IMPORTANCE OF RAPID PROTOTYPING TO PRODUCT DESIGN

Mihaiela ILIESCU[1], Kamran TABESHFAR[2], Adelina IGHIGEANU[3], Gabriel DOBRESCU[4]

Se pot obține prototipuri de, aproape, orice complexitate geoemtrică, într-un timp, relativ scurt, prin Prototipare Rapdă, tehnologia de fabricare abordată fiind cea a fabricării "aditive".

Lucrarea evidențiază importanța tehnologiei de prototipare rapidă, prin imprimare cu jet,"Ink-Jet Printing", în design-ul unui reper component al unui produs foarte important şi scump. S-a obținut prototipul reperului, observându-se elemente „rele" şi/sau „lipsă". Astfel, devine posibilă economisirea timpului şi a banilor implicați în dezvoltarea produsului studiat

Rapid Prototyping is capable of producing prototypes of almost any geometrical complexity in relatively short time using the additive manufacturing approach.

This paper describes the advantages and limitations of Z Corporation Three Dimensional Printing rapid prototyping technique in the very important and costly stage of product design. A product design case study is used to illustrate the various stages of the process and appraise the result. It will show the time and cost savings that can be achieved in the development of the product under consideration.

Keywords: rapid prototyping, 3D printing, prototype, process, product.

1. Introduction

Prototyping is an important stage in any product development process and the prototype can be defined as "an approximation of a product (or system) or its components in some form for a definite purpose in its implementation" [1]. Prototype definition, mainly, involves the three aspects that follow:

- the implementation of prototype - from the entire product, to its sub-assemblies and components;
- the form of prototype – from virtual shape (computer aided drawing) to real, physical object;

[1] Reader, Dept.of Manufacturing Technologies, University POLITEHNICA of Bucharest, Romania, e-mail: iomi@clicknet.ro
[2] Professor in Design Engineering, Bournemouth University, UK
[3] Eng., Optoelectronica 2001 SA Company, Romania
[4] Eng., Optoelectronica 2001 SA Company, Romania

• the degree of approximation of a prototype – from a rough representation to an accurate replicate of the part.

In Rapid Prototyping (RP) virtual designs are "taken" from computer aided design (CAD) or animation modeling software and transformed into thin, virtual, horizontal cross-sections. Each cross-section is created in physical space, one after the next until the model is finished, so it is a WYSIWYG (What You See Is What You Get) process where the virtual model and the physical model correspond almost identically. An important difference between this and conventional machining is that the prototype is obtained by layer to layer addition, as opposed to removing material from a "block".

In Rapid Prototyping, objects can be formed with any geometric complexity or intricacy without the need for elaborate machine setup or final assembly. They can be made from multi materials such as composites, and materials can be varied in a controlled fashion at any location in the object. So, the construction of complex parts can be reduced to a manageable, straightforward, and relatively fast process [5].

There are three main Rapid Prototyping systems, depending on initial the form of materials involved:

• liquid-based RP systems – the initial form of material is in liquid state and, by a curing process, the liquid is converted into solid state; the system includes: 3D Systems' Stereolithography (SLA), Light Sculpting, Rapid Freeze and Two Laser Beams;

• solid-based RP systems – the initial form of material is in solid state, except for powders (wire, roll, laminates, pellets); this system includes: Stratasys 'Fused Deposition Modeling (FDM), 3D Systems', Multi-Jet Modeling System (MJM) and Pares lamination Technology (PLT);

• powder-based RP systems – the initial form of material is powder; the system includes: 3D Systems' Selective Laser Sintering (SLA), Precision Optical Manufacturing's Direct Metal Deposition (DMD) and Z Corporation's Three Dimensional Printing (3DP).

A commonly used Rapid Prototyping technique is that of Z Corporation. It is based on three-dimensional printing, which involves shooting droplets of binder on a powder layer to selectively bind powder together for each layer [6]. Therefore, relatively quick and not too expensive models can be obtained for checking the product design process or for testing products' characteristics, by prototype testing. Usually, the model's surface finish is not very good but, after impregnation, several machining procedures can be applied to improve the surface or, even to obtain surface configuration, such as threads, that could not be safely obtained by Rapid Prototyping [3].

A schematic representation of ink jet 3D printing process is represented in figure 1 [2].

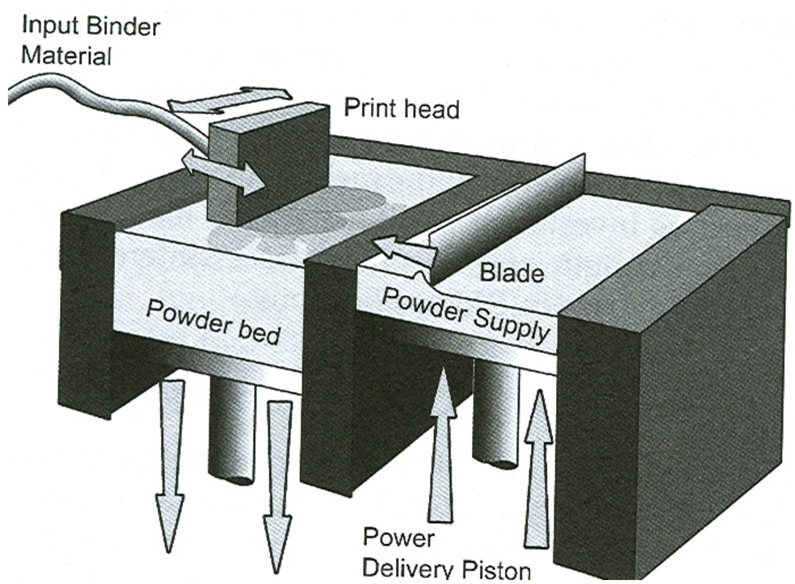

Fig. 1 Schematic representation of 3D printing process [2]

2. Prototyped part

Document security, nowadays, is a very important international issue; this includes combating fraud in official documents such as bank notes and identity papers and there has been much effort in developing effective anti-fraud tools.

One very modern device is a “video-mouse” – see figure 2, used in identification of fraud for documents such as visas, bank notes, identity cards, passports, holograms and stamps. It works in visible, ultraviolet and infrared radiation fields, and allows direct checking and processing of video signals and images, by USB port transfer.

The video-mouse can print the security elements that are visible or hidden into high security documents, such as: ultraviolet sensitivity fibers, micro-texts, wire marks, hidden images, optical-variable printing, invisible ink, infrared fields, and mechanical manipulation. It plots out ink pigments variation, by adsorption, transmission and reflection in different spectrum lengths, from 375 nm to 950 nm.

The above device is a modern and very efficient one, enabling the officials to obtain as much reliable important information as they would using a complex investigation system.

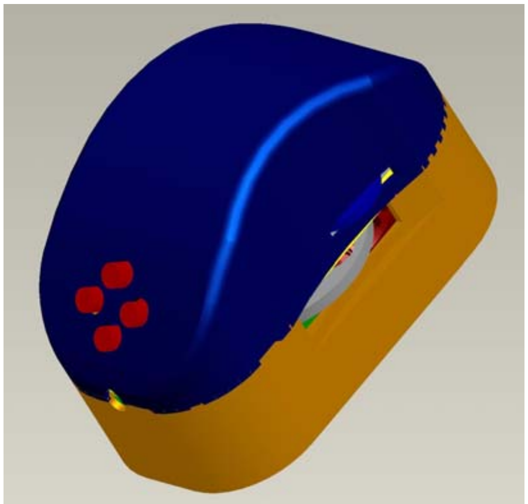

Fig. 2 Video-mouse assembly drawing

The part whose prototyping benefits are going to be shown in this paper is the upper case of an anti-fraud device – see figure 3. Other components of the assembly were also prototyped (e.g. the lower case) and they were all finally joined/fitted together, in order to have an "image" of the whole device.

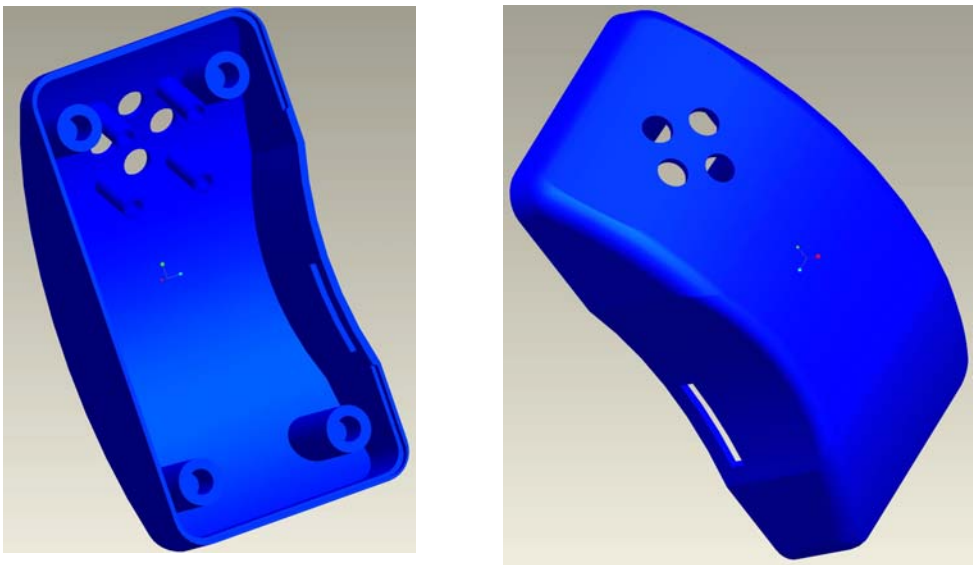

Fig. 3 Computer aided design of the part (upper case) to be prototyped

3. Rapid prototyping by 3D printing

Rapid prototyping by three dimensional printing, involved a technological system based on:

- ZPrinter 310 Plus printing machine (Z Corporation) [7];
- zp®131 *powder* (high performance composites for tough parts and very good resolution); zb60 *binder solution* and z-max *high strength epoxy* [7] – representing materials used for rapid prototyping;
- compressed air cleaning enclosure;
- electric oven.

Three dimensional printing is carried out using the “steps” outlined below.

a. Computer aided designing of the part to be prototyped – see figure 3.

b. “Recognizing” the design by printing machine software, ZPrint and models positioning within machine’s modeling enceinte – see figure 4.

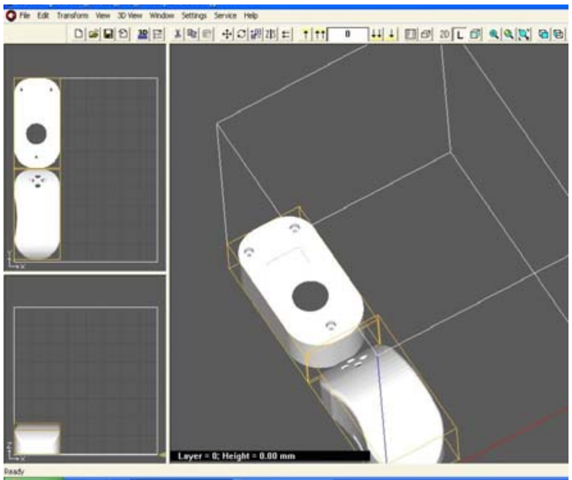

Fig. 4 Positioning parts to be prototyped

c. Automatic calculation of the required volume / mass amount of binder / powder (estimated binder usage: 37,0 ml; total volume of parts: 78.78 cm^3) – see figure 5.

d. Setting machining parameters, such as 0.0889 mm layer thickness, and the automatic calculation of layers and prototyping time (number of layers: 484; estimated build time: 1 hour and 26 min) – see figure 5.

e. Three dimensional printing process – i.e., successively layer by layer additive fabrication, obtaining the prototype.

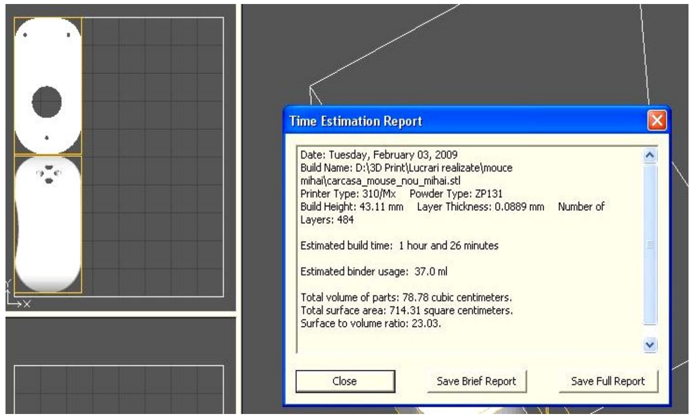

Fig. 5 Automatic calculi of printing process characteristics

f. Once the process is over and the powder prototypes harden (the estimated time for it is given on the computer screen after the models construction is carried out), the prototype is carefully extracted out of ZPrinter modeling enceinte.

g. The produced model is ‘cleaned’ from the support structure (not bonded to the main model), and put into a special vacuum enclosure and the edges manually trimmed, if necessary.

h. The prototype is dried in an electric oven and then impregnated by a mixture of special binder and high strength epoxy. Thus, a hard and ready to use part is obtained.

4. Importance of rapid prototyping in product design case study

The product under consideration, the video-mouse, will be manufactured in mass production; the process of prototyping its important components, possible mistakes or “misfits” in parts design can be avoided or corrected.

The problems discussed here will all relate to the case study under consideration.

An important mechanical property of the model produced is its tensile strength value. The mathematical relation for it is given by [2]:

$$\sigma = K\sigma_0(1-\varepsilon)^m = K\sigma_0(\Delta)^m \tag{1}$$

where: σ is the tensile strength and σ_0 - wrought strength of the same alloy [MPa]

K – geometric and process dependent constant;

m – constant;

ε - relative porosity;

Δ - relative density $(\Delta = 1-\varepsilon)$

When considering the characteristics of the powder (zp®131) and the binder used, applying equation (1), *should give a result similar to* that of the mass produced manufactured component (injection molding of polymeric material). Accordingly, σ = (87.68 – 101.27) [MPa].

Thus, it is assumed that any problem in the prototype "behavior" is similar to that of the real, injected molded part obtained. Thus, observing the failures, features of the prototype will inform on the changes needed in the part design.

Some important features that were carefully studied (see figure 6) are:

- failures and cracks of the corners, because of too small value of the corner radius;
- the cylindrical parts that had to be drilled and threaded (by further drilling and threading) broke off during machining, as their wall thickness had not enough resistance;
- one of the positioning "shafts", also broke off because its diameter was too small and its position did not fit well with the corresponding positioning of the "holes" of the mating component.

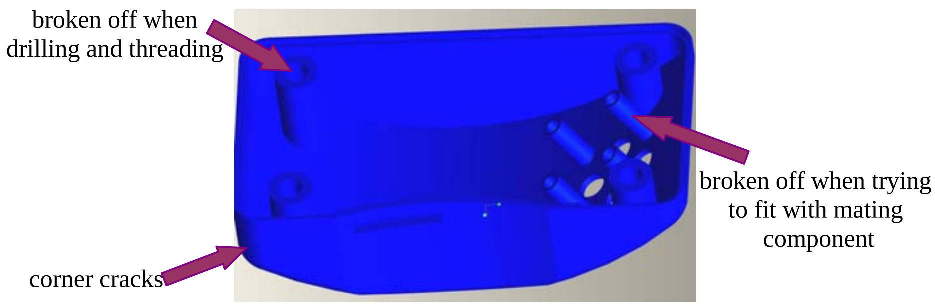

Fig. 6 Severe problems pointed out by prototyping

So, appropriate changes in part design were carried out and the prototyping process was performed again. The new model obtained did not have any of the previous problems– see figure 7.

Fig. 7. New part rapid prototype

5. Conclusions

♦ In rapid prototyping, using additive fabrication, the physical, real, model and the virtual components all have similar features. A commonly used Rapid Prototyping technique is that of Z Corporation and is based on three-dimensional printing.

♦The paper describes rapid prototyping benefits in designing a critical component, “upper case”, of a “video-mouse” security device.

♦ As a result of 3D printing technology, it was possible to discover errors or “misfits” in the design of the part and, thus achieve time and cost savings.

♦Once the required corrections were carried out no more problems were encountered in the subsequent prototype, and the further steps of the component’s mass production process could be carried out. For the studied “upper case” part, injection molding, the risk of component failure was reduced.

♦ Further research should be developed for all of the product’s component parts, using this or other different rapid prototyping techniques. Also, possible influencing factors for the prototype’s mechanical characteristics and geometric features may be studied.

R E F E R E N C E S

[1]. *C.K. Chua, K.F. Leong, C.CL im*, “Rapid Prototyping, Principles and Applications”, World Scientific Publishing Co. Ltd., 2005

[2]. *N. Hopkinson, R.J.M. Hague, P.M. Dickens,* “Rapid Manufacturing, an Industrial Revolution for the Digital Age”, John Wiley & Sons Ltd., 2006

[3]. *Mihaela liescu, E. Nuțu, L. Georgescu,* “Finite Element Method Simulation and Rapid Prototyping”, 8th WSEAS International Conference on ELECTRIC POWER SYSTEMS, HIGH VOLTAGES, ELECTRIC MACHINES (POWER '08), pag. 257-262, ISBN 978-960-474-026-0, ISSN 1790-5117, Venice, Italy, November 21-23, 2008 (ISI)

[4]. Rapid Prototyping, Available from: http://en.wikipedia.org/wiki/Rapid_prototyping, *Accessed: 2009-02*.

[5]. http://www. Rapid Manufacturing\Rapid Prototyping and Solid Freeform Fabrication - The Worldwide Guide.htm, *Accessed: 2009-02*.

[6] Ink Jet Printing, *Available from:* http://www. Rapid Prototyping Inkjet.html, *Accessed: 2009-02*.

[7] Z CORPORATION, *Available from:* http://www.zcorp.com/Products/3D-Printers, *Accessed: 2009-02*.