Z Printing Rapid Prototyping Technique and SolidWorks Simulation – Major Tools in New Product Design

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Abstract: - 3D rapid prototyping is a fast, precise enough and affordable technique of producing prototypes with almost any geometrical complexity. This paper presents the advantages of applying Z Corporation three dimensional printing in obtaining a new product's prototype. A case study is used to illustrate the various stages of the process and to enhance the results. Simulation with ANSYS software, of further processes involved by studied product geometrical characteristics, is important and efficient. Both, rapid prototyping and simulation, techniques resulted in important time and cost savings achieved in the development of the studied product.

Key-Words: - Z printing, rapid prototyping, prototype, product, process, simulation.

1 Introduction

Present time, when referred to manufacturing products techniques, can be characterized by computer aided systems through the whole life of a product, from idea and concept, to design, production process, marketing and sales.

So, time and cost pressure has resulted in new fast and accurate techniques of rapid prototyping / rapid manufacturing, as well as in new powerful software enabling modeling and simulation of the involved processes.

Most of the times, before mass production manufacturing, product prototype is worth to be obtained, knowing that [8] prototype is a "model or preliminary version of something that has been or, will be developed".

The prototype helps: *experimenting and learning* – when designing the product; *testing and proofing ideas* – when developing the product; *discovering possible errors* in shape and dimension – before manufacturing product's components; *integrating the whole components into the whole product* – when testing if assembling is possible etc.

Rapid Prototyping (RP) represents the new modern prototyping technique where 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 process where the virtual model and the physical model correspond almost identically [1].

That is why, there can be obtained objects with, almost, any geometric complexity and the construction of complex parts can be reduced to a manageable, straightforward, and relatively fast process [5].

There are three main Rapid Prototyping systems [2], [4] depending on materials' the initial form:

→ 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; some systems are: 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); some systems are: 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; some systems are: 3D Systems' Selective Laser Sintering (SLA), Precision Optical Manufacturing's Direct Metal Deposition (DMD) and Z Corporation's Three Dimensional Printing (3DP).

As, sometimes, further machining process of prototypes is required, simulation of the involved process is worth to be done. It enables discovering of possible errors in cutting tool's trajectory, as well as the shape and position of the surfaces to be obtained. There are many specialized software to be used, best being the one specific to CNC machine-tool where machining process is done.

Simulation and modelling of product and/or its component elements behavior, when submitted to various machinig processes or to loading condition – similar to real ones, represent some more important tools used for a new product design.

Both product's design, as well as process simulation, presented by this paper, "involves" SolidWorks software.

2. Z Print Rapid Prototyping

One important Rapid Prototyping technique is that of Z Corporation, meaning three-dimensional printing. It involves shooting droplets of binder on a powder layer to selectively bind powder together for each layer [6]. Most of the times, 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].

The case study presented by this paper refers to a "video-mouse" – see Figure 1, used in identification of any kind of false documents, like: visas, bank notes, identity cards, passports, holograms, stamps, checks, etc.

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.

The studied video-mouse "works" in visible, ultraviolet and infrared radiation fields, and allows direct checking and processing of video signal and image, by USB port transfer.

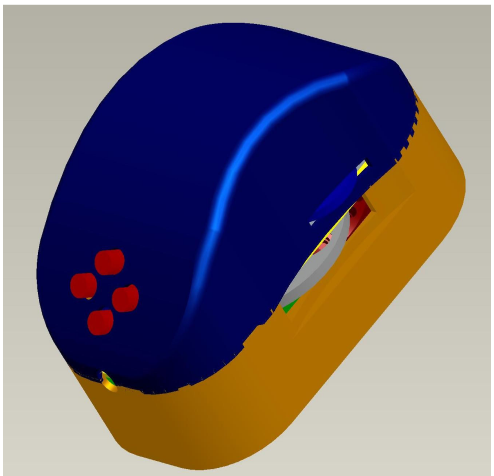

Fig. 1 Video-mouse product

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

Drawings of two component elements of the studied product, meaning upper case and lower case, obtained by SolidWorks software, are shown in Figure 2 and, respectively, Figure 3.

Other components of the assembly were also prototyped and they were all finally joined/fitted together, in order to have an "image" of the whole device. Thus, it was possible to make any necessary correction needed, before starting the mass production process of the studied product.

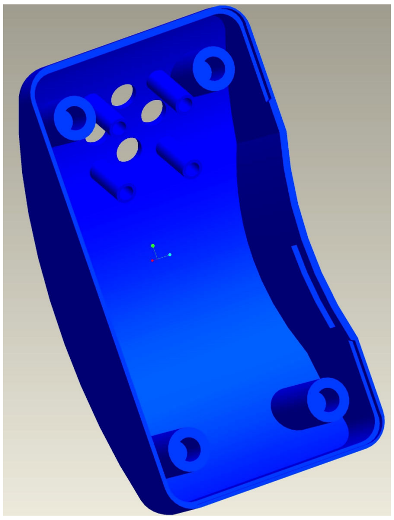

Fig. 2 Upper case drawing

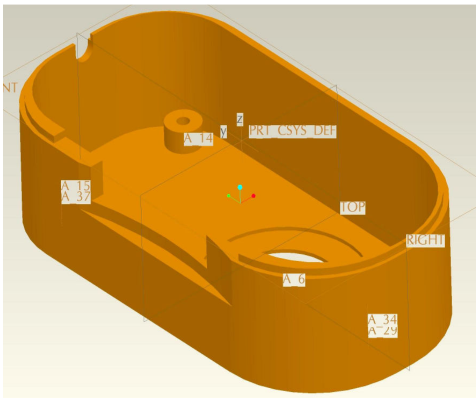

Fig. 3 Lower case drawing

Three dimensional printing, involved a technological system based on:

→ ZPrinter 310 Plus (Z Corporation) [7] printing machine – see Figure 4;

→ 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.

Z printing involved the "steps" mentioned below:

→ computer aided designing of the part to be prototyped (see Figure 2 and Figure 3);

→ models' position into machine's modeling enceinte, so that prototypes' extraction with no damaged can be done – see Figure 4.

→ automatic calculus of powder and binder required quantity - see Figure 5.

→ setting layer thickness (at 0.0889 mm) and, thus, automatic calculus of layers number, as well as of prototyping time – see Figure 5.

→ 3D printing process, successively layer by layer additive fabrication,

→ extraction of prototypes, out of ZPrinter modeling enceinte, once the process is over and the powder prototypes harden

→ "cleaning" of the models not bounded powder, in a special vacuum enclosure and manually trimming of the edges, if necessary.

→ electric oven drying of the prototypes.

→ models impregnation with a mixture of special binder and high strength epoxy.

Once Z printing process is over, hard parts are obtained and further machining processes can be performed, if necessary.

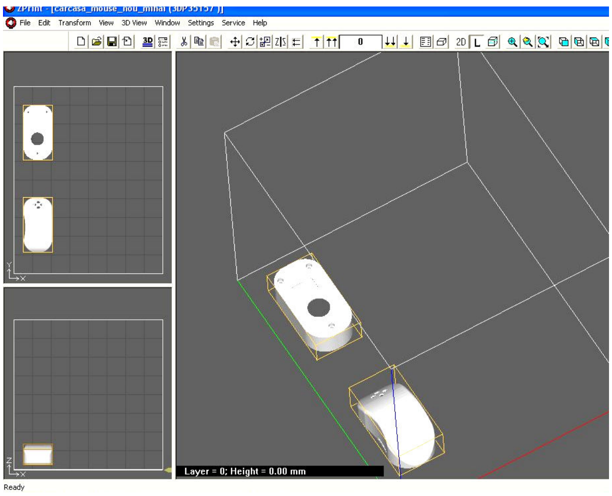

Fig. 4 Models position into ZPrinter 310 Plus enceinte

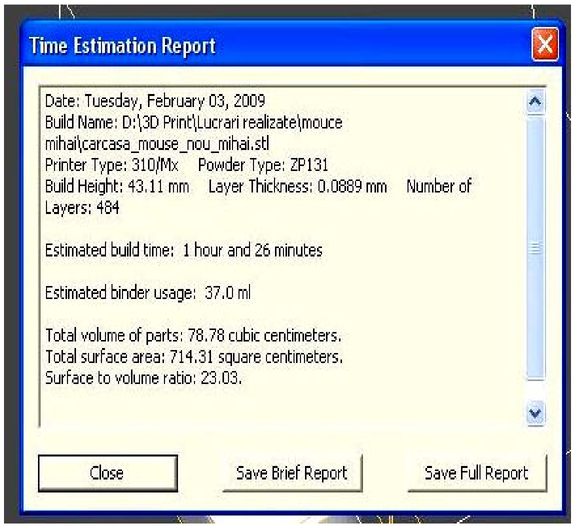

Fig. 5 Automatic calculi of Z printing process characteristics

3. Drilling Process Simulation

For the upper case of the video-mouse device, it is necessary to perform further drilling and threading of the four (wider) cylindrical shape parts – see Figure 6. That is, because four screws will fix this case to the lower one of the product.

It is important that cutting tool axis be exactly the same as cylindrical part's one and that is why, for accurate machining (drilling and threading), an Isel-automation manufacturing system has been used.

It, mainly, consisted in the following parts [9]:

→ isy CAM software – operating under Windows, enabling Isy-CAM CAD part (for designing and modeling parts 2D or, 3D) and Isy-CAM CAM part (for machining on CNC machine-tools with 3, 3.5 or 5 axes);

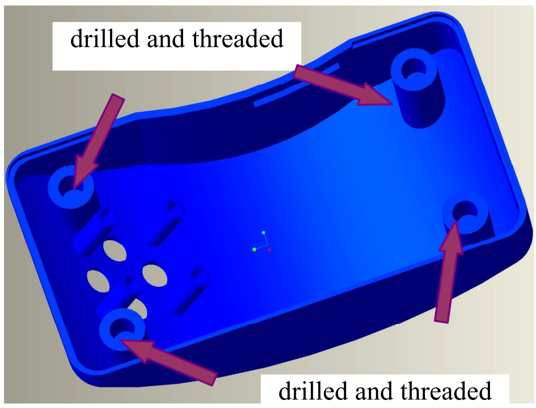

Fig. 6 Upper case parts to be machined

→ ProNC software – modern interface for operating and programming of machine-tools, according to isel PAL or, DIN 66025 specifications,

→ CNC EUROMOD basic units, used for parts machining and/or control, with rigid and low vibration structure.

An image of cutting tool trajectory simulation, is shown in Figure 7, while phases of drilling simulation process are presented in Figure 8 (**a.** – beginning of process and **b.** – end of process).

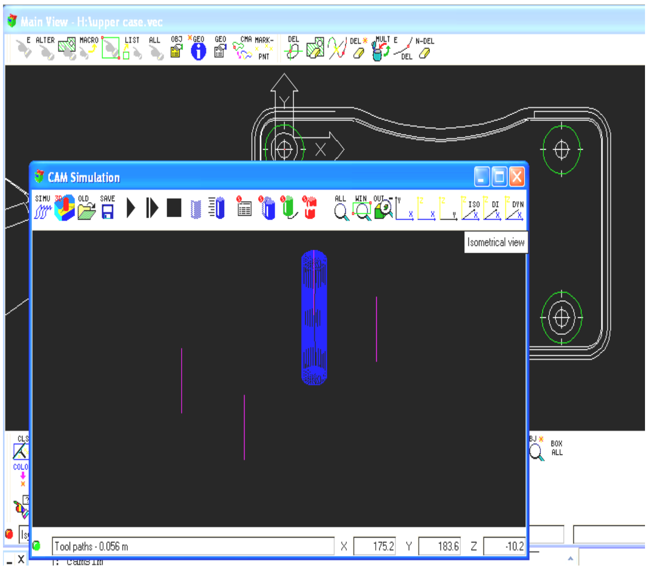

Fig. 7 Cutting tool trajectory simulation

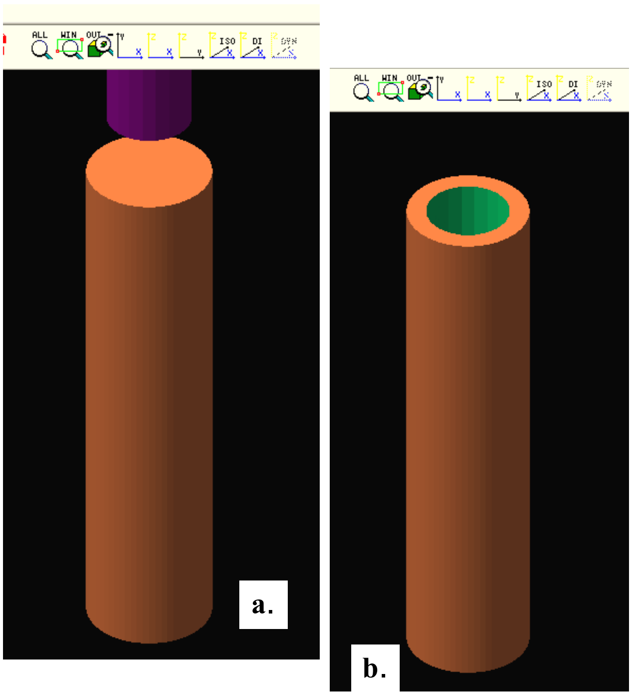

Fig. 8 Drilling process simulation

As an observation, should be pointed out the fact that, even both drilling and threading are required, the references are on drilling process as it involves higher cutting efforts (force and torque) than threading.

If considering the characteristics of powder (zp®131) and binder used, there are obtained [9] mechanical characteristics of prototype material similar to that of the mass produced manufactured parts. (by injection molding of polymeric material).

That it is it is assumed that any problem in the prototype “behavior” is similar to that of the real, injected molded part obtained.

Thus, some drilling process specific parameters have been determined [10] as below :

→ cutting depth, t and cutting feed, s

$$t = \frac{D}{2} = \frac{4}{2} = 2 \ \text{[mm]} \qquad (1)$$

$$s = C_s \cdot D^{0,6} \cdot K_s \ \text{[mm/rev]} \qquad (2)$$

where:

C_s – feed coefficient , Cs = 0,053 ‘

D – drilling tool diameter, D = 4 mm;

K_s – correction coefficient ,Ks = 1;

resulting in:

$$s = 0{,}053 \cdot 4^{0,6} \cdot 1 = 0{,}13 \ \text{[mm/rev]}$$

→ cutting speed, v

$$v = \frac{C_v \cdot D^{zv}}{T^{mv} \cdot s^{yv}} \cdot K_v \ \text{[m/min]} \qquad (3)$$

where:

C_v , K_v – correction coefficients

z_v, m_v, y_v – polytropic exponents

T – cutting tool durability [min]

resulting in:

$$v = \frac{10{,}5 \cdot 4^{0,25}}{28^{0,125} \cdot 0{,}14^{0,55}} \cdot 0{,}85 \cdot 1 \cdot 1 \cdot 1 = 10{,}15 \ \text{[m/min]}$$

→ main spindle rotation, n

$$n = \frac{1000 \cdot 10{,}15}{\pi \cdot 4} = 808{,}12 \ \text{[rev/min]}$$

→ cutting force and torque

$$F_X = C_{Fx} \cdot D^{u_{Fx}} \cdot s^{y_{Fx}} \cdot k_{Fx} \ \text{[daN]} \qquad (4)$$

$$M_t = C_{Mt} \cdot D^{u_{Mt}} \cdot s^{y_{Mt}} \cdot k_{Mt} \ \text{[daNmm]} \qquad (5)$$

where:

C_{Fx}, C_{Mt} , k_{Fx}, k_{Mt} – correction coefficients

$x_{Fx}, y_{Fx}, x_{Mt}, y_{Mt}$ – polytrope exponents

resulting in:

$$F_X = 60 \cdot 4^{1} \cdot 0.14^{0.8} \cdot 1.08 = 53{,}77 \ \text{[daN]}$$

$$M_t = 23 \cdot 4^{1.8} \cdot 0.14^{0.8} \cdot 1.08 = 64{,}28 \ \text{[daN m]}$$

which multiplied by 1.4 (safety coefficient) results:

$$F_z^c = F_z \cdot K_F = 53.77 \cdot 1{,}4 \cong 75.3 \ \text{[daN]}$$

$$M_t^c = M_t \cdot K_M = 64{,}28 \cdot 1{,}4 \cong 89{,}99 \ \text{[daNmm]}$$

which represent the values right to be considered when further calculi are required.

4. **SolidWorks Stress State Simulation**

SolidWorks software finite element analysis was done, so that any fails, of the final product, while the drilling process is on, could be avoided.

A static analysis was considered enough relevant for the study knowing that, when drilling, the load is characterized by the axial force and the torque, both being, approximately, constant in drilling, if the material is homogenous. Although the axial force effect was taken into account within this simulation, it should be mentioned that its effect can be neglected.

As both axial load and torque do not depend on cylindrical part's length, the simulation results are the same whether the load is applied on the top of the cylindrical part (simulating the beginning of the drilling process) or on the bottom of the hole (the end of the drilling process). The images and comments in this paper refer to the end of the drilling process.

Material properties required for the analysis were experimentally determined so, the values resulted in:

- Young modulus: $E = 5900$ MPa,
- Poisson's ratio $\nu = 0.3$,
- yield limit $\sigma_c = 92$ MPa.

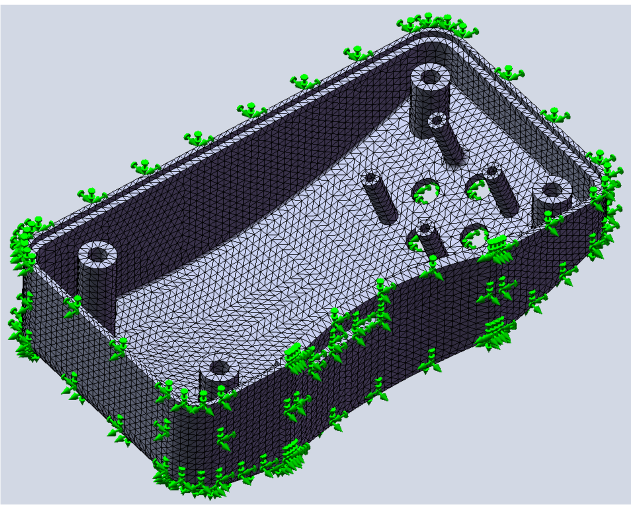

Fig. 9 Mesh and boundary conditions view

In Figure 9 there are presented the meshed part and the applied boundary conditions. The model was meshed with tetrahedron solid elements.

A very fine mesh was produced in order to catch the stress concentration effect which may occur in the cylindrical part base. As a result, a total of 55962 elements and 95948 nods were generated.

All the external part surfaces were blocked as the drilling is done by fixing the part into a special device.

This analysis was done four times, each of them corresponding to one cylindrical shape (of the studied product) that involves drilling. Values of the axial force and the torque are the ones determined above (F≈750 N, M≈900 Nmm). Von Misses stress field with two detailed views, in case of the most stressed cylindrical part, are presented in Figure 10..

It can be noticed that maximum von Misses stress is about 87.6 MPa [N/mm^2], value lower than the yield limit of the material. More, the maximum stresses appear were the drill point "reaches" product base and not over the cylindrical part shape or, near its basis, were stress concentrations may occur.

The other two cylindrical shape parts (in front of the product) are subjected to stresses a little lower than the one presented. The small differences between results is because of the different position of the cylindrical parts studied.

There should be mentioned that the maximum stress value (which is near to the yield limit) corresponds to the axial force and torque values multiplied by a safety coefficient (1.4); as a consequence, any particular risk, coming from materials imperfections (that can lead to an increase) is prevented.

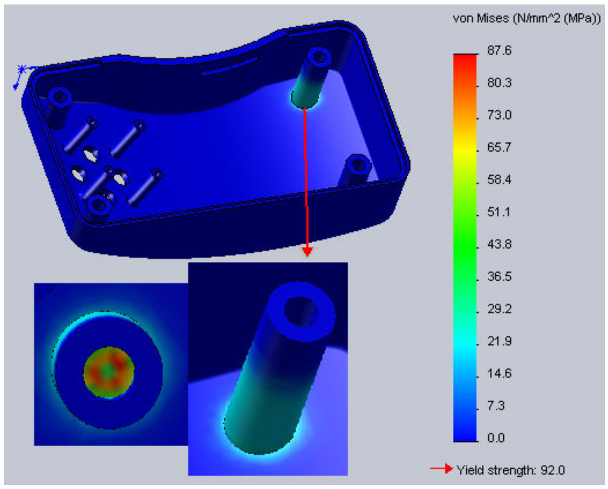

Fig. 10 SolidWorks simulation results of von Misses stress field

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5. Conclusion

As result of prototyping process, there could be noticed some negative aspects that needed correction,

So, for the upper case there were:

→ 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.

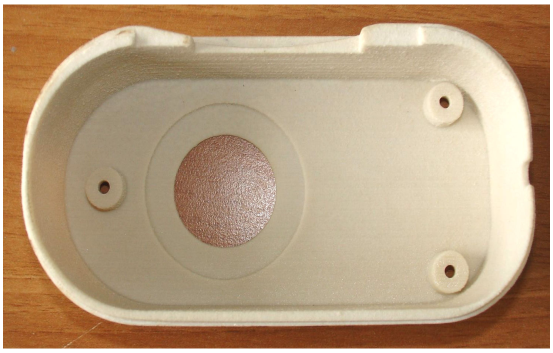
For the lower part, there could also be noticed:

→ cracks around the corners, fact that evidenced the need of enlarging corner radius;

→ few cracks appeared to the bottom , near screw hole regions.

Simulation of drilling process proved to be opportune as there could be ensured a correct position of the inner whole, with respect to the exterior cylindrical surface.

Upper case prototype



Lower case prototype

Fig. 11 Rapid Prototypes

As for stress state simulation, the SolidWorks software analysis pointed out the fact that none of the four cylindrical parts fails while the drilling process is on.

Based on all the above noticed facts, changes in the product design have been performed, but in concordance to whole component elements of the video-mouse. Images of, both, lower case and upper case prototypes can be noticed in Figure 11.

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