of ice by depositing and rapidly freezing water droplets layer by layer. This technique gives the opportunity to build more precise models with an excellent surface roughness and the possibility to form transparent and colourful pieces. By using modular structural elements it can be generated various types of machines adapted to the customer's needs. The price of such equipment is visible reduced compared with those obtained by utilising traditional design methods. The design time of such equipment is considerable reduced. There have been designed two types of machines, one of them being constructed and tested by the authors. The machine is based on a three axis, actuated by stepper motors. The motors rotate a ball screw – nut assembly which transforms rotary movement into linear movement, all of them being implemented on the modular structure created by the authors.

Key words: ice, freeze, prototyping, structure, design, model

1. INTRODUCTION

The development of unconventionally technologies has influenced the appearance of some technical products with exceptional technical features. This evolution was generated by the following general trends: the increase of the share of hard workable materials, the increase of the geometric complexity of shapes, of surfaces, the enlargement of the scale among which the size of the pieces can be found (miniaturization and large size gauges) and the increase of the precision and of the efficiency of the manufacturing process. These tendencies are maintain due to overcoming the technological limits of manufacturing, by the development and diversification both of classical manufacturing technologies and of unconventionally ones.

The creation of a new product is a long term and high complexity process which is based on designing and analyzing several stages (CAD) until the product is properly manufactured in the class of fabricated products. These stages can be done quicker by implementing the 3D modeling methods. The actual manufacturing systems allow for the mitigation both of the time needed for constructive and detailed design and of the manufacturing cost of it.

The main problem is the related to manufacturing the first real model or an assembly element with a high complexity shape due to the fact that it is needed that the technological process of the assembly mark and of its elements has to be implemented, which implies high expenses among the manufacturing costs.

Having the real model of the future piece designed, it can be detected and eliminated the problems of the designing and functionality process. The piece prototype can be used as a conceptual model for the visualization and analyzing process. The prototype models decrease the value of designing expenditures, the time needed to launch the product in the class of fabricated products as the technical mistakes can be detected in the initial stages and they increase the relationship between designing engineers and beneficent owners.

Presently, there are relatively well developed the technologies based on generated the 3D objects layer by layer considering the prototype of the electronic 3D version. These technologies are known as rapid prototyping technologies (RP-Rapid Prototyping). They appeared in the 80's and they were used with companies that have hugely budgets like the companies from the aerospace industry or the F1 companies. For example, the cars engineers of F1 could create with the equipment of rapid prototype the components with extremely precise shape, like spoilers. The production of these complex elements through classical models could last for several weeks, while by using the 3D printer, the time period was reduced to 48 hours. As a fact, the remained time allow for the car producer to test more various solutions of the components and to detect the final version quicker [1].

Another advantage of using the 3D printers is their capacity of creating shapes that are impossible to be designed by using mass production techniques. This aspect allows companies to sue to bio-mimicry by reproducing shapes that can be found in the nature.

Such an example comes from MIT, where the researchers, who have Neri Oxman as their chief, have used a 3D printer in order to construct the easiest and also the most durable concrete pillar [2]. Considering the fact that the plant's stem is formed from vertical filum with different densities, Oxman has used a 3D printer in order to create a structure formed from concrete filums with different densities.

Each of these techniques has its advantages and disadvantages, but all are based on the fact that the process implies pay material coating and not on the take of techniques, which is specific for the classical processes.

Considering the improvements that have been achieved in the last years, the main disadvantage of the RP-Rapid Prototyping processes is that they imply higher costs for the assembly elements mark (higher costs of equipment and of raw materials).

One way to reduce the expenses associated with the RP-Rapid Prototyping processes is to use low cost-raw materials. As a fact, the rapid prototyping with ice is based on using a really low cost resource like water. At the global level, the achievements of it are still in the experimental research stage.

The present article provides evidence about some research conducted by the authors which point out in achieving in the final stage of an equipment of rapid prototyping machine with ice.

2. STRUCTURAL MODEL

The development of a structural general model is based on the need of the existence of the CNC structure. This can create tree axis movements and it's used as a model for constructing the rapid prototyping machine with ice.

As there are several conceptual solutions for the functions of rapid prototyping machine with ice, the outcomes had to be analyzed in order to detect the real solution for designing it. The design of the assembly elements was implemented considering also how they can be achieved and what is their consistence.

Considering the execution features, the most simple scenarios have been selected, but which are properly worthy for achieving the creation of a rapid prototyping machine with ice. A dimensional repeatability of 0.02 mm of the equipment, some components were compatible with the designed equipment. Other components, such as linear motors with 0.001 mm repeatability were not used as they are not in accordance with the objective of our research.

Several concepts of the product have been analyzed in order to choose and to improve a product which is practical and which creates value that provides evidences about its distinction with other products.

There are three different approaches of the equipment of rapid prototyping machine with ice. The first one refers to equipment with compact dimension with a small frame that can be mounted on a workbench. This approach is presented in figure 1.

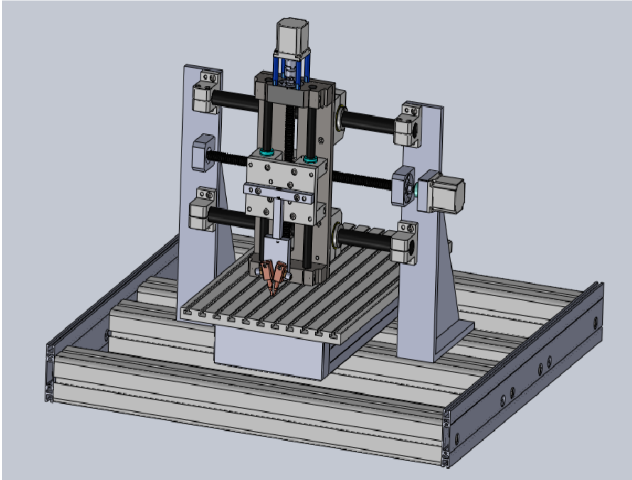

Fig. 1. Equipment with compact dimension with a small frame that can be mounted on a workbench, 3D model.

This solution does not have high rigidity and the Z axis stroke is limited due to the fact that X axis is between the frame and the pillars of Y axis. The electronic command components cannot have a compartment partitioned off for the spray water circulation system, which is associated with a major danger.

In the figure 2 is presented the model that was built. It can be seen clearly that the equipment has a compact dimension but the auxiliary systems are not built inside the equipment.

By using modular elements for the frame, the assembly of the equipment was done in about 4 hours using non-specialised tools.

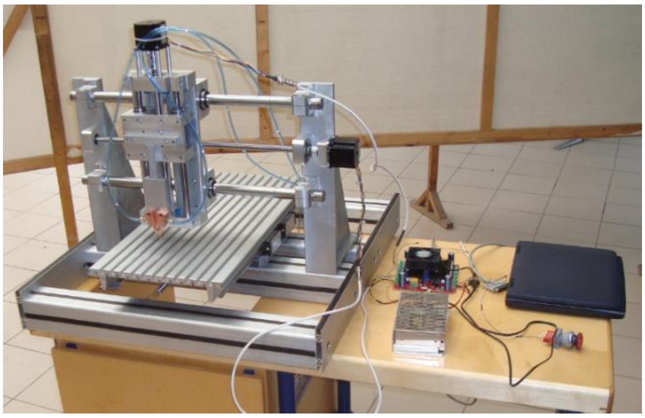

Fig. 2. Built model of the rapid freeze prototyping machine (version 1).

The second approach is developed among a frame that is properly dimensioned both considering the rigidity aspect and the correlation with Z axis stroke that can be implemented inside the frame. This equipment that is designed considering this approach is presented in figure 3.

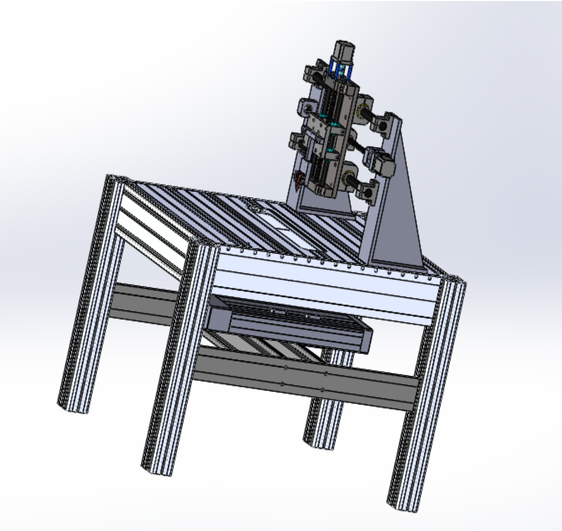

Fig. 3. Equipment of rapid prototyping with modular frame, 3D model

Due to the fact that the frame is closed with panels, the existing space is divided in order to mount the electronic equipment and the spray water circulation system, achieving a better lining in order to prevent the accidents. This partitioning element helps also to the isolation of the spray water or liquid nitrogen towards the natural environment, by using expanded polystyrene panels which is mounted inside the frame.
In the figure 4 is presented the model that was built.

3. METHODOLOGY OF RESEARCH

This part of the research provides evidence about the preliminary design of the equipment, both considering the assembly and the component parts, the result being a preliminary documentation.
Among the constructive design of the assembly, the architecture of the product, the pattern of the assembly marks and of the components and their dimension has been realized. The equipment was designed in order to satisfy a large range of criteria, such as functionality, utilization, ergonomic aspect, the work safety component, ecological aspects, design features, the manufacturing process and the minimum cost.
The main elements were divided in 5 groups such as: the software equipment, the electronic command equipment, the movement and positioning equipment, the water deposition equipment and the water freezing equipment. Considering these elements, the second approach has been chosen as the one that is reliable for designing a rapid prototyping machine with ice. From the mechanical point of view, it is a construction that has enough rigidity, considering the facts that are no forces among the tool-piece system.
One of the most important feature is related to the fact that the machine construction should let the deposition system to function is a thermally insulated area of external factors, but on the same time, should create the necessary condition to protect the electronic equipment with the water or liquid nitrogen interactions.

Fig. 4. Built model of the rapid freeze prototyping machine (version 2)

4. MODULAR ELEMENTS USED IN THE DESIGN AND BUILDING OF THE RFP EQUIPMENT

4.1. Designing the RFP equipment

In designing the product an important element was the establishment of its general shape, its proportionality and its dimension. It has been established that the equipment has to have a mostly parallelepiped shape, without sharp edges. The shape and the components have to provide enough robustness and strength and to assist in achieving the operator's projection.
As minimum costs were attempted to be obtained, several problems have been detected by us, the main one being the concentration of processing the component parts of the mechanical characteristics in order to achieve them simple and as cheaper as possible.
In selecting the components and the kinematic chain of the machine, several manual lines catalogs of specialized companies, 3D modeling software, finite element stress calculation, the manufacturing components, their testing and improvement and remanufacturing under new technical specifications have been used.

4.2. Modular elements used for constructing the frame of the RFP equipment

The frame is an irreplaceable component when designing any machine and moreover it has an important significance as its function is related to

rigid link support of all mechanisms and their parts.
One characteristic that the frame has to have for a reliable functionality of the machine is that the base areas upon which the fixed or mobile subassemblies are mounted has to remain unchanged in relation to each other, in time and at all operating conditions of the machine, namely that do not have to get damage or to vibrate and they have to long time withstand at all stressing elements that tend to wear it out.
As a fact, a modular construction has been chosen, based on extruded aluminum profiles, which are manufactured by a CNC equipment specialized company.
The construction is a parallelepiped one, based on four PS80 vertical supports (figure 5), which is reinforced at both ends with PP100 and PP150 profiles (figure 6). The manual lines data catalogues were used for the finite element analysis in order to detect if the assembly has enough rigidity.

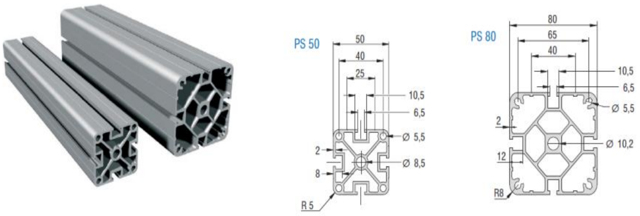

Fig. 5. Vertical profile supports [3]

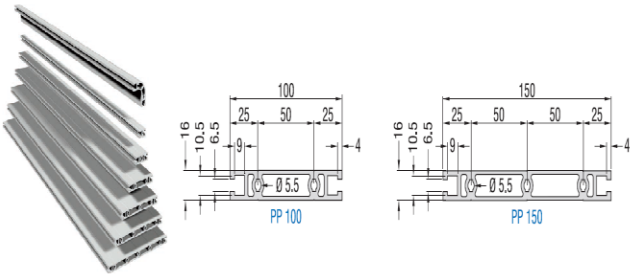

Fig. 6. Profile of lateral reinforcement [3]

The frame structure (figure 7) has been designed with CAD 3D modeling software, SolidWorks. After designing, a simulation regarding the static loading of the frame has been done by using a simulation finite element modeling software. The main drawback of using extruded aluminium profiles in the finite element analysis is the geometrical complexity of the profiles that will be simulated in software, thus this means a more performant computer is required to perform the FEA.

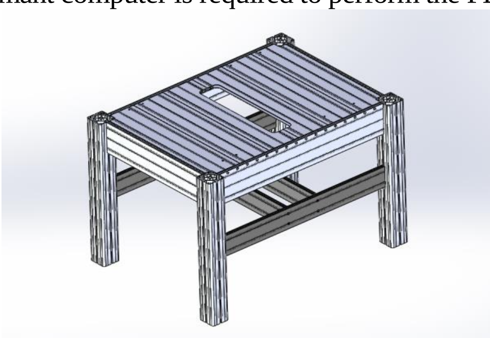

Fig. 7. The modular frame, CAD model

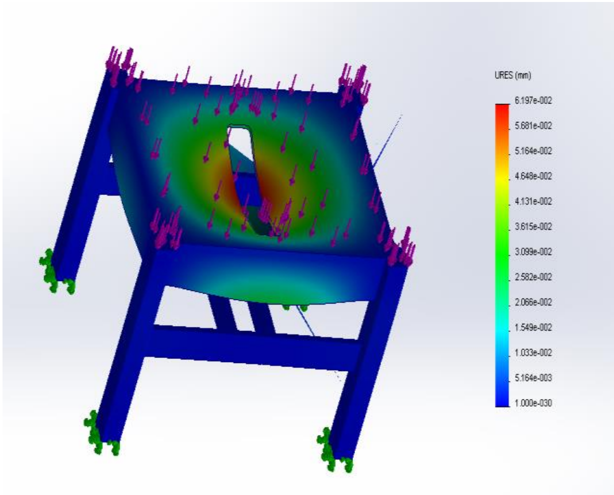

Fig. 8. The analysis of the deformations with a finite element analysis (FEA)

The results provide evidence about a maximum distortion of 0.06 mm. The distortion appears in the area where the Z axis descends the working end in the practicable slot from frame's center. The deformations are unimportant due to the fact that the pillars of X axis and of Y axis are stiffening the frame close to the pillars of frame's support. Moreover, the loading with which the simulation has been done is three times higher than the physical charge the frame has to support. This new modular frame used in the construction of the rapid freeze prototyping equipment has great advantages of cost, built time and weight, compared with classical weld frame used in the construction of prototype equipment.
Based on the fact that aluminium alloys were used entirely building the frame, the thermal expansion of the frame in use will be constant in the frame elements and no deformation will appear in use of the rapid freeze prototyping equipment.
The equipment is based on a CNC 3 axis machine that is powered by step-by-step motors. The motor spins a ball screw – nut assembly which transforms rotary movement into linear movement. In figure 9 is presented the schematic of the design.

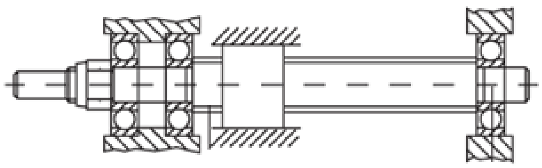

Fig. 9. Schematic of the driveline [3]

The component parts were custom built from 6060 aluminum alloy and assembled by the author. The ball screw – nut assembly was bought from ISEL, a well known supplier of CNC equipment. The load carrier bearings are linear type bearing Ø16h6 and Ø25h6 hardened and grinded shafts [4].

In figure 10 is presented the 3D model of the Z axis, designed using SolidWorks CAD software.

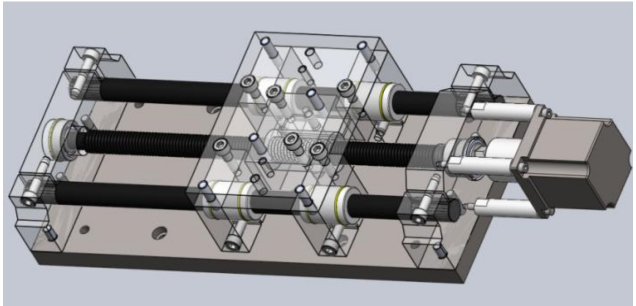

Fig. 10. Schematic of the driveline

The movement axes had to be fixed on a housing frame, that is lightweight, durable, and temperature difference would not cause warping on itself.

The software used to control this RFP machine is classical CNC drived by software that is using G-code in order to rotate the step-by-step motors. With good results author used Mach3 software [5]. In figure 11 is presented the control panel for this software, and in figure 12 is presented the electronic controller. Electronic controller is based on H-bridge MOSFET power drive [6], interconnecting the power motors and Mach3 interface panel. The G-code reading is made by a programmed ATMEL chip.

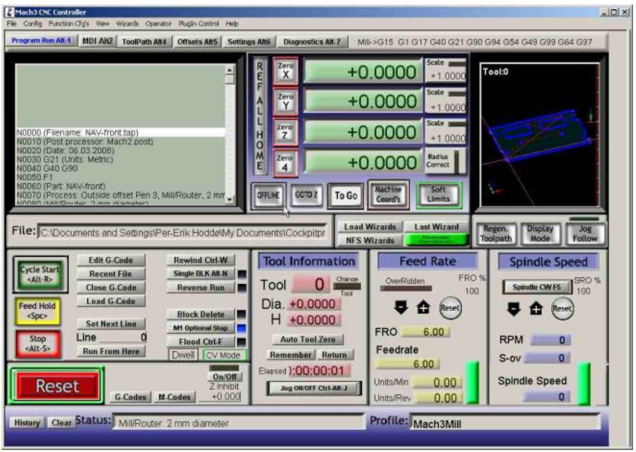

Fig. 11. Mach3 interface [5]

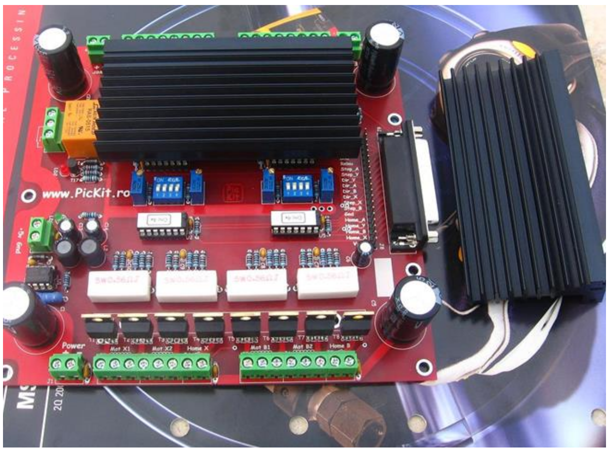

Fig. 12. Electronic controller [7]

Assembly of the rapid freeze prototyping equipment, performed by the author, went smoothly. Using modular elements proved to have great advantages in assembly and adjustment. Subsequent verification showed that the repeatability of the equipment has been reached. Checks involved fitting a comparator on the machine's head, and the movement of the axis in the three directions, checking with a gauge block. These verifications are carried out for three values of 100 mm, 200 mm, respectively 400 mm, of the active stroke motion for all three movement axes.

Centering the elements was achieved by using of centering pins, where installation tolerance has been achieved by a H7/k6 tolarance for the holes and for the linear dimensions of ±0.01 mm tolerance.

Execution of the components was performed on CNC milling machines, fits prescribed in drawings being measured with a Mitutoyo coordinate measuring machine by the author.

After installation, to check the perpendicularity between the axes along their whole length, a Mitutoyo coordinate measuring machine was used (figure 12).

Fig. 12. Mitutoyo coordinate measuring machine

5. CONCLUSIONS

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

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

Two alternative solutions were prepared [8] of the rapid freeze prototyping equipment. The first solution refers to rapid freeze prototyping equipment built to be mounted on a workbench.

In the second alternative solution the rapid freeze prototyping equipment is built by using modular elements for the frame and linear axis.

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.

The construction of three-dimensional prototypes layer by layer, using rapid prototyping technique allows the manufacturer of building complex parts directly from their CAD models.

The rapid freeze prototyping machine with a modular construction can be adapted to any requirements on the market, satisfying a wide range of customers.

The equipment has been developed as a modular system that can add or change various systems, motion axes of different sizes, other types of frames, and other equipment necessary for the rapid freeze prototyping equipment.

The frame was built on extruded aluminium profiles that gives strength and a high degree of flexibility in relation to the structures welded or casted, in order to choose a suitable design solutions. It also provides a lightweight frame for the rapid freeze prototyping technology.

In order to protect the system from deposition of droplets of liquid nitrogen the X-axis has been lowered inside the frame. This descent enables the insulation of the equipment from the action of spray system.

Analyzing the main types and sizes of equipment for rapid freeze prototyping technologies, the author developed small equipment (1000x800x800 mm) that can be easily used in a factory or small laboratory.

The recommended area of use is the manufacture of products by gravity casting fusible models. The prototype of the ice will melt, leaving room for molten alloy that will be cast in the form. The ice melted, is nothing but water, which means there will not be toxic residues that will affect the environment. Also retouching fuse model casting changes to the model ice is easily executed by both mechanical and effectively melted surfaces that do not fall within specifications.

Another recommendation is the use of medicine. The affected area is scanned by magnetic resonance imaging and 3D model built virtually on the computer. Through rapid freeze prototyping, will be obtain a physical 3D model that can be evaluated and modified by the physician to determine the phases and the specific elements of the reconstruction operation. Through rapid freeze prototyping 3D model obtained is cheaper, and also more easily processed.

Particular importance should be given to storage and transportation of the models. They require storage and transportation temperatures below 0°C, to prevent damage of melting model and part geometry.

The author believes that rapid freeze prototyping technology [9], will find other areas in which to apply for the use of cheap and environmentally friendly material as water, also in areas where is very difficult to use other rapid prototyping technologies.

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