ABSTRACT

Rapid Prototyping (RP) technique is one among the manufacturing activities that leads in reduction of product development time. One of the important techniques is stereolithography, which is the area of this work. This research work aims at developing a machine using stereolithography approach. In the second phase, the development of CAD interfacing tool, "PSG slice" for the RP machine has been undertaken. Computer programming language 'C' is used to build this software. This is exclusive software for Rapid Prototyping machine developed. PSG Slice software is used to interface RP machine with CAD models created in any package. The software uses the simplest uniform slicing algorithm, which takes only the slice thickness as a parameter. The model created in a CAD package has to be converted to STL format to be used with the software. The STL model supplied to the software is displayed in 3D view and the software is capable of re-scaling and re-orienting the STL model supplied to it. These capabilities of the software eliminate the need for multiple STL files, to represent a model in different orientations and with different scale factors.

The software is also capable of estimating the time requirements for making a prototype in RP machine developed. Prototype making is an important step in product development involving all stages of manufacture such as process planning, machining, assembly, etc. The long cycle time and the high cost of this process, limit the number of design alternatives that could be evaluated. This leads to the development of rapid prototyping.

With the advent of solid modelers and analysis packages, a doubt arises whether a physical prototype is required. The answer to this question is logical.

Even though these packages are able to simulate the functional requirements, assembly, analysis, etc., if the application is critical, like in the case of a nuclear reactor component or an aircraft component, a physical model is required to get convinced.

The efficiency and possibilities of RP are very advanced. The equipment gives engineers and designers an opportunity to put their ideas and concepts in the prototype and check for their correctness in a short period of time and with minimal cost. RP provides the concurrent engineering representatives of tool design, production planning, design and marketing with the prototype very similar to real object, in an early phase of the product development process. Practical experiences show that tangible prototypes are substantially better suited for conveying ideas, functions and need of the object than expressing in pictures, simulations or verbal descriptions.

Solid CAD models makes the process easier, but surface CAD models that are watertight have also been used successfully. Next, the boundaries and surfaces of the CAD description are tessellated - formed as connected triangles. The triangles may be large or small as desired. Smaller triangles result in finer resolution of curved surfaces and improved accuracy through reduced chordal deviations, while larger triangles minimize the system storage requirements, at the expense of accuracy.

The difficulties in the improvement of accuracy and surface finish arise from material shrinkage with uncertain variation during phase change, influence of temperature, stair-step effect, build resolution, and balance concern between build resolutions and build time.

Stereolithography rapid prototyping machine has been developed in this work. This machine works on the principle of Stereolithography, which is a layer-by-layer addition rapid prototyping technique. Here, the model is created layer by layer by curing epoxy resin subjecting it to an Argon Ion Laser. The photopolymer is contained in a vat. After each layer has been cured, to make the photo curable resin level uniform over the previously build layer, a wiping blade arrangement has been provided which is actuated by a pneumatic cylinder. The Z-axis is used as an elevator for platform movement for each layer model manufacturing. The machine is basically a vertical machining center without automatic tool changer, spindle head, and rotary table.

The major components of the machine are base, slides (X and Y-axes), column, bed and vertical slide (Z axis). The components are fabricated with welding and are subjected to heat treatment and brought to a final shape by machining and finishing operations.

This machine also has provisions for including positioning accuracy and rotary table in later stages. A centralized lubricating unit lubricates all sliding and rotating parts; ball screw support bearings are lubricated by life long grease. The laser source is mounted on the machine separately.

The machine has two deflector mirrors to deflect the laser beam on to the vat. The three axes are moving on linear motion guides to reduce stick slip with improved positioning accuracy, high traverse rate and repeatability. Three axes are controlled by AC servomotors with built in pulse coders and 3-axes control system.

In this RP machine, a vat is filled with a photo curable resin which when exposed to laser gets cured. The resin after curing forms a thermosetting plastic. After each layer is created, the elevator in the Z-axis moves down, so that the next layer can be formed. Simultaneous motions of laser beam in X and Y-axes are made possible by having a special supporting device to mount laser head with 90-degree deflector to the X and Y table.

To start with, a CAD model is developed in any 3D modeling software. Then, the developed model is converted into a STL format, which is further, sliced using slicing software “PSG slice”. The software slices and generates codes for the rapid prototyping machine to develop the required prototype. The generated NC codes are transferred to the machine from the PC, via RS-232/C serial port. The movement of the laser beam in the machine in X and Y axes are governed by these NC codes. The laser beam cures the first layer by scanning, which is filled by the next layer of resin to be cured. The uniformity in the layer thickness is governed by a wiping mechanism. Thus, the above process is repeated until the whole model is built layer by layer. After the model is built, rinsing is done using methanol to remove the uncured resin over the model. Then, it is post-cured in an UV Fluorescent chamber. Finishing operation follows the post-curing operation.

In the present work, the software is developed for interfacing CAD models with RP machine. The software takes STL files representing CAD models as its input. It slices the input STL model and generates NC codes for creating prototype layer by layer in RP machine.

Finally, software testing and validation are given. The capabilities of the software tested with many complex components are explained. Validation of the software is also discussed with reference to sample prototypes made in RP machine.

The software PSG Slice is mouse driven and requires no previous knowledge in C language. The Graphical User Interface (GUI) of PSG Slice has twenty-two button controls, a view window, an input and message window and a status bar to make the user interaction easy. The software when initialized prompts a screen with twenty-two button controls and the user is free to click any button and execute the function.

The status bar of PSG Slice displays the default values of all the process parameters considered in the software and updates the display when the user changes them. The user is guided by a series of prompts and messages when he/she goes wrong. The view window displays the input model when the input file is successfully read. It is also used to display the slicing process, build process and build time calculation.

PSG Slice accepts three dimensional design files from all standard software packages that can produce files in STL format. It is important for STL files to be relatively free from defects before reading them into PSG Slice. The user is free to set the major process parameters like slice thickness, hatch spacing, and line width compensation and hatch pattern.

The other important process parameter, laser power is not controllable by the NC codes fed into the control system of RP machine and it is the operator's job to set an optimum laser power according to the travel speed of laser delivery system.

The build space of RP machine is 500 X 500 X 500 mm, so the input models larger than this size are automatically scaled down by the software. The user is allowed to re-scale the input models, but the maximum dimensions of the model are not allowed to exceed the build space of the machine.

The 3D display of input model and its dimensions help the user to understand its orientation. Since the orientation of the model plays an important role in minimizing build time and improving surface finish, PSG Slice provides options for the user to re-orient the model by rotating X, Y and Z axes separately.

The NC code generation module generates NC codes to make slices with the process parameters set by the user. The user is also allowed to vary with the datum point and output file name. Varying datum point helps the user to build models in a selected area of the platform. PSG Slice provides two options for the user to generate NC codes for a sliced model - fast build and slow build. As the name indicates, slow build is purposefully made slow and it provides a means of verification by displaying the generated NC codes beside the 2D display of laser path. Fast build generates NC codes with a maximum speed at which the computer can do and displays the laser path in 3D view.

The build time estimation tool finds the time required for building a model in RP machine. It is possible for the user to optimise the model orientation by choosing one which gives the least time estimation. PSG Slice does not create support structures automatically; the user has to include necessary supports in the model itself according to its orientation. The supports provided in the model can be removed after post curing.

The software is mainly tested for its re-orientation capability, slicing capability and NC code generation capability. The software can rotate the test models about all axes ranging from 0° to 360°. The models are successfully sliced with various slice thickness values. The software also used slice thickness with six decimal accuracy without any problem.

The software generates NC codes for all the models with various orientations. The display of laser path is closely followed and no deviation is found for any value of hatch spacing. The software is able to generate NC codes with three different fill patterns. The line width compensation and the datum point specified by the user are successfully used in the NC code generation. The software can handle thin sections and isolated areas without any jumps. The build time estimation given by the software depends on the number of slices and hatch spacing used for the model and matches with time taken by the machine.

The capabilities of PSG Slice are compared with the commercial slicing software. PSG Slice is found to be equivalent to commercial software in all aspects except the slicing speed. The time taken by commercial software depends on the model height but in case of PSG Slice it depends on the number of triangles used to represent the model. The NC codes generated by the software have been successfully used in RP machine for taking some sample prototypes.

The prototypes made using the software have proved the capability of the software to interface any complex geometry with RP machine. All the major parameters of stereolithography process are considered in the software and the user can change them within the allowed range. The STL model is sliced with a user specified thickness and the slices are displayed on the screen. The data extracted in slicing the model defines the outline of each slice. The slice data is then used to generate NC codes to create layers by tracing hatch lines of the slice cross sections. The hatch pattern and spacing between hatch lines could be changed to improve the integrity of the prototype.

Almost all RP process are based on a layered manufacturing methodology in which objects are built as a series of horizontal cross-sections, each one being formed individually from the relevant raw materials and bonded to preceding layers until the object is completed. The idea is to optimize the process parameters of the newly developed Stereolithography RP machine using the Taguchi method. It is one of the best optimizing technique. The quality characteristic chosen for this is surface roughness. Initially, the model has to be created in Pro/E. After the generation of the model, the model has been sliced, to get the NC codes. Four process parameters are recognized (like scanning velocity, laser power, hatch spacing and layer thickness). Three levels are chosen for each of these parameters. A L18 OA is chosen for optimizing and the matrix has been prepared. Interaction of any two parameters can also be found out from the above matrix. Eighteen different parts are made in the machine. The models are cleaned in methanol and then surface roughness was measured. The S/N ratio was calculated for each of the parts. An ANOVA analysis was carried out to find the relative influence of the factors in the surface finish. Then ANOVA analysis with pooling is carried out. The RP machine developed in this work can be effectively used for the fabrication of prototype using photopolymer resin. It is envisaged that the industries involved in the manufacture of prototype, will find a useful design and development oriented methodologies to follow from this work. The present work aims at fulfilling the above requirements which will be of immense use to the small and medium scale industries in the country.