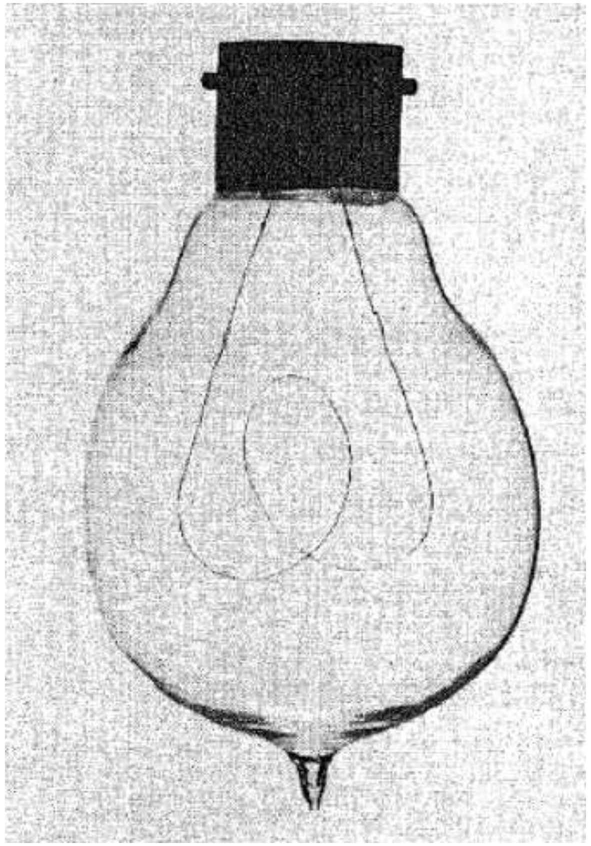
Powder Metallurgy

Material and Energy Considerations

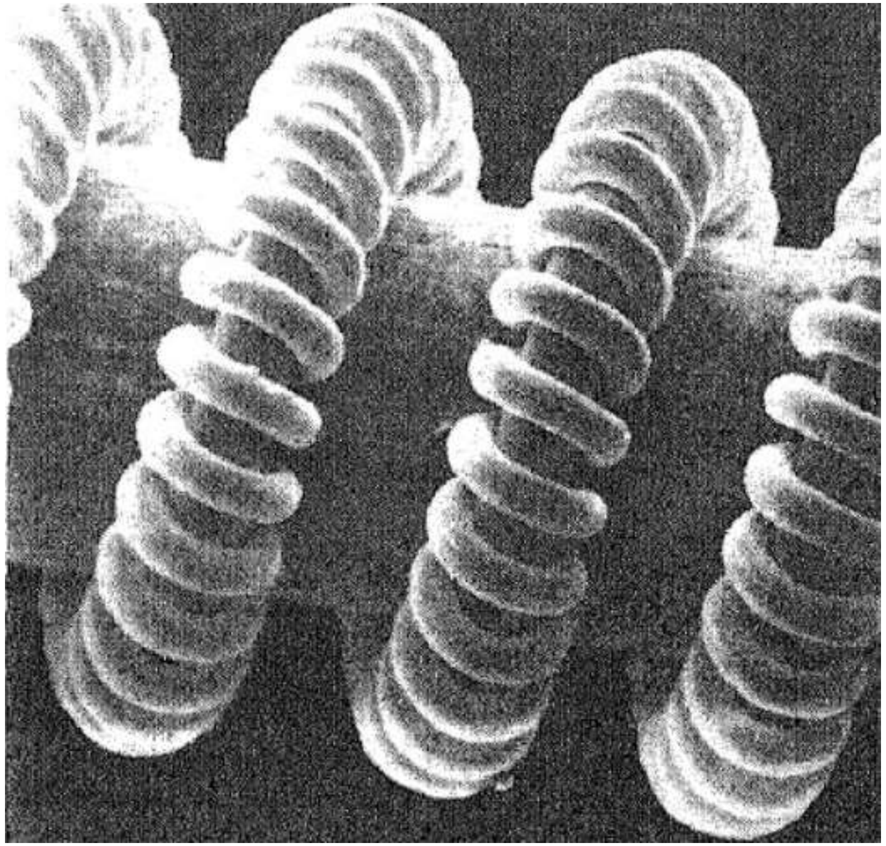
The old fashioned way

The better alternative

Products



Carbon filament lamp

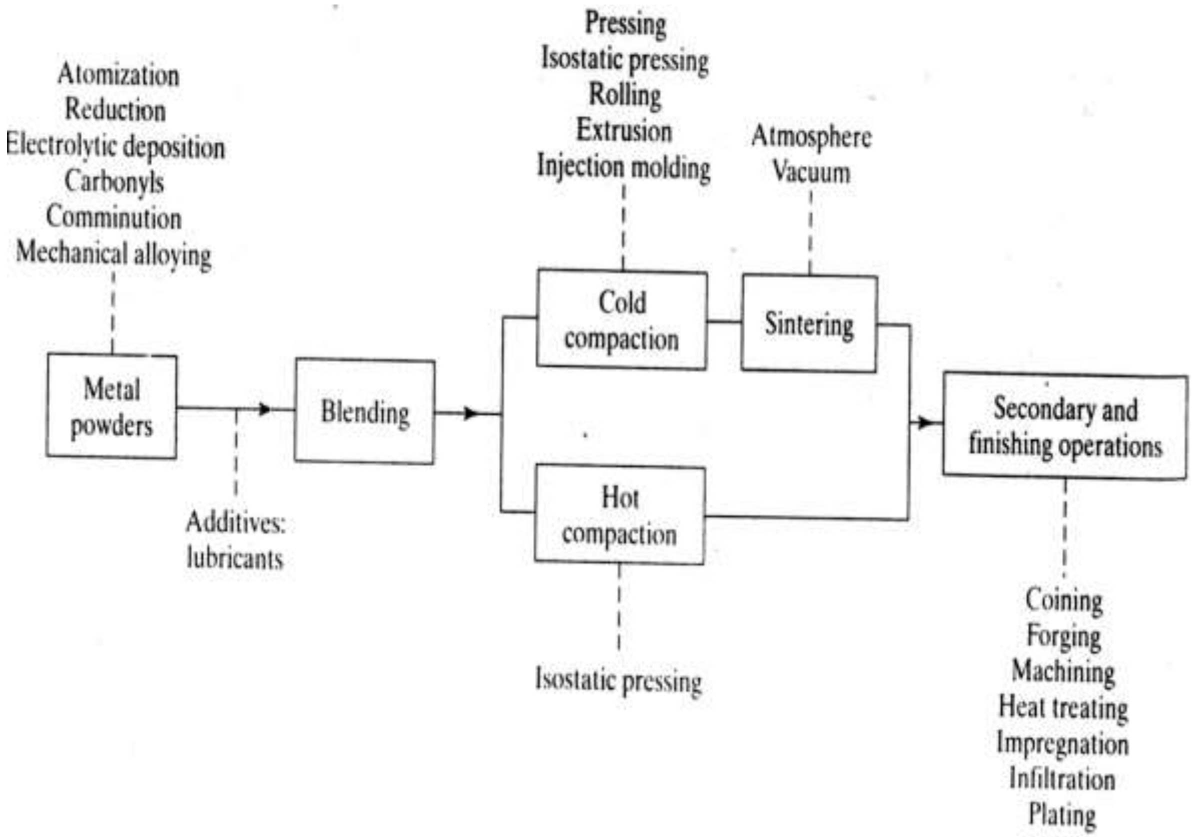


Coiled coil tungsten filament

Sintered Platinum coins

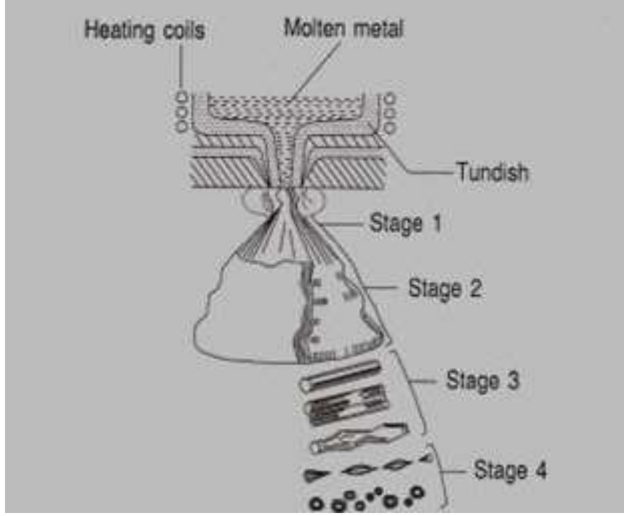
Definition

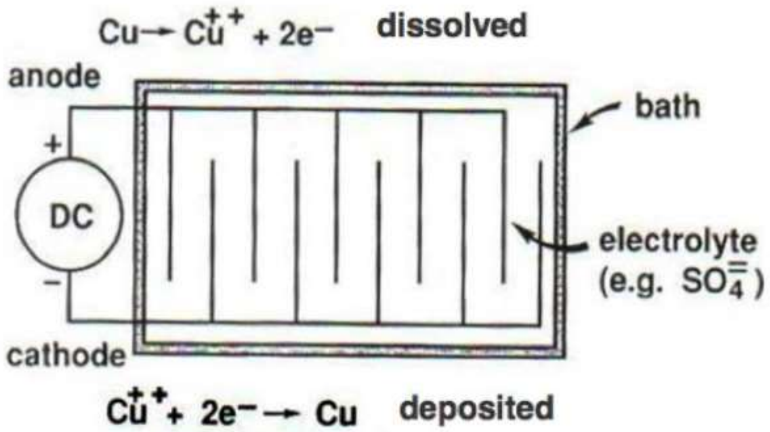
- Powder metallurgy science of producing metal powders and making finished /semi finished objects from mixed or alloyed powders with or without the addition of non metallic constituents.
- Powder production, Compaction, Sintering, & Secondary operations

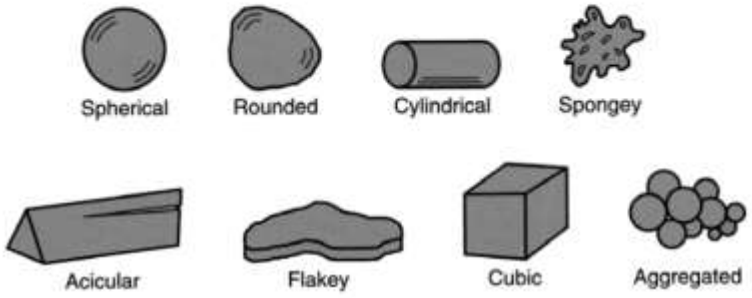


Powder production

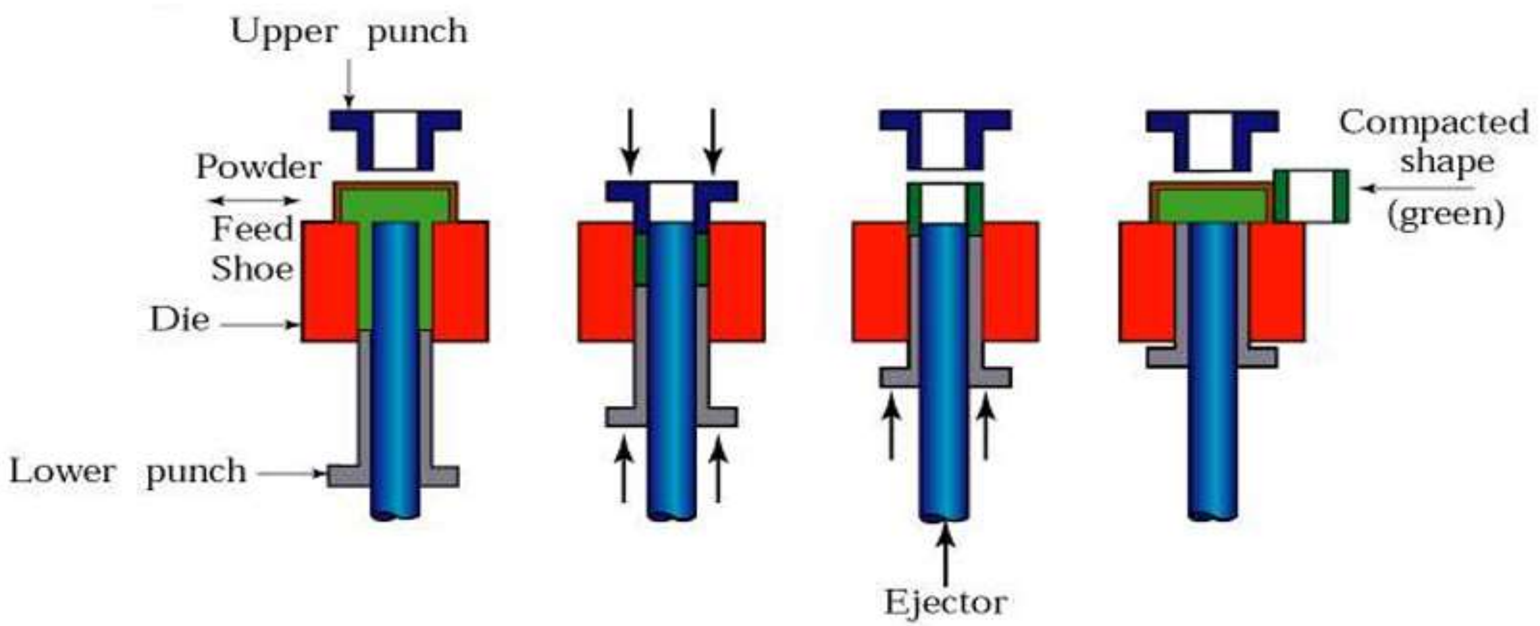
- Methods for making powders
  - Atomization: Produces powders of both ferrous and nonferrous powders like stainless steel, super alloys, Ti alloy powders
  - Reduction of compounds: Production of iron, Cu, tungsten, molybdenum
  - Electrolysis: for making Cu, iron, silver powders
  - Powder characterization– size, flow, density, compressibility tests







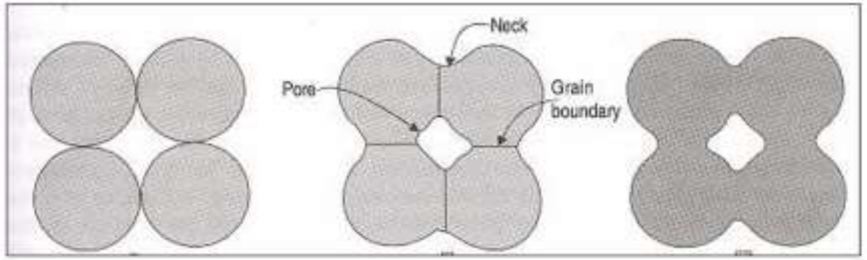
Compaction



- Compaction is performed using dies machined to close tolerances.
- Dies are made of cemented carbide, die/tool steel; pressed using hydraulic or mechanical presses .
- The basic purpose of compaction is to obtain a green compact with sufficient strength to withstand further handling operations.
- The green compact is then taken for sintering.
- Hot extrusion, hot pressing, hot isostatic pressing (consolidation at high temperatures.)

Sintering

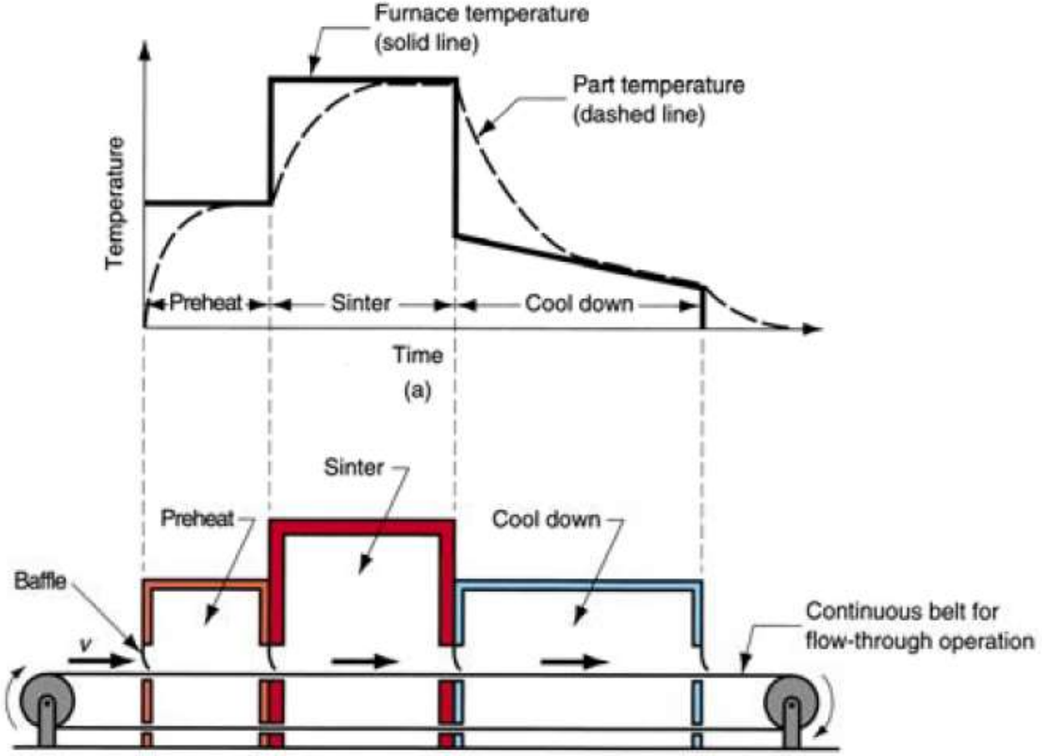
- Performed at controlled atmosphere to bond atoms metallurgically; Bonding occurs by diffusion of atoms; done at 70% of abs. melting point of materials.
- It serves to consolidate the mechanically bonded powders into a coherent body having desired on service behaviour.
- Densification occurs during the process and improvement in physical and mechanical properties are seen.
- Furnaces– mesh belt furnaces (upto 1200 C), walking beam, pusher type furnace, batch type furnaces are also used.
- Protective atmosphere: Nitrogen (widely used).



Particles in contact

Formation of necks, grain boundaries, pores

Final sintered geometry



(a)

(b)

Secondary operations:

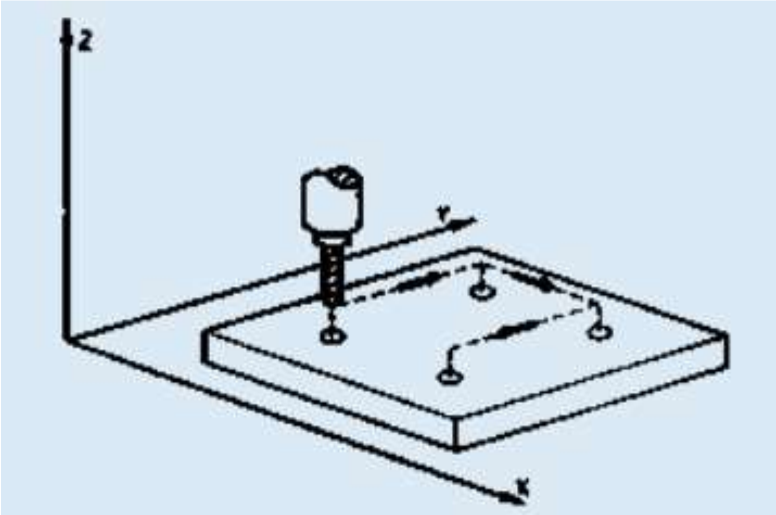
Operations include repressing, grinding, plating can be done; They are used to ensure close dimensional tolerances, good surface finish, increase density, corrosion resistance etc.

Computer Numerical Control (CNC)

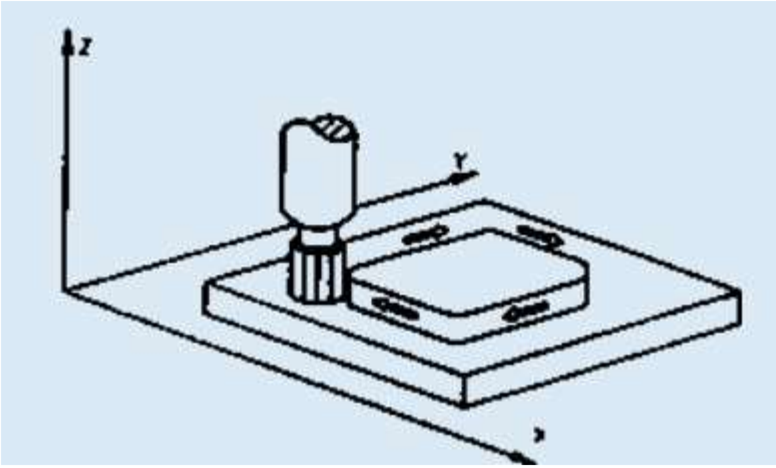
- NC (numerical control) refer to control of a machine or a process using symbolic codes consisting of characters and numerals.
- CNC came into existence in seventies when microprocessors and microcomputers replaced integrated circuit IC based controls.
- The development of numerical control owes much to the United States air force.
- The concept of NC was proposed in the late 1940s by John Parsons who recommended a method of automatic machine control that would guide a milling cutter to produce a curvilinear motion in order to generate smooth profiles on the work-pieces.

CLASSIFICATION OF CNC MACHINE TOOLS

- **Point-to-point systems**
  - Some machine tools for example drilling, boring and tapping machines etc, require the cutter and the work piece to be placed at a certain fixed relative positions at which they must remain while the cutter does its work.
  - Feed rates need not to be programmed.
  - In theses machine tools, each axis is driven separately.

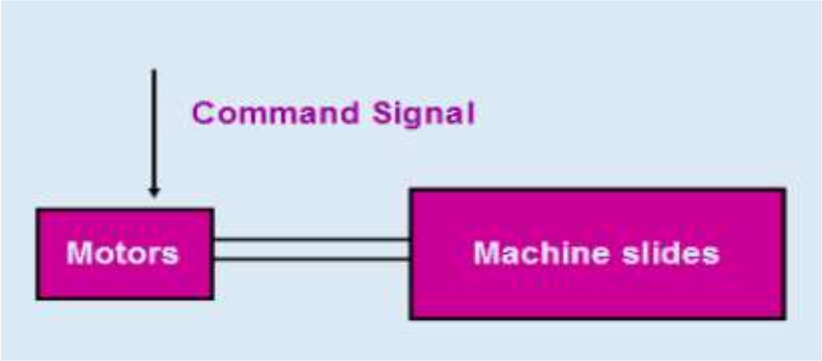


- **Contouring systems (Continuous path systems)**
  - These machine tools include milling, routing machines etc. and are known as contouring machines.
  - These machines require simultaneous control of axes.
  - In contouring machines, relative positions of the work piece and the tool should be continuously controlled.
  - Feed rates should be programmed.

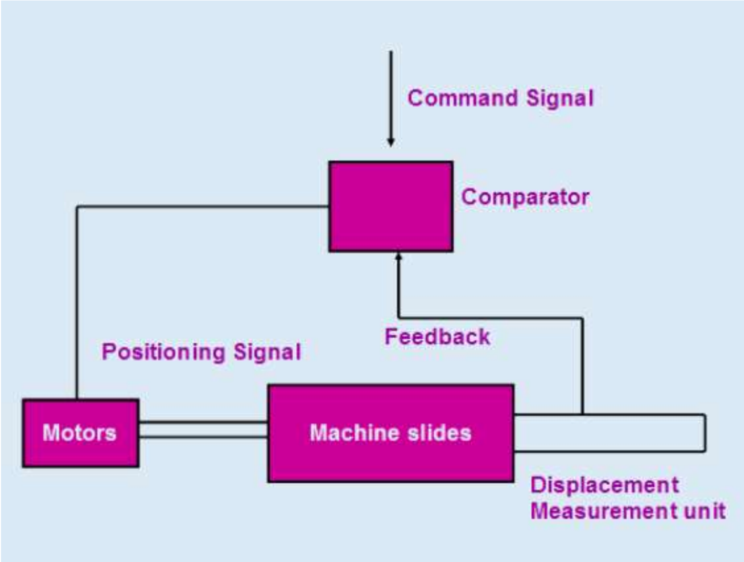


CLASSIFICATION OF CNC MACHINE TOOLS

- **Based on the control loops**
- **Open loop systems:**
  - Programmed instructions are fed into the controller through an input device.
  - These instructions are then converted to electrical pulses (signals) by the controller and sent to the servo amplifier to energize the servo motors.



- **Closed loop systems:**
  - The closed-loop system has a feedback subsystem to monitor the actual output and correct any discrepancy from the programmed input.
  - These systems use position and velocity feed back.
  - Majority of CNC systems operate on servo mechanism, a closed loop principle.
  - Closed-loop systems are very powerful and accurate because they are capable of monitoring operating conditions through feedback subsystems and automatically compensating for any variations in real-time.

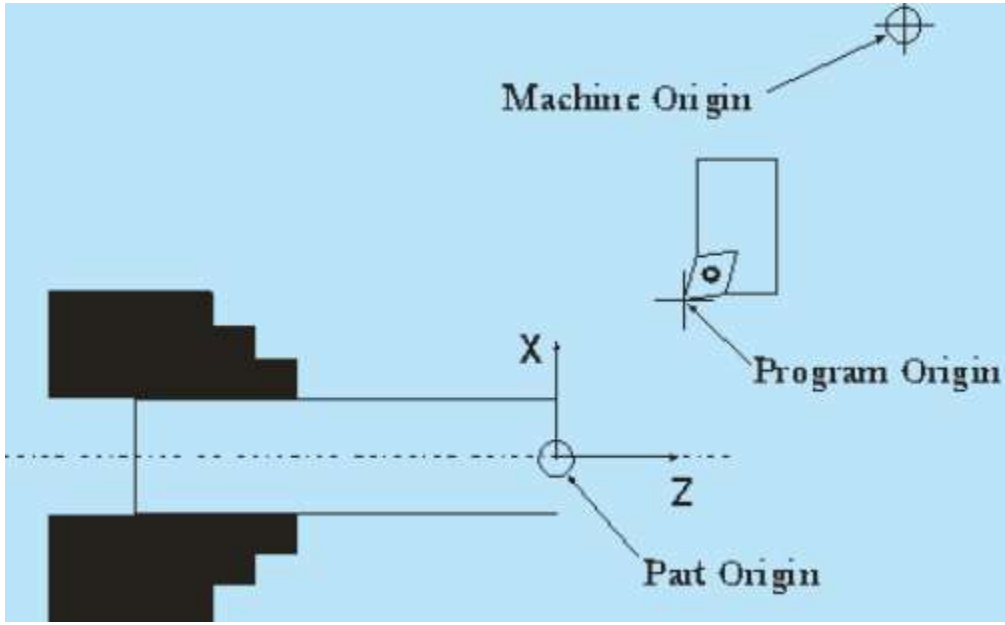


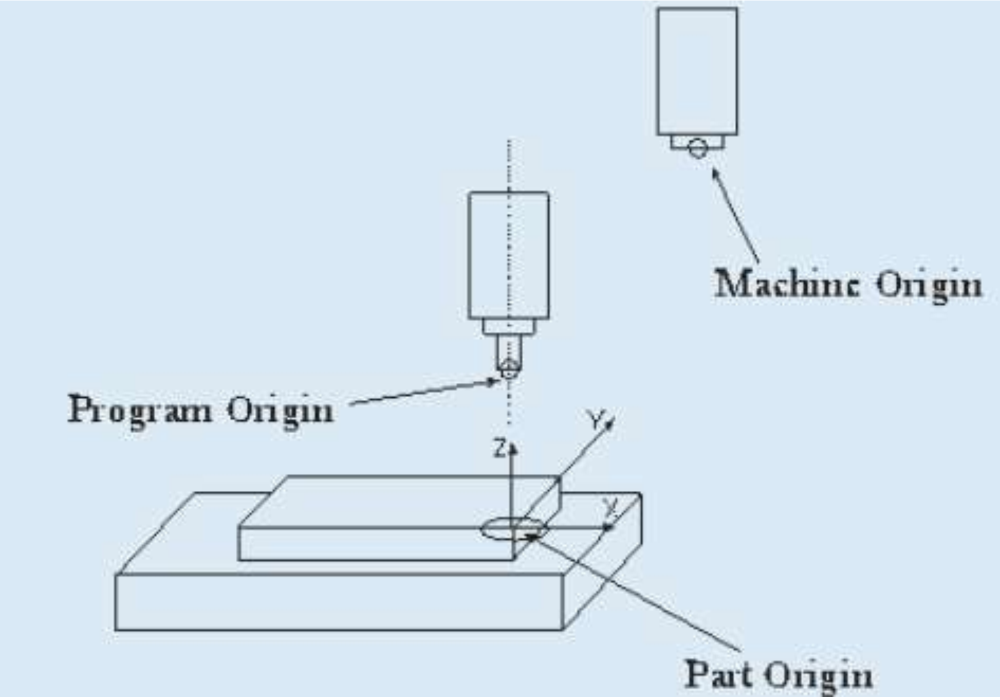
Programming fundamentals

- Machining involves an important aspect of relative movement between cutting tool and workpiece.
- In machine tools this is accomplished by either moving the tool with respect to workpiece or vice versa.
- In order to define relative motion of two objects, reference directions are required to be defined.
- These reference directions depend on type of machine tool and are defined by considering an imaginary coordinate system on the machine tool.
- A program defining motion of tool / workpiece in this coordinate system is known as a part program.

Programming fundamentals

- **Reference Points**
- **Machine Origin**
  - The machine origin is a fixed point set by the machine tool builder.
  - Any tool movement is measured from this point.
- **Program Origin**
  - It is also called home position of the tool.
  - Program origin is point from where the tool starts for its motion while executing a program and returns back at the end of the cycle.
- **Part Origin**
  - The part origin can be set at any point inside the machine's electronic grid system.
  - Part origin is also known as zero shift, work shift, floating zero or datum.





Programming fundamentals

- **Axis Designation**
  - An object in space can have six degrees of freedom with respect to an imaginary Cartesian coordinate system.
  - Three of them are liner movements and other three are rotary. Machining of simple part does not require all degrees of freedom.
  - With the increase in degrees of freedom, complexity of hardware and programming increases.
  - Number of degree of freedom defines axis of machine.
- **Setting up of Origin**
  - Origin can set by selecting three reference planes X, Y and Z. Planes can be set by touching tool on the surfaces of the workpiece and setting that surfaces as X=x, Y=y and Z=z.
- **Coding Systems**
  - The programmer and the operator must use a coding system to represent information, which the controller can interpret and execute.
  - A frequently used coding system is the Binary-Coded Decimal or BCD system.
  - This system is also known as the EIA Code set because it was developed by Electronics Industries Association.
  - The newer coding system is ASCII and it has become the ISO code set because of its wide acceptance.

Types of CNC codes

- **Preparatory codes**
  - The term "preparatory" in NC means that it "prepares" the control system to be ready for implementing the information that follows in the next block of instructions.
  - A **preparatory function** is designated in a program by the word address G followed by two digits.
  - Preparatory functions are also called **G-codes** and they specify the control mode of the operation.
- **Miscellaneous codes**
  - Miscellaneous functions use the address letter M followed by two digits. They perform a group of instructions such as coolant on/off, spindle on/off, tool change, program stop, or program end.
  - They are often referred to as machine functions or **M-functions**.
  - Some of the M codes are given below.

    M00 Unconditional stop

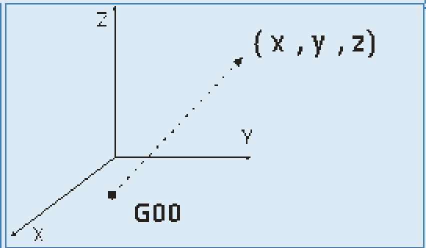
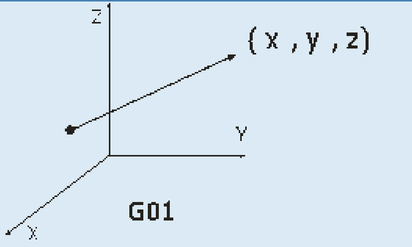
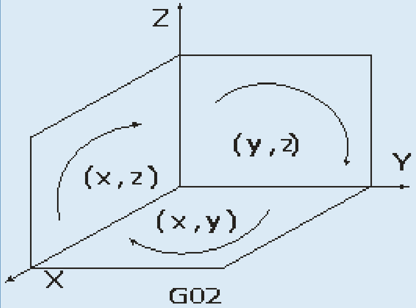
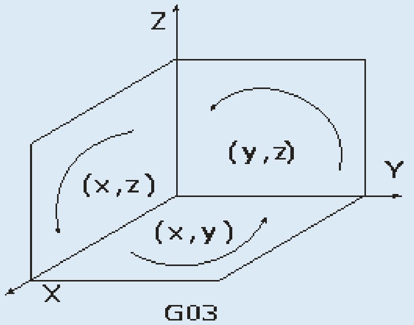
    M02 End of program

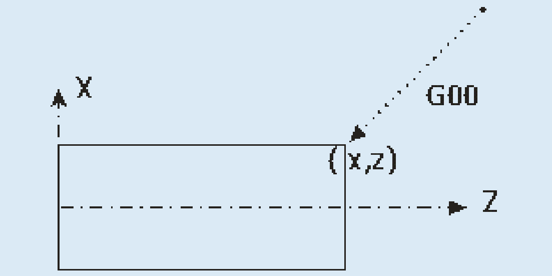
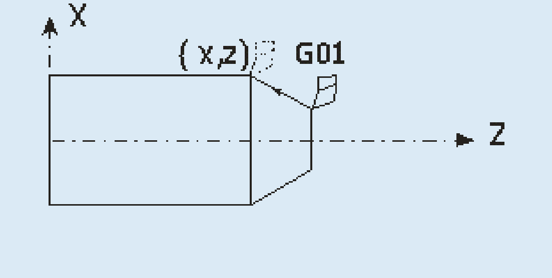
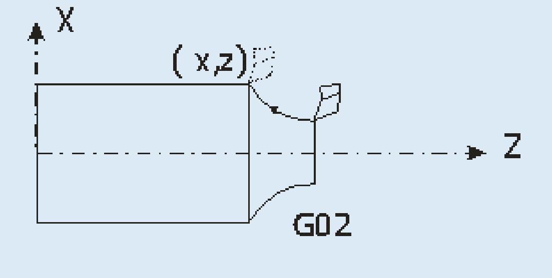
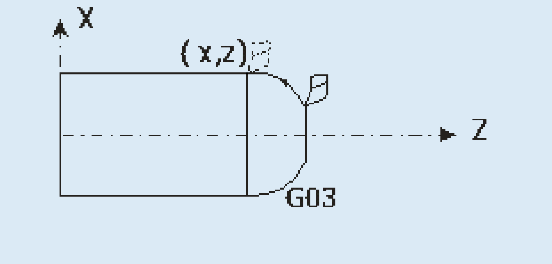
    M03 Spindle clockwise

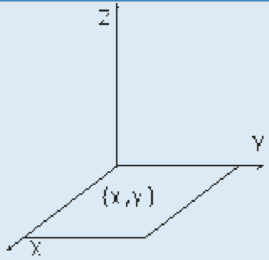
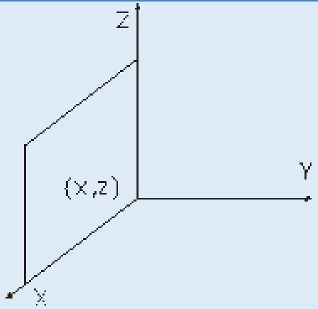
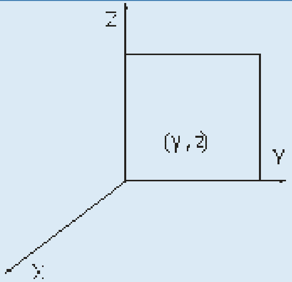
    M04 Spindle counterclockwise

    M05 Spindle stop

CNC codes

Command group	G-code	Function and Command Statement	Illustration
Tool motion	G00	Rapid traverse G00 Xx Yy Zz	
	G01	Linear interpolation G01 Xx Yy Zz Ff	
	G02	Circular Interpolation in clock-wise direction G02 Xx Yy Ii Jj G02 Xx Zz Ii Kk G02 Yy Zz Jj Kk	
	G03	Circular interpolation in counter-clockwise direction G03 Xx Yy Ii Jj G03 Xx Zz Ii Kk G03 Yy Zz Jj Kk	

Command group	G-code	Function and Command Statement	Illustration
Tool motion	G00	Rapid traverse G00 Xx Zz	
	G01	Linear interpolation G01 Xx Zz	
	G02	Circular Interpolation in clock-wise direction G02 Xx Zz Ii Kk (or) G02 Xx Zz Rr	
	G03	Circular interpolation in counter-clockwise direction G03 Xx Zz Ii Kk (or) G03 Yy Zz Rr	

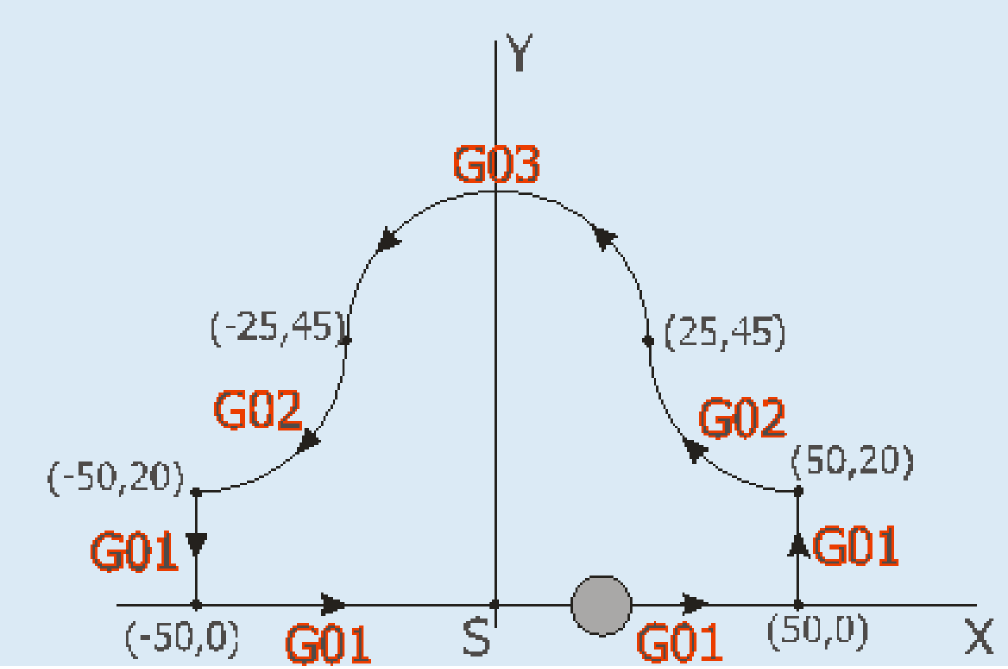
Command group	G-code	Function and Command Statement	Illustration
Plane Selection	G17	XY - Plane selection	
	G18	ZX - Plane selection	
	G19	YZ - plane selection	

Command group	G-code	Function and Command Statement	Illustration
Unit Selection	G20 or G70	Inch unit selection	
	G21 or G71	Metric unit selection	

Illustrative Example Program

CNC milling machine

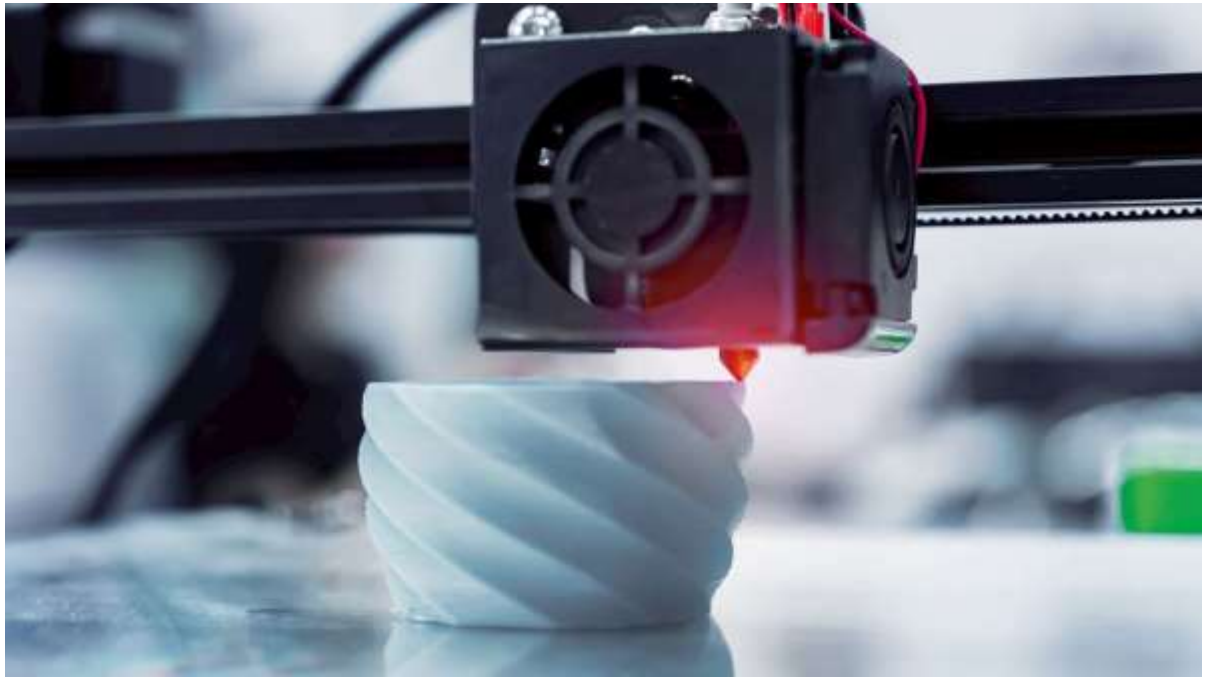
N02 G21	Metric programming
N03 M03 S1000	Spindle start clockwise with 1000rpm
N04 G00 X0 Y0	Rapid motion towards (0,0)
N05 G00 Z-10.0	Rapid motion towards Z=-10 plane
N06 G01 X50.0	Linear interpolation
N07 G01 Y20.0	Linear interpolation
N08 G02 X25.0 Y45.0 R25.0	Circular interpolation clockwise(cw)
N09 G03 X-25.0 Y45.0 R25.0	Circular interpolation counter clockwise(ccw)
N10 G02 X-50.0 Y20.0 R25.0	Circular interpolation clockwise(cw)
N11 G01 Y0.0	Linear interpolation
N12 G01 X0.0	Linear interpolation
N13 G00 Z10.0	Rapid motion towards Z=10 plane
N14 M05 M09	Spindle stop and program end



3D-PRINTING AND SCANNING

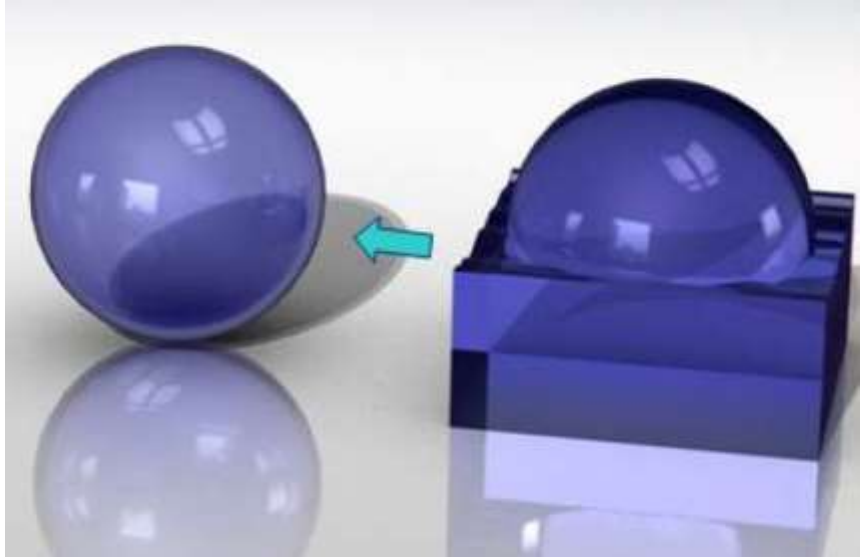
Definition

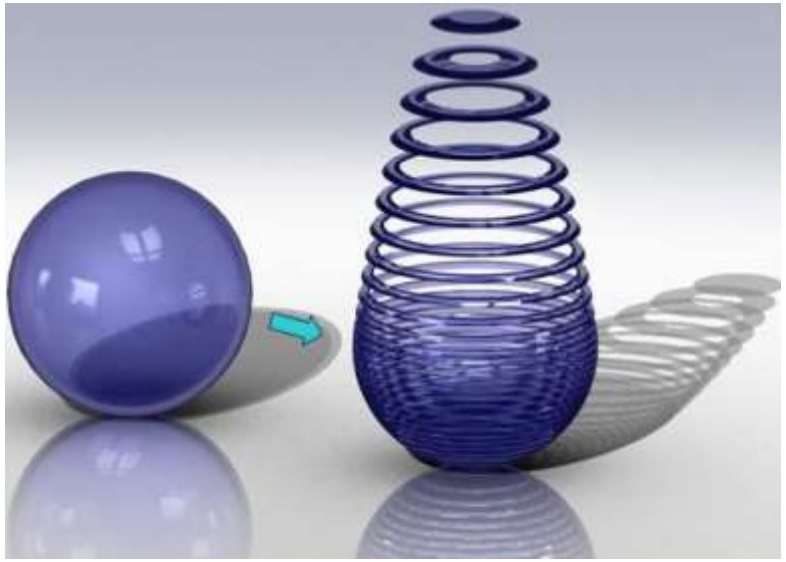
Additive Manufacturing (AM) refers to a process by which digital 3D design data is used to build up a component in layers by depositing material.



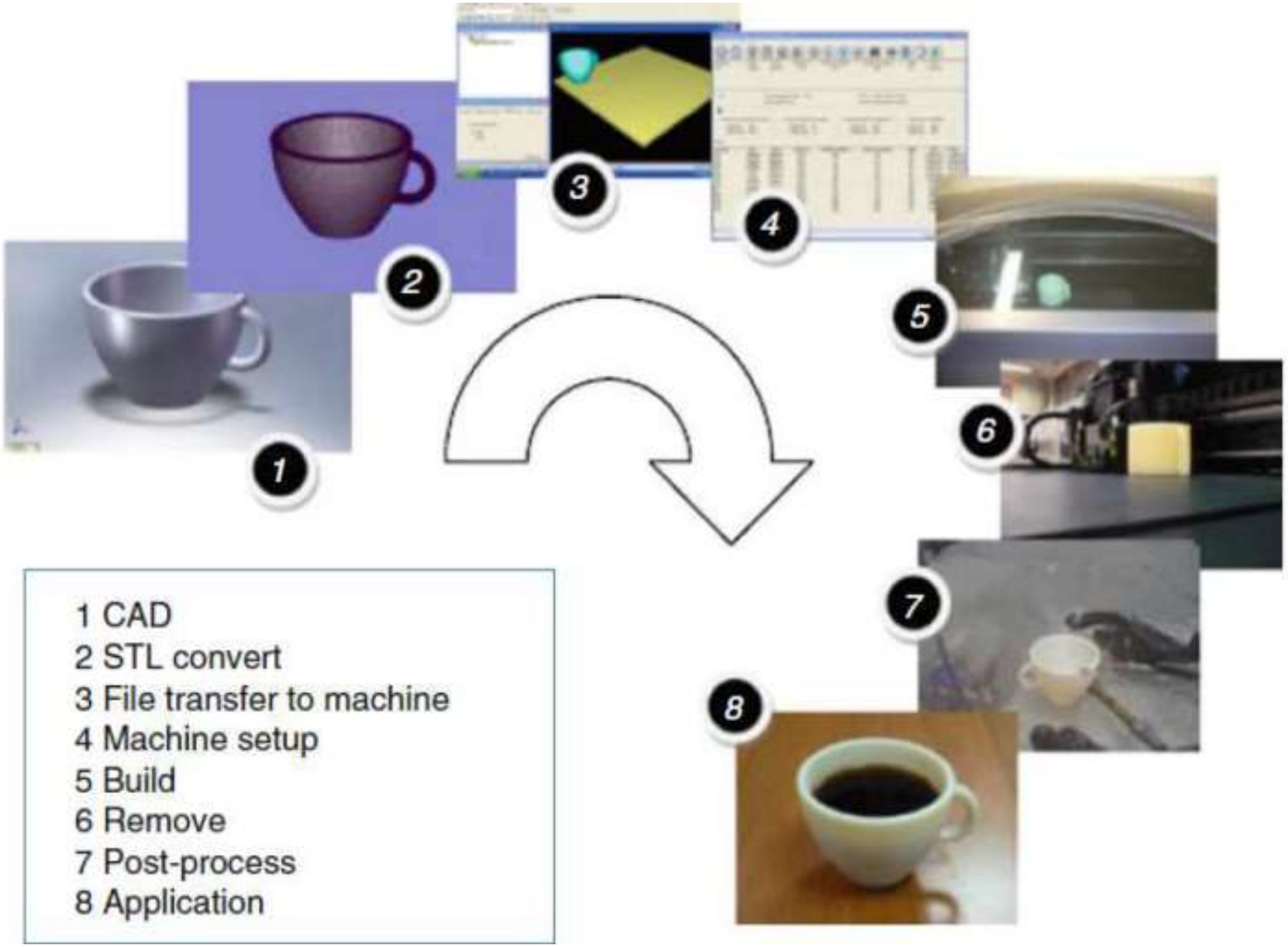
Additive vs Subtractive Manufacturing

- Part Complexity,
- Material,
- Speed,
- Part Quantity,
- Cost.



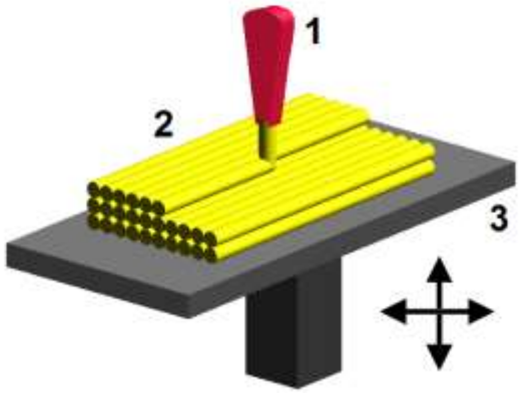


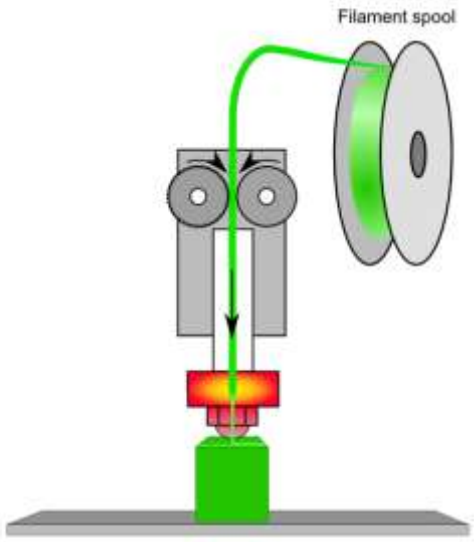
Generic AM Process



Fused Deposition Modeling (FDM)

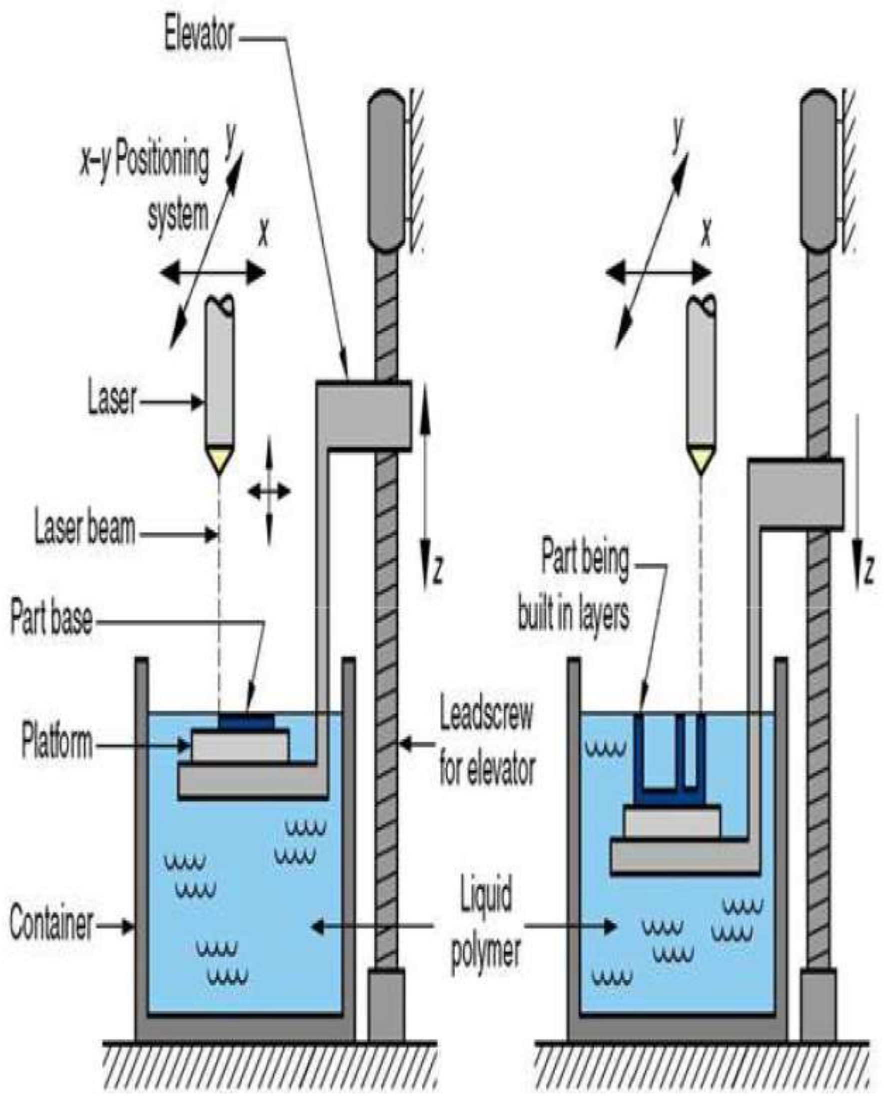
- Commonly used for modeling, prototyping, and production applications.
- FDM works on an "additive" principle by laying down material in layers.
- A plastic filament or metal wire is unwound from a coil and supplies material to an extrusion nozzle which can turn the flow on and off.
- The nozzle is heated to melt the material and can be moved in both horizontal and vertical directions by a numerically controlled mechanism, directly controlled by a computer-aided manufacturing (CAM) software package.
- Filament is made of thermoplastic materials – Acrylonitrile butadiene styrene (ABS) – Polylactide (PLA) – biodegradable!





Stereolithography

- The UV light comes from a laser, which is controlled to scan across the surface according to the cross-section of the part that corresponds to the layer.
- The laser penetrates into the resin for a short distance that corresponds to the layer thickness.
- The first layer is bonded to a platform, which is placed just below the surface of the resin container.
- The platform lowers by one layer thickness and the scanning is performed for the next layer. This process continues until the part has been completed.



Facts About STL

- Each layer is 0.076 mm to 0.50 mm (0.003 in to 0.020 in.) thick
  - Thinner layers provide better resolution and more intricate shapes; but processing time is longer.
- Starting materials are liquid monomers.
- Polymerization occurs on exposure to UV light produced by laser scanning beam.
  - Scanning speeds ~ 500 to 2500 mm/s

Part Build Time in STL

- Time to complete a single layer :

$$T_i = \frac{A_i}{vD} + T_d$$

where T_i = time to complete layer i; A_i = area of layer i; v = average scanning speed of the laser beam at the surface; D = diameter of the “spot size,” assumed circular; and T_d = delay time between layers to reposition the worktable.

- Once the T_i values have been determined for all layers, then the build cycle time is:

$$T_c = \sum_{i=1}^{n_l} T_i$$

- where T_c = STL build cycle time; and n_l = number of layers used to approximate the part.

Numerical Problem

- A prototype of a tube with a square cross-section is to be fabricated using stereolithography. The outside dimension of the square = 100 mm and the inside dimension = 90 mm (wall thickness = 5 mm except at corners). The height of the tube (z-direction) = 80 mm. Layer thickness = 0.10 mm. The diameter of the laser beam ("spot size") = 0.25 mm, and the beam is moved across the surface of the photopolymer at a velocity of 500 mm/s. Compute an estimate for the time required to build the part, if 10 s are lost each layer to lower the height of the platform that holds the part. Neglect the time for postcuring.
- Answers: T_i = 25.2 sec, T_c = 5.6 hours

3D Scanning

- Laser based 3D Scanners
- Laser based 3D scanners use a process called trigonometric triangulation to accurately capture a 3D shape as millions of points.
- Benefits of 3D Laser Scanners
  - Able to scan tough surfaces, such as shiny or dark finishes
  - Less sensitive to changing light conditions and ambient light
  - Often more portable
  - Simpler design – easier to use and lower cost

Application of robots in manufacturing process

- Material handling
  - Material transfer and machine loading and unloading.
- Processing operations
  - The robot manipulates a tool to perform a process on the work part. Examples of such applications include spot welding, continuous arc welding, and spray painting.
- Assembly and inspection
  - The use of robots in assembly is expected to increase because of the high cost of manual labour common in these operations.