UNIT 5
Robotics, CNC and Additive Manufacturing

INTRODUCTION

The field of robotics has its origins in science fiction. The term robot was derived from the English translation of a fantasy play written in Czechoslovakia around 1920. It took another 40 years before the modern technology of industrial robotics began. Today Robots are highly automated mechanical manipulators controlled by computers. We survey some of the science fiction stories about robots, and we trace the historical development of robotics technology. Let us begin our chapter by defining the term robotics and establishing its place in relation to other types of industrial automation.

Robotics: -

Robotics is an applied engineering science that has been referred to as a combination of machine tool technology and computer science. It includes machine design, production theory, micro electronics, computer programming & artificial intelligence.

OR

"Robotics" is defined as the science of designing and building Robots which are suitable for real life application in automated manufacturing and other non-manufacturing environments.

Industrial robot: -

The official definition of an industrial robot is provided by the robotics industries association (RIA). Industrial robot is defined as an automatic, freely programmed, servo-controlled, multi-purpose manipulator to handle various operations of an industry with variable programmed motions.

Need for using robotics in industries: -

Industrial robot plays a significant role in automated manufacturing to perform different kinds of applications.

1. Robots can be built a performance capability superior to those of human beings. In terms of strength, size, speed, accuracy…etc.

2. Robots are better than humans to perform simple and repetitive tasks with better quality and consistence's.
3. Robots do not have the limitations and negative attributes of human works .such as fatigue, need for rest, and diversion of attention…..etc.
4. Robots are used in industries to save the time compared to human beings.
5. Robots are in value poor working conditions
6. Improved working conditions and reduced risks.

CAD/CAM & Robotics:-

CAD/CAM is a term which means computer aided design and computer aided manufacturing. It is the technology concerned with the use of digital computers to perform certain functions in design & production.

CAD:- CAD can be defined as the use of computer systems to assist in the creation modification, analysis OR optimization of design.

Cam:- CAM can be defined as the use of computer system to plan, manage & control the operation of a manufacturing plant, through either direct or in direct computer interface with the plant's production resources.

Specifications of robotics:-

1.Axil of motion

2.Work stations

3.Speed

4. Acceleration

5.Pay load capacity

6.Accuracy

7.Repeatability etc…

Overview of Robotics:-

"Robotics" is defined as the science of designing and building Robots which are suitable for real life application in automated manufacturing and other non-manufacturing environments. It has the following objectives,

1.To increase productivity

2.Reduce production life

3.Minimize labour requirement

4. Enhanced quality of the products

5.Minimize loss of man hours, on account of accidents.

6.Make reliable and high speed production.

The robots are classified as,
Programmable/Reprogrammable purpose

robots

*Tele-operated, Man controlled robots

*Intelligent robots.

Robots are used in manufacturing and assembly units

such as,

1. Spot or arc welding
2. Parts assembly
3. Paint spraying
4. Material, handling
5. Loading and unloading

The feature and capabilities of the robots are as follows,

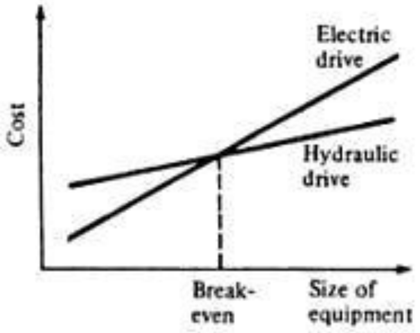
1. Intelligence
2. Sensor capabilities
3. Telepresence
4. Mechanical design
5. Mobility and navigation
6. Universal gripper
7. System integration and networking.

Types of drive systems:-

1.Hydraulic drive

2.Electric drive

3.Pneumatic drive



drive.

1. Hydraulic drive:-

Hydraulic drive and electric drive arc the two main types of drives used on more sophisticated robots.

Hydraulic drive is generally associated with larger robots, such as the Unimate 2000 series. The usual advantages of the hydraulic drive system are that it provides the robot with greater speed and strength. The disadvantages of the hydraulic drive system are that it typically adds to the floor space required by the robot, and that a hydraulic system is inclined to leak on which is a nuisance.

This type of system can also be called as non-air powered cylinders. In this system, oil is used as a working fluid instead of compressed air. Hydraulic system need pump to generate the required pressure and flow rate. These systems are quite complex, costly and require maintenance.

2. Electric drive:-

Electric drive systems do not generally provide as much speed or power as hydraulic systems. However, the accuracy and repeatability of electric drive robots are usually better. Consequently, electric robots tend to be smaller. Require less floor space, and their applications tend toward more precise work such as assembly.

In this System, power is developed by an electric current. It required little maintenance and the operation is noise less.

3. Pneumatic drive:-

Pneumatic drive is generally reserved for smaller robots that possess fewer degrees of freedom (two- to four-joint motions).

In this system, air is used as a working fluid, hence it is also called air-powered cylinders. Air is compressed in the cylinder with the aid of pump the compressed air is used to generate the power with required amount of pressure and flow rates.

Applications of robots:-

Present Applications of Robots:-

(i) Material transfer applications

(ii) Machine loading and unloading

(iii) Processing operations like,

(a) Spot welding

(b) Continuous arc welding

(c) Spray coating

(d) Drilling, routing, machining operations

(e) Grinding, polishing debarring wire brushing

(g) Laser drilling and cutting etc.

(iv) Assembly tasks, assembly cell designs, parts mating.
(v) Inspection, automation.

Future Applications of Robots:-

The profile of the future robot based on the research activities will include the following,

(i) Intelligence

(ii) Sensor capabilities

(iii) Telepresence

(iv) Mechanical design

(v) Mobility and navigation (walking machines)

(vi) Universal gripper

(vii) Systems and integration and networking

(viii) FMS (Flexible Manufacturing Systems)

(Ix) Hazardous and inaccessible non-manufacturing environments

(x) Underground coal mining

(xi) Fire fighting operations

(xii) Robots in space

(xiii) Security guards

(xiv) Garbage collection and waste disposal operations

(xv) Household robots

(xvi) Medical care and hospital duties etc.

Classification of Robots (or) Classification by co-ordinate system and control system:-

Co-ordinate systems:-

Industrial robots are available in a wide variety of sizes, shapes, and physical configurations. The vast majority of today's commercially available robots possess one of the basic configurations:

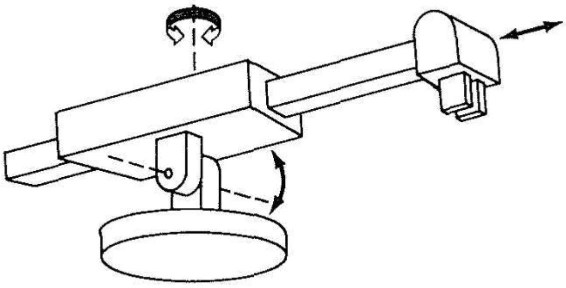
I. Polar configuration

2. Cylindrical configuration

3. Cartesian coordinate configurable

4. Jointed-arm configuration

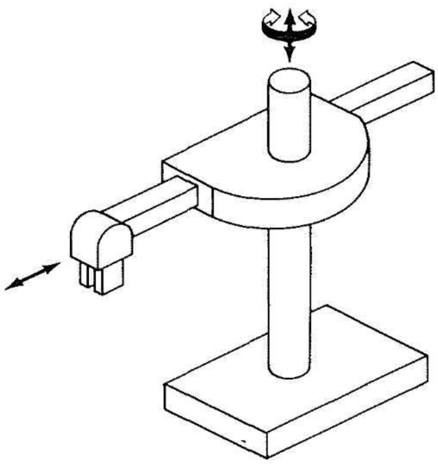
1. Polar configuration:-



Spherical

The polar configuration is pictured in part (a) of Fig. It uses a telescoping arm that can be raised or lowered about a horizontal pivot The pivot is mounted on a mta6ng base These various joints provide the robot with the capability to move its arm within a spherical space, and hence the name "spherical coordinate" robot is sometimes applied to this type. A number of commercial robots possess the polar configuration.

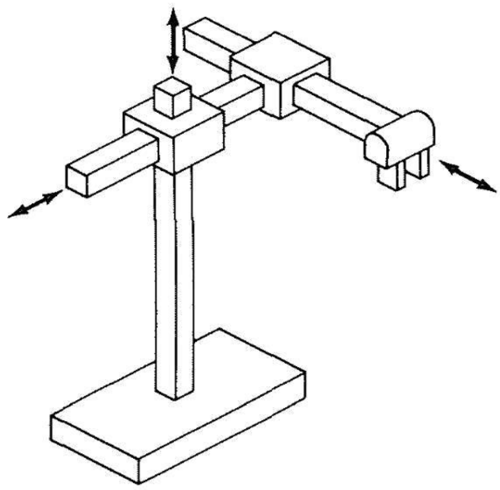
2. Cylindrical configuration:-



Cylindrical

The cylindrical configurable, as shown in fig, uses a vertical column and a slide that can be moved up or down along the column. The robot arm is attached to the slide so that it cm he moved radially with respect to the column. By routing the column, the robot is capable of achieving a work space that approximation a cylinder.

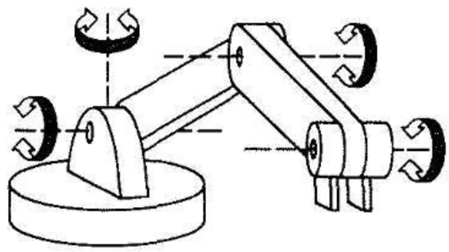
3. Cartesian coordinate configurable:-



Cartesian or *xyz*

The cartesian coordinate robot, illustrated in part Cc) of Fig, uses three perpendicular slides to construct the x, y, and z axes. Other names are sometimes applied W this configuration, including xyz robot and rectilinear robot, By moving the three slides relative to one another, the robot is capable of operating within a rectangular work envelope.

4. Jointed-arm configuration:-



Revolute

The jointed-arm robot is pictured in Fig. Its configuration is similar to that of the human arm. It consists of two straight components. Corresponding to the human forearm and upper arm, mounted on a vertical pedestal. These components are connected by two rotary joints corresponding to the shoulder and elbow.

Control systems:-

With respect to robotics, the motion control system used to control the movement of the end-effector or tool.

1.Limited sequence robots (Non-servo)

2.Playback robots with point to point (servo)

3.Play back robots with continuous path control,

4.Intelligent robots.

Limited sequence robots (Non-servo):-

Limited sequence robots do not give servo controlled to inclined relative positions of the joints; instead they are controlled by setting limit switches & are mechanical stops. There is generally no feedback associated with a limited sequence robot to indicate that the desired position, has been achieved generally thin type of robots involves simple motion as pick & place operations.

Point to point motion:-

These type robots are capable of controlling velocity acceleration & path of motion, from the beginning to the end of the path. It uses complex control programs, PLC’s (programmable logic controller’s) computers to control the motion.

The point to point control motion robots are capable of performing motion cycle that consists of a series of desired point location. The robot is tough & recorded, unit.

Continuous path motion:-

In this robots are capable of performing motion cycle in which the path followed by the robot in controlled. The robot move through a series of closely space point which describe the desired path.

Ex:- Spray painting, arc welding & complicate assembly operations.

Intelligent robots:-

This type of robots not only programmable motion cycle but also interact with its environment in a way that years intelligent. It taken make logical decisions based on sensor data receive from the operation.

There robots are usually programmed using an English like symbolic language not like a computer programming language.

Precision of movement (or) parameters of robot:-

The preceding discussion of response speed and stability is concerned with the dynamic performance of the robot. Another measure of performance is precision of the robot's movement. We will define precision as a function of three features:

1.Spatial resolution

2.Accuracy

3.Repeatability

These terms will be defined with the following assumptions.

1) The definitions will apply at the robot’s wrist end with no hand attached to the wrist.
2) The terms apply to the worst case conditions, the conditions under which the robot's precision will be at its wont. This generally means that the robot’s arm is fully extended in the case of a jointed arm or polar configurable.
3) Third, our definitions will he developed in the context of a point-to-point robot.

1. Spatial resolution:-

The spatial resolution of a robot is the smallest increment of movement into which the robot can divide its work volume. Spatial resolution depends on two factors: the system's control resolution and the robot's mechanical inaccuracies. It is easiest to conceptualize these factors in terms of a robot with 1 degree of freedom.

2. Accuracy:-

Accuracy refers to a robot's ability to position its wrist end at a desired target point within the work volume. The accuracy of a robot can be denned in terms of spatial resolution because the ability to achieve a given target point depends on how closely the robot can define the control increments for each of its joint motions.

3. Repeatability:-

Repeatability is concerned with the robot's ability to position its wrist or an end effector attached to its wrist at a point in space is known as repeatability. Repeatability and accuracy refer to two different aspects of the robot’s precision. Accuracy relates to the robot's capacity to be programmed to achieve a given target point. The actual programmed point will probably be different from the target point due to limitations of control resolution Repeatability refers to the robot’s ability to return to the programmed point when commanded to do so.

5 NUMERICAL CONTROL OF MACHINE TOOL

History of numerical control

Numerical control is nothing new. As early as 1808 weaving machines utilized metal cards with holes punched in them to control the pattern of the cloth being produced. Each needle on the machine was controlled by the presence or absence of a hole on the punched cards. The punched cards were the program for the machine to get the desired pattern.

In the late 1940, Parasons conceived a method of using punched cards containing coordinate position data to control a machine tool. Parsons envisioned the following system.

A computer would calculate the path that the tool should follow and store that information on punched cards. A reader at the machine would then read the cards. The machine control would take the data from the reader and control the motors attached to each axis. The first machine produced by Parsons and MIT (Massachusetts Institute of Technology) was demonstrated in 1952. It was a three-axis vertical spindle milling machine and vacuum tubes were used in machine control.

Up until about 1976 these machines were called NC machines. In 1976 CNC machines were produced. These machine controls utilized microprocessors to give them additional capability. The NC *machines typically read one short program step (block) at a time and executed it,* however, CNC machine could store whole programs. Improvements in computer technology in the late 1970s and 1980s brought the cost of numerical control machines very low.

Numerical control

Numerical control (NC) may be defined as a method of controlling the operation of a machine tool by a series of coded instructions, consisting of numbers, letters of alphabet and symbols that the machine control unit can understand. The numerical data required to produce a part is known as *part program* and is used to control the relative position of work-to-tool, tool selection, turning on cutting fluid, feeds and speeds, etc. A numerical control machine tool system consists of the following three components (fig. 5.1).

1. Program of instructions, 2. Machine control unit (MCU) and 3. Machine tool

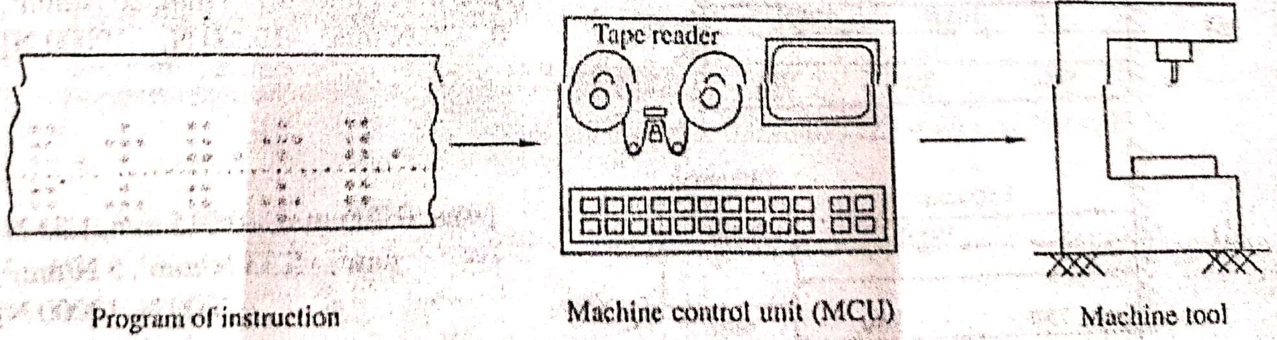


Fig. 5.1 Basic components of NC

Program of instructions: The part program (program of instructions) is the detailed step by step instructions by which the sequence of processing steps is to be performed. The programmer write the program on paper and recorded on a tape by means of tape punch. The most commonly used punched tape is 25 mm wide, 8 tracks, i.e., eight punched holes can be accommodated in one line across the width of tape. The tape is then played on a tape reader. The tape reader has the capacity of reading the punched holes either mechanically or electronically.

Machine control unit (MCU): The punched tape is played on a tape reader in the machine control unit. The controller unit interprets the program of instructions received from the tape reader and convert it into mechanical actions of machine tool, i.e., the signals are forwarded to servomotors which control the movement of the slides or spindle along X, Y and Z-axis. The controller unit controls the path to be followed by the cutting tool spindle speeds, feed rate, tool changes and several other functions of the machine tool.

Machine tool: The machine tool perform the machining operations. It consists of work table motors, spindle motors and controls. It also includes the cutting tools, fixtures and other auxiliary equipment needed in the machining operation. The machine tool has the capacity to change the tools automatically under tape command. The machine table can orient the job so that it can be machined on several surfaces as required.

NC procedure

The following steps must be accomplished to utilize the numerical control in manufacturing.

1. *Process planning:* In process planning, the work part drawing must be interpreted in terms of manufacturing processes to be used and to prepare route sheet. The route sheet is a listing of the sequence of operations which must be performed on the workpart.

2. *Part programming:* Part program is the procedure by which the sequence of processing steps to be performed on the NC Machine is planned and documented. There are two ways to program for NC. i) Manual part programming ii) Computer - assisted part programming.

The manual part programming consists of (i) calculating dimensional relationships of the tool and work piece, based on engineering drawings of the part, and (ii) the manufacturing operations to be performed and their sequence. A program sheet is then prepared, which consists of the necessary information to carry out the operation, such as cutting tools, spindle speeds, feeds, depth of cut cutting fluids, and tool or workpiece relative positions and movements.

Computer assisted part programming involves special symbolic programming languages that determine the coordinate points of corners, edges, and surfaces of the part. Thus the tedious computational work required in manual part programming is transferred to the computer.

3. *Tape preparation:* The program of instructions are placed on the NC tape by punching a specific pattern of holes. This is accomplished on a special typewriter tape punch machine. The typewriter keyboard operates in a similar manner as a standard typewriter. The tape punch is activated as each typewriter key is depressed. This produces a unique pattern of holes in the tape.

4. *Tape verification:* The typewriter tape punch also has a tape reading head. The reader is used to obtain a printed record of a punched tape. This is useful for verifying tape accuracy. If there is an error in the tape information, it can be detected and corrected. The typewriter reader is also used to duplicate tapes. The tape can also be checked by running it through computer program which plots the various tool movements.

5. Production: The final step in NC procedure is to use NC tape in production. The operator has to load new stock in the machine and play the tape in the tape reader usually found in the machine control unit. The NC system then takes over and machine the part according to the instructions on tape. When the part is completed, the operator remove the finished part from the machine and loads the next stock. Except for downtime due to re-sharpening of cutting tools or routine maintenance, the NC machine tool can function continuously.

Axes and coordinate system

In order for the part programmer to plan the sequence of positions and movements of the cutting tool relative to the workpiece, it is necessary to establish a standard axis system by which the relative positions can be specified. The machine tool motions are generally described in X-Y-Z Cartesian space. The axis of the spindle or the axis parallel to the spindle represented as Z-axis. The X-axis lies on a horizontal plane parallel to the work table. The positive or negative movement of the three axis is based on right hand rule.

Lathes or *turning center* typically use only X and Z axis as shown in fig. 5.2. The Z denotes the movement parallel to the spindle axis and controls the length of the part. The X-axis is perpendicular to the spindle and controls the diameter of the part.

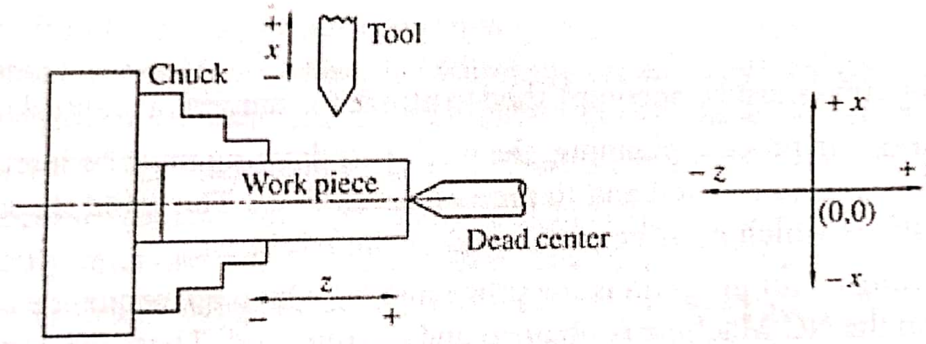


Fig. 5.2 Turning machine axis orientation

Milling machines or *machining center* use all the three axes as shown in fig. 5.3. On a vertical milling machine, the Z-axis denotes the movement parallel to the spindle axis, i.e., the up and down movement of the spindle or table. The X-axis (longest motion of the table) moves to the operator's left and right. The Y-axis moves toward and away from the operator. The Y-axis usually has the shortest travel.

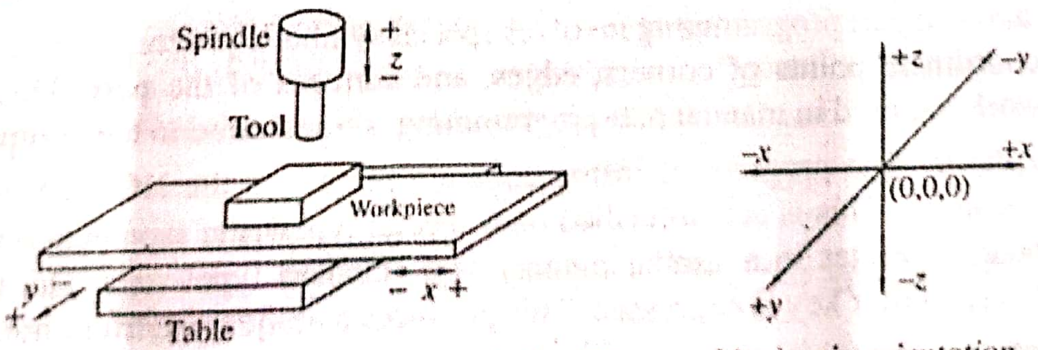


Fig. 5.3 Machining center (vertical milling machine) axis orientation

Fixed zero and floating zero (datum location): The programmer must determine the position machines are of an absolute type. The incremental programming implies that each move is specified as an incremental move from the previous position. An absolute and incremental measurement of a part are shown in fig. 5.6a and fig. 5.6b respectively.

Absolute positioning systems have a major advantage over incremental positioning. If the programmer makes a mistake when using absolute positioning, the mistake is isolated to the one location. When the programmer makes a positioning error using incremental positioning, all future positions are affected. Most NC machines allow the programmer to mix absolute and incremental programming.

Control-loops

Every control system, including NC systems may be designed as either an open loop or a closed-loop control system. Open loop systems provide no check or measurement to verify that a specific position has actually been reached. No feedback information is passed from the machine tool back to the controller. In an open loop system, a stepping motor is generally employed as the driving component to provide the machine-slide motion.

The program commands are converted into electric pulses or signals by the controller unit. These pulses are fed to the stepping motor. The stepping motor is an electromechanical device driven by an electrical pulse train to produce a sequence of angular movements corresponding to the number of pulses. Since there is no feedback from the slide position, the systems accuracy is solely a function of the motor's ability to step through the exact number of steps provided as its input. Fig. 5.7 shows an open-loop control system for a single axis of motion.

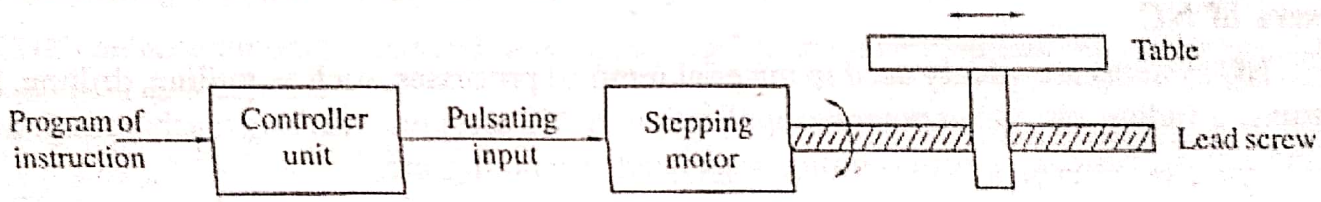
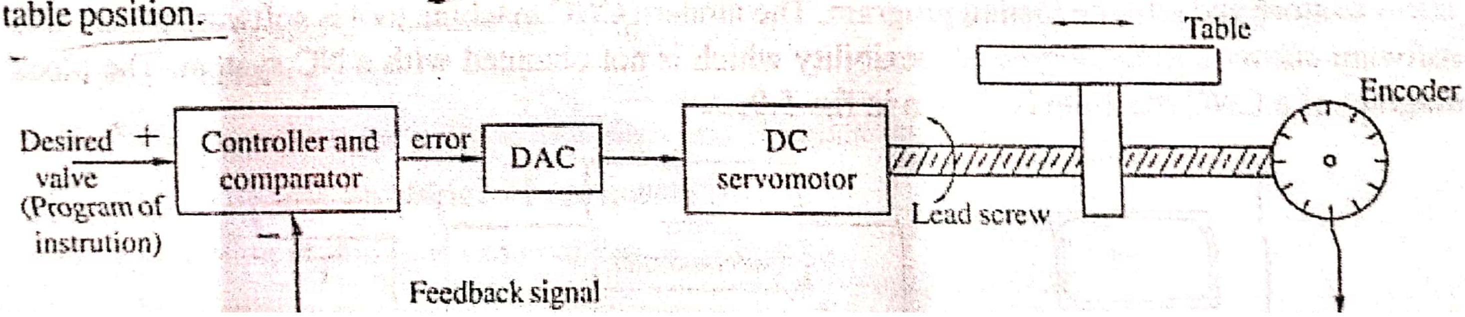


Fig. 5.7 Open-loop control in NC

One of the disadvantages of the stepping motor as the drive unit is the possible loss of one or more pulses when the motor is operating under heavy loads. This results in a loss in accuracy of table position.



Advantages and disadvantages of NC

Advantages:

1. Flexibility of operation is improved, as is the ability to produce complex shapes with good dimensional accuracy.
2. Reduced non machining and lead time.
3. Reduced inventory.
4. Reduced floor space requirements.
5. Reduced tool costs, since templates and other fixtures are not required.
6. High productivity.
7. High product quality.
8. Longer tool life.
9. Easy to modify the design of components.
10. Consistency using the correct speeds, feeds and tooling to achieve optimum productivity.

Disadvantages:

1. Relatively high initial cost of the equipment.
2. High maintenance cost.
3. Requires skilled programmers and operators.

Users of NC

NC systems are widely used in material removal processes, such as milling, drilling, boring, turning, grinding, etc. Other potential applications of NC are, press working machine tool, welding, flame cutting, bending, plasma cutting, laser beam machining, etc.

Computer Numerical Control (CNC)

NC controls must read the program each time a part is run. They have no means of storing or editing the existing programs. In CNC machine, the control unit contains a computer which will allow to store and edit the loaded program. The modern CNC machine tool is software driven. The software allows a great degree of flexibility which is not obtained with a NC system. The block diagram of a CNC machine is shown in fig. 5.9.

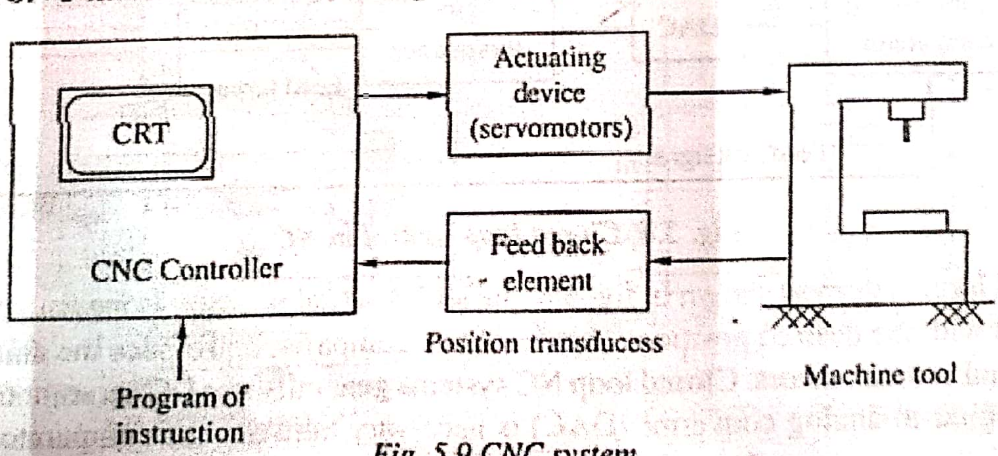


Fig. 5.9 CNC system

can see the loaded program, tool and cutter offsets, machine position
tool path simulation, etc. The tool path simulation can be used to
program is run to eliminate programming errors that could damage to

The information for each operation is fed from the control unit
motors turn the ball screws, which in-turn drive the different axes of th
capability and speed of computers make it possible to continuously
and velocity while it is operating. CNC machine offers accuracy
productivity.

Advantages and disadvantages of CNC machines

Advantages:

1. Part program tape and tape reader are used only once to ente memory. This results in improved reliability.
2. Tape editing is possible at the machine site.
3. CNC can accommodate conversion of tapes prepared in units c system of units.
4. High degree of accuracy and reduction of scrap.
5. Greater flexibility and capabilities.
6. Reduced non-machining time and lead time for production.
7. Faster in operation and high productivity.
8. Easy to produce components of high quality and accuracy manufacturing cost.

...d complex geometry.

Scanned with CamScanner

Disadvantages:

1. High initial cost.
2. High maintenance cost.
3. Requires skilled programmers and operators.

Direct Numerical Control (DNC)

In direct numerical control, several machines are directly controlled step by step by a central mainframe computer. In this system, the operator has access to the central computer through a remote terminal. Thus handling tapes and need for computers on each machine are eliminated. The computer is designed to provide instructions to each machine tool on demand. With DNC, the status of all machines in a manufacturing plant can be monitored and assessed from the central computer. However, DNC has the disadvantage that if the computer goes down, all the machines become inoperative.

Components of DNC system

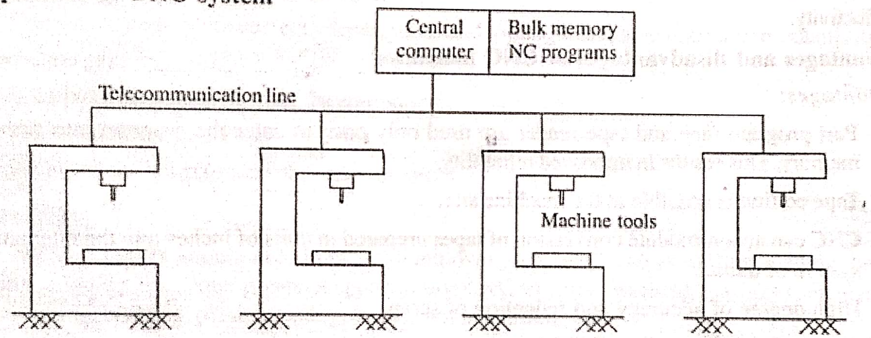


Fig. 5.10 DNC system

Fig. 5.10 illustrates the configuration of the basic DNC system. It consists of four basic components.

1. Central computer,
2. Bulk memory to store NC programs,
3. Telecommunication lines and
4. Machine tools.

The computer calls the part program instructions from the bulk storage and sends them to the individual machines as the need arises. The feature of DNC system is that the computer is servicing a large number of separate machine tools, all in real time.

A more recent DNC (Distributed Numerical Control) includes the use of central computer serving as the control system over a number of individual computer numerical control machines with onboard micro computers (fig. 5.11). This system provides large memory and computational capabilities, thus offering flexibility while overcoming the previous disadvantage of DNC. The central computer downloads complete programs to CNC machines as required. These machines may store one or more programs in their local storage, and they are thus independent of the central

Disadvantages:

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2. High maintenance cost.
3. Requires skilled programmers and operators.

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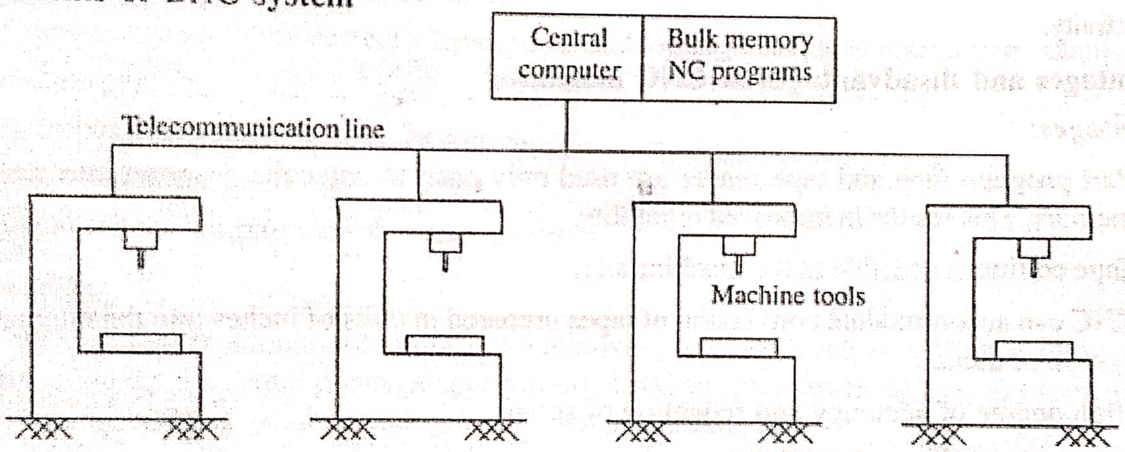

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STEREOLITHOGRAPHY APPARATUS (SLA)

Company

3D Systems was founded in 1986 by inventor Charles W. Hull and entrepreneur Raymond S. Freed. Amongst all the commercial RP systems, the Stereolithography Apparatus, or SLA® as it is commonly called, is the pioneer with its first commercial system marketed in 1988. It has been awarded more than 40 United States patents and 20 international patents, with additional patents filed or pending internationally. 3D Systems Inc. is currently headquartered in 26801 Avenue Hall, Valencia, CA 91355, USA.

Process

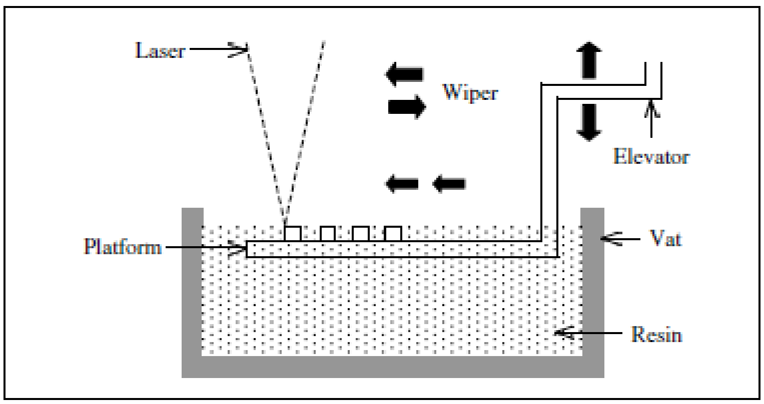


Figure 3.2: Schematic of SLA process

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 (see Figure 3.2). The operator loads a three-dimensional CAD solid model file into the system. Supports are designed to stabilize the part during 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 (0.001 to 0.020 in) 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 (for ZephyrTM 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 the part. The part is then raised out of the vat and cleaned of excess polymer. The main components of the SLA system are a control computer, a control panel, a laser, an optical system and a process chamber. The a workstation software used by the SLA system, known as 3D Lightyear exploits the full power of the Windows NT operating system, and delivers far richer functionality than the UNIX-based Maestro software. Maestro includes the following software modules

(1) *3dverify*TM *Module.* This module can be accessed to confirm the integrity and/or provide limited repair to stereolithography (STL) files before part building without having to return to the original CAD software. Gaps between triangles, overlapping or redundant triangles and incorrect normal directions are some examples of the flaws that can be identified and corrected.

(2) *View*TM *Module*. This module can display the STL files and slice file (SLI) in graphical form. The viewing function is used for visual inspection and for the orientation of these files so as to achieve optimal building.

(3) *MERGE Module.* By using MERGE, several SLI files can be merged into a group which can be used together in future process.

(4) *Vista*TM *Module.* This module is a powerful software tool that automatically generates support structures for the part files. Support structures are an integral part to successful part building, as they help to anchor parts to the platform when the part is free floating or there is an overhang.

(5) *Part Manager*TM *Module*. This software module is the first stage of preparing a part for building. It utilizes a spreadsheet format into which the STL file is loaded and set-up with the appropriate build

and recoat style parameters.

(6) *Slice*TM *Module.* This is the second stage of preparing a part for building. It converts the spreadsheet information from the *Part Manager*TM module to a model of three-dimensional cross sections

or layers.

(7) *Converge*TM *Module.* This is the third and last stage of preparing a part for building. This is the module which creates the final build files used by the SLA.

Principle

The SLA process is based fundamentally on the following principles

(1) Parts are built from a photo-curable liquid resin that cures when exposed to a laser beam (basically, undergoing the photopolymerization process) which scans across the surface of the resin.

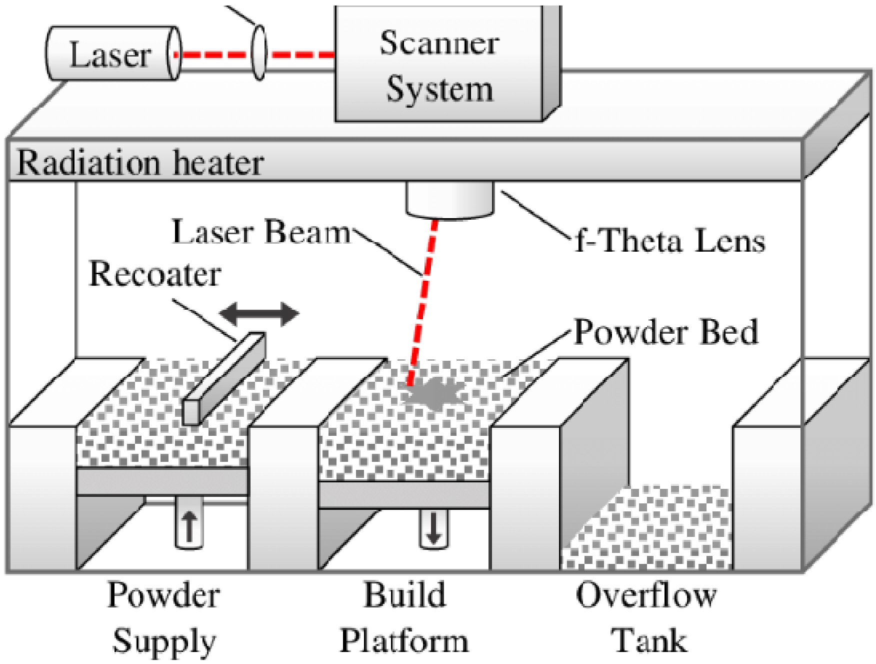
(2) The building is done layer by layer, each layer being scanned by the optical scanning system and controlled by an elevation mechanism which lowers at the completion of each layer. These two principles will be briefly discussed in this section to lay the foundation to the understanding of RP processes. They are mostly applicable to the liquid-based RP systems. This first principle deals mostly with photo-curable liquid resins, which are essentially photopolymers and the photopolymerization process. The second principle deals mainly with CAD data, the laser, and the control of the optical scanning system as well as the elevation mechanism.

SELECTIVE LASER SINTERING (SLS)

Company

3D Systems Corporation was founded by Charles W. Hull and Raymond S. Freed in 1986. The founding company, DTM Corporation, was established in 1987 to commercialize the SLS® technology. With the financial support from the BFGoodrich Company, and based on the technology that was developed and patented at the University of Texas at Austin, the company shipped its first commercial machine in 1992. DTM had worldwide exclusive license to commercialize the SLS technology until they were bought over by 3D Systems in August 2001. 3D Systems’ head office address is 26081 Avenue Hall, Valencia,
CA91355, USA.

Process



Schematic diagram of Selective Laser Sintering

The SLS® process creates three-dimensional objects, layer by layer, from CAD-data generated in a CAD software using powdered materials with heat generated by a CO2 laser within the VanguardTM 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 starts and operates as follows:

(1) A thin layer of heat-fusible powder is deposited onto the partbuilding chamber.

(2) 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 CO2 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 remain a loose compact and serve as supports.

(3) 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.

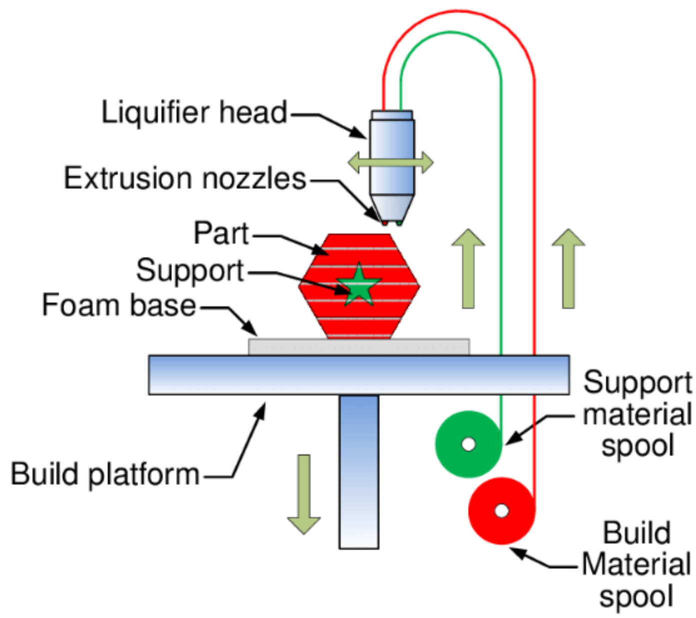
(4) Steps 2 and 3 are repeated, with each layer fusing to the layer below it. Successive layers of powder are deposited and the process is repeated until the part is completed.

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.

The software that comes with the VanguardTM si2TM SLS® System includes the Windows 2000 operating system and other proprietary application software such as the slicing module, automatic part distribution module, and part modification application software.

Fused Deposition Modeling (FDM)



SCHEMATIC OF FDM PROCESS

FDM is a registered, protected trade name for a fused layer process offered by Stratasys Company, Eden Prairie, MN, USA. Because it was the first commercialized FLM process worldwide, the name FDM is often used synonymously with FLM even as a generic name. A FDM machine consists of a heated (app. 80 °C for ABS plastic processing) build chamber equipped with an extrusion head and a build platform. Consequently, the machine does not use a laser. The extrusion head provides the material deposition in the x-y area according to the contour of the actual layer. It is a plotter-type device. The build material is a prefabricated filament that is wound up and stored in a cartridge from which it is continuously fed to the extrusion head. The cartridge has a build-in sensor that communicates with the material management system of the machine. In the head, the material it is partly molten by an electric heating system and extruded through a nozzle that defines the string diameter that nearly equals the layer thickness.

Usually, string diameters range from 0.1 mm to 0.25 mm. The platform moves in z-direction and defines the layer thickness, as the material is squeezed on the top of the partly finished part. The process needs supports. They are made by a second nozzle that extrudes another plastic support material simultaneously with the build material. The simultaneous processing of two materials indicates that the FLM process is basically capable of handling multi-material print heads. Therefore, the manufacture of multimaterial parts can be expected in the future. After deposition, the pasty string (of the build material as well as of the support material) solidifies by heat transfer into the preceding layer and forms a solid layer. Then the platform is lowered by the amount of one layer thickness and the next layer is deposited. The process repeats until the part is completed. There are a wide variety of machines that follow the principle of the FDM process. The machines range from the personal printer µPrint (starting at € 11,900; status 2011) and the almost double priced Dimension office printers to the high-end Fortus Production Systems brand, including the Fortus 900mc that offers the largest build space (914 × 610 × 914 mm) currently available. There are many plastic materials available for FDM processes, including engineering materials such as ABS, PC-ABS, and specialty grades for medical modeling. Some machines are restricted to only a limited number of different materials. There is a big variety of colors available, amongst it even translucent, black, and white qualities. Because the color is linked to the filament, it cannot be changed during the build process (Fig. 2.16, left). The Fortus 400 and 900 machines process the high temperature thermoplastic material polyphenylsulfone (PPSF/PPSU). They were the first machines on the market to handle these high performance plastics.

Typical part properties resemble those of plastic injection molded parts; however, they tend to show anisotropic behavior that can be reduced by properly adjusted build parameters. The parts are either used as concept models, functional prototypes, or as (direct manufactured) final parts. FDM parts show typical surface textures that result from the extrusion process. According to the layer thickness and the orientation of the part in the build chamber, these textures are more or less visible. Therefore, the positioning (orientation) in the build chamber has a big influence on the appearance of the part. Post processing requires the removal of the supports, which can be done manually, or using a special washing device. Finishing requires manual skills and time; but together with artisan capabilities leads to perfect surface qualities and astonishing results. It is needless to say that intensive finishing affects the part's accuracy.

Applications of Additive Manufacturing Technology

Metals are the fastest-growing segment of 3D printing. Metal AM is increasingly being used to fabricate end-use products for

- Aerospace Industry & Suppliers
- Automotive Industry & Suppliers
- Machinery (e.g. Turbines, Special Machinery)
- Medical implants (Dental, Orthopedic)
- Handling and Robotics
- Lifestyle & Sports (e.g. Jewelry, Biking)
- Custom Parts (e.g. Classic Car Parts, Surgical Tools)

Rapid Prototyping (RP) is a continuously evolving technology. RP models are becoming widely used in many industrial sectors. Initially conceived for design approval and part verification, RP now meets the need for a wide range of applications from building test prototypes with material properties close to those of production parts to fabricating models for art and medical applications. In order to satisfy the specific requirements of a growing number of new applications, special software tools, build techniques and materials have been developed. This chapter discusses the use of RP in five different application areas: building functional prototypes, patterns for castings, medical models, artworks and models for engineering analysis. In addition, the chapter outlines the technological capabilities of RP processes in the context of each particular application and discusses specific issues relating to the efficient integration of these techniques into existing manufacturing routes.

Functional Models

There are a number of RP technologies that now meet the need for building functional prototypes with material properties close to those of production parts. One of the RP processes that is widely used for producing models for functional tests is SLS. Initially, four Nylon-based materials (Standard Nylon, Fine Nylon, Fine Nylon Medical Grade, Nylon Composite) were available commercially for this process. In 1999, these four materials were replaced by two new materials, DuraForm PA and glass reinforced DuraForm GF. DuraForm prototypes can be relatively easily finished to a smooth appearance [DTM, 2000]. The production of Nylon parts is generally cost effective when a small number (1-5) of parts is required. Before the introduction of Duraform PA, a Nylon Composite known as the ProtoForm composite was used widely for producing functional parts. A case study discussing some accuracy aspects of building functional models in ProtoForm is presented below. Also, this case study addresses some general technological issues regarding the fabrication of functional models in Nylon-based materials.

ProtoForm is a blend of *SO%* by weight Nylon powder with a mean particle size of SOf.lm and *SO%* by weight spherical glass beads with an average diameter of 3Sf.lm. This SLS glass-filled Nylon can be processed to near full density and has a high modulus and good heat and chemical resistance The housing in Figure *S.3* is a test part and is built in ProtoForm Composite because it is required to withstand harsh testing conditions including temperatures of about 100°C. As a base part for mounting precision components, it has to keep its dimensions within close limits.

Due to its overall dimensions (l90xSOx2S0 mm), the part was constructed vertically to fit within the build area (030Sx410 mm) of the DTM Sinterstation 2000. To speed up cooling, the downdraft (downward forcing of gas through the powder) capability of the machine was utilised. However, the geometry of the housing prevented the downdraft, leaving a hot area inside the part and causing post-build warping of the walls.

The first part manufactured suffered from much distortion: there was vertical growth and "wash out" (loss of definition and rounding of edges) on the downward facing surfaces and the external dimensions of the sidewalls varied by more than 1 mm. This problem was solved by making the wall thickness uniform and reducing it to 2mm. Furthermore, 2mm non-functional ribs were added across the housing to stiffen it. Two ribs were positioned vertically and two others horizontally . The number and size of the ribs were determined from experience to constrain post process distortion in the X and Y directions without adding too much build time. The ribs were also located so that they could easily be removed by machining after completing the build. Subsequently manufactured parts had much better dimensional accuracy. The main functional dimensions were measured but no form or geometrical accuracy measurements were taken. The distribution of errors in the dimensions of the housings with and without ribs. The error in 90% of all dimensions for the modified part was between +0.35 and - O.3lmm.

Patterns for Investment and Vacuum Casting

RP technologies are widely used for building patterns for investment and vacuum casting. For example, models built employing SLA, SLS and FDM can be used as patterns for both casting processes. A case study is presented below that discusses some accuracy aspects of producing SLS patterns and also addresses general issues regarding the technological capabilities of the process.

Two SLS materials are currently available for producing casting patterns, CastForm and TrueForm. In this case study, TrueForm, which is an acrylic-based powder of spherical particles with a mean diameter of 30flm, is used to build casting patterns. It is processed at relatively low temperatures compared with nylon-based materials which limits shrinkage to 0.6% [Van de Crommert et ai., 1997] and is the preferred material for making parts with good accuracy but moderate strength. The density of TrueForm parts can vary from 70 to 90% depending on build parameters and they can be polished to a mirror-like finish. Dense parts are used as patterns for vacuum casting while rather porous parts are better suited for investment casting; unlike dense models they do not expand to cause shell cracking during the burning out of the patterns

Medical Models

RP technologies are applied in the medical domain for building models that provide visual and tactile information. In particular, RP models can be employed in the following medical applications.

• *Operation planning.* Using real size RP models of patients' pathologic regions, surgeons can much more easily understand physical problems and gain a better insight into the operations to be performed. RP models can also assist surgeons in communicating the proposed surgical procedures to the patients.

• *Surgery rehearsal.* RP models offer unique opportunities for surgeons and surgical teams to rehearse complex operations using the same techniques and tools as during actual surgery. Potentially, such rehearsals can lead to changes in surgical procedures and significantly reduce risk.

• *Training.* RP models of specimens of unusual medical deformities can be built to facilitate the training of student surgeons and radiologists. Such models can also be employed for student examinations.

• *Prosthesis design.* RP models can be used to fabricate master patterns which are then replicated using a bio-compatible plastic material. Implants produced in this way are much more accurate and cost effective than those produced employing conventional techniques.

The building of RP models of anatomical structures involves the following steps:

1. Data acquisition with medical equipment. Conventional 3D medical scanners (CT Scans, MRI Scans, 3D Ultrasound) are employed to capture a sequence of images of a particular anatomic structure. In Figure S.16, a CT scanner is shown together with a captured image.

Generation of STL files from the scan data. Interactive software tools exist for segmentation of scanned images and generation of STL files. For example, the MIMICS software developed by Materialise enables users to control and correct the segmentation of scanned images. The segmentation volume is defined by all pixels with a grey value higher than a predefined threshold. Also, the software allows a definition of the segmentation volume with a grey value in-between two threshold values. This technique can be employed for segmentation of soft tissue in CT images or for segmentation of several structures in MR images.

3. Building RP models from the generated STL files. Any RP technology can be employed for building medical models. In addition to the general-purpose materials for each RP technology, special materials have been developed for medical applications. For example, a Fine Nylon Medical Grade for the SLS process and a resin, Stereocol, for the SLA process are dedicated to medical applications. Fine Nylon MG is a modification of the fine nylon that can be sterilised in an autoclave. The Stereocol resin is not as accurate as an epoxy resin but offers several advantages for medical applications. For instance, this resin can be coloured by hatching up certain areas of the models a second time with an UV laser. Because SLA models are translucent, the coloured regions can be viewed within the parts.