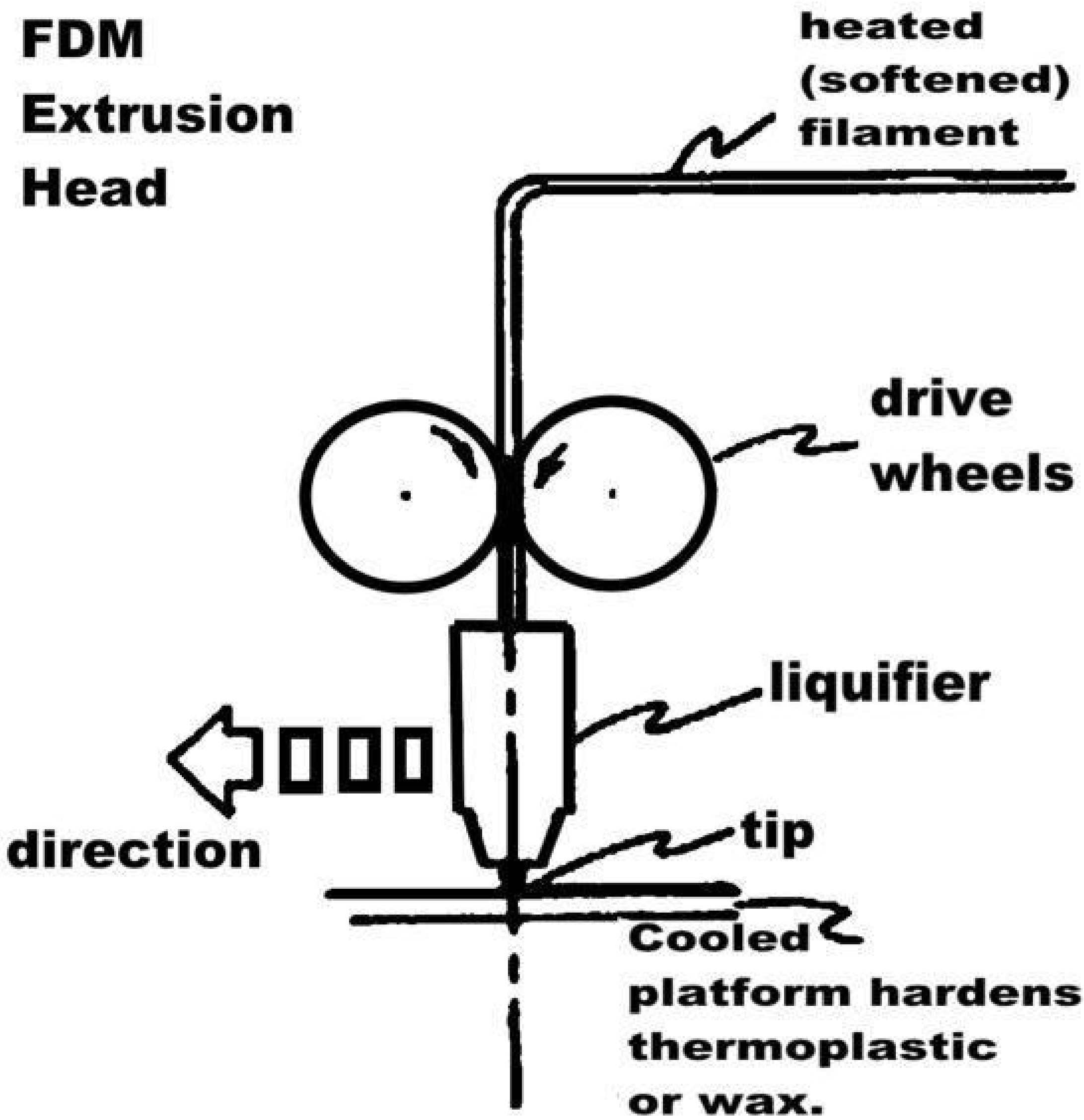
FUSED DEPOSITION MOULDING

Introduction:

Fused Deposition Modelling is an extrusion based rapid prototyping process although it works on the same layer by layer principle as other RP systems. Fused Deposition Modelling relies on standard STL data file for input and is capable of using multiple build materials in a build or support relationship.

Fused Deposition Modeling (FDM) machine is basically a CNC-controlled robot carrying a miniature extruder head. By feeding the head with a plastic wire, solid objects are built "string by string". In this 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.



Fused Deposition Modeling (FDM)

Software Used:
FDM machine uses Quick Slice software to manipulate and prepare the incoming STL date for use in FDM machines. Software can be operated on various types of workstations from UNIX to PC based.
Build Materials:
1) Investment Casting Wax.

2) Acrilonitrile Butadiene Styrene plastic.

3) Elastomer.

Extrusion Head:
1) It is a key to FDM technology.

2) Compact and removable unit.

3) It consists of Dry Blocks, Heating Chamber and Tips.
Dry Blocks:
a) These are raw material feeding mechanisms and are mounted on back of head.

b) These are computer controlled.

c) Capable of precision loading and unloading of filament.

d) It consists of two parallel wheels attached to a small electric motor by gears.

e) The wheels have a plastic and rubber thread and are spaced approximately 0.07inches apart and turn opposite to one another.

f) When the wheels are turned in and end of the filament is placed between them, they continue to push or pull the material depending on direction of rotation.

g) When loading the filament is pushed horizontally into the head through a hole, a little longer than the filament diameter which is the entry to the heating chamber.
Heating Chamber:
a) It is a 90' curved elbow wrapped in a heating element which serves two primary functions

To change the direction of the filament flow so that the material is extruded vertically downwards.

To serve as a melting area for the material

b) The heating element is electronically controlled and has feedback thermocouple to allow for a stable temperature throughout.

c) The heating elements are held at a temperature just above the melting point of the material so that the filament passes from the exit of the chamber is in molten state. This allows for smooth extrusion as well as time control on material placement.

d) At the end of the heating chamber which is about 4 inch long is the extrusion orifice or tip.

Tip:

a) The two tips are externally threaded and screwed up into the heating chamber exit and are used to reduce the extruded filament diameter to allow for better detailed modelling

b) .The tips are heated by heating chamber up to above the melting point of the material.

c) The tips can be removed and replaced with different size openings, the two most common being 0.012 inch and 0.025 inches.

d) The extruding surface of the tip is flat serving as the hot shearing surface to maintain a smooth upper finish of extruded material.

e) The tip is the point at which the material is deposited onto a foam substrate to build the model..

Build Substrate:

1) The foam substrate is an expendable work table once which parts are built.

2) The substrate is about 1 inch thick and is passed on into a removable tray by one quarter inch pins.

3) The foam used is capable of withstanding higher temperature. As for the first few layers of the part, the hot extrusion orifices are touching the substrate.

4) The support material is used to support overhangs, internal cavities and thin sections during extrusion as well as to provide a base to anchor (part) to the substrate while building.

FDM OPERATION:

i i. CAD file preparation: • Before building the part, the STL file has to be converted into the machine language understood by FDM. Quick Slice software is used for this purpose.

ii • The STL file is read into Quick Slice and is displayed graphically on screen in Cartesian co-ordinate system (XYZ)
iii • Building box represents maximum build envelope of FDM.
iv • Quick slice gives us options on the FDM system being used, the slice layer thickness, the build and support materials as well as tip sizes.

i ii. **Part Size:**
The part must fit into the building box, if not it will either have to be scaled down to fit or be sectioned so that the pieces can be built separately and then bonded together later.
i iii. Orientation and Positioning:

Once the part has been built in appropriate built size, the part should be oriented in an optimum position for building. The shape of the part plays an important role in this, in that some orientations may require less supporting of overhangs than the others.
i iv. Slicing:

Once the part has been properly oriented and or scaled it must be sliced. Slicing is a software operation that creates thin horizontal cross sections of STL file that will later be used to create control code for the machine.
In Quick Slice, the slice thickness can be changed before slicing, the typical slices ranging from 0.005 inches to 0.015 inches.

Quick Slice allows
• To perform simple editing functions on slice files. Also editing function allows repair of minor flaws in the STL file with the options of closing and merging of curves.
Build Parameters:

A. Sets:
Quick Slice uses sets or packages of build parameters. Sets contain all of the build instructions for a selected set of curves in a part. Sets allow a part to be built with several different settings
E.g. One set may be used for supporting structure of the part, one for part face, another for thicker sections of the part and still another for exposed surfaces of the part. This allows flexibility of building bulkier sections and internal fills quickly by getting finer details on visible areas of a part.
Sets also allow chosen sections of a part to build hollow, cross hatched or solid if so desired.
Two of the build parameters commonly worked with are road width and fill spacing.

B. Road Width:

Road Width is the width of the ribbon of molten material that is extruded from the tip.

When FDM builds a layer, it usually begins by outlining the cross section with a perimeter road, sometimes followed by one or more concentric contours inside of perimeters.

Next it begins to fill remaining internal area in a raster or hatched pattern until a complete solid layer is finished.

Therefore three types of roads are Perimeter, Contour and Raster.

C. Fill Spacing:

Fill spacing is the distance left between raster's or contours that make up interior solids of the parts. A fill spacing set at zero means that part will be built solid.

D. **Creating and Outputting Roads:**

Once all parameters have been set, road are created graphically by Quick Slice. The user is then allowed to preview each slice if so desired to see if the part is going to build as required.

E. Getting a Build Time Estimate:

Quick slice has a very good build time estimator which activates when an SML file is written. SML stands for Stratasys Machine Language. Basically it displays in the command windows, the approximate amount of time and material to be used for given part. Build time estimate allows for a efficient tracking and scheduling of FDM system work loads.

F. Building a part:

The FDM receives a SML file and will begin by moving the head to the extreme X and Y portions to find it and then raises the platen to a point to where the foam substrate is just below heated tips. After checking the raw material supply and temperature settings, the user then manually places the head at point where the part has to be built on the foam and then presses a button to begin building. After that FDM will build part completely without any user intervention.

G. Finishing a FDM part:

FDM parts are an easiest part to finish.

Applications:

a. Concept or Design Visualization.

b. Direct Use Components.

c. Investment Casting.

d. Medical Applications

e. Flexible Components.

f. Conceptual modeling.

g. Fit, form and functional applications and models for further manufacturing procedures.

h. Investment casting and injection molding.

Advantages:

a. Strength and temperature capability of build materials.

b. Safe laser free operation.

c. Easy Post Processing.

d. Quick and cheap generation of models.

e. Easy and convenient date building.

f. No worry of possible exposure to toxic chemicals, lasers, or a liquid polymer bath.

g. No wastage of material during or after producing the model.

h. No requirement of clean-up.

i. Quick change of materials.

Disadvantages:

a. Process is slower than laser based systems.

b. Build Speed is low.

c. Thin vertical column prove difficult to build with FDM.

d. Physical contact with extrusion can sometimes topple or at least shift thin vertical columns and walls.

e. Restricted accuracy due to the shape of the material used: wire of 1.27 mm diameter.

FDM Material Properties:

Material	Tensile Strength (Mpa)	Tensile Modulus (Mpa)	Flexural Strength (Mpa)	Flexural Modulus (Mpa)

ABDP400	35.2	1535	66.9	2626
Medical Grade ABSP 500	38	2014	58.9	1810
Investment casting wax (ICW06)	3.6	282	49.6	282
Elastomer	6.55	70	89.69	141

Diagrams:

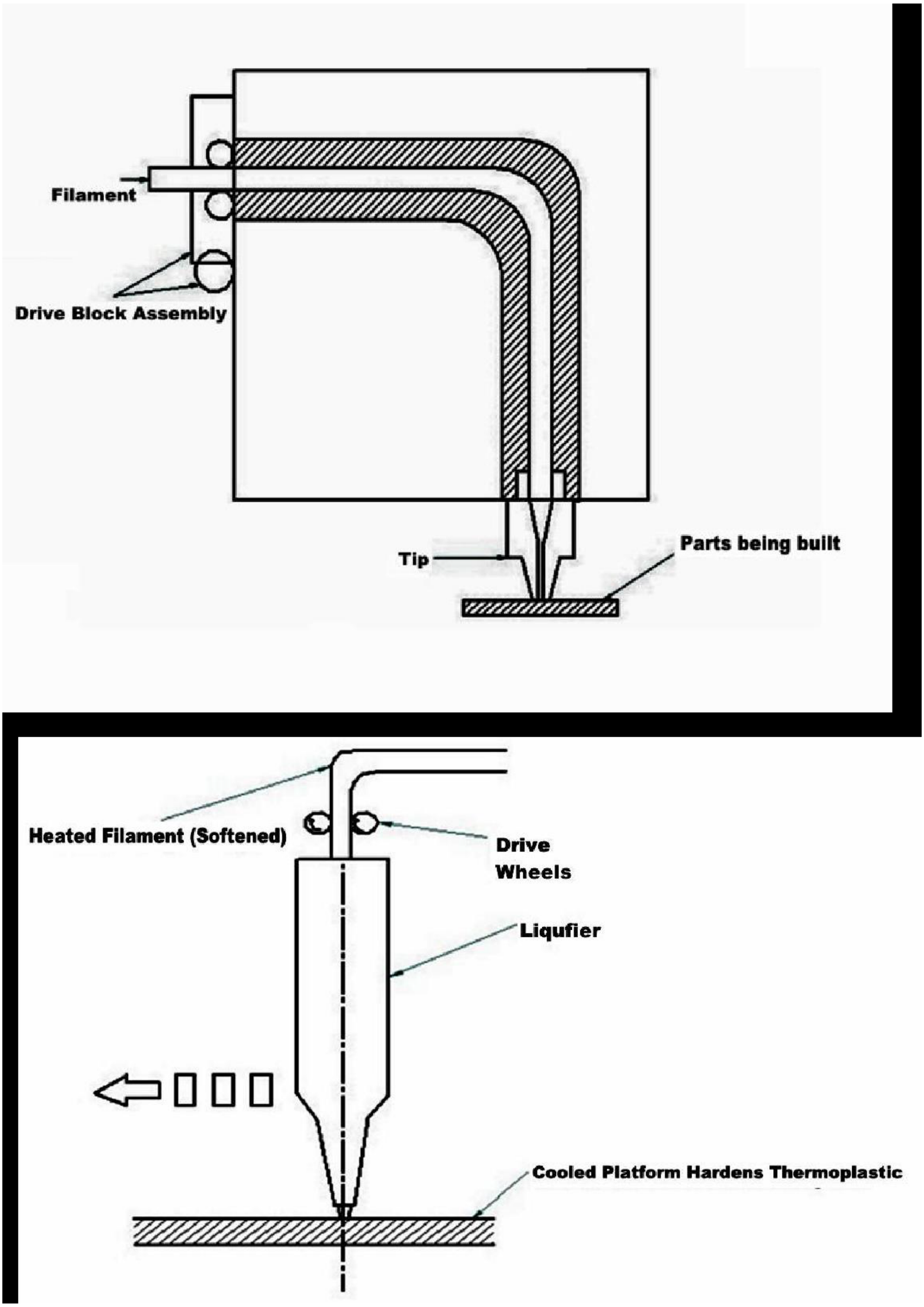


Fig a: FDM Extrusion Head

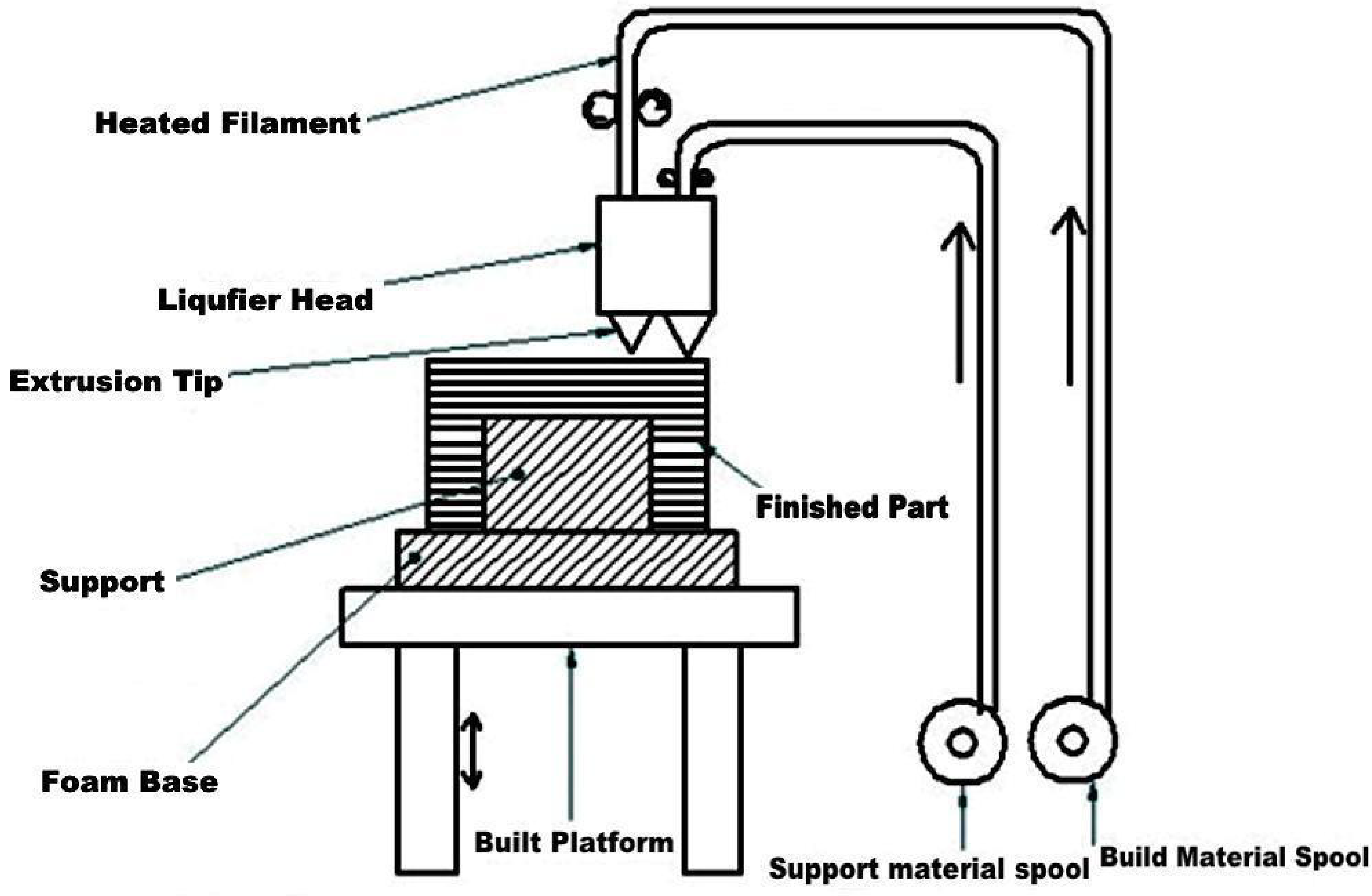


Fig b: Fused Deposition Model Apparatus

Fused Deposition Modelling

5.1 History
5.2 Principle
5.3 Machine Details
5.4 Process parameters
5.5 Path generation
5.6 Advantages and Disadvantages
5.7 Applications

History

Fused deposition modelling (FDM) is an extrusion-based rapid prototyping (RP) process, although it works on the same layer-by layer principle as other RP systems. Fused Deposition Modelling relies on the standard STL data file for input, and is capable of using multiple build materials in a build/support relationship. FDM was developed by Stratasys, Inc. of Eden 58

Prairie, MN, in the early 1990s as a concept modelling device that is now used more for creating casting masters and direct-use prototyping.

Principle

There are a number of key features that are common to any extrusion-based system:

– Loading of material
– Liquification of the material
– Application of pressure to move the material through the nozzle
– Extrusion
– Plotting according to a predefined path and in a controlled manner
– Bonding of the material to itself or secondary build materials to form a coherent solid structure
– Inclusion of support structures to enable complex geometrical features

These will be considered in separate sections to fully understand the intricacies of extrusion-based AM.
A mathematical or physics-based understanding of extrusion processes can quickly become complex, since it can involve many nonlinear terms. The basic science involves extrusion of highly viscous materials through a nozzle. It is reasonable

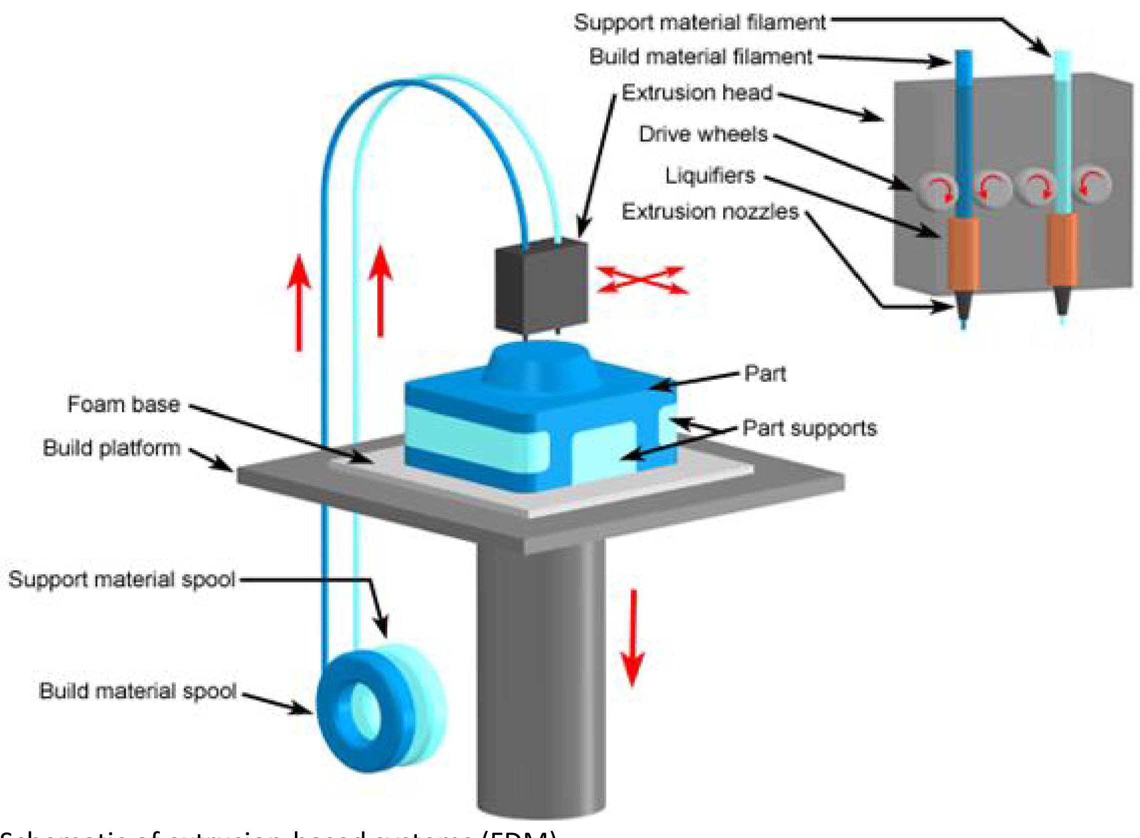
to assume that the material flows as a Newtonian fluid in most cases. Most of the discussion in these sections will assume the extrusion is of molten material and may therefore include temperature terms. For solidification, these temperature terms are generally expressed relative to time; and so temperature could be replaced by other time-dependent factors to describe curing or drying processes.

Material Loading:

Since extrusion is used, there must be a chamber from which the material is extruded. This could be preloaded with material, but it would be more useful if there was a continuous supply of material into this chamber. If the material is in a liquid form, then the ideal approach is to pump this material. Most bulk material is, however, supplied as a solid and the most suitable methods of supply are in pellet or powder form, or where the material is fed in as a continuous filament. The chamber itself is therefore the main location for the liquification process. Pellets, granules, or powders are fed through the chamber under gravity or with the aid of a screw. Materials that are fed through the system under gravity require a plunger or compressed gas to force it through the narrow nozzle. Screw feeding not only pushes the material through to the base of the reservoir but can be sufficient to generate the pressure needed to push it through the nozzle as well. A continuous filament can be pushed into the reservoir chamber, thus providing a mechanism for generating an input pressure for the nozzle.

Liquification:

The extrusion method works on the principle that what is held in the chamber will become a liquid that can eventually be pushed through the die or nozzle. As mentioned earlier, this material could be in the form of a solution that will quickly solidify following the extrusion, but more likely this material will be liquid because of heat applied to the chamber. Such heat would normally be applied by heater coils wrapped around the chamber and ideally this heat should be applied to maintain a constant temperature in the melt (see Fig5.2). The larger the chamber, the more difficult this can become for numerous reasons related to heat transfer, thermal currents within the melt, change in physical state of the molten material, location of temperature sensors, etc.



Schematic of extrusion-based systems (FDM)

Machine Details

- The FDM systems have evolved through several models, beginning with the original 3D Modeller, a floor unit, and progressing through the various "desktop units", including the 1500, 1600, 1650, 2000, 3000, 8000, and Quantum.

- Basically, the 1500 through 2000 models are capable of building parts in the 10" x 10" X 10" range, whereas the 8000 and the Quantum can build 24" x 20" x 24" parts.

FDM Machine 3000

Software:

- All of the machines use the powerful QuickSlice (QS) software, manufactured by Stratasys to manipulate and prepare the incoming STL data for use in the FDM machines.

- The software can be operated on various types of workstations, from UNIX to PC based, and the modellers can either be operated directly from the workstation or by a "dummy" PC whose sole purpose is to free up time and space on the workstation.

Build materials:

The FDMs can be equipped to build with investment casting wax, acrylonitrile butadiene styrene (ABS) plastic, medical grade ABS thermoplastic, and/or Elastomer, although the ABS is currently used the most. The build and support materials come in filament form, about 0.070 inches in diameter and rolled up on spools. The spools mount on a spindle in the rear or side of the machine, and the filament feeds through a flexible tube attached to the back of the extrusion head.

The Extrusion Head:

The extrusion head is the key to FDM technology. The head is a compact, removable unit (good for materials changeover and maintenance), and consists of the following crucial components. Figure 5.2b is a schematic of the extrusion head that shows the various components described.

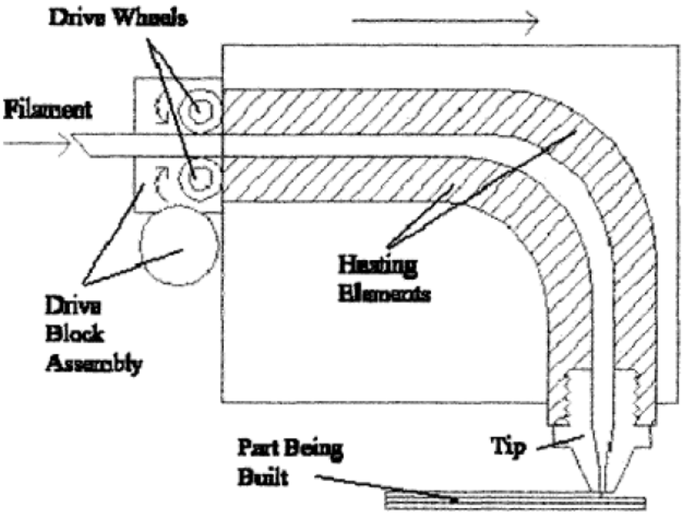


Fig 5.2b Extrusion Head

Drive Blocks

The *drive blocks* are the raw-material feeding mechanisms, and are mounted on the back of the head. The drive blocks are computer controlled and are capable of precision loading and unloading of the filament. They consist of two parallel wheels attached to a small electric motor by gears. The wheels have a plastic or rubber treads, and are spaced approximately 0.070 inches apart and turn opposite to one another. When the wheels are turning and the end of the filament is placed between them, they continue to push or pull the material, depending on the direction of rotation. When loading, the filament is pushed horizontally into the head through a hole a little larger than the filament diameter, which is the entry to the heating chamber.

The Heating Chamber

The heating chamber is a 90-degree curved elbow wrapped in a heating element, which serves two primary functions. One is to change the direction of the filament flow so that the material is extruded vertically downward. Secondly, and most important, is to serve as a melting area for the material. The heating element is electronically controlled, and has feedback thermocouples to allow for a stable temperature throughout. The heating elements are held at a temperature just above the melting point of the material, so that the filament passing from the exit of the chamber is in a semi molten state. This allows for smooth extrusion as well as tight control on the material placement. At the end of the heating chamber, which is about 4 inches long, is the extrusion orifice, or tip.

Tips

The two tips are externally threaded and screw up into the heating chamber exit, and are used to reduce the extruded filament diameter to allow for better detailed modelling. The tips are heated by the heating chamber up to above the melting point of the material.

The tips can be removed and replaced with different size openings, the two most common being the 0.012 and 0.025 inch sizes. The extruding surface of the tip is flat, serving as a hot shearing surface to maintain a smooth upper finish of the extruded material. The tip is the point at which the material is deposited onto a foam substrate to build the model.

8.1.4 Build Substrate

The foam substrate is an expendible work table onto which parts are built. The substrate is about one-inch thick and is fastened into a removable tray by one-quarter-inch pins. The pins are inserted horizontally through holes in either side of the tray, and pierce about two inches into the substrate to stabilize it during building. The substrates can sometimes be used several times for smaller parts by selectively placing them on unused sections, and by flipping them over to use the other side of the foam. The foam used is capable of withstanding higher temperature, as for the first few layers of the part the hot extrusion orifices are touching the substrate. Modelers higher than the 1500 model have two drive blocks, heating chambers, and extrusion orifices in the head with independent temperature and extrusion control to accommodate two different materials. This allows for a build material, of which the part is made, and a support material. The support material is used to support overhangs, internal cavities, and thin sections during extrusion, as well as to provide a base to anchor the part to the substrate while building.

5.4 Process parameters

a) Liquifier temperature:

b) Chamber temperature

c) Stand – off distance

d) Filament feed rate

e) Nozzle diameter

f) Deposition speed

g) Material type

h) Road width

i) Fill spacing

5.5 Path generation

CAD file preparation:

- Before building a part, the STL file has to be converted into the machine language understood by the FDM
- QS software is used for this purpose
- The STL file is read into QS, and is displayed graphically on screen in the Cartesian coordinate system (x, y, and z)
- QS gives you options on the FDM system being used, the slice layer thickness, the build and support materials, as well as the tip sizes

Part size

- First it must be affirmed that the part will fit into the bounding box; if not, it will either have to be scaled down to fit, or be sectioned so that the pieces can be built separately and then bonded together later.

- It is good practice for the designer to add alignment bosses and slots so that proper alignment of the subsections is achieved with ease. In some cases, for instance if the part fits in –x and -y but is too tall in the -z, QS can be used to section the part by
slicing to a certain height, then starting a new build later at that height and finishing the part.

- This technique results in flat mating surfaces with no alignment bosses or slots, therefore it is up to the postprocessing person to align the subsections properly during bonding.

Part orientation/position

- Once the part has been deemed an appropriate build size, the part should be oriented in an optimum position for building

- The shape of the part plays the major role in this, in that some orientations may require less supporting of overhangs than others.

- Also, rounded surfaces tend to turn out smoother if built in the plane of movement of the extrusion head (x, y), as curvatures in the z direction are affected by the layering build technique

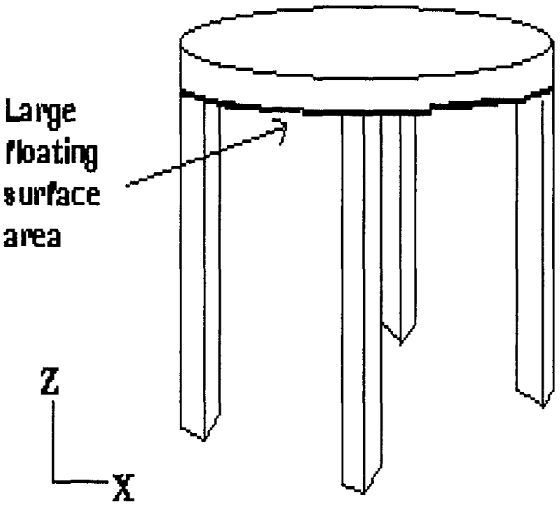


Fig 5.2c The upright table requires excessive supports for the top

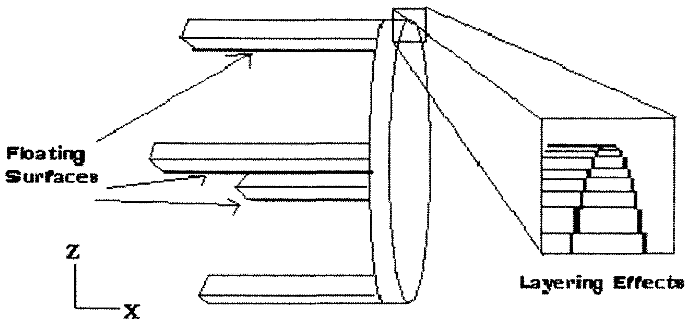


Fig 5.2d Orienting the table sideways reduces the necessary supports; however the definition of the circular area is lost due to the stair-stepping effect.

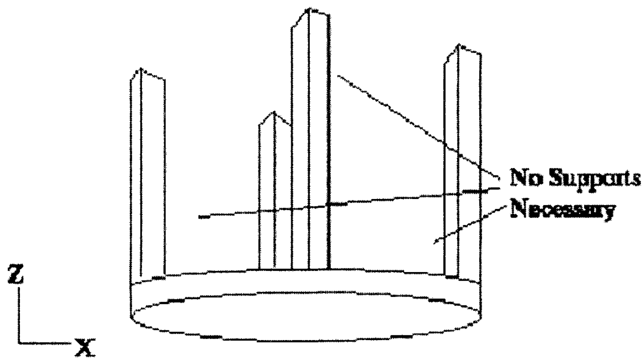
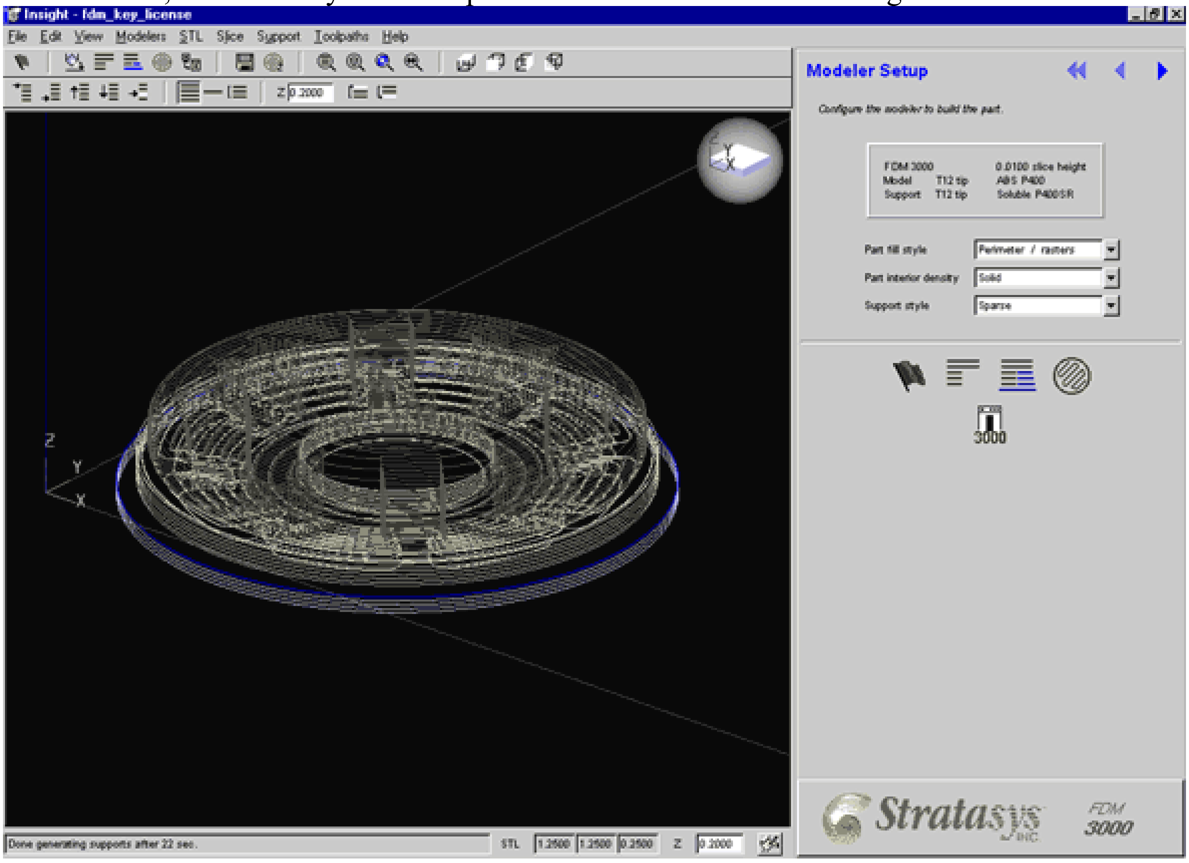


Fig 5.2e Upside down, the table requires minimal support material, gets finer definition on curvature, and also reduces the build time.

Best option, is to build the table upside down (Figure 5.2e). Again, the rounded top will have good definition due to the precision control of the head. Now the necessary support material has been minimized, as there are no floating surfaces that require support. Essentially, the only support material used will be for the anchoring base layers. This simple change of orientation has saved material, time, and accuracy! There is less support material required, which also cuts down on the build time, and the desired definition will be obtained. Of course, parts are usually never this simple, but nonetheless much time and cost can be spared if the build orientation is well thought out before the part is built. This applies to most all of the RP techniques currently available as well.

Slicing

- Once the part has been properly oriented and/or scaled, it must be sliced.
- *Slicing* is a software operation that creates thin, horizontal cross sections of the STL file that will later be used to create the control code for the machine.
- In QS, the slice thickness can be changed before slicing, the typical slices ranging from 0.005 inches to 0.015 inches.
- Thinner slices may be used for higher definition models, but this increases the time required to complete a part build.
- Likewise, less accuracy-sensitive parts can be built much faster using a thicker slice value.



5.6 Advantages and Disadvantages

The strength and temperature capability of the build material is possibly the most sought-after advantage of FDM. Other major advantages include safe, laser-free operation and easy postprocessing with the new water-soluble support material. Although significant speed advancements have been made with newer FDM systems, the mechanical process itself tends to be slower than laser-based systems; therefore lack of build speed is a key disadvantage. Also, small features like a thin vertical column prove difficult to build with FDM, due to the fact that each layer must have a physical start-and-stop extrusion point. In other words, the physical contact with the extrusion tip can sometimes topple, or at least shift, thin vertical columns and walls.

5.7 Applications

Concept/Design Visualization

Like other RP systems, the FDM systems provide an excellent route to obtaining prototype models for initial observation of a design. The ABS and Elastomer parts are rigid enough to survive handling and transporting from meeting to meeting, or even down to the shop floor. Parts can be made with various colours to represent different components of a system. The build materials are also relatively inexpensive, so models can be re-iterated more so than if prototypes were being machined or formed.

Direct-use Components

Due to the rigidity of the ABS parts, they can be used in various applications to replace traditionally machined, extruded, or injected plastic parts. The FDM can build directly usable electronics housings, low-speed wind-tunnel models, and working gear assemblies among other uses. This allows users to directly fabricate prototypes and test them before actually machining the final design.

Investment Casting
The investment-casting wax offered by FDM opens up yet another avenue of applications. If prototypes are needed in a metal form, the parts can be prototyped using the investment-casting wax, and then carried through the traditional investment-shell casting process to obtain usable metal components. The investment-shell process basically consists of shelling the wax part in ceramic, and then melting out the wax to have a mold into which molten metal can be cast. Hence, prototype castings can reduce design-to-market costs by getting it right before the final manufacturing step is initiated.
Medical Applications
The Medical Grade ABS has been approved by the U.S. Food and Drug Administration (FDA), and therefore is used by the medical industry to produce various parts within the industry. Since CAT Scan and MRI data can be converted into the .STL file format, custom models of internal organs, bones, etc. can be reconstructed and studied before a patient ever goes into surgery!
Flexible Components
The recently released Elastomer material opens yet another dimension of functionality for the FDM systems. Flexible test components such as seals, shrouds, and tubing can be prototyped with the Elastomer material to proof out the concepts or "make the sale" on crucial designs.

Process optimization

The parameters of rapid prototyping can be classified as nuisance parameters, constant and control parameters. Nuisance parameters include age of the laser, beam position accuracy, humidity and temperature, which are not controlled in the experimental analysis but may have some effect on a part. Constant parameters include beam diameter, laser focus and material properties, etc. the constant parameters will affect the output of the process and are controllable in a run. These include layer thickness, hatch space, scan pattern, part orientation, shrinkage of the material and beamwidth compensation, etc. Layer thickness , hatch space, part orientation and depth of cure are the most vital among the control parameters.

Identification of requirements and key manufacturing parameters
The functional requirements of a manufacturing process include accuracy, strength, build-time and efficiency of the process. All the manufacturing requirements are also applicable to RP. Surface accuracy is gaining a greater significance as more parts are used as master patterns for secondary manufacturing process. Build time is important in the general context of manufacturing for scheduling and cost estimation. Layer thickness, hatch space and orientation are the key control parameters for SLS and SLA. These are required indeed process-independent parameters, and can be applied to other processes, such as LOM, FDM, etc. Support structures are essential for SLA and FDM, but they are not needed for LOM and SLS processes.

Factors influencing accuracy

Accuracy of a model is influenced by the errors caused during tessellation and slicing at data preparation stage. Decision of the designer about part deposition orientation also affects accuracy of the model.
Errors due to tessellation: In tessellation surfaces of a CAD model are approximated piecewise by using triangles. It is true that by reducing the size of the triangles, the deviation between the actual surfaces and approximated triangles can be reduced. In practice, resolution of the STL file is controlled by a parameter namely chordal error or facet deviation as shown in figure 11.1

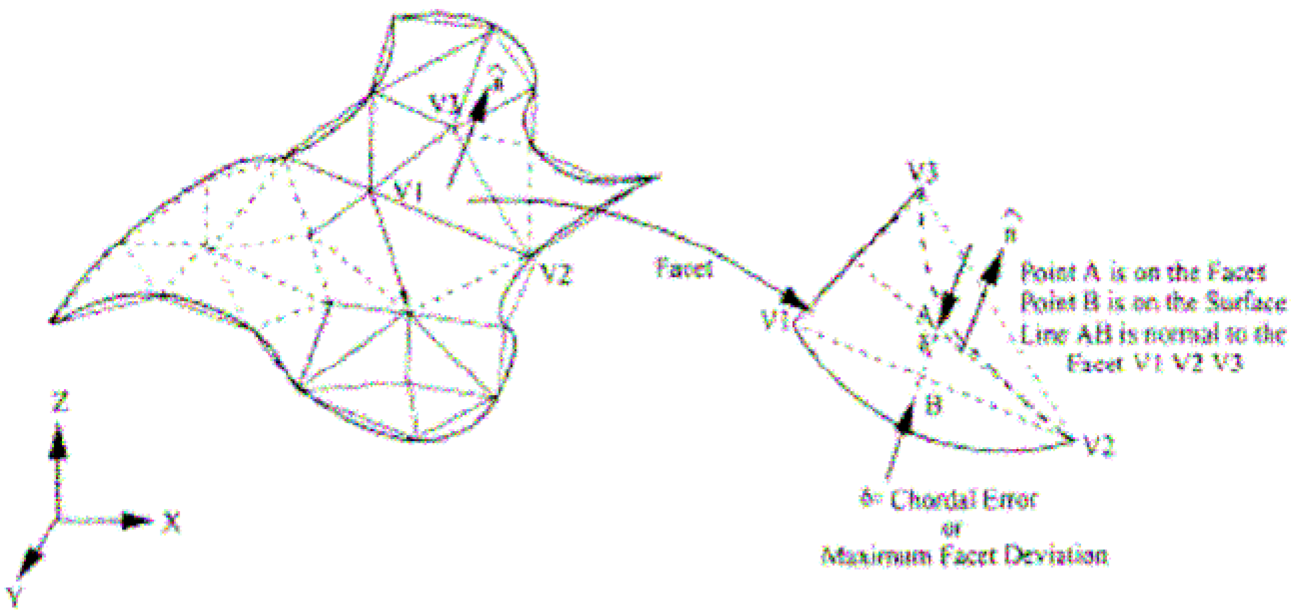
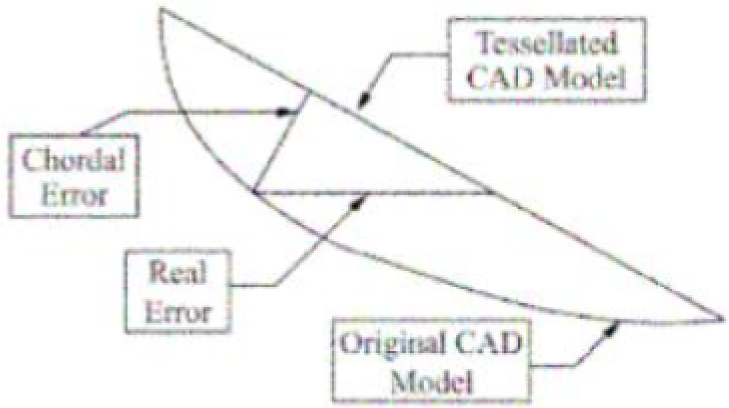


Fig 11.1 Tessellation of a typical surface of CAD model

It has also been suggested that a curve with small radius (r) should be tessellated if its radius is below a threshold radius (ro) which can be considered as one tenth of the part size, to achieve a maximum chordal error of (r/ro). Value of can be set equal to 0 for no improvement and 1 for maximum improvement.

Errors due to slicing: Real error on slice plane is much more than that is felt, as shown in figure 11.2



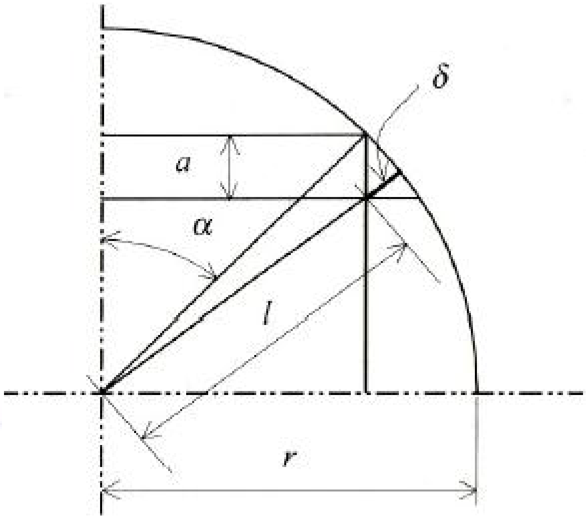


Fig 11.2 Real error slice plane **Fig 11.3** Error due to replacement of arcs with stair-steps cusp height (after Pham and Demov, 2001)

For a spherical model Pham and Demov (2001) proposed that error due to the replacement of a circular arc with stair-steps can be defined as radius of the arc minus length up to the corresponding corner of the staircase, i.e., cusp height (figure 11.3). Thus maximum error (cusp height) results along z direction and is equal to slice thickness. Therefore, cusp height approaches to maximum for surfaces, which are almost parallel with the x-y plane. Maximum value of cusp height is equal to slice thickness and can be reduced by reducing it; however this results in drastic improvement in part building time. Therefore, by using slices of variable thicknesses (popularly known as adaptive slicing, as shown in figure 11.4), cusp height can be controlled below a certain value. Except this, mismatching of height and missing features are two other problems resulting from the slicing. Although most of the RP systems have facility of slicing with uniform thickness only, adaptive slicing scheme, which can slice a model with better accuracy and surface finish without loosing important features must be selected.

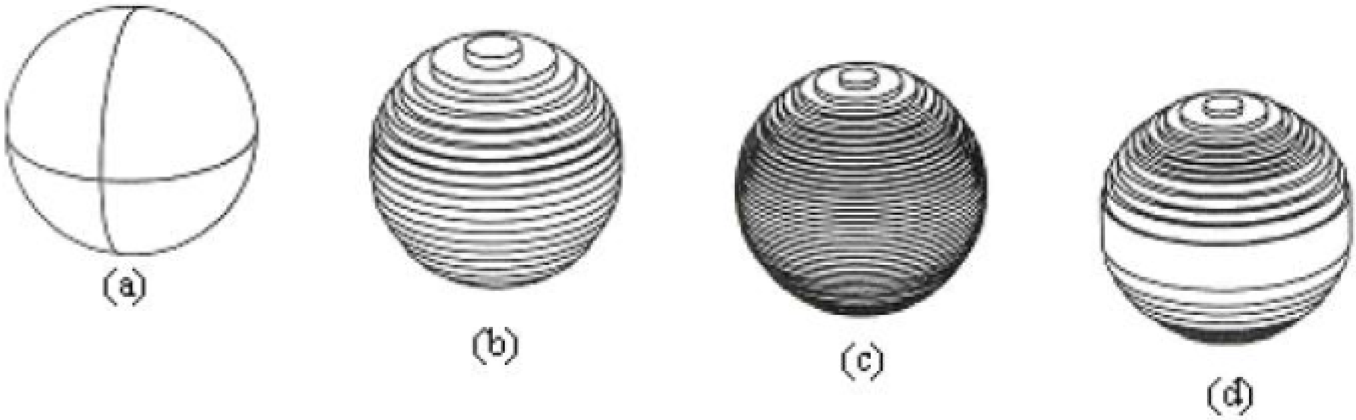
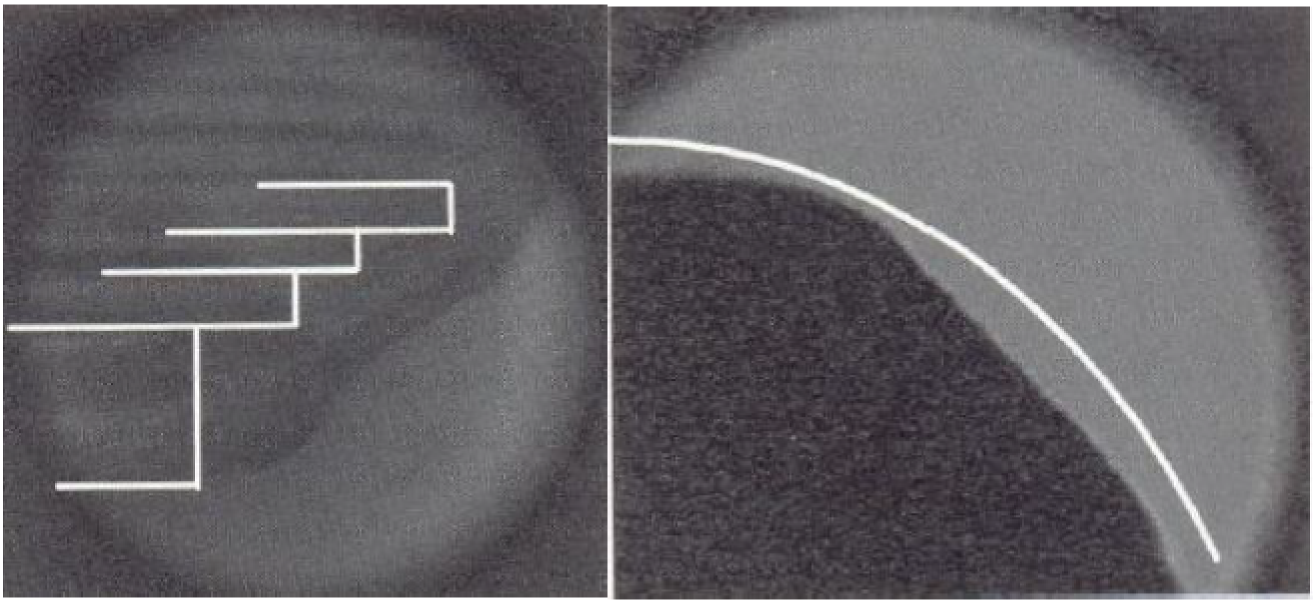


Figure 11.4: Slicing of a ball, (a) No slicing (b) Thick slicing (c) This slicing (d) Adaptive slicing

Part building

During part deposition generally two types of errors are observed and are namely curing errors and control errors. Curing errors are due to over or under curing with respect to curing line and control errors are caused due to variation in layer thickness or scan position control. Figures 11.5 illustrate effect of over curing on part geometry and accuracy. Adjustment of chamber temperature and laser power is needed for proper curing. Calibration of the system becomes mandatory to minimize control errors. Shrinkage also causes dimensional inaccuracy and is taken care by choosing proper scaling in x, y and z directions. Polymers are also designed to have almost negligible shrinkage factors. In SL and SLS processes problem arises with downward facing layers as these layers do not have a layer underneath and are slightly thicker, which generate dimensional error. If proper care is not taken in setting temperatures, curling is frequently observed.



(a) Thicker bottom layer (b) Deformed whole boundary

Figure 11.5 Over-curing effects on accuracy in Stereolithography

Part finishing

Poor surface quality of RP parts is a major limitation and is primarily due to staircase effect. Surface roughness can be controlled below a predefined threshold value by using an adaptive slicing. Further, the situation can be improved by finding out a part deposition orientation that gives minimum overall average part surface roughness. However, some RP applications like exhibition models, tooling or master pattern for indirect tool production etc. require additional finishing to improve the surface appearance of the part. This is generally carried by sanding and polishing RP models which leads to change in the mathematical definitions of the various features of the model. The model accuracy is mainly influenced by two factors namely the varying amount of material removed by the finishing process and the finishing technique adopted. A skilled operator is required as the amount of material to be removed from different surfaces may be different and inaccuracies caused due to deposition can be brought down. A finishing technique selection is important because different processes have different degrees of dimensional control. For example models finished by employing milling will have less influence on accuracy than those using manual wet sanding or sand blasting.

Selection of part deposition orientation

This is one of the crucial decisions taken before slicing the part and initiating the process of deposition for a particular RP process. This decision is important because it has potential to reduce part building time, amount of supports required, part quality in terms of surface finish or accuracy and cost as well. Selection of part deposition orientation is process specific where in designer and RP machine operators should consider number of different process specific constraints. This may be a difficult and time consuming task as designer has to trade-off among various conflicting objectives or process outcomes. For example better part surface quality can be obtained but it will lead to increase in the building time.