DESIGN OF MANUFACTURING SYSTEMS BY RAPID PROTOTYPING TECHNOLOGY APPLICATION

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Abstract: Rapid Prototyping (RP) presents the automatic production of physical parts using by additive manufacturing technology. The start techniques for Rapid Prototyping became available in the late 1980s and were used to produce models and prototype parts. Today they are used for a much wider range of applications and are even used to manufacture production-quality parts in relatively small numbers. Rapid Prototyping is widely used in the automotive, aerospace, medical, and consumer products industries. In paper is presented process of design product development, product production and testing of products produced by Fused Deposition Modelling rapid prototyping technology.

Key-words: design, manufacturing systems, rapid prototyping technology, stereolithography method

1. INTRODUCTION

Rapid Prototyping presents relatively new type of manufacturing technology that is often used for production of the automatic construction of physical objects using additive principle. Beginnings of Rapid Prototyping technology are dated in the late 1980's when Stereolithography technology was defined as a method and device was built for making solid objects by successive "printing" of thin layers of the ultraviolet curable material one on top of the other, what led to production of models and prototype parts. In 1986 the first company was founded which generalized and commercialized such procedure, 3D Systems Inc. The term "Stereolithography" was defined in U.S. Patent 4,575,330, entitled "Apparatus for Production of Three-Dimensional Objects by Stereolithography", issued on March 11, 1986. Today, there is much wider range of Rapid Prototyping methods that are used to manufacture the models, parts or final products. Before application of Rapid Prototyping technology we must to handle the models of future parts while using Computer Aided Design (CAD)

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systems, then to transform them into STL format that is further used in Rapid Prototyping devices for parts production [1].

2. PRINCIPLE OF RAPID PROTOTYPING TECHNOLOGIES

While with traditional methods the prototype needed to be constructed and finished manually, rapid prototyping attitude brings the possibility of changing the necessary properties usually responding with geometrical characteristics and to simply create the new prototype on the base of the file from the previous version. This makes prototype creation much faster and easier. There is a more of developed rapid prototyping technologies either in development or used for production by small groups of prototypes, including Stereolithography (SLA), Selective Laser Sintering (SLS), Fused Deposition Modelling (FDM), Solid Ground Curing (SGC) and 3D Ink Jet printing [1].

Company 3D Systems were founded in 1986 by inventor Charles W. Hull and entrepreneur Raymond S. Freed. Amongst all the commercial RP systems, the Stereolithography Apparatus (SLA) as it is commonly called is the pioneer with its first commercial system of Rapid Prototyping technology. 3D Systems' Stereolithography process creates three-dimensional plastic objects directly from CAD data. The process begins with the vat filled with the photo-curable liquid resin and the elevator table set just below the surface of the liquid resin (Fig. 1).

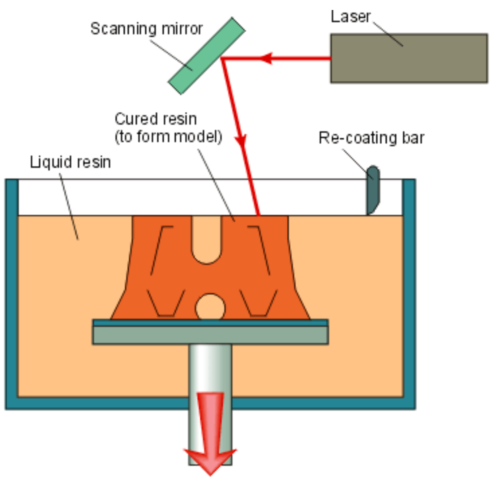

Fig. 1. Principle of Stereolithography method [1]

The operator loads a three-dimensional CAD solid model file into the system. Supports are designed to stabilize the part during the building. The translator converts the CAD data into a STL file. The control unit slices the model and support into a series of cross sections from 0.025 to 0.5 mm thick. The computer-controlled optical scanning system then directs and focuses the laser beam so that it solidifies a two-dimensional cross-section corresponding to the slice on the surface of the photo-curable liquid resin to a depth greater than one layer thickness. The elevator table then drops enough to cover the solid polymer with another layer of the liquid resin. A leveling wiper or vacuum blade (from Zephyr recoating system) moves across the surfaces to recoat the next layer of resin on the surface. The laser then draws the next layer. This process continues building the part from bottom up, until the system completes it. Part is then raised out of the vat and cleaned of excess polymer.

The SLS process creates three-dimensional objects, layer by layer from CAD-data generated in CAD software using powdered materials with heat generated by a CO_2 laser within the Vanguard system. CAD data files in the STL file format are first transferred to the Vanguard system where they are sliced. From this point, the SLS process (Fig. 2) starts and operates as follows: A thin layer of heat-fusible powder is deposited onto the part-building chamber. The bottom-most cross-sectional slice of the CAD part under fabrication is selectively "drawn" (or scanned) on the layer of powder by a heat-generating CO_2 laser. The interaction of the laser beam with the powder elevates the temperature to the point of melting, fusing the powder particles to form a solid mass. The intensity of the laser beam is modulated to melt the powder only in areas defined by the part's geometry. Surrounding powder remains as a support.

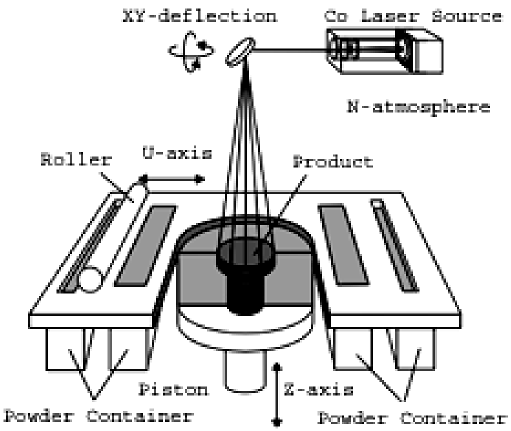

Fig. 2. Selective Laser Sintering technology

When the cross-section is completely drawn, an additional layer of powder is deposited via a roller mechanism on top of the previously scanned layer. This prepares the next layer for scanning. Steps 2 and 3 are repeated, with each layer fusing to the layer below it. Successive layers of powder are deposited and the process is repeated until the part is completed. As SLS materials are in powdered form, the powder not melted or fused during processing serves as a customized, built-in support structure. There is no need to create support structures within the CAD design prior to or during processing and thus no support structure to remove when the part is completed. After the SLS process, the part is removed from the build chamber and the loose powder simply falls away, SLS parts may then require some post-processing or secondary finishing, such as sanding, lacquering and painting, depending upon the application of the prototype built [4].

Selective laser melting (SLM) is an additive manufacturing process that uses 3D CAD data as a digital information source and energy in the form of a high powered laser beam (usually an ytterbium fibber laser) to create three-dimensional metal parts by fusing fine metallic powders together. The industry standard term, chosen by the ASTM F42 standards committee, is laser sintering, although this is acknowledged as a misnomer because the process fully melts the metal into a solid homogeneous mass. The process is also sometimes referred to by the trade names DMLS or LaserCusing. A similar process is electron beam melting (EBM or E-beam), which, as the name suggests, uses electron beams as an energy source. What is called Selective Laser Melting started at the Fraunhofer Institute ILT in Aachen, Germany, in 1995 with a German research project, resulting in the so called basic ILT SLM. The process starts by slicing the 3D CAD file data into layers, usually from 20 to 100 micrometres thick, creating a 2D image of each layer; this file format is the industry standard .stl .file used on most layer-based 3D printing or stereolithography technologies. This file is then loaded into a file preparation software package that assigns parameters, values and physical supports that allow the file to be interpreted and built by different types of additive manufacturing machines [4].

With SLM (Fig. 3) thin layers of atomized fine metal powder are evenly distributed using a coating mechanism onto a substrate plate, usually metal, that is fastened to an indexing table that moves in the vertical (Z) axis. This takes place inside a chamber containing a tightly controlled atmosphere of inert gas, either argon or nitrogen at oxygen levels below 500 parts per million. Once each layer has been distributed each 2D slice of the part geometry is fused by selectively applying the laser energy to the powder surface, by directing the focused laser beam using two high frequency scanning mirrors in the X and Y axes. The laser energy is intense enough to permit full melting (welding) of the particles to form solid metal. The process is repeated layer after layer until the part is complete.

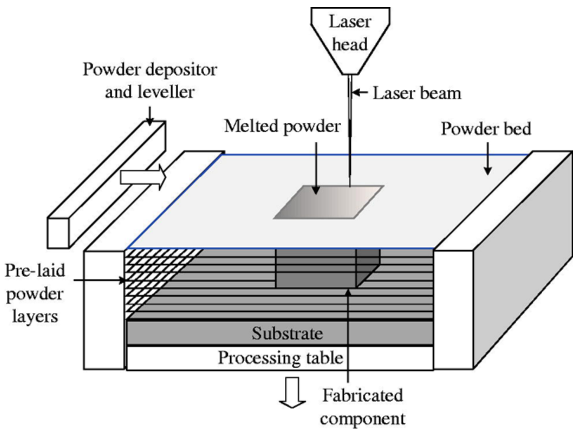

Fig. 3. Selective Laser Melting technology

Fused Deposition Modelling (FDM) was developed by Stratasys in Eden Prairie, Minnesota. In this process, a plastic or wax material is extruded through a nozzle that traces the part's cross sectional geometry layer by layer. The build material is usually supplied in filament form, but some setups utilize plastic pellets fed from a hopper instead. The nozzle contains resistive heaters that keep the plastic at a temperature just above its melting point so that it flows easily through the nozzle and forms the layer. The plastic hardens immediately after flowing from the nozzle and bonds to the layer below. Once a layer is built, the platform lowers, and the extrusion nozzle deposits another layer. The layer thickness and vertical dimensional accuracy is determined by the extruder die diameter, which ranges from 0.013 to 0.005 inches. In the X-Y plane, 0.001 inch resolution is achievable. A range of materials are available including ABS, polyamide, polycarbonate, polyethylene, polypropylene, and investment casting wax [2].

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. All the attempts were realized as a part of preparation stage for printing on UPrint machine that utilize FDM technology to build the prototype. This technology, developed by Stratasys, uses the software program to orient the model and generate building slices. Printer dispenses with basic building material and support material which is used if necessary for creation of holes, cavities, drafts, etc. Each material has its own nozzle. Creation of particular prototype layers with use FDM method is shown in Fig. 4.

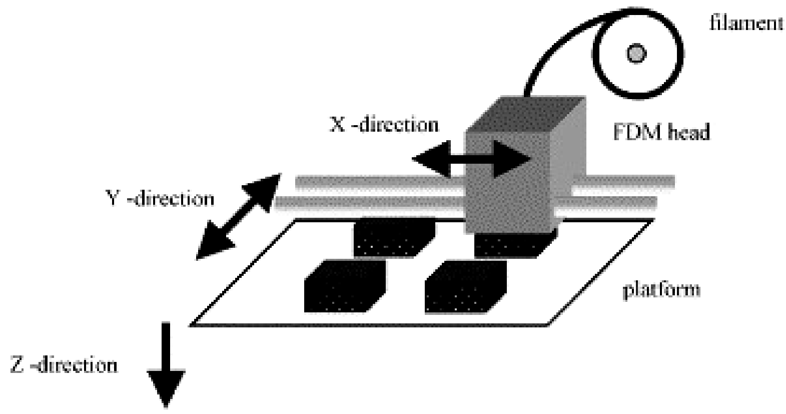

Fig. 4. Fused Deposition Modelling method

3. PRODUCTION OF MANUFACTURING DEVICES BY RAPID PROTOTYPING

As a precondition for utilization of all methods of Rapid Prototyping we can consider the existence of full three-dimensional geometrical description of manufactured part. The geometry of 3D described in CAD system is for the purpose of simplification of further mathematical processing firstly approximated using the triangles (triangulation) and converted into output format STL (standard of Rapid Prototyping). STL data can be further processed by special computing algorithm, which distributes the 3D geometry for particular cross sections of defined height (Slicen, SLI-format). The conversion of STL data to SLI format is realized with the use of special software tools, which are included in Rapid Prototyping system. Information about particular cross sections obtained in this way is transferred directly to the specific manufacturing device of Rapid Prototyping [2].

One of the most important factors of successful implementation of Rapid Prototyping systems is the ability to achieve an exact definition of prototyped part from CAD system. Optimal way to assure the required accuracy is to use the system based on volume modelling of objects in the phase of creation of model design. 2D and 3D data of planar or edge modelling software are inaccurate, or not fully complete for creation of parts using the Rapid Prototyping technologies. Volume modelling has the greatest capability to meet the requirement of clear mathematical definition of the geometry of part for Rapid Prototyping machine. From the viewpoint of problem-free utilization of Rapid Prototyping methods and necessity of assuring the full integration in the process of part development it is suitable for preparation of the data for prototyping devices to use some of top-class CAD/CAM/CAE systems, while it is ideal if the system includes specialized module for supporting of the relevant technology. Examples of these systems can be found in CAD/CAM/CAE systems Pro/Engineer, Catia and NX, which include special modules serving for interconnection and running of Rapid Prototyping devices.

Modules for support of Rapid Prototyping present the interconnection of CA systems to fast developing area of rapid prototyping. They allow create the data for production of prototypes of 3D parts from volume models, or from planar models of CA systems without the need to use the external software. By adaptation of industrially standard STL format of output files, it is possible for creation of the prototype to use basically any technology of Rapid Prototyping. STL files are also suitable from the viewpoint of import into the different applications which have no relation to the Rapid Prototyping. For created STL file it is important that Rapid Prototyping modules allow fast and effective imaging of volume or planar models in the form of series if triangles while providing determined tolerance. In case of using the planar model created in CA system the neigh boring surfaces and closed holes are localized with suitable tolerances that are defined by the user. The software informs the constructer also in the case when the surfaces of the model do not create complete defined body. Capability to display the triangles allows the resolution of the model, which can be with use of standard visualization tools of CA systems displayed in section (shaded) form. Presentation of possibility to display the part using the STL format in Catalyst software is on Fig. 5 [3].

Between basic functional attributes of modules of CA systems designated for support of Rapid Prototyping technologies belong:

- possibility of creation of 3D parts from volume or planar models created in

CA systems without using any additional software tools;

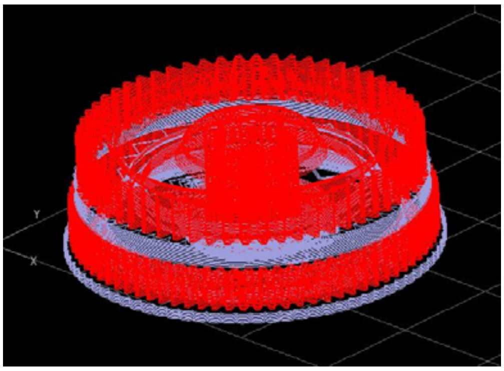

Fig. 5. Generated paths of printing of material in Catalyst software

- support of all existing methods of rapid prototyping, including stereo-lithography, selective laser sintering, solid ground curing, laminated object manufacturing, fused deposition modelling, ballistic particle manufacturing and direct shell production casting;
- acceleration of the process from the creation of the proposal design all the way to the selling of the product on the market;
- selection of fast and effective tools for creation of industrially standard STL file in binary or ASCII code;
- providing possible visual checking of layers application prior to the production of prototypes of the models;
- support of user-defined triangular tolerance (chord of deviation);
- support of user-defined tolerance of adjacency of the surfaces;
- warning about the possible incompleteness of planar bodies;
- providing the ability of specific connection, which allows the user to join more parts into the one file designed for rapid prototyping.

Example of the prototype of the product created by the technology of Rapid Prototyping on the base of data prepared in CA system is on Fig. 6.

Fig. 6. Example of printed parts by FDM method

4. CONCLUSIONS

In industrial practice there are currently more than 20 vendors for RP systems, the method employed by each vendor can be generally classified into the following categories: photo-curing, cutting and glueing/joining, melting and solidifying/fusing and joining/binding. Photo-curing can be further divided into categories of single laser beam, double laser beams and masked lamp. The initial state of material in Rapid Prototyping technologies can come in either solid, liquid or powder state. In solid state, it can come in various forms such as pellets, wire or laminates. The current range materials include paper, nylon, wax, resins, metals and ceramics. Most of the RP parts are finished or touched up before they are used for their intended applications. Applications can be grouped into design engineering, analysis and planning and tooling and manufacturing. A wide range of industries can benefit from RP and these include automotive, aerospace, biomedical, consumer, electrical and electronic products.

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