

SOME ASPECTS OF RAPID PROTOTYPING TECHNOLOGY UTILIZATION

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Abstract: *Rapid Prototyping (RP) can be described as a group of technologies used to quickly manufacturing a scale model of a part or product using three-dimensional computer aided design (CAD) data. What is commonly considered to be the first RP technique, Stereolithography, was developed by 3D Systems of Valencia, CA, USA. The company was founded in 1986, and since then, a number of different RP techniques have become available.*

Key words: *Rapid Prototyping (RP), RP methods, RP utilization, gearbox, CAD model, prototype.*

1. INTRODUCTION

Rapid Prototyping can be referred as solid free-form manufacturing, computer automated manufacturing or layered manufacturing. RP has obvious use as a tool for visualization. In addition, RP models can be used for testing, such as when an airfoil shape is put into a wind tunnel. RP models can be used to create main models for tooling, such as silicone rubber moulds and investment casts. In some cases, the RP part can be the final part, but typically the RP material is not strong or accurate enough. When the RP material is suitable, highly convoluted shapes (including parts nested within parts) can be produced because of the nature of RP.

There is a multitude of experimental RP technologies either in development or used by small groups of individuals. This section will focus on RP techniques that are currently commercially available, including Stereolithography (SLA), Selective Laser Sintering (SLS), Laminated Object Manufacturing (LOM), Fused Deposition Modelling (FDM), Solid Ground Curing (SGC) Ink Jet 3D printing techniques and Laser Engineering Net Shaping (LENS).

2. MAIN RAPID PROTOTYPING TECHNOLOGY

Patented in 1986, Stereolithography started the rapid prototyping revolution. The technique builds three-dimensional models from liquid photosensitive polymers that solidify when exposed to ultraviolet light. In time of prototype production the model is built upon a platform situated just below the surface in a vat of liquid epoxy or acrylate resin. A low-power highly focused UV laser traces out the first layer, solidifying the model cross section while leaving excess areas liquid. Next, an elevator incrementally lowers the platform into the liquid polymer. A sweeper re-coats the solidified layer with liquid,

and the laser traces the second layer atop the first. This process is repeated until the prototype is complete. Afterwards, the solid part is removed from the vat and rinsed clean of excess liquid. Supports are broken off and the model is then placed in an ultraviolet oven for complete curing. Stereolithography Apparatus (SLA) machines have been made since 1988 by 3D Systems of Valencia, CA. To this day, 3D Systems is the industry leader, selling more RP machines than any other company. Because it was the first technique, Stereolithography is regarded as a benchmark by which other technologies are judged [5].

Developed by Carl Deckard for his master's thesis at the University of Texas, Selective Laser Sintering (SLS) was patented in 1989. The technique uses a laser beam to selectively fuse powdered materials, such as nylon, elastomer, and metal, into a solid object. Parts are built upon a platform which sits just below the surface in a bin of the heat-fusible powder. A laser traces the pattern of the first layer, sintering it together. The platform is lowered by the height of the next layer and powder is reapplied. This process continues until the part is complete. Excess powder in each layer helps to support the part during the build. SLS machines are produced by DTM of Austin, TX.

In Laminated Object Manufacturing (LOM) technique, developed by Helisys of Torrance, CA, layers of adhesive-coated sheet material are bonded together to form a prototype. The original material consists of paper laminated with heat-activated glue and rolled up on spools. Feeder/collector mechanism of LOM device advances the sheet over the build platform, where a base has been constructed from paper and double-sided foam tape. Next, a heated roller applies pressure to bond the paper to the base. A focused laser cuts the outline of the first layer into the paper and then cross-hatches the excess area (the negative space in the prototype). Cross-hatching breaks up the extra material, making it easier to remove during post-processing. During the build, the excess material provides excellent support for overhangs and thin-walled sections. After the first layer is cut, the

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platform lowers out of the way and fresh material is advanced. The platform rises to slightly below the previous height, the roller bonds the second layer to the first, and the laser cuts the second layer. This process is repeated as needed to build the part, which will have a wood-like texture. Because the models are made of paper, they must be sealed and finished with paint or varnish to prevent moisture damage.

In Fused Deposition Modelling (FDM) technique, filaments of heated thermoplastic are extruded from a tip that moves in the x-y plane. Like a baker decorating a cake, the controlled extrusion head deposits very thin beads of material onto the build platform to form the first layer. The platform is maintained at a lower temperature, so that the thermoplastic quickly hardens. After the platform lowers, the extrusion head deposits a second layer upon the first. Supports are built along the way, fastened to the part either with a second, weaker material or with a perforated junction. Stratasys, of Eden Prairie makes a variety of FDM machines ranging from fast concept modellers to slower, high-precision machines. Materials include ABS, elastomer, polycarbonate, polyphenylsulfone and investment casting wax [2].

Developed by Cubital, solid ground curing (SGC) is somewhat similar to Stereolithography (SLA) in that both use ultraviolet light to selectively harden photosensitive polymers. Unlike SLA, SGC cures an entire layer at a time. SGC is also known as the solidex process. First, photosensitive resin is sprayed on the build platform. Next, the machine develops a photomask (like a stencil) of the layer to be built. This photomask is printed on a glass plate above the build platform using an electrostatic process similar to that found in photocopiers. The mask is then exposed to UV light, which only passes through the transparent portions of the mask to selectively harden the shape of the current layer. After the layer is cured, the machine vacuums up the excess liquid resin and sprays wax in its place to support the model during the build. The top surface is milled flat, and then the process repeats to build the next layer. When the part is complete, it must be de-waxed by immersing it in a solvent bath. SGC machines are distributed in the U.S. by Cubital America Inc. of Troy, MI. The machines are quite big and can produce large models [3].

Ink-Jet Printing refers to an entire class of machines that employ ink-jet technology. The first was 3D Printing (3DP), developed at MIT and licensed to Soligen Corporation, Extrude Hone, and others. The ZCorp 3D printer, produced by Z Corporation of Burlington is an example of this technology. Parts are built upon a platform situated in a bin full of powder material. An ink-jet printing head selectively deposits or "prints" a binder fluid to fuse the powder together in the desired areas. Unbound powder remains to support the part. The platform is lowered, more powder added and levelled, and the process repeated. When finished, the green part is then removed from the unbound powder, and excess unbound powder is blown off. Finished parts can be infiltrated with wax, CA glue, or other sealants to improve durability and surface finish. Typical layer thicknesses are on the order of 0.1 mm. This process is very fast, and produces parts with a slightly grainy surface. ZCorp uses two different materials, a starch based powder (not as strong, but can

be burned out, for investment casting applications) and a ceramic powder. Machines with 4 colour printing capability are available [3].

Laser engineering net shaping (LENS) is a process developed at Sandia National Laboratories and Stanford University that can create metal tools from CAD data. Materials include 316 stainless steel, Inconel 625, H13 tool steel, tungsten, and titanium carbide cermets. LENS method uses a high power laser focused onto a substrate to create a molten puddle on the substrate surface. Metal powder is injected into the melt pool to increase its volume. The powder ejection head moves according to the geometry of the first layer. After the first one new layer are built upon it until the entire object is reproduced. Involving of a substrate makes this process different from others. So far it is the most advanced process in terms of the range of mechanical properties of the generated metallic parts among all commercialised processes based on the layered production principle [6].

3. SELECTION OF KEY PARAMETERS IN PREPARATION OF RP PROCESS

For better orientation of user in process of setting of suitable parameters during the preparation of printing there was algorithm elaborated which accumulates all factors and steps that lead to selection of most suitable variant (Fig. 1) [7].

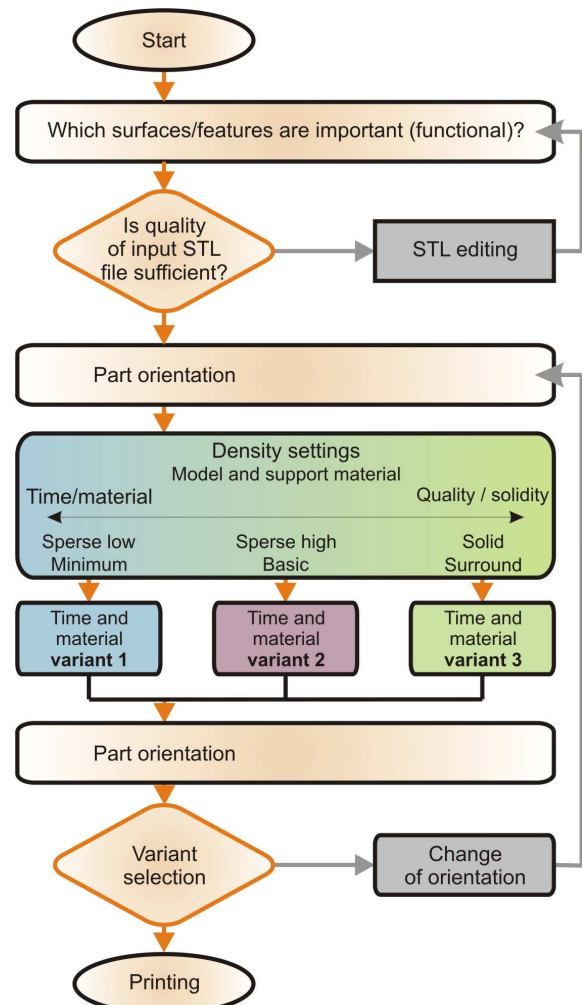


Fig. 1. Algorithm created for 3D printing preparation process.

First step is to define the surfaces and constructional points that represent functional features of part and thus they should condition requirements on quality. Considering these surfaces it is necessary to think about number and type of existing reference entities in model that can be used for part orientation. In case that STL data do not have required quality there is need to increase the number of polygons and re-export to STL format (STL editing). After importing of STL file we get to the part orientation. Commonly there is automatic option solved by several software procedures. These steps can be in contrary to users requirements. More effective way would often be manual orientation, where is position of part defined by relation of its surface or edge to the working board or to some coordinate axis of used environment. Available are also standard functions like rotation and scaling. With part oriented we can proceed to another settings that include style and density of particular printing layers. Value of minimal thickness of single layer is conditioned by hardware properties of printer or building material. There is parameter usually called Model interior, for setting of quality of basic building material. Among standard options there is Solid mode, advised by manufacturer, as printed material results in one whole. Other possibilities are Sparse-Low density and Sparse-high density. They save basic material by creating the grid of cavities inside the volume. Last mentioned options are applied mainly in huge models without requirement on technical functionality. Walls are partially weakened and have lower strength. Support fill is another parameter that is very similar to the previous one except for it defines the usage of support material. It is often applied for skew surfaces and holes. Common options are Minimum, Basic, Sparse and Surround. For construction reasons it is wise to use Sparse variant to avoid the wall crash because of their small thickness. Surround option on the other hand is used for complicated models. Support material then covers all the model and needs to be removed in special washing device. Lowering settings for density and volume of used basic and support material answer to lower strength and functional properties but present assumption for lowering the cost of 3D printing. Models created by using low parameters are sufficient for most common application purposes – for presentations. Higher parameters of quality mean longer printing times and higher energy consumption, but utilization possibility of such models is much higher as they can be used instead of real functional parts. Next step in 3D printing preparation process is to define the location of the model on working board of printer. Goal is to optimally place printed model considering possibility of allocation of other prototypes (printed together or later) on the same printing board. After thinking of all mentioned parameters, the user is supposed to make the decision based on information about printing economy, volumes of both kinds of material and relevant printing times. Good start for making such decision right is to have all information cumulated at one place and thus to have much better idea of expected printing results. In case of interest there is a way to get back to the part orientation step [1].

4. EXAMPLE OF RP UTILIZATION

Rapid prototyping involves creating of realistic model of a product's user interface to get prospective customers involved early in the design of the product. Using rapid prototyping, you model the look and feel of the user interface without investing the time and labor required to write actual code. Then you show the prototype to prospective customers, revise the prototype to address their comments, and keep repeating these two steps. Your goal is to produce a complete, agreed-upon design of the product's user interface before writing a single line of actual code. When walkthroughs and usability tests show you that customers are delighted with your prototype user interface, then programmers can model it when they code the actual product [9].

In order to minimize the prototype it was decided to model the small four-graded gearbox with reverse operation and self-shift shown in Fig. 2. We did not want to design and produce any unusable parts with large surface breakdown to put it to make measurements but the prototype which would itself perform a function and was suitable for visualizing the accuracy of the printing [4].

This gearbox is used only as preview tool for functional prototypes printed with FDM method and also for testing of achieved printing accuracy and quality. In frame of gearbox design we take into account savings of basic material and also support material. Gearbox has four gears, of which one is reverse. Their ratios are 4, 3, 2, and reverse gear, with fourth gear ratio. All levels are kept as transfers to slow. Because the teeth presented most accurate part of the draft, we decided to generate them using the Design Accelerator module included in Autodesk Inventor Professional 2009. This step is necessary to enter the desired parameters of gearing as a module, the distance axis, gear ratio, width of teeth and after conversion to generate a 3D model of the sprocket, which can be further modified.

Model gearing was subsequently modified in CAD/CAM/CAE system CATIA V5 R19. Transfer of models between Inventor and Catia system was implemented using the exchange format IGES where they were treated.

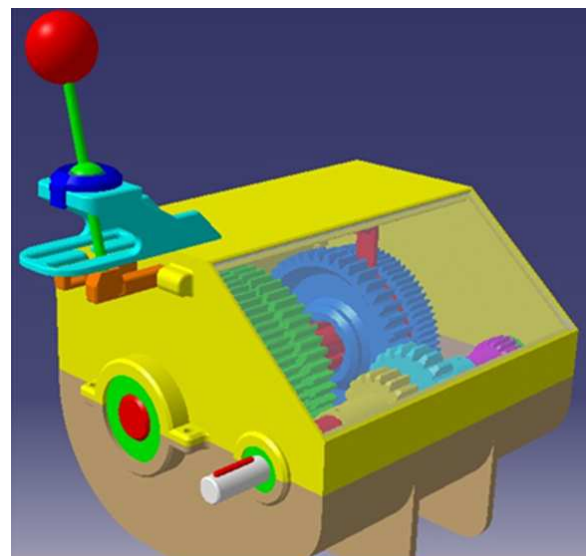


Fig. 2. CAD model of experimental gearbox.



Fig. 3. Prototype of experimental gearbox produced by RP.

In AutoCAD 2008 we ran the full dimension designing of the gear with gradually adding of proposed model arrangements through which it was possible to determine the dimensions of the gearbox. After creating the reports and rechecking of all dimensions the models were exported to STL format and sent to printer control program that could handle their geometry.

On the Department of Manufacturing Technologies there is UPrint 3D printer from Dimension available. It is a small 3D printer with $635 \times 660 \times 787$ mm dimensions suitable for office environment which uses the printing principle of Fused Deposition Modelling. Maximum dimensions of printed prototype are $203 \times 152 \times 152$ mm. This printer prints only one layer of constant thickness 0.254 mm which is as the accuracy of the print in the Z axis very acceptable. This printer used as building material thermoplastic ABCplus Ivory which comes in standardized packages as fiber with a diameter of 1.6 mm rolled onto a reel. Each spool contains 500 cubic centimetres of material. The support material used is resin Soluble SR-P400 which comes in the same package as a building material. After printing the prototype it is necessary to clean the prototype of the auxiliary material.

For this printer we use Catalyst program which serves to complete printing settings such as disposition of components on working desktop or set-saving modes where savings can be achieved by building and supporting material to 40% depending on the shape and parts at the expense of strength of the prototype. In a first step we generated STL data in the CAD system that can be loaded to the Catalyst program for layered rendering of the model. After starting of print cycle the system warms up printing jet and whole work area for working temperature. This lasts about 15 minutes, during which the nozzle and purifying device are calibrated. Followed by the print itself, the nozzle is moving over X-Y pad and working in the Z axis. After printing it is necessary to separate the support material from the building one. In the semi-simple components the support material can be separated without any problems, as because of reducing temperature it is particularly fragile [8].

However, for complex parts with cavities there is need to use the washer to remove support material from places that are not accessible for any instrument. The last step is gear assembly, which consists of forty parts and testing of prototype functionality (Fig. 3). During the functional testing, we used an electric motor with a speed regulator connected to the input shaft. The test showed flawless shifting and fixing of rates in the desired position.

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5. CONCLUSIONS

Rapid prototyping is widely used in the automotive, aerospace, medical, and consumer products industries. Although the possible applications are virtually limitless, nearly all fall into one of the following categories: prototyping, rapid tooling, or rapid manufacturing.

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