STUDY MATERIAL ON

ADVANCE MANUFACTURING PROCESSES

6^{TH} SEMESTER

Prepared by

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PROGRAMME: MECHANICAL ENGINEERING

COURSE: ADVANCE MANUFACTURING PROCESSES **(TH4), 6TH SEM**

COURSE OUTCOMES:

At the end of this subject Students will be able to:

CO1. Explain the working of unconventional machining processes.
CO2. Explain the various processes in making of plastic components for engineering / domestic applications.
CO3. Explain the additive manufacturing process and other related technologies.
CO4. Understand the concepts of Special Purpose Machines.
CO5. Summarize the Maintenance of various Machine Tools.

MAPPING OF COURSE OUTCOMES WITH PROGRAM OUTCOMES AND PROGRAM SPECIFIC OUTCOMES

CO-PO	PO1	PO2	PO3	PO4	PO5	PO6	PO7	PSO1	PSO2
CO.1	3	2	3	1	2	2	2	2	3
CO.2	2	2	3	1	2	2	1	2	3
CO.3	3	3	3	1	3	2	2	2	3
CO.4	2	2	3	1	3	2	2	2	3
CO.5	3	2		1	2	2	1	2	

PSOs:

PSO – 1: Develop the knowledge and skill relevant to Automobile, Thermal and fluid power industries.

PSO – 2: Exhibit the ability to make a product related to Mechanical Engineering and allied engineering fields.

SYLLABUS

CONTENTS

1.0 Modern Machining Processes: 1.1 Introduction – comparison with traditional machining. 1.2 Ultrasonic Machining: principle, Description of equipment, applications. 1.3 Electric Discharge Machining: Principle, Description of equipment, Dielectric fluid, tools (electrodes), Process parameters, Output characteristics, applications. 1.4 Wire cut EDM: Principle, Description of equipment, controlling parameters; applications. 1.5 Abrasive Jet Machining: principle, description of equipment, Material removal rate, application. 1.5 Laser Beam Machining: principle, description of equipment, Material removal rate, application. 1.6 Electro Chemical Machining: principle, description of equipment, Material removal rate, application. 1.7 Plasma Arc Machining – principle, description of equipment, Material removal rate, Process parameters, performance characterization, Applications. 1.8 Electron Beam Machining - principle, description of equipment, Material removal rate, Process parameters, performance characterization, Applications.

2.0 Plastic Processing: 2.1 Processing of plastics. 2.2 Moulding processes: Injection moulding, Compression moulding, Transfer moulding. 2.3 Extruding; Casting; Calendering. 2.4 Fabrication methods-Sheet forming, Blow moulding, Laminating plastics (sheets, rods & tubes), Reinforcing. 2.5 Applications of Plastics.

3.0 Additive Manufacturing Process: 3.1 Introduction, Need for Additive Manufacturing 3.2 Fundamentals of Additive Manufacturing, AM Process Chain 3.3 Advantages and Limitations of AM, Commonly used Terms 3.4 Classification of AM process, Fundamental Automated Processes, Distinction between AM and CNC, other related technologies. 3.5 Application –Application in Design, Aerospace Industry, Automotive Industry, Jewelry Industry, Arts and Architecture. RP Medical and Bioengineering Applications. 3.6 Web Based Rapid Prototyping Systems. 3.7 Concept of Flexible manufacturing process, concurrent engineering, production tools like capstan and turret lathes, rapid prototyping processes.

4.0 Special Purpose Machines (SPM): 4.1 Concept, General elements of SPM, Productivity improvement by SPM, Principles of SPM design.

5.0 Maintenance of Machine Tools: 5.1 Types of maintenance, Repair cycle analysis, Repair complexity, Maintenance manual, Maintenance records, Housekeeping. Introduction to Total Productive Maintenance (TPM).

CHAPTER 1

UNCONVENTIONAL MACHINING PROCESSES

The recent increase in the use of hard, high strength and temperature resistant materials in engineering has necessitated the development of newer machining techniques. With the exception of grinding, conventional methods of removing material from a workpiece are not readily applicable to these new materials.

New materials such as hastalloy, nitralloy, waspalloy, nimonics, carbides etc., are difficult to machine and find applications in aircrafts, nuclear reactors, turbines, special cutting tools etc.

Conventional machining processes when applied to these newer materials:

- (i) Are uneconomical,
- (ii) Produce poor degree of accuracy and surface finish
- (iii) Produce some stress in the metal being cut whereas newer machining techniques are essentially stress free.
- (iv) Are slow and highly insufficient.

Although most of the new machining processes have been developed specifically for newer materials that are difficult to machine, some of them (processes) have found use in the production of complex shapes and cavities in softer, more readily machined materials.

CLASSIFICATION

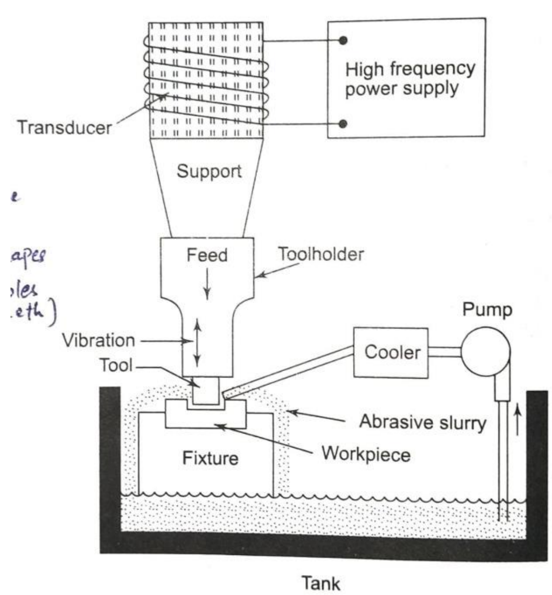
Type of Energy	*Newer Machining Processes*
(*a*) Mechanical	1. Ultrasonic machining (USM) 2. Abrasive jet machining (AJM) 3. Water jet machining (WJM)
(*b*) Chemical	1. Chemical machining (CHM)
(*c*) Electro-chemical	1. Electro-chemical machining (ECM) 2. Electrolytic grinding (ECG)
(*d*) Electro-thermal	1. Electrical discharge machining (EDM) 2. Electron beam machining (EBM) 3. Plasma arc machining (PAM) 4. Laser beam machining (LBM)

Type of Energy	*Mechanism of Metal removal*	*Energy Transfer media*	*Energy Source*	*Process*
(*a*) Mechanical	Erosion	High velocity particles	Pneumatic/hydraulic pressure	AJM, USM, WJM
	Shear	Physical contact	Cutting tool	Conventional machining
(*b*) Chemical	Ablative reaction	Reactive environment	Corrosive agent	CHM
(*c*) Electrochemical	Ion-displacement	Electrolyte	High current	ECM, ECG
(*d*) Electrothermal	Fusion	Hot gases	Ionized material	EBM
	Fusion	Electrons	High voltage	EDM
	Vaporization	Radiation	Amplified light	LBM
	Vaporization	Ion stream	Ionized gas	PAM

ULTRASONIC MACHINING

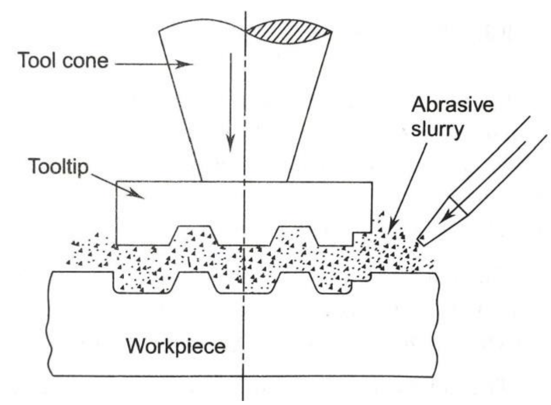
Ultrasonic machining (USM) is a mechanical metal-removal process for brittle materials by using high frequency oscillations of a shaped tool using abrasive slurry. The term ultrasonic refers to the frequency range above the audible range and is above 16 kHz.

A schematic of the ultrasonic machining set-up is shown in Fig. The transducer generates the high frequency vibrations of the order of 20 to 30 kHz with amplitude of the order of 0.02 mm. This vibration is transmitted to the tool made of soft material, through a mechanical coupler known as tool holder. The tool shape is a close complementary shape of the final surface to be generated.



The tool while oscillating would be pressed against the workpiece and fed continuously. Slurry of abrasive grains suspended in a liquid is fed into the cutting zone under pressure as shown in Fig. The slurry is about 30% concentration. Abrasive particles are driven into the work surface by the oscillating tool. The force is typically about 150 000 times the weight of the individual grains. A small crater will be formed at the impact site of the grain, if the workpiece is brittle. A very large number of such small craters remove sufficiently large material from the workpiece.

As the material is removed, the tool is gradually advanced into the workpiece by a servomechanism such that constant gap is maintained between the tool and the workpiece. Finally the shape of the tool is impressed into the workpiece as shown in Fig.



The material removal rates in USM are relatively small, but in materials, which are brittle; this is the only way to produce economically complex cavities without breaking the workpiece. Since there is no direct contact between the workpiece and the tool, fragile workpieces can be conveniently used in USM.

1. **Transducer**

- The transducer in USM is utilized to convert the electrical energy to vibratory motion utilising either the piezoelectric or magnetostrictive principles.
- Piezoelectric materials such as quartz or lead-zirconate-titanate, comes to normal size when an electric current is applied to them and will increase in size when the current is removed.

- The magnetostrictive transducers constructed from nickel, permalloy (Ni 45% and Fe 55%) or permedur (Co 49%, Fe 49% and V 2%) plates which when exposed to strong magnetic field will change length.

2. Tool Cone (Horn)

- Tool cone amplifies the mechanical energy produced by the transducer. Horn mechanically amplifies the vibratory energy to give the required force-amplitude ratio.
- It should have adequate strength. Titanium, monel and stainless steels are generally used as tool-cone materials. Stainless steel is used only for low-amplitude applications.

3. Tool

- Tool tip is attached to the cone by means of silver brazing or by screws. Shape of the tool and its dimensions are governed by the size of abrasive used.
- Length of the tool should be short, since massive tools absorb the vibration energy, reducing the efficiency of machining. Also long tools cause overstressing of the tool and the brazed point. Typically, they are about 25 mm long.
- Slenderness (length to diameter) ratio of the tool should not be greater than 20.
- The tool material should be tough and ductile, but should not be too soft. Generally, low-carbon steel and stainless steel are good tool materials.

4. Abrasive Slurry

- A large variety of abrasives are available for using in USM. The abrasive selected should be harder than the material being machined. Typical abrasives used are aluminium oxide, silicon carbide and boron carbide.
- Aluminium oxide wears fast and are good for glass and ceramics.
- Boron carbide is the most popularly used abrasive. It is harder than silicon carbide and expensive. It has faster material-removal rate and can withstand high-vibrational forces. It is best for tungsten-carbide, tool steel and precious stones.
- Diamond dust is sometimes used for good accuracy, surface finish and cutting rate. It is used for diamonds and rubies.
- Abrasive grain sizes used are from 200 to 2000. The choice of grain size depends upon the finish desired. Generally, 20 to 400 size is used for roughing while 800 to 1000 grit is used for finishing.

- The abrasive is suspended in a liquid with about 30 to 60% by volume of abrasive.

The liquid serves several functions.

- It acts as an acoustic bond between the vibrating tool and the workpiece, to give efficient transfer of energy between the two.
- It acts as a coolant on the tool face.
- It also provides a medium to carry the abrasive to the cutting zone and carry the spent abrasive and dwarf away.

The liquid requires the following properties.

- A density approximately equal to that of the abrasive.
- A low viscosity to carry the abrasive down the sides of the hole between the tool and workpiece.
- High thermal conductivity to carry away the heat.

ADVANTAGES OF USM

a) USM is used for machining hard and brittle materials to complex shapes with good accuracy and reasonable surface finish.
b) It is not affected by the electrical or chemical characteristics of the work material. e Holes of any shape can be produced. It has no high-speed moving parts. Working is not hazardous.
c) Power consumption is about 0.1 watt hour/mm^3 for glass and about 5.0 watt hour/mm^3.

LIMITATIONS OF USM

a) Metal-removal rates are low.
b) Depth of hole produced is limited.
c) Tool wear is high and sharp corners cannot be produced.
d) Flat surfaces cannot be produced at the bottom of the cavity because of the ineffective slurry distribution.

APPLICATIONS:

1. Tool and die making
2. Several machining operations like turning, threading, griding, milling etc
3. Machining of hard to machine and brittle materials
4. Producing holes of round shapes
5. Dentistry work

MRR

Abrasive particles are assumed to be spherical in shape having diameter as'd' units. Abrasive particles (suspended in carrier) move under the high frequency vibrating tool. There are two possibilities when the tool hits an abrasive particle. If the size of the particle is small and the gap between the bottom of the tool and work surface is large enough, then the particle will be thrown by the tool, to hit the work surface (throwing model). Under the reverse conditions, the particle will be hammered over the work surface. In the both cases, a particle after hitting the work surface generates a crater of depth 'h' and radius 'r'.

It is also assumed that the volume of the particle removed is approximately proportional to the diameter of indentation (2r). The volume of material (Vg) removed (shown by dashed lines in Fig. 3.3a and 3.3b, assuming hemi-spherical crater) due to fracture per grit per cycle is given by

$$V_g = \frac{1}{2}\left(\frac{4}{3}\pi r^3\right). \quad \ldots(3.1)$$

From the geometry of Fig. 3.3b, it can be shown that

$$r^2 = \left(\frac{d}{2}\right)^2 - \left(\frac{d}{2} - h\right)^2$$

$$\approx dh \text{ (neglecting } h^2 \text{ terms as } h \ll d). \quad \ldots(3.2)$$

From Eqs. (3.1) and (3.2), we can write

$$V_g = K_1 \,(hd)^{3/2} \quad \ldots(3.3)$$

where, K_1 is a constant.

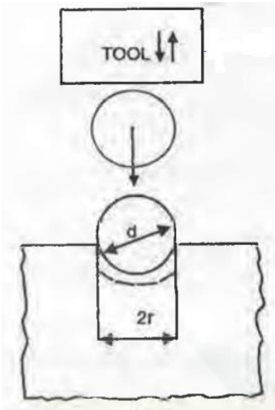


Fig. 3.3 (a) Throwing

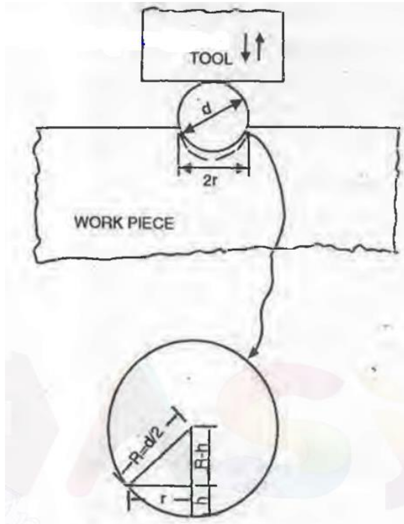


Fig. 3.3 (b) Hammering

Number of impacts (N) on the workpiece by the grits in each cycle will depend upon the number of grits beneath the tool at any time. This is inversely proportional to the diameter of the grit (assumed spherical) as given below.

$$N = K_2 \frac{1}{d^2}$$

Where, K_2 is a constant of proportionality.

All abrasive particles under the tool need not be necessarily effective. Let K_3 be the probability of an abrasive particle under the tool being effective.

Then volume (V) of material removed per second will be equal to the frequency (f) times the amount of material removed per cycle (Vc)

$$V = V_c \times f = K_1 K_2 K_3 \sqrt{\frac{h^3}{d}} \cdot f$$

Also:

The metal removal rate for this process according to Prof. Shaw is given by the relation

$$M.R.R. = 5.9\, f\,(Ry_0)^{1/2}\, \frac{\sigma}{H} \text{ mm/sec.}$$

where f = frequency of the active grits striking work surface in c.p.s.

R = Radius of grit in mm

y_0 = Amplitude of vibration in mm

σ = Stress developed in tool in kg/mm^2

H = Surface hardness of the workpiece in kg/mm^2

= $\pi \times$ Compression fracture strength of abrasive particles.

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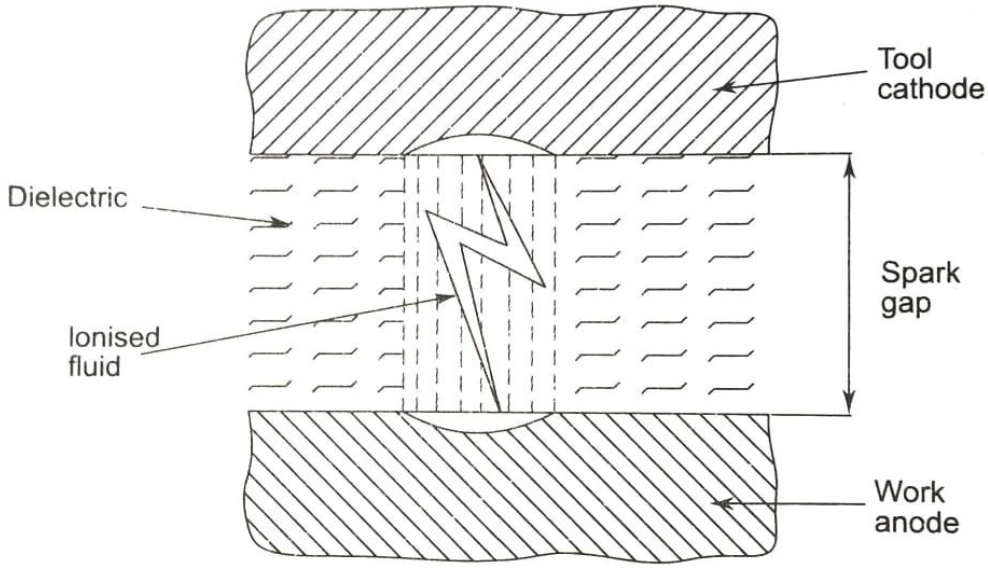
ELECTRIC DISCHARGE MACHINING

Russian scientists Boris and Lazarenko in 1943 at Moscow University found during an experiment that the sparks were more uniform and predictable in oil than in air. They came up with the idea of using this controlled sparking as a method of removing metal. They developed the Lazarenko circuit which is a relaxation circuit based on the resistance-capacitance circuit that remained the standard EDM generator for years. The tool and workpiece are immersed in a dielectric fluid and connected to a dc power supply. The capacitor gets charged from the dc power supply until it is greater than the breakdown potential of the gap between the tool and the workpiece, at which time it will be discharged as an arc-removing material from the workpiece and the tool. They have found this process to be extremely useful for machining hard metals such as tungsten or tungsten carbide.

PRINCIPLE:

- It has been recognized for many years that a powerful spark will cause pitting or erosion of the metal at both the anode (+) and cathode (-), e.g. automobile battery terminals, loose plug points, etc. This process is utilized in electric-discharge machining. This process is also called spark machining or spark-erosion machining.
- The EDM process involves a controlled erosion of electrically conductive materials by the initiation of rapid and repetitive spark discharges between the tool and workpiece separated by a small gap of about 0.01 to 0.50 mm.
- This spark gap is either flooded or immersed in a dielectric fluid. The controlled pulsing of the direct current between the tool and the work produces the spark discharge.
- Initially, the gap between the tool and the workpiece, which consists of the dielectric fluid, is not conductive; however, the dielectric fluid in the gap is ionized under pulsed application of dc as shown in Fig., thus enabling the spark discharge to pass between the tool and the work.
- Heat transfer from the spark to both tool and the workpiece melts, partially vaporizes and partially ionizes the metal in a thin surface layer.

Due to the inertia of the surrounding fluid, the pressure within the spark becomes quite large and may possibly assist in blasting the molten material from the surface leaving a fairly flat and shallow crater. The amount of metal removed per spark depends upon the electrical energy expended per spark and the period over which it is expended.



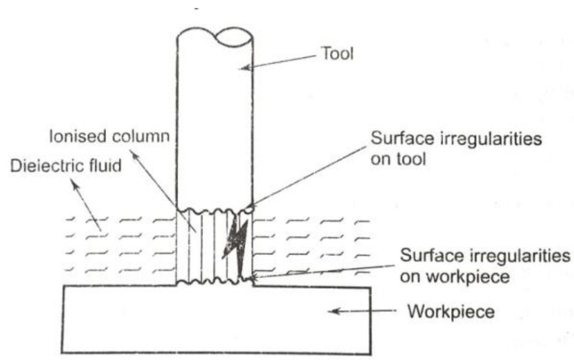
Schematic of the arc formation in EDM process

Thus, the sequence of events in EDM can be summarized as given here:

1. With the application of voltage, an electric field builds up between the two electrodes at the position of least resistance. The ionization leads to the breakdown of the dielectric, which results in the drop of the voltage and the beginning of flow of current.
2. Electrons and ions migrate to the anode and cathode respectively at very high current density. A column of vapour begins to form and the localized melting of work commences. The discharge channel continues to expand along with a substantial increase of temperature and pressure.
3. When the power is switched off, the current drops; no further heat is generated, and the discharge column collapses. A portion of molten metal evaporates explosively and/or is ejected away from the electrode surface. With the sudden drop in temperature, the remaining molten and vaporised metal solidifies. A tiny crater is thus generated at the surface.
4. The residual debris is flushed away along with products of decomposition of dielectric fluid. The application of voltage initiates the next pulse and the cycle of events.
5. Also due to the inertia of the surrounding fluid, the pressure within the spark becomes quite large and may possibly assist in 'blasting' the molten material from the surface,

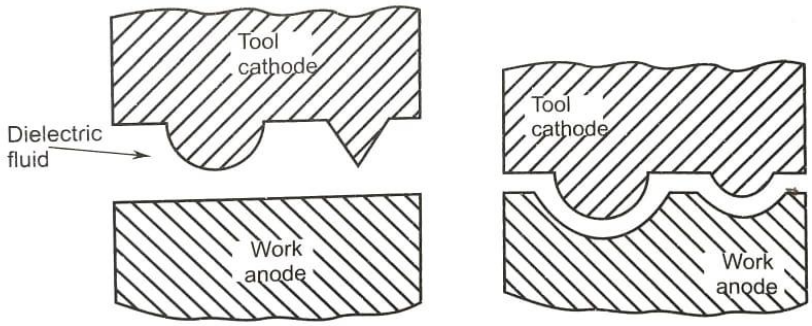
leaving a fairly flat and shallow crater. The amount of metal removed per spark depends upon the electrical energy expended per spark and the period over which it is expended.

6. At any given time only one spark will be made between the tool and workpiece at the shortest path as shown in Fig. As a result of this spark, some volume of metal is removed from both the tool and the workpiece. Then the spark will move to the next closest distance. This process continues till the required material is removed from the workpicce.



Schematic of the arc forming at the smallest distance between the tool and the workpiece in the EDM process

The temperature of the arc may reach about 10000°C. The vapour of the metal would be quenched by the dielectric medium when the arc is terminated by the electric pulse and thus, the wear debris is always spherical in nature. The wear debris would be carried away by the dielectric fluid, which is in continuous circulation. The same process as described above would be continued a number of times per second with each pulse removing a small wear particle from the workpiece, thereby causing the material to take the shape of the electrode. The arc will always be struck at a point between the workpiece which is closest from the tool (electrode); thereby the complimentary tool surface will be reproduced in the workpiece as shown in Fig.



Typical surface generation in EDM process: (a) Initial shape of electrode and workpiece (b) Final complimentary shapes of electrode and workpieces after machining

A typical schematic of the various elements present in a commercial EDM machine is shown in Fig. The main power unit consists of the required controlled pulse generator with the dc power to supply the power pulses. The pulse frequency as well as the on and off time of the pulses can be very accurately controlled using electronic controllers.

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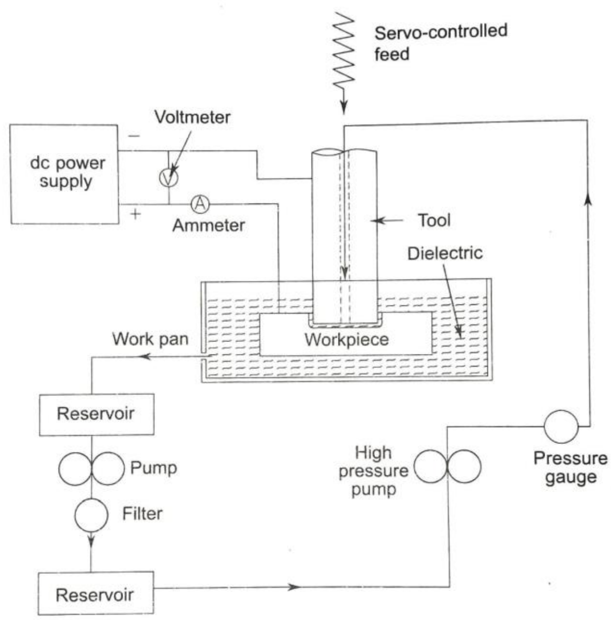


The gap between the electrode and the workpiece increases with the removal of metal. The EDM power supply voltage is dependent upon the spark gap, which needs to be maintained constant. A servo-controlled electrode feeding arrangement would be available which continuously senses the spark gap and moves the tool (electrode) to maintain this gap.

Dielectric Fluid:

1. The dielectric fluid is a spark conductor, coolant, and also a flushing medium. The requirements are explained here:
2. The dielectric fluid should have sufficient and stable dielectric strength to serve as insulation between the tool and work till the breakdown voltage is reached.
3. It should de-ionize rapidly after the spark discharge has taken place.
4. It should have low viscosity and a good wetting capacity to provide effective cooling mechanism and remove the dwarf particles from the machining gap.
5. It should flush out the particles produced during the spark out of the gap. This is the most important function of the dielectric fluid. Inadequate flushing can result in arcing, decreasing the life of the electrode and increasing the machining time.
6. It should be chemically neutral so as not to attack the electrode, the workpiece, the table or the tank.
7. Its flash point should be high to avoid any fire hazards.
8. It should not emit any toxic vapours or have unpleasant odours.
9. It should maintain these properties with temperature variation, contamination by working residuals, and products of decomposition.
10. It should be economical and easily available.

A large number of fluids satisfy the requirement and are used as dielectric fluids. Most popular are the hydrocarbon fluids, silicone-based oils and de-ionized water. Kerosene and water with glycol are generally used.

Electrodes

As explained earlier, in the EDM process, the shape of the electrode is impressed on the workpiece in its complementary form and as such the shape and accuracy of the electrode plays a very important role in the final accuracy of the workpiece machined.

The electrode material should have the following characteristics to serve as a good tool.

1. It should be a good conductor of electricity and heat.

2. It should be easily machinable to any shape at a reasonable cost.

3. It should produce efficient material-removal rates from the workpieces.

4. It should resist the deformation during the erosion process.

5. It should exhibit low electrode (tool) wear rates.

6. It should be available in a variety of shapes.

Various electrode materials used are graphite, copper, graphite, copper-graphite, brass, zinc alloys, steel, copper- tungsten, silver- tungsten, tungsten, etc.

Assignment 1:

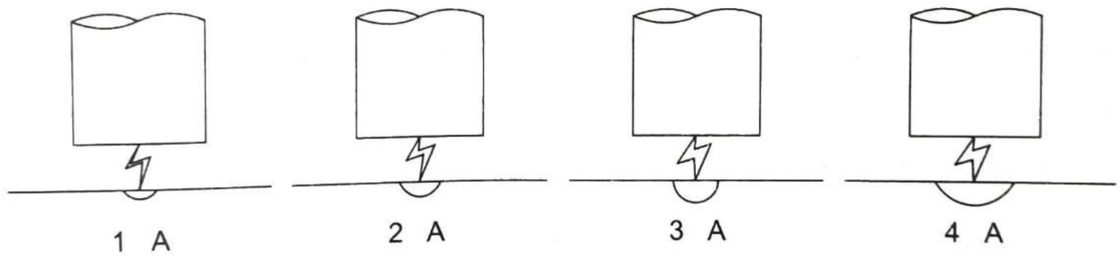
Briefly describe about all the tool materials, their properties and application.

PROCESS PARAMETERS

The metal-removal rates in EDM depend upon the following parameters, which are discussed in greater depth below:

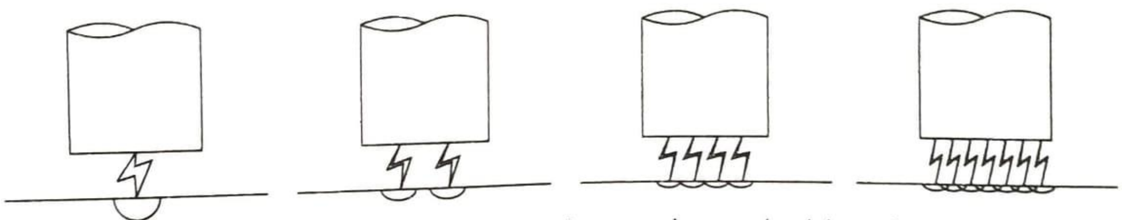
1. Current in each spark
2. Frequency of the discharge
3. Electrode material
4. Workpiece material

The amount of material removed and the surface finish produced is dependent upon the current in the spark. The material removed by the spark can be assumed to be a crater as shown in Fig. The amount removed, therefore, will depend upon the crater depth, which is directly proportional to the current. Thus, as shown schematically in Fig, the material removed increases and at the same time the surface finish also decreases.



Schematic representation of the effect of the current in each spark, which determines the material removed

However, decreasing the current in the spark, but increasing its frequency will improve the surface finish in view of the small crater size, but at the same time the material-removal rate can be maintained by increasing the frequency. The same is shown schematically in Fig.



Schematic representation of the effect of spark frequency on the material removed and the surface finish

Typical parameters used in EDM process are

- Spark gap 0.0125 to 0.125 mm
- Current 0.5 to 400 A
- Voltage (dc) 40 to 300 V
- Pulse duration 2 to 2000 μs
- Dielectric pressure < 0.2 MPa

The metal-removal rates are about 16.4 cm^3/hour per 20 A of current. This can go as high as 250 cm^3/hour per 20 A of current.

Surface finish 3 to 10 μm Rough
0.8 to 3 μm Finish

Characteristics of EDM Process

Mechanism of process	Controlled erosion (melting and evaporation) through a series of electric sparks.
Spark gap	0.010—0.125 mm
Spark frequency	200—500 kHz
Peak voltage across the gap	30—250 V
Metal removal rate (max.)	5000 mm^3/min
Specific power consumption	2-10 W/mm^3/min
Dielectric fluid	Kerosene liquid paraffin, silicon oil
Tool material	Brass, copper, graphite, Ag-W alloys, Cu-W alloys.
$\frac{\text{Material removal rate}}{\text{Tool wear rate}}$	0.1—10
Materials that can be machined	All conducting metals and alloys.
Shapes	Microholes, narrow slots, blind complex cavities.
Limitations	High specific energy consumption, non-conducting materials can't be machined.

APPLICATIONS

The EDM process is extensively used because of its many advantages. A few of them are discussed below:

1. There is no physical contact between the tool and the workpiece and hence, no cutting forces are acting on the workpiece. Even fragile workpieces can be machined using this process.
2. Any complex shape required in dies and moulds can be easily produced to the required degree of accuracy and finish. Since the process copies the tool shape in a complementary form, making a male electrode is easier than the complementary female form required.
3. The process is not affected by the hardness of the work material. Hence, even the hardened material can be machined.
4. The material-removal rates are almost comparable with that of the conventional machining processes.

5. Since there are no cutting forces acting on the tool, high-aspect ratio surfaces can be machined using EDM process.
6. The process is generally highly automated with very little operator skill required.
7. The actual surface produced by EDM consists of small craters, which may help in the retention of the lubricants.

DISADVANTAGES

1. The wear rate on the electrode is considerably higher.
2. Sometimes it may be necessary to use more than one electrode to finish the job.
3. The workpiece should be electrically conductive to be machined using the EDM process.
4. Energy required for the operation is more than that of Conventional process and hence will be more expensive.

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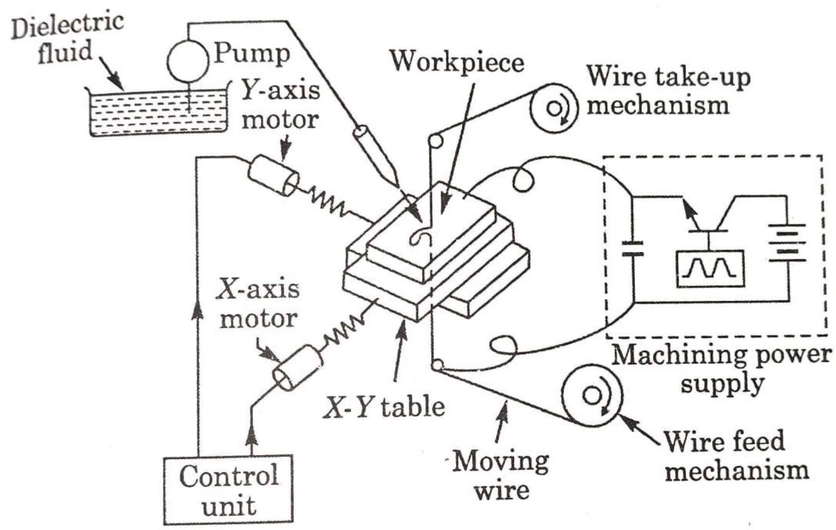
WIRE-CUT EDM

The wire-cut EDM uses a very thin wire 0.02 to 0.3 mm in diameter as an electrode and machines a workpiece with electrical discharge like a band saw by moving either the workpiece or wire.

PRINCIPLE AND DESCRIPTION OF EQUIPMENT

Erosion of the metal utilizing the phenomenon of spark discharge is the very same as in conventional EDM. The prominent feature of a moving wire is that a complicated cutout can be easily machined without using a forming electrode. Fig shows in schematic form the principle of wire-cut EDM process.



Wire-cut EDM machine basically consists of a machine proper composed of a workpiece contour movement control unit (NC unit or copying unit), workpiece mounting table and wire drive section for accurately moving the wire at constant tension; a machining power supply which apples electrical energy to the wire electrode; and a unit which supplies a dielectric fluid (distilled water) with constant specific resistance.

THE VARIOUS FEATURES OF WIRE-CUT EDM PROCESS ARE:

(i) Forming Electrode Adapted to Product Shape is not required. Since a thin wire of copper or tungsten is used as the electrode to machine the workpiece as programmed, there is no need for forming electrodes which are traditionally made by cutting and grinding an expensive alloy of silver and tungsten or copper and tungsten. This feature helps reduce man-hour requirements and insures greater economy due to use of an inexpensive electrical material. The consumption of wire on the EDM machine is about 0.03 kg/ hr. The 0.2 mm dia copper wire which is most frequently used for wire-cut EDM can generally machine for 50 to 60 hours.

(ii) Electrode Wear is Negligible. Since the wire electrode is constantly fed during machining, its wear can be practically ignored.

(iii) Machined Surfaces are Smooth. Since a new portion of wire electrode is constantly supplied at a speed of about 10 to 30 mm/sec, machining can be continued without any accumulation of chips and gases. Since a very thin electrode is used, an extremely small amount of discharge energy suffices for one spark and the workpiece is machined under conditions for finishing as specified for conventional EDM.

(iv) Geometrical and Dimensional Tolerances are Tight. Wire-cut EDM is not a sinking process with a formed electrode as in conventional EDM. The table is driven in increments of 1 μm per pulse, enabling two-dimensional contours to be machined to close tolerance and repeatability.

(v) Relative Tolerance between Punch and Die is Extremely High and Die Life is extended. A programmed full scale figure can be enlarged or reduced in 1 μm increments of compensation value. This capability allows the punch and dies to be machined with a minimum required clearance, which has been traditionally done by skill and fitting the punch and die.

(vi) Straight Holes can be produced to Close Tolerance. The wire is maintained at optimum tension by a unique wire tension control mechanism. This prevents tapers, barrel Shaped holes, machining streaks, wire breakage and wire Vibration.

(vii) EDM Machine can be Operated Unattended for Long Time at High Operating Rate. Distilled water is used as the dielectric fluid and all machine motions are controlled by NC. As a result, the wire-cut EDM machine can be operated unattended day and night without any fire hazards.

APPLICATIONS

- Wire EDM is used for machining the sheet metal dies, extrusion dies and prototype parts. It is relatively a very slow process.
- Used to cut plates as high as 300mm thick for making punches, tools and dies.

PROCESS PARAMETERS

Pulse on time: it represents the duration of current flow in microseconds in each cycle. It is set in the range of 105-125μs. The discharge energy increases with increasing pulse on time, resulting in higher cutting rate. With higher values of pulse on time, surface roughness tends to be higher. The higher value of discharge energy may also cause wire breakage.

Pulse off time: It is referred as toe and it represents the duration elapse in microseconds between the two consecutive pulses on time. It is set in the range of 43 to 63 ps. With lower value of pulse off time, there is more number of discharges in a given time, resulting in an increase in the sparking efficiency. As a result, the cutting rate also increases. Very low value of pulse off time may cause wire breakage which in turn reduces the cutting efficiency. With an increase in the discharge pulse duty factor (pulse off time increases), average gap current is reduced.

Peak current: Peak current is represented as IP and it is the maximum value of the current passing through the electrode during pulse on time. The peak current is set in the range of 150-230 A. Increase in the peak current increases the pulse discharge energy which improves the cutting rate. For higher value of the peak current, gap conditions may become unstable with improper combination of pulse on time and pulse off time settings.

Wire tension: it is represented as WT and it shows how much the wire is being stretched between upper and lower wire guides. The wire tension is set at the range of 4-12 g and maintained with the tension so, that it remains straight between the wire guides.

MRR:

Material removal rate increases with increase in discharge current. However, in case of brass and copper, it decreases after some limit, because pulse energy increases as the current increases. Material removal rate does not observe linearity with pulse energy. This may be due to the possible losses of thermal energy by conduction to the surrounding material and to the dielectric fluid. An increase in current beyond certain limit for a given electrode area and material has adverse effects on material removal rate.

Material Removal Rate is the principle of conversion of electrical energy into thermal energy. During the process of machining, the sparks are produced between the work piece and the electrode. Thus, each spark produces a tiny crater and crater formation in the material along the cutting path by melting and vaporization erodes the workpiece.

After machining, the Material Removal Rate has been measured.

Material removal rate has been calculated by the following formula:

$$MRR = \frac{W_i - W_f}{\rho \times t}$$

Where,

W_f is the final weight of workpiece material

W_i is the initial weight of the workpiece material

't' is the machining time

'ρ' is the density of the material.

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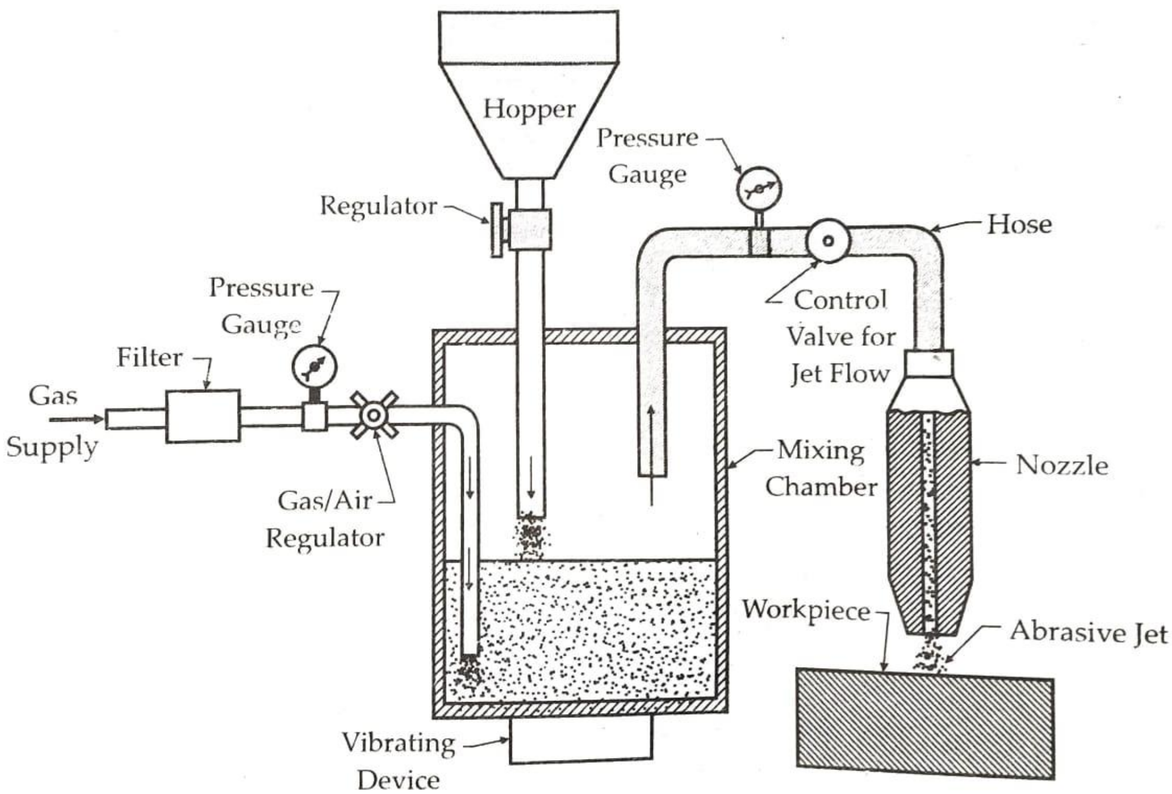
ABRASIVE JET MACHINING (AJM)

PRINCIPLE, DESCRIPTION OF EQUIPMENT

This process consists of directing a stream of fine abrasive grains, mixed with compressed air or some other gas at high pressure, through a nozzle on to the surface of the workpiece to be machined. These particles impinge on the work surface at high speed and the erosion caused by their impact enables the removal of metal. This process is mainly employed for such machining works which are otherwise difficult, such as thin sections of hard metals and alloys, cutting of materials which are sensitive to heat damage, producing intricate holes, deburring, etching, polishing etc. However this process should not be misunderstood as sand blasting because this process is basically meant for metal removal with the use of small abrasive particles, where as the sand blasting process is a surface cleaning process which does not involve any metal cutting.

Fine grained abrasive powder is filled in a vibrating chamber, called 'mixing chamber'. The gas or air at high pressure is forced into this chamber, the pressure of the gas varying from 2kg/cm2 to 8.5kg/cm2. For normal machining work the nozzle can be manipulated by hand, but for cutting critical shapes or precision cutting along an intricate contour either the workpiece or the nozzle is mounted on suitable fixtures and moved by means of well designed mechanisms along a predetermined path, such as cams, pantographs, etc.

A typical set-up for Abrasive Jet Machining (AJM) is shown in Fig. The abrasive particles are contained in a suitable holding device, like a hopper, and fed into the mixing chamber. A regulator is incorporated in the line to control the flow of abrasive particles. Compressed air or high pressure gas is supplied to the mixing chamber through a pipe line. This pipe line carries a pressure gauge and a regulator to control the gas flow and its pressure. The mixing chamber, carrying the abrasive particles, is vibrated and the amplitude of these vibrations controls the flow of abrasive particles. These particles mix in the gas stream, travel further through a hose and finally pass through the nozzle at a considerably high speed. This outgoing high speed stream of the mixture of gas and abrasive particles is known as Abrasive Jet.



GASES, ABRASIVES AND NOZZLE MATERIALS:

- The carrier gas used in this process should be nontoxic, easily available, cheap and the one that dries quickly. The gases commonly used are air, nitrogen or carbon dioxide.

- The abrasives commonly used include aluminium oxide, silicon carbide, sodium-bi-carbonate, dolomite and small size glass beads. Aluminium oxide is used for general purpose machining, grooving and cutting, silicon carbide for faster machining of hard materials, sodium-bi-carbonate for fine finishing work, dolomite for etching and light cleaning and glass beads for fine deburring and light polishing.
- The nozzles used are made of tungsten carbide or synthetic sapphire because the nozzles are required to be highly abrasion resistant.

MRR:

The material removal rate in abrasive jet machining

$$= KNd^3v^{3/2}\left(\frac{\rho}{12H}\right)^{3/4}$$

where K = constant, N = number of abrasive particles impacting per unit time

d = mean diameter of abrasive particles, v = velocity of abrasive particles

ρ = density of abrasive particle, H = hardness of work material.

For best cutting results Al_2O_3 abrasive particles of size 15 μm to 20 μm are used. Since the cutting capacity of particles decreases after one cutting action, these are normally not reused.

APPLICATIONS OF AJM

This process is widely used for machining of brittle materials like glass, ceramics, refractories, etc., cleaning and cutting operations on materials like germanium, silicon, quartz, mica and many other operations like etching, marking, deburring, etc. Some typical applications of this process include:

(i) Fine drilling and micro welding, (ii) Aperture drilling for electronic microscopes, (iii) Machining of semiconductors, (iv) Machining of intricate profiles on hard and fragile materials, and (v) Frosting and abrading of glass articles.

ADVANTAGES OF AJM

I. Intricate cavities and holes of any shape can be machined in materials of any hardness.
II. Brittle materials of thin sections can be easily machined.
III. Normally inaccessible portions can be machined with fairly good accuracy. >» Low capital investment required.
IV. There is no direct contact between the tool and workpiece.
V. Amount of heat generated is not appreciable.

DISADVANTAGES OF AJM

a) It is not suitable for machining of ductile materials.
b) Metal removal is slow.
c) Machining accuracy is relatively poorer.
d) There is always a danger of abrasive particles getting embedded in the work material. Hence, cleaning needs to be necessarily done after the operation.
e) The abrasive powder used in the process cannot be reclaimed or reused.

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LASER BEAM MACHINING (LBM)

Laser is an electro-magnetic radiation. It produces monochromatic light which is in the form of collimated beam.

It finds uses for microdrilling it microwelding, etc. However it has low efficiency and high energy input requirements.

Light amplification by stimulated emission of radiation is called laser beam. In this process, use is made of laser beam (a narrow beam of coherent, monochromatic light) which is focused on the work-piece by lens to give extremely high energy density to melt and vaporise any material.

PRINCIPLE OF LASER BEAM PRODUCTION

Electrons are arranged in different cells in an atom and each cell has a set number of electrons. If any atom is excited, i.e. we pump some amount of external energy (either by heat, or bombardment with protons), then the atomic cell will be in excited condition and some electrons will jump up to next energy level, i.e. electrons jump from one orbit to next one.

When an atom gets some sort of energy from external source, three types of behaviours can be possible.

(1) Normally atom is not excited. (It remains at same energy level). Then it will absorb external energy, and shoot up to higher energy level.
(2) If nothing happens to that atom in the excited condition, it will radiate the energy received by it. This emission of energy will take some time but will be spontaneous,
(3) If any photon bombards an atom at the excited condition, or at higher energy level, then it will emit the excess energy instantaneously.

For production of laser beam, we generally use Ruby rod in which aluminium is the main ingredient, chromium being present as impurity in the ratio of 1 to 5000 atoms. The chromium plays very important role for laser beam production and is most desirable. If it was not there then no laser beam could be produced.

When chromium receives any radiation, it absorbs it except red and blue light photons, and thereafter emission of various colours by it takes place. This emission in normal phenomena will not be instantaneous as the atoms are not at excited level. In the case of Ruby rods, chromium will impede external radiation and after some time emit spontaneously all the radiation and light can be seen coming out of it.

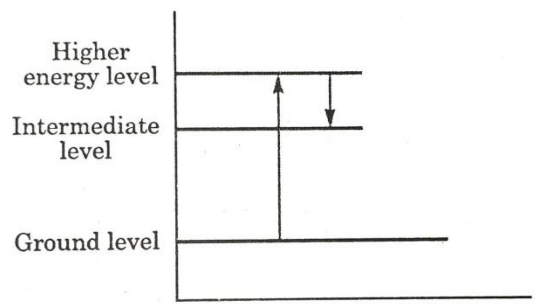
For production of laser beam it is desirable that the energy be pumped in, and pumped energy should come out instantaneously, of course, it will be of great intensity.

Thus we find that, laser beam technique involves

(1) Pumping of energy

(2) Production of stimulation effect.

When atoms are excited to higher energy level and emit energy, at one stage these come to metastable state and they remain at this metastable state for 3/1000th sec. or even smaller time. It is at this condition we try to bring stimulation of energy in case of chromium.



When chromium atom is bombarded, it jumps from ground level to higher energy level and instantaneously drops down to intermediate energy level. (Because upper position is most unstable). It has further tendency to return to ground level unless bombarded by other photons.

In case of chromium before jumping to ground level, it rests at intermediate level. Intermediate level is metastable position and it remains at this stage for 3/1000 sec. and after that to ground level radiating out the energy absorbed by it.

Stimulation effect: At intermediate stage, atom is at high energy level. If a photon hits at this stage, then it will instantaneously emit the photon received by it (because it is at higher energy level) and this is stimulation effect. This energy is utilised for various purposes like cutting, drilling, welding, etc.

The major difficulty faced was of attaining metastable condition, i.e. artificially bringing at higher energy level and keeping at that level for sufficient time so as to be bombarded by other photons.

After several reflections, all photons will come out from window (partially reflecting mirror) with great intensity. If the two faces of the rod are perfectly parallel, then the condition of all the photons moving in same direction can be achieved. Otherwise the photons will move in random way.

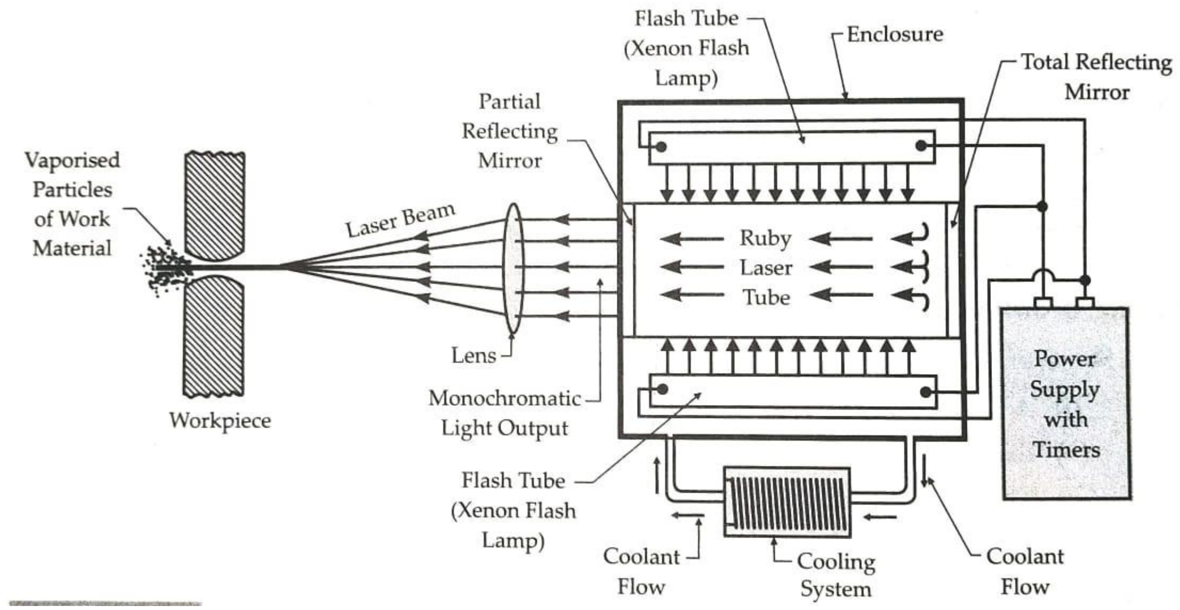


Fig. shows the setup for Laser Beam Machining, together with its circuit. It mainly consists of a Laser tube or rod, a pair of mirrors one at each end of the tube, a flash tube or lamp (energy source), a power supply source, a cooling system and a lens. The main setup is fitted inside an Enclosure, which carries a highly reflective surface inside.

The method of laser beam production: Xenon Flash lamps (photon energy) continuously bombard the chromium atoms of Ruby rod. This excites the atoms of the inside media, which absorb the radiation of incoming light energy. This results in the to and fro travel of light between the two reflecting mirrors. But, the partial reflecting mirror does not reflect the total light back and a part of it goes out in the form of a coherent stream of monochromatic light. This highly amplified stream of light is focussed through a lens, which converges it to a chosen point on the workpiece. This high intensity converged laser beam, when falls on the workpiece, melts the workpiece material, vaporises it almost instantaneously and penetrates into it. Thus, it can be called a type of thermal cutting process.

The cutting rate (mm/min.) can be expressed as

$$= C \frac{P}{EAt}$$

where C = is a constant dependent upon the material and conversion efficiency of laser energy into the material

P = laser power incident on surface, W,

E = vaporisation energy of material, W/mm^3

A = area of laser beam at focal point, mm^2,

t = thickness of material, mm.

It has been observed that material cutting rate is dependent upon the thickness of the workpiece, being maximum for thin materials and reduces exponentially for higher thickness. Thus while holes of 0.1 mm diameter may be drilled to a depth of 50 times the diameter, but hole of 1 mm diameter can be drilled through 2.5 mm thick material.

Characteristics of LBM Process

Material removal technique	Heating, melting and vaporisation.
Tool	Laser beams in wavelength range of 0.4—0.6 μm.
Power density	As high as 10^7 W/mm^2.
Output energy of laser and its pulse duration	20 J, 1 milli second.
Peak power	20 kW.
Medium	Normal atmosphere.
Material removal rate	5 mm^3/min.
Specific power consumption	1000 W/mm^3/min.
Material of workpiece	All materials except those with high thermal conductivity and high reflectivity.
Applications	Drilling micro holes (upto 250 μm) and cutting very narrow slots.
Dimensional accuracy	± 0.025 mm.
Efficiency	0.3—0.5%.
Limitations	Taper of 0.05 mm when work thickness is more than 0.25 mm. Very large power consumption.

Two types of lasers are now in common use: (a) Solid lasers, (b) Gas lasers.

Solid lasers are only capable of providing short bursts of power, whereas gas lasers produce a continuous laser beam. Solid lasers best suited to production work use a neodymium-doped glass rod as the lasing medium. The rod ends are finished as optical surfaces with reflective coatings. One end has a partially reflective coating to permit escape of the laser beam when it has reached the required intensity. The laser rod is initially excited by a high intensity flash lamp.

At present, carbon dioxide gas (CO_2) lasers are most efficient for converting electricity into laser power. Gas lasers operate in basically the same manner as solid lasers, except that a gas serves as the lasing medium and is capable of providing a continuous laser beam. This feature makes the gas laser best suited to continuous cutting or welding.

Advantages of laser beam machining

(i) Ability to machine through air, inert gas, vacuum or optically transparent liquids or solids.
(ii) Applicability to any known material.
(iii) Absence of direct contact and large forces between the tool and workpiece.
(iv) Suitability for cutting ceramic and other materials that are readily damaged by heat shock.
(v) Accuracy and ability to make very small holes and cuts.

Disadvantages of Laser beam machining

(i) Need for skilled operators.
(ii) High capital and operating cost.
(iii) Slow production rate, because precise alignment is required.
(iv) Heat damage effects on workpieces.
(v) Limited applicability (thin workpieces and removal of small amounts of material.)

Applications of laser beam machining

(i) Drilling holes in tungsten, brass and ceramic.
(ii) To generate the complex pattern on film that is used to make integrated circuits (IC).

(iii) To repair or cut patterns in thin gold film on electronic equipment.

(iv) To trim carbon resistors to accurate readings.

(v) In garment industry for cutting of patterns from single ply or multi-layer stacks of fabrics.

(vi) Dynamic balancing of gyro-rotors, watch or clock balance wheels or precision rotating parts; high Speed balancing is accomplished by vaporizing away excess metal as the part rotates on the balancing machine.

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ELECTROCHEMICAL MACHINING

Introduction

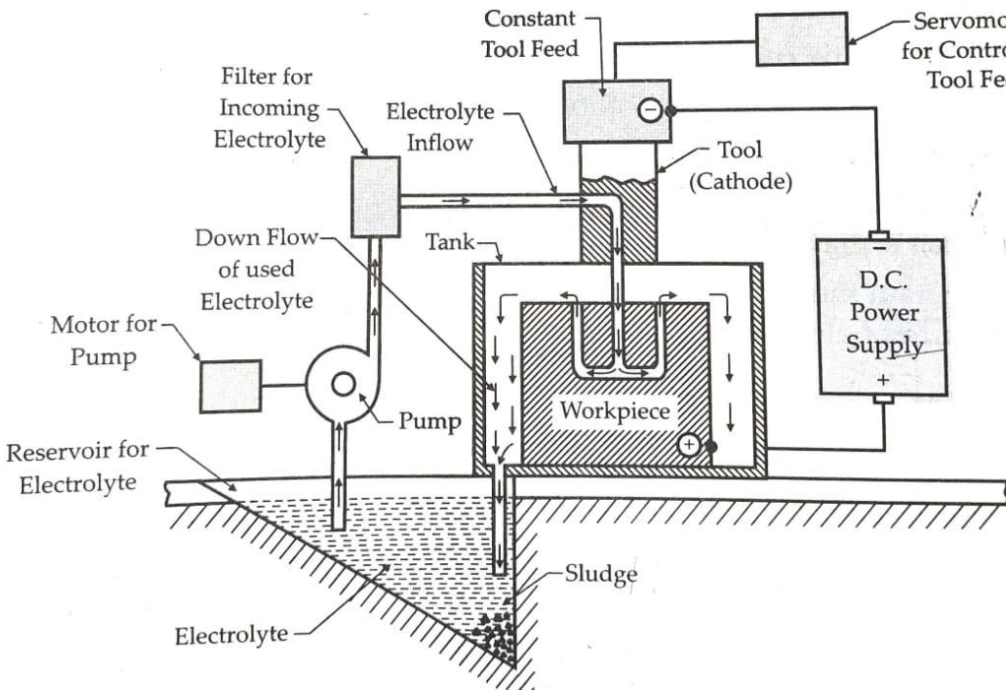
Electrochemical machining is a machining process that may be described as the reverse of electroplating. In electroplating, the metal is deposited on the workpiece, whereas instead of depositing metal on the workpiece, electrochemical machining reverses the process so that the metal is depleted or removed from the workpiece.

PRINCIPLE OF OPERATION

Electrochemical machining process is based on the fundamental laws of electrolysis which states that the amount of material deposited or dissolved is directly proportional to the current density multiplied by time.

High density direct current is passed through an electrolyte solution that fills the gap between the workpiece (anode) and the shaped tool (cathode). The electrochemical reaction depletes the metal of the workpiece.

Referring to Fig. the workpiece (which must be a conductor of electricity) is placed in a tank on the machine table and connected to the positive terminal of a D.C. supply. Thus, workpiece is made anode in the ECM process. (In electroplating the workpiece is made cathode by connecting the same to the negative terminal).



The tool electrode, shaped to form the required cavity in the workpiece, is mounted in the tool holder and connected to the negative terminal of the supply.

An electrolyte flows through the gap (which is 0.0254 to 0.76 mm) between the tool and the workpiece and is then pumped back to the working zone, either through the tool or externally, depending upon the application.

The action of the current flowing through the electrolyte is to dissolve the metal at the anode, that is, the workpiece. The electrical resistance is lowest (and hence the current is highest) in the region where the tool and the workpiece are closest. Since the metal is dissolved from the workpiece most rapidly in this region, the form of the tool will be reproduced on the workpiece. .

There is no mechanical contact between the workpiece and the tool, and any tendency of the workpiece metal to be plated on the tool (the cathode) is counteracted by the flow of the electrolyte, which removes the dissolved metal from the working zone.

MATERIAL REMOVAL RATE

Hence, the material-removal rate (MRR) in ECM (assuming 100% current efficiency) is given by

$$MRR = \frac{A\,I}{Z\,F}\ \text{kg/s}$$

The volumetric material-removal rate is given by dividing the above with the density of the workpiece material,

$$MRR = \frac{A\,I}{Z\,F\,\rho_a}\ \text{mm}^3/\text{s}$$

where
A = Atomic weight of the work material,
I = Current, amperes
Z = Valency of the work material,
F = Faraday's constant = 96 540 coulombs, and
ρ_a = Density of work material

The gap resistance R is given by

$$R = \frac{\rho\,h}{A_{\text{Gap}}}$$

where
ρ = Specific resistance of the electrolyte,
h = equilibrium gap, and
A_{Gap} = Cross-sectional area of the gap.

ELECTROLYTE

Electrolytes used in ECM should be carefully selected such that they provide the necessary reactions without plating the cathode. The typical functions expected to be served by an electrolyte in ECM are

- Completes the electrical circuit between the tool and the workpiece
- Allow desirable machining reactions to takes place
- Carry away heat generated during the operation
- Carry away products of reaction from the zone of machining

The properties that should be carefully looked into during the selection of the electrolyte to serve the function are

- ✓ High electrical conductivity
- ✓ Low viscosity and high specific heat
- ✓ Chemical stability
- ✓ Resistance to formation of passivating film on workpiece surface
- ✓ Noncorrosive and nontoxic
- ✓ Inexpensive and readily available

The salt solutions, with water forming a large proportion, satisfy many of the above conditions and, therefore, are generally used. Some general electrolytes used are the following:

1. Sodium chloride or potassium chloride. Most widely used because of low cost and stable conductivity over a broad range of pH values. However, it is corrosive and produces large amount of sludge. It cannot be used on tungsten-carbide or molybdenum.
2. Sodium nitrate. Less corrosive but forms a passive film on the workpiece surface. Hence, not used as a general-purpose electrolyte. It is used for machining aluminium and copper.

ECM TOOLS:

The properties expected of the tool materials are

1. High electrical and thermal conductivity
2. Good stiffness
3. Easy machinability
4. High corrosion resistance

Generally, aluminium, copper, brass, titanium, cupro-nickel and stainless steel are used as tool materials.

Typical ECM parameters used are

- Current: 50 to 40 000 Amperes
- Current density: 8 to 233 Amperes/cm^2
- Voltage: 4 to 30 V dc
- Gap: 0.025 to 0.75 mm
- Electrolyte velocity: 15 to 60 m/s
- Electrolyte pressure: 0.069 to 2.700 MPa
- Electrolyte temperature: 24 to 65°C
- Feed rate: 0.5 to 19.0 mm/min

ADVANTAGES OF ECM

1. Any good electrically conducting material can be machined and its mechanical properties have no bearing on its machinability through this process.
2. Intricate and complex shapes can be machined easily through this process.
3. Metal removal rate is quite high in comparison to traditional machining, specially in respect of high tensile and high temperature resistant materials.
4. Wear on tool is insignificant or (say) almost non-existent.
5. The machined work surface is free of stresses.
6. No cutting forces are involved in the process.
7. High surface finish, of the order of 0.1 to 2.0 microns, can be obtained.
8. Very thin sections, such as sheet metal, can be easily machined without any danger ot damage or distortion.
9. It is an accurate process and close tolerances of the order of 0.05 mm can be easily obtained. :
10. With the application of this process, many machining operations, like grinding, milling, polishing, etc., can be dispensed with.

DISADVANTAGES OF ECM

a) Materials which are non-conductors of electricity cannot be machined.
b) Power consumption is very high.

c) Corrosion and rusting of workpiece, machine tool, fixtures, etc., by electrolyte
d) Required initial investment is quite high.
e) Extremely fine corner radii, say less than 0.2 mm, cannot be produced.
f) Designing and fabrication of tools is relatively more difficult.
g) Larger floor space is required.
h) Specially designed fixtures are required to hold the workpiece in position, because it may be displaced due to the pressure of the inflowing electrolyte.
i) A constant monitoring is required to suitably vary the tool feed rate and supply pressure of electrolyte so as to avoid formation of cavitations.

APPLICATIONS OF ECM

(i) Machining of hard to machine and heat resistance materials.
(ii) Machining of blind holes and pockets, such as in forging dies.
(iii) Machining of complicated profiles, such as of jet engine blades, turbine blades, turbine wheels, etc.
(iv) Drilling small deep holes, such as in nozzles.
(v) Machining of cavities and holes of irregular shapes.
(vi) Deburring of parts.

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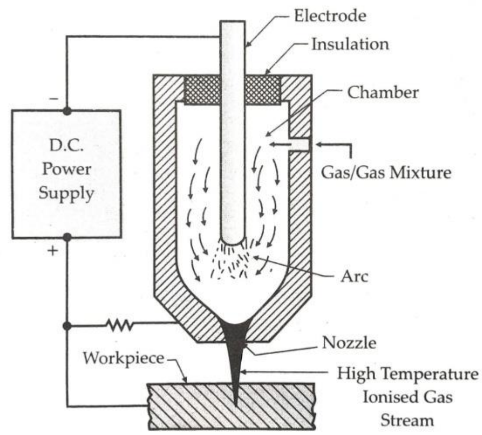
PLASMA ARC MACHINING (PAM)

When gases are heated to temperatures above 5500°C, they are partially ionised and exist in the form of a mixture of free electrons, positively charged ions and neutral atoms. This mixture is termed as plasma. The temperature of central part of plasma goes as high as between 11000°C to 28000°C, where the gas is completely ionised. In Plasma arc machining or Plasma arc cutting, a high velocity jet of this high temperature ionised gas is directed on to the workpiece surface by means of a well designed plasma-arc cutting torch, shown in Fig. This jet melts the metal of the workpiece and displaces the molten metal away from its path. The heating of workpiece material is not due to any chemical reaction but on account of the continuous attack of electrons which transfer the heat energy of high temperature ionised gas to the work material. This process can, therefore, be safely used for machining of any metal, including those which can be subjected to chemical reaction.



Material to be cut	Gas or gas mixture used
Aluminium	Nitrogen, Nitrogen-hydrogen, argon-hydrogen.
Magnesium	Nitrogen, Nitrogen-hydrogen, argon-hydrogen.
Stainless steel and some other non-ferrous metals	Nitrogen-hydrogen, argon-hydrogen.
Carbon and alloy steels, cast iron	Nitrogen-hydrogen, compressed air.

PRINCIPLE OF OPERATION

As shown in Fig, the Plasma-arc cutting torch carries a tungsten electrode fitted in a small chamber. This electrode is connected to the negative terminal of a d.c. power supply source and, therefore, acts as a cathode. The other (+ve) terminal of the power supply is connected to the nozzle formed near the bottom of the chamber. The nozzle acts as an anode. On one side of the torch is provided a passage for supply of gas into the chamber. There is also q provision of water circulation around the torch so that the electrode and the nozzle both remain water cooled.

A strong arc is struck between the electrode (cathode) and the nozzle (anode) and the gas forced into the chamber. As the gas molecules collide with the high velocity electrons of the arc, the former get ionised and a very large amount of heat energy is evolved. The flow of gas is so controlled that the arc remains stable. This high velocity stream of hot ionised gas, called plazma, is directed on to the workpiece to melt its material and also blow it away.

Some of the advantages offered by this process include:

(i) A faster process,
(ii) Excessively high temperatures are generated for use
(iii) Can be used to cut any metal.

However, the initial cost of the equipment is quite high and adequate safety precautions are always needed for the operator. Also, the work surface may undergo some metallurgical changes.

Main Applications

The main applications of this process include cutting of stainless steel and non-ferrous metals (such as aluminium alloys), particularly their profile cutting. With feasibility of its use under water, it is used in shipyards. Other industries using this technique include nuclear power plants, chemical industries, etc. Also, this technique has been successfully used for turning and milling of ‘hard to machine’ materials.

Characteristics of PAM Process

Technique of machining	Heating of workpiece by high temperature ionised gas (plasma) and causing quick melting
Tool	Plasma jet
Velocity of plasma jet	500 m/sec.
Material removal rate	150 cm^3/min
Specific energy	1000 W/cm^3-min
Power range	2 to 200 kW
Material of workpiece	All materials which conduct electricity
Voltage	30—250 V
Current	Upto 600 amp.
Cutting speed	0.1—7.5 m/min
Applications	Profile cutting of stainless steel, monel, and superalloy plates
Plate thickness	200 mm (max)
Limitation	Low accuracy.

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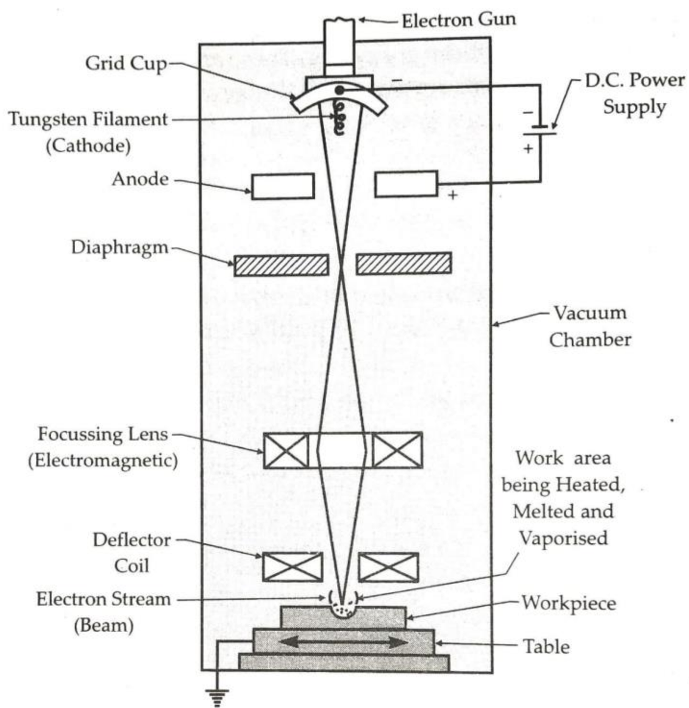
ELECTRON BEAM MACHINING (EBM)

It is a process of machining materials with the use of a high velocity beam of electrons. The workpiece is held in a vacuum chamber and the electron beam focused on to it magnetically. As the electrons strike the workpiece, their kinetic energy is converted into heat. This concentrated heat raises the temperature of workpiece materials and vaporises a small amount of it, resulting in removal of metal from the workpiece. The reason for using a vacuum chamber is that, if otherwise, the beam electrons will collide with gas molecules and will scatter.



- The main elements of Electron Beam Machining setup are shown in Fig. The complete EBM setup is enclosed in a Vacuum Chamber, which carries vacuum of the order of 10^{-5} mm of mercury. This chamber carries a door, through which the workpiece is placed over the table. The door is then closed and sealed.
- The Electron gun, which is mainly responsible for emission of electrons, consists of three main parts: a tungsten filament, the grid cup and the anode. The filament is connected to

the - ve terminal of the D.C. Power supply, to act as cathode, and the anode to the + ve terminal, as shown.

- The filament wire is heated to a temperature of about 2500°C in the vacuum. With the result, a cloud of electrons is emitted by the filament, which is directed by the grid cup to travel downwards. As the electrons are attracted by the anode, they pass through its aperture in the form of a controlled beam without colliding with it.
- A potential difference of 50 to 150 kV is maintained between the filament and the anode. As such, the electrons passing through the anode are accelerated to achieve as high a velocity as around two-third of light.
- The maximum velocity attained by the electrons, while passing out of anode, is maintained by them till such time as they strike the workpiece. It becomes possible because the electrons travel through the vacuum.
- This high velocity electron stream, after leaving the anode, passes through the tungsten diaphragm and then through the electromagnetic focussing coils (or focussing lens). By then, the stream is quite aligned and the focussing lens manages to focus it precisely on to the desired spot on the workpiece.
- The electromagnetic Deflector Coil then deflects this aligned stream (beam) on to the work, through which the path of cut can be controlled. Further, the table on which the workpiece is loaded can also be traversed to feed the workpiece as needed.
- This high velocity beam of electrons impinges on the workpiece, where its kinetic energy is released and gets converted into heat energy. The high intensity heat, so produced, melts and vaporises the work material at the spot of beam impingement. By alternately focussing and turning off the beam, the cutting process can be continued as long as it is needed.
- Melting and vaporising of the metal takes only a small fraction of a second and turning off of the beam is necessary to conduct away the heat from the workpiece. A suitable viewing device is always incorporated so as to enable the operator to observe the progress of machining operation.
- Adequate vacuum is required to be maintained inside the chamber so that the electrons can travel from cathode to anode without any hindrance, there is no arc discharge between the electrodes, there is no loss of heat from cathode, there is no contamination of

cathode and the high velocity attained by the electron beam while leaving anode is maintained upto the event of its impingement on the work.

Characteristics of EBM Process

Material Removal Technique	High speed electrons impinge on surface and kinetic energy of electrons produces intense heating to melt or vaporise the metal
Voltage	150 kV
Electron velocity	228 × 1000 km/sec.
Power density	6500 billion W/mm^2
Operations performed	Annealing, welding, or metal removal by cutting narrow slots, drilling holes of 25—125 μm in 1.25 mm thick shells. Complex contours possible by deflection by coils
Medium	Vacuum (10^{-5} mm Hg)
Materials of workpiece	All materials
Material removal rate	10 mm^3/min (max)
Specific powe consumption	500 W/mm^3 min
Limitations	Not suitable for large workpieces. Small crates produced on beam incident side of work. A little taper produced on holes. Very high specific energy consumption, necessity of vacuum, high cost of machine
Advantage	There is no effect of local heat on workpiece as the temperature of surrounding material (25—50 μm away from the machining spot) is not raised.

ADVANTAGES OF EBM

- Any material can be machined.
- Workpiece is not subjected to any physical or metallurgical damage.
- Problem of tool wear is non-existent. So, close dimensional tolerances can be achieved.
- Heat can be concentrated on a particular spot.
- An excellent technique for micro machining.
- There is no contact between the work and tool.

DISADVANTAGES OF EBM

1. High initial investment needed.
2. Highly skilled operator required to perform the operation.
3. Not suitable for producing perfectly cylindrical deep holes.
4. Suits for small and fine cuts only.
5. Workpiece size is limited due to requirement of vacuum in the chamber.
6. Low rate of metal removal.
7. High power consumption.
8. Difficult to produce slots and holes of uniform shapes and dimensions.

APPLICATIONS OF EBM

(i) Very effective for machining of materials of low heat conductivity and high melting point.

(ii) Micro-machining operations on workpieces of thin sections.

(iii) Micro-drilling operations (upto 0.002 mm) for thin orifices, dies for wire drawing, parts of electron microscopes, fibre spinners, injector nozzles for diesel engines, etc.

PROCESS PARAMETERS

The important parameters in EBM process are beam current, duration of pulse, lens current and signals for the deflection of beam. The values of these parameters during EBM are controlled with the help of a computer. Beam current varies from 100μA to 1A and it governs the energy/pulse being supplied to the workpiece.

Higher the energy/pulse more rapidly the hole can be drilled. Pulse duration during EBM varies in the range of 50 μs to 10 ms depending upon the depth and diameter of the hole to be drilled. Drilling using longer pulse duration results in a wider and deeper drilled hole. It also affects HAZ as well as the thickness of the recast layer which is normally 0.025 mm or less. The extent of both these effects should be minimum possible.

The working distance (i.e. the distance between the electron beam gun and the focal point) and the focused beam size (diameter) are determined by the magnitude of lens current. The shape o f the hole along its axis (straight, tapered, etc.) is determined by the position of the focal point below the top surface of the workpiece. To obtain the hole shape other than circular, the movement of the beam can be programmed.

The material removal rate (MRR) at which the workpiece material is vaporized can be calculated from Eq.

$$MRR = \eta \frac{P}{W}$$

Where, η is the cutting efficiency, P is the power (J/s) and W is the specific energy (J/cm^3) required to vaporize the work-material. Specific energy (W) can be calculated as follows:

$W = CPs\,(T_m - T_i) + CP_l\,(t_b - t_m) + H_f + H_v$

where, Cp is specific heat, Tm is melting temperature, Ts is initial temperature of workpiece, Tb is boiling temperature, Hf is latent heat of fusion, and Hv is the latent heat of vaporization. The cutting efficiency is usually below 20%. Here, CP is assumed constant although it varies with temperature. Suffix s and I indicate solid and liquid states, respectively.

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CHAPTER 2

PLASTIC PROCESSING

In general terms, the word Plastic has been used in the past for all those materials which could be readily molded by heating or pressure or both. But, the modern applications have changed this concept and have limited the area of this word to cover only those Synthetic Organic Materials which become Plastic when heated and can be formed into different shapes under pressure. After having been processed and finished, they are observed to be fairly hard and rigid. Various useful articles can be produced from them rapidly, accurately and with excellent surface finish. They are marked by their extreme lightness in weight, high corrosion resistance and good dielectric strength. Also they can be produced in different colours or as transparent. Plastics are also known as 'Synthetic Resins'.

In scientific terms these organic compounds are called polymers. The term polymer has its base in Greek terminology, where poly' means 'many' and 'mers' means 'parts'. Thus, the term Polymer stands to represent a substance built up of several repeating units, each unit being known as a Monomer. Thousands of such units or Monomers join together in a polymerization reaction to form a Polymer. There are some natural polymers like starch, resins, shellac, cellulose, proteins, etc., but our studies in this chapter will mostly confine to the synthetic polymers only, because they find a wide application in engineering work.

CLASSIFICATION

All the plastics are broadly classified into two main groups as under:

1. Thermosetting Plastics. Those plastics which are hardened by heat, effecting a non reversible chemical change, are called Thermosetting Plastics. In other words, we can say that they acquire a permanent shape when heated and pressed and cannot be softened by reheating. They are also known as Heat-setting or Thermosets.

2. Thermoplastics. Those plastics which can be softened again and agian by heating are called Thermoplastics. Thus, they can be heated and reshaped by pressing many times. On cooling, they

become hand. They are also known as Cold-setting Materials. They can be shaped into bars, tubes, sheets, films, and many other shapes.

POLYMER ADDITION

One or more of the following materials are added to the Polymers, either before or during Polymerization, to make them processable plastics:

1. Catalysts or Accelerators. They are also known as Hardeners. They are the catalysts which are added to accelerate the chemical reactions during polymerization of plastics.

2. Fillers. These are the materials added to synthetic resins to dilute them in order to reduce their consumption. They also increase their bulk and, thus, reduce the material cost. Many of them, especially when they are finely distributed, help in increasing strength, stiffness and thermal resistance of the plastics. Materials added for this purpose include clay, tale, wood flour, mica, quartz, alumina, carbon black, calcium carbonate, asbestos, glass fibres, etc.

3. Modifiers. These are the chemicals added to plastics for changing the properties of base resin. Some of them help in improving mechanical properties as well.

4. Plasticizers. They are the chemicals added for either softening the resins at forming temperature or to improve their toughness at the finished stage and to impart flexibility to their finished products. A Plasticizer is normally a fluid of high molecular weight.

5. Stabilizers. Their additions to plastics help in preventing deterioration due to the action of heat and light.

6. Initiators. They help in initiating or starting the reaction, i.e. Polymerization. H_2O_2 is commonly used for this purpose.

7. Dyes and Pigments. They are the colouring agents, added to impart different colours and shades to plastics.

USEFUL COMMON PROPERTIES OF PLASTICS

The following useful properties are common with most of the plastics

1. Lightness in weight

2. Good resistance to most of the chemicals

3. Good corrosion resistance.

4. High electrical insulation.

5. Easy to shape and mould.

6. Can be made transparent or coloured.

7. Non-resonant.

8. Good resistance to peeling.

9. Non-conductance of heat.

10. Resistance to moisture and greases.

PLASTIC PROCESSING METHODS

The following methods are commonly employed for processing plastics into various usable articles:

1. Compression moulding
2. Transfer moulding
3. Injection moulding
4. Extrusion
5. Casting
6. Calendering
7. Slush moulding

Moulding Methods

Moulding of plastics comprises forming an article to the desired shape by application of heat and pressure to the moulding compound in a suitable mould and hardening the material in the mould.

Selection of moulding process is largely determined by the moulding material selected to provide the desired physical properties in the finished moulded pieces. Often the moulding method is determined by such elements design as thin sections, long delicate inserts; and requirements of exact concentricity and accuracy of dimensions. Process determination is sometimes complex because there are two types of moulding materials in general use, i.e., thermosetting and thermoplastic, and four basic moulding methods, i.e. compression, transfer, injection and extrusion moulding.

Thermosetting materials are generally processed by compression and transfer moulding and for thermoplastic materials injection and extrusion processes are used.

Compression moulding is usually employed except when delicate inserts, intricate mould details or close tolerances are involved, in which case transfer moulding is preferable.

Thermoplastic materials are generally moulded by extrusion calendering and injection moulding methods. There are exceptions in as much as thermoplastic materials are sometimes compression moulded or cast in heavy sections: also, thermosetting materials are sometimes extruded or injection moulded.

1. COMPRESSION MOULDING.

In compression moulding and transfer moulding the monomers are partially polymerised in a separate operation and the polymerisation reaction is completed in the mould. The partially polymerised material is prepared as pallets for compression moulding. It is placed in a heated mould. After the compound is softened and becomes plastic, the upper part of the die moves downwards, compressing the materials to the required shape and density ; continuous heat and pressure produce the chemical reaction, leading to cross linking between the molecule chains, that hardens the thermosetting material. The mould remains closed until the curing is complete. Compression moulding is suitable for large, bulk parts of both thermosetting and thermoplastic materials and for small parts of thermosetting materials. Thick sections can be a problem as centre may not be properly heated and the curing action may be incomplete. The moulding compound may be in granular form or in a performed slug.

The moulding temperature of thermosetting materials ranges from 150°C to 180°C. The moulding pressure ranges from 135-535 kgf/cm^2.

The temperature and pressure for thermoplastic materials depend upon type of material and percentage of plasticizer. The time required to harden the mould piece ranges from 1 to 15 minutes depending upon the maximum thickness of the moulded article and the cooling facilities in the die.

MOULDS FOR COMPRESSING PROCESS

These moulds range from relatively simple one cavity form to large multiple cavity dies. The number of cavities is dictated by the quantity of parts to be produced, size of the part and size or capacity of the moulding press.

There are four basic types of processes for compression moulding.

(1) Flash type. (2) Positive type. (3) Landed positive type. (4) Semi positive type.

Flash Type. This type of mould is widely used because it is simple to construct and holds the part thickness and density within close limits. As the mould closes, the excess material escapes over the land where it forms a very thin fin. This fin hardens first, preventing the escapement of the mould charge. Flash type moulds may be loaded by volume since excess material is permitted to escape. Material lost through flashing is higher than for other types of compression moulds.

Positive Type. The characteristics of positive type mould are deep cavity and a piunger that compresses the compound at the bottom of the mould. As there is very little escapement of material, it is necessary to weight the charge accurately if the size of the part is to be controlled. Such moulds are used for high impact materials and parts requiring deep draw.

Landed Positive Type. This type of mould is similar to the positive mould except that lands are incorporated in the design to stop the travel of the plunger at a predetermined point. The density may vary depending upon the charge. In this process, greater loading space is provided thus making possible the processing of bulky materials.

Semi-Positive Mould. This is a combination of flash tvpe and landed mould. In addition to the flash ridges, land is incorporated to restrict the travel of the plunger while some of the pressure is taken up by the land, much pressure is being exerted on the part being moulded.

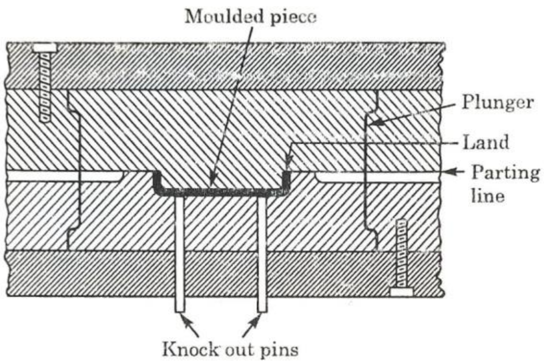


Fig. 4.1. Flash type.

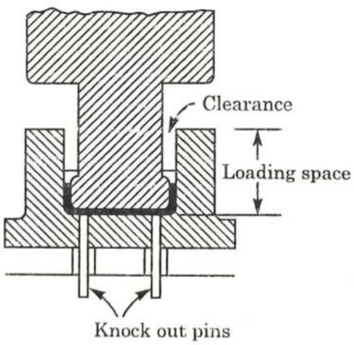


Fig. 4.2. Positive Type.

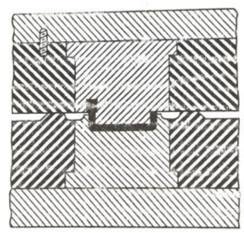


Fig. 4.4. Semi-positive type.

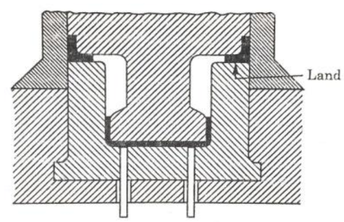


Fig. 4.3. Landed positive type.

TRANSFER MOULDING

It is also known as Extrusion Moulding or Gate Moulding. It is actually a modified form of Compression Moulding. In this, the heat and pressure are applied to the compound separately outside the mould, and when the latter becomes fluid it is transferred to the mould under pressure, through a sprue and gate, where it cures finally. This mould is costlier, but the operation is easier and enables trouble free production of intricate parts with thin sections as the mould is not directly subjected to the compression force. An example is illustrated in Fig.

In transfer moulding the following points are to be kept in mind while designing:

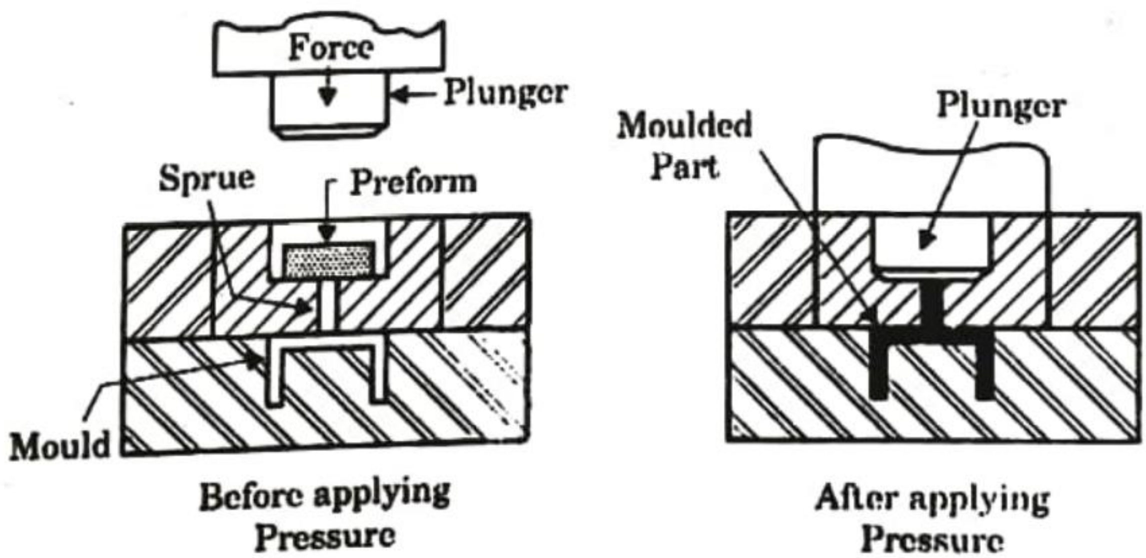
(i) Material should flow easily in the mould to take the required shape.

(ii) All parts of the charge must be heated so as to harden, i.e. none of the materials should harden before other parts of the charge had an opportunity to flow into the correct position.

When sections are thick, it becomes necessary to preheat the charge of material before placing it in the mould.

(iii) Facilities for removing the product from the mould without damage.

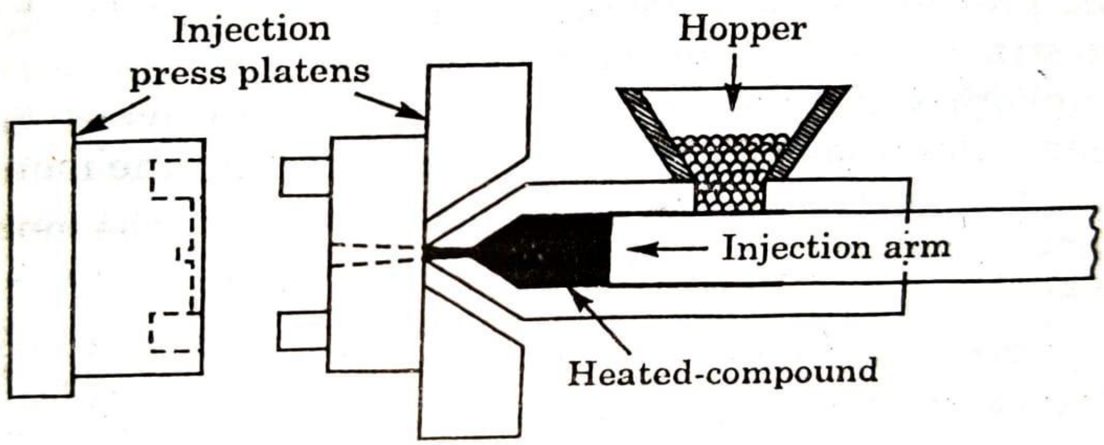
Transfer molding is generally employed for thick sections.



INJECTION MOULDING

It makes use of heat softening characteristics of thermoplastic materials. These materials soften when heated and reharden when cooled. No chemical change takes place when the material is heated or cooled, the change being entirely physical. For this reason, the softening and rehardening cycle can be repeated any number of times.

The granular moulding material is loaded into a hopper from where it is metered out in a heating cylinder by a feeding device. The exact amount of material is delivered to a cylinder which is required to fill the mould completely. The injection ram pushes the material into the heating cylinder and in doing so pushes a small amount of heated material out of the other end of cylinder through the nozzle and screw bushing and into the cavities of the closed mould. The material is cooled to a rigid state in the mould. The mould is then opened and piece is ejected out. The temperature to which the material is raised in the heating cylinder is usually between 180—280°C, The higher the temperature the lower the viscosity and more readily it can be pushed into the die. Every type of material has a characteristic moulding temperature, the softer formulations require lower temperature, and the harder formulations require higher temperature. Intricate pieces, large pieces, several cavities in the die and long runners al] tend to increase the temperature requirements. When the plastic material is pushed from nozzle end of the cylinder, it enters through channels into the closed mould. In the majority of cases, the mould is kept cold, in order to cool the moulded articles ready to the point at which the mould can be opened and pieces ejected without distortion. This is done by circulating water through the mould frame. Sometimes, it is necessary to use a warm mould, and mould temperature as high as 150°C is used for very special jobs. However material sets faster in a cold die and the cycles are shorter. The cooling of plastics under pressure is desirable to avoid "shrink" marks on the surface. Automatic devices are commercially available to maintain mould temperature at required level.



ADVANTAGES AND LIMITATIONS

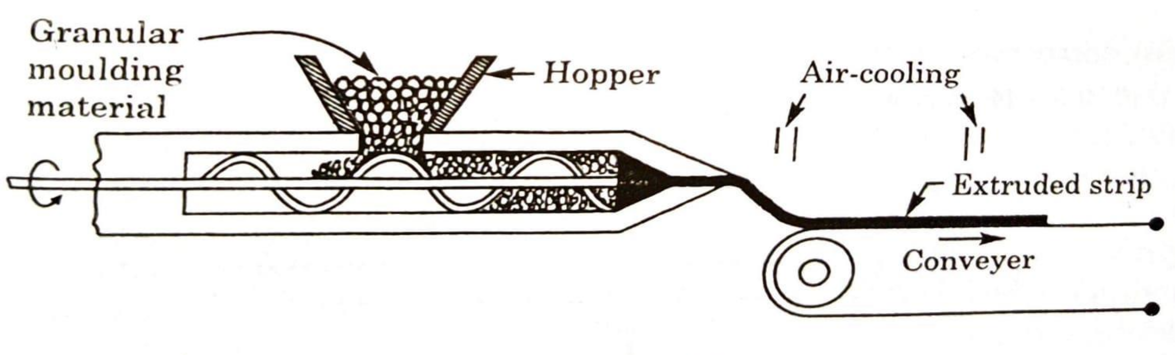
Since speed is one main advantage in injection moulding, complicated moulds with inserts should be avoided, if possible. Injection moulding need not be single cavity, but the higher rate of production reduces the need for large number of cavities. Moulding normally requires no further machining. The savings resulting from higher production rates are partially offset by higher capital expenditure for machines and higher operating costs. Injection moulding is generally limited to forming thermoplastic materials, but equipment is available for converting the machines for moulding thermosetting plastics and compounds of rubber.

In the case of thermosetting plastics the sprue and runner material is wasted as recycling of this product is not possible. Further it is difficult to mould parts with large variations in wall thickness.

EXTRUSION MOULDING

Extrusion process is a continuous operation in which powdered polymer or monomers is fed by a screw along a cylindrical chamber, As the powder moves toward the die, it is heated and melts, The molten plastic is forced through a die opening of the desired shape. The material in granular form together with necessary additives is placed into a feed hopper which feeds the cylinder of the extruding machine; the hopper portion is kept cool by Circulating water in order to avoid pre-mature softening of the feed and a blockage in the supply system. The cylinder is so heated by electricity, oil or steam that closely controlled temperature zones are set up along its length.

A rotating Screw is used for carrying and mixing of material through cylinder and forcing it through a die of required shape. The Screws are designed to suit each application. These vary in size and form. Generally a screw has three zones, viz., (i) feed zone in which case screw core is of smaller size and fins (blades) are bigger to carry more low density stock, (ii) compression zones in which screw core diameter gradually increases or the screw pitch decreases, and (iii) metering stage.



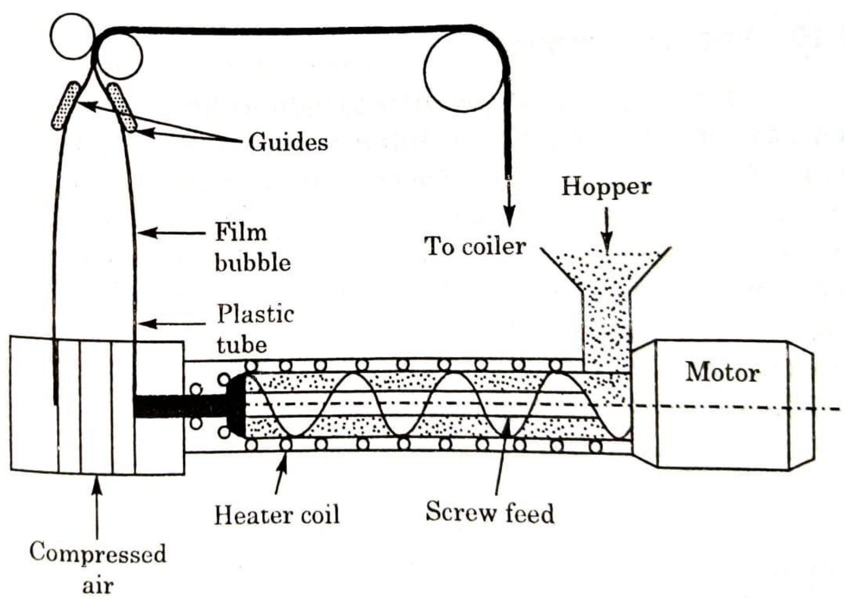
The extruded shape (which may be in the form of rod, tube, section, or sheet) coming from the die is carried through a cooling medium by a conveyor and when it has been cooled sufficiently to retain shape, it is cut into lengths or coils. In some instances, the material must be held to a shape during its cooling.

Cooling is done by exposure to air at room temperature, by passing through a liquid bath at a controlled temperature, or by jets of compressed air. Too rapid cooling must be prevented as it causes warpage and sets some internal strains in the finished pieces.

The raw material must have a uniform particle size and a controlled moisture content to maintain close dimensional tolerances and smooth finished surface on the extruded product. The temperature of each heat zone of cylinder must be held constant to ensure good extrusion.

Depending on die design and opening, forms like meter wide sheets, solid and hollow sections of many forms, blown film to about 2 m diameter, wire covering and blow mouldings can be produced. Several take off and post extrusion operations are carried out to produce some modifications.

Advantages of extrusion are low initial cost, continuous production, introduction of anisotropy to provide high uniaxial strength. However some further work may be required in assembling the components.



Extrusion die can also be used to produce a tube into which compressed air or nitrogen is blown to give a film bubble from which sheet of upto 0.7 mm thickness can be produced.

LAMINATING PLASTICS

Laminating plastics comprise sheets of paper, fabric, asbestos, wood or similar materials, which are first impregnated or coated with resin and bonded together by heat and pressure to form commercial materials. These materials are hard, strong, impact resisting, unaffected by heat or water and have good machining characteristics which permit is fabrication into gears, handles, bushings, furniture and many other articles. Laminations are classified into three categories depending upon the pressure required to cure the resin in manufacture. Laminations cured at 0 to 2 kgf/cm^2 are called contact pressure laminations. Those cured at pressures below 27 kgf/cm^2 are called low pressure laminations and those cured between 80 to 140 kgf/cm^2 are referred to as high pressure laminations. Commercially laminates are available in sheets, rods, tubes and special shapes. Among these, sheet form is more common.

HIGH PRESSURE LAMINATES

Phenolics, melamines, ureas and silicons are the most commonly used resins in high pressure laminates. Commercially they are available in sheet, rod, tube and some simple moulded parts, such as refrigerator's inner doors etc. Manufacturing sequence of laminated products is as follows. Firstly, the resinoid material is dissolved by a solvent to convert it into liquid varnish. Rods of fabric paper are then passed through a bath for impregnation. They are then passed through a drier which evaporates the solvent, leaving a fairly stiff sheet impregnated with the plastic material. The whole of operation is a continuous process and is shown in Fig. The sheets are cut into convenient sizes and staked together by hydraulic press, sufficient to make up the desired thickness of the final sheet. Under action of heat and pressure, a hard rigid plate having desirable properties for many industrial applications is formed.

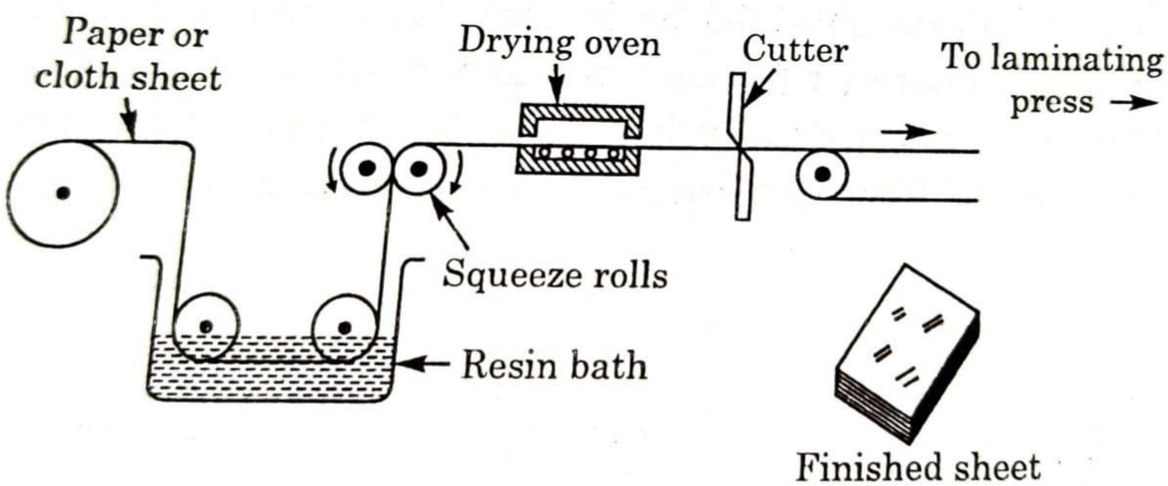
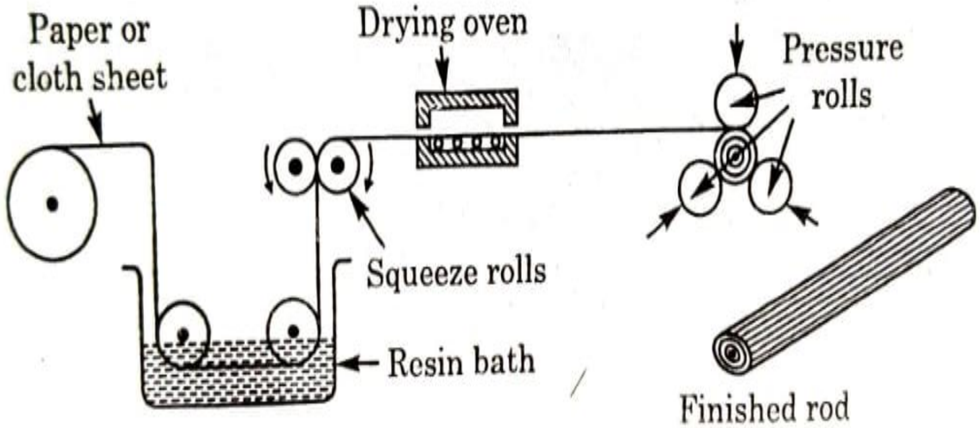


Fig. Manufacture of Laminating Sheet.

For the production of tubes, the paper or the fabric is rolled on a steel mandrel of desired diameter and then placed within the steel mould for the final processing as shown in Fig. In the production of rods, the paper or fabric is rolled over the mandrel of very small diameter, which is withdrawn before the material is placed in the mould.

High pressure laminations are chiefly composed of cotton-cloth, paper, asbestos and glass fabrics. Heavy cloth laminates are used for gear blanks, cams and other industrial purposes. Electrical insulation and punch stock materials are made from paper laminates.



LOW PRESSURE LAMINATES

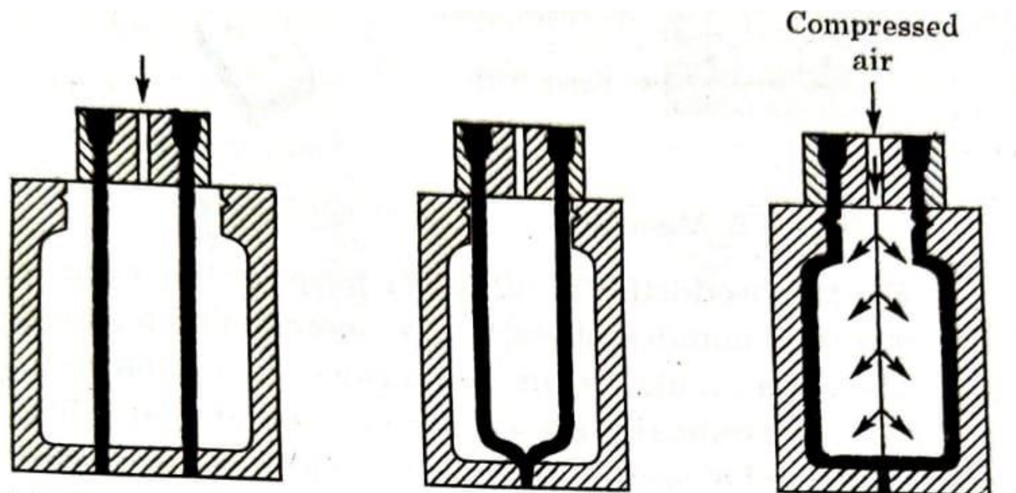
Commercially available low pressure laminates are plywood and glass reinforced polyester parts. Now-a-days, its application is also extended to sandwich-type construction such as foam, resin bonded paper or balsa wood which gives superior strength and weight.

BLOW MOULDING

The process is applied to only thermoplastics which are used for producing hollow objects such as bottle and floatable objects by applying air pressure to the sheet material when it is in heated and in soft pliable condition.

Blow moulding can be accomplished in two manners; one is direct blow moulding and the other indirect blow-moulding. In the former case, a measured amount of material in the form of tube is either injected or extruded in a split cavity die. The split mould is closed around the tube, sealing off the lower end. The air under pressure is blown into the tube, which causes the tube to expand to the walls of cavity.

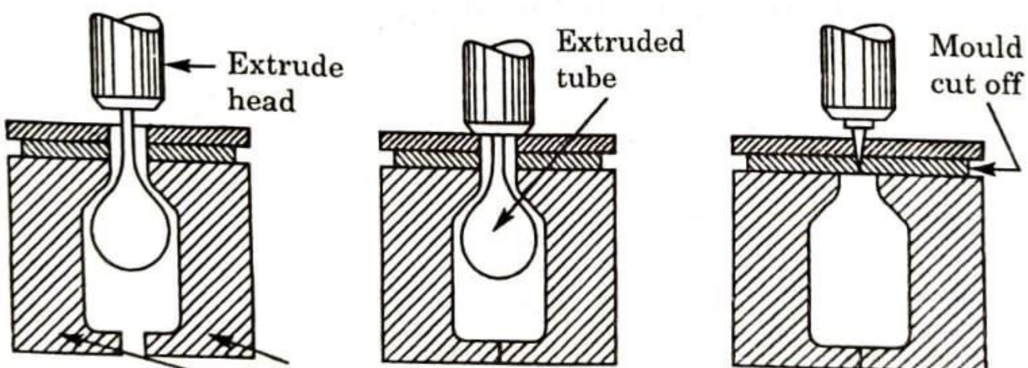
In the latter case, a uniformly softened sheet material by heat is clamped at the edges between the die and cover. The air under pressure is applied between the sheet and cover, which causes the sheet to attain a hemispherical shape or the configuration of mould whatever it may be. Parts obtained by indirect blow moulding have excellent appearance but they are more costly as only 50 per cent of the sheet stock is utilized and also there is a tendency for excessive thinning of sheet at the deepest point.



(a) Measured length of plastic tube extruded.

(b) Mould closed, cutting off length, and sealing end of tube.

(c) Compressed air expands tube to fit shape of mould.

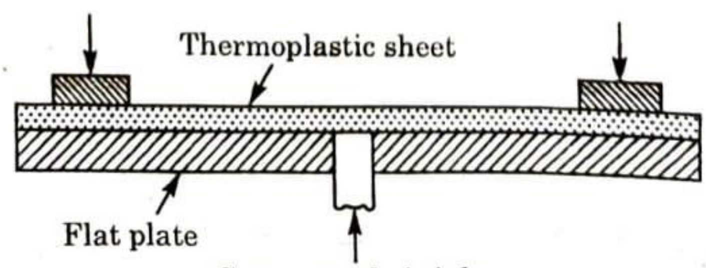


(a) Sealed tube-extruded in open mould.

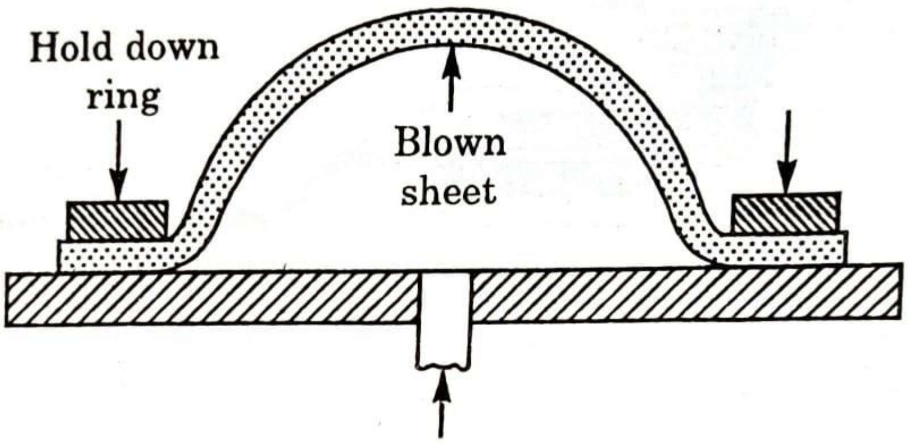
(b) Mould closed, tube expanding under pressure.

(c) Tube fully expanded and sealed into mould.

Direct blow moulding (Thermoplastic bottle).



(a) Sheet in place ready for heating.

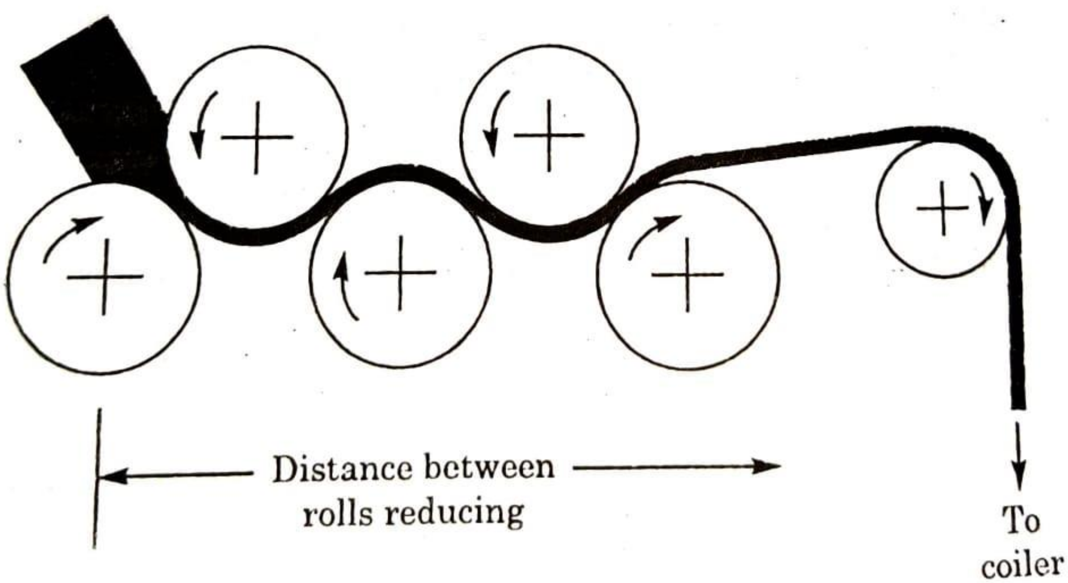


(*b*) Heated sheet blown to the desired shape.

Fig. Indirect blow moulding.

CALENDERING

Sheets (of PVC) can be produced by calendering process. The polymer is first mixed with the plasticizers and other additives such as colouring agents. The mix is then heated for a short time to produce a rough sheet which is fed through a series of rolls. The thickness is gradually reduced, and at the same time a smooth or textured surface, as required, is produced. The finished thickness is determined by the setting of the gap between the last pair of rolls.



PLASTICS AS ENGINEERING MATERIALS

At present, plastics in many fields have become indispensable and at some places they have safely replaced other materials. In many fields plastics are going to replace even steel. People at present are thinking of making plastic wheels and plastic cycles have already been made. There is no single type of plastic; rather there is a huge variety of its forms. Its versatility renders them of service in solving many problems. The important properties of plastics which have made them suitable for large number of engineering uses are: (i) electrical insulation, (ii) freedom from corrosion, (iii) resistance to chemical attack, (iv) attractive appearance, (v) low weight, (vi) transparency, (vii) easy manufacture and (viii) their capability of taking variety of colours.

These are being consumed in nearly all industries in the form of laminated sheets and tubes, in the form of reinforced plastics. Polyvinyl chloride has been very much successful in replacing rubber in distribution of electricity. They are being used in radios, telephone hand pieces, in telecommunication as high frequency insulation, in automobiles, in film industry and even in clothing.

Their latest uses include many unstressed and semi stressed parts of aircraft due to its weight saving potentialities. A great credit for all this goes to research in chemical technology which has been able to give us complete properties of a wide variety of plastics.

Name of Plastic	*Typical Applications*
Nylons	Automotive king pins, pedal shafts seat, swivels, steerings and controls, bearings, wear strips, guides, stop pins, valve seats, gaskets, and hold down pedals.
Acetals	Bearings, sleeves, plugs, flexible shafts, conveyor parts, impeller and pump parts, valve liners and for slides to eliminate jerky starts and slip-stick.
Polyimides	Valve parts, bushings and slide blocks.
Phenolics	Housings, automotive transmission rings, transmission thrust washers, oil well plugs, diaphragm plates, automotive power brake systems, small tool housings and laminated gears.

Plastic	*Application*
Nylons	Heavy gears, for vibration damping, cams, low friction gears.
Acetals	For gears working under humid conditions, for maximum fatigue life of gears, precision gears, conveyor rollers, creep resistant parts, racks, submerged couplings and pump parts, cams, sprockets, leaf springs, bushings, mechanical and pencil parts.
Phenolics	Large size gears for dimensional stability, marine couplings, steel mill and other heavy duty machinery, aircraft landing gear unit.
Polycarbonates	For intermittent very high impact rollers and dimensional stability, centrifuge tubing, material handling equipment.

Plastic	*Application*
Alkyd	Insulating brackets, small switch gears.
Ceramoplastic	High temperature insulation. Hermetic seals.
Diallyl phithalate	Air ducts
Epoxy	Corrosion resistant liners.
FPR	Flexible hoses, seals and bellows.
Polycarbonate	Pump impellers.
Polyimides	Valves, soldering fixtures, welding gun components.
Polyphenylene Oxide	Pump and blower housings, fan shrouds, blower wheels.
PTFE	Gaskets, flexible joints, brake linings, piston rings, bellows and seals.

ADDITIVE MANUFACTURING

WHAT IS ADDITIVE MANUFACTURING?

The term Rapid Prototyping (or RP) is used in a variety of industries to describe a process for rapidly creating a system or part representation before final release or commercialization of the product.

In other words, the emphasis is on creating something quickly and that the output is a prototype or basis model from which further models and eventually the final product will be derived.

In a product development process, the term rapid prototyping was used widely to describe technologies which created physical prototypes directly from digital data. This text is about these technologies, first developed for prototyping, but now used for many more purposes.

Users of RP technology have now come to realize that the quality of the output from these machines has a much closer link to the final product. Many parts are in fact now directly manufactured in these machines; so it is not possible for us to label them as "prototypes."

The term Rapid Prototyping also overlooks the basic principle of these technologies in that they all fabricate parts using an additive approach. A recently formed Technical Committee within ASTM International agreed that new terminology should be adopted. While this is still under debate, recently adopted ASTM consensus standards now use the term **Additive Manufacturing.**

Referred to in short as AM, the basic principle of this technology is that a model, initially generated using a three-dimensional Computer Aided Design (3D CAD) system, can be fabricated directly without the need for process planning.

The key to how AM works is that parts are made by adding material in layers; each layer is a thin cross-section of the part derived from the original CAD data. Obviously in the physical world, each layer must have a finite thickness to it and so the resulting part will be an approximation of the original data.

The thinner each layer is, the closer the final part will be to the original. All commercialized AM machines to date use a layer-based approach; and the major ways that they differ are in the materials that can be used, how the layers are created, and how the layers are bonded to each other.

WHAT ARE AM PARTS USED FOR?

Initially, AM was used specifically to create visualization models for products as they were being developed. It is widely known that models can be much more helpful than drawings or renderings in fully understanding the intent of the designer when presenting the conceptual design. While drawings are quicker and easier to create, models are nearly always required in the end to fully validate the design.

Following this initial purpose of simple model making, AM technology developed as materials, accuracy, and the overall quality of the output improved. Models were quickly employed to supply information about what is known as the "3 Fs" of Form, Fit, and Function.

AM, when used in conjunction with other technologies to form process chains, can be used to significantly shorten product development times and costs.

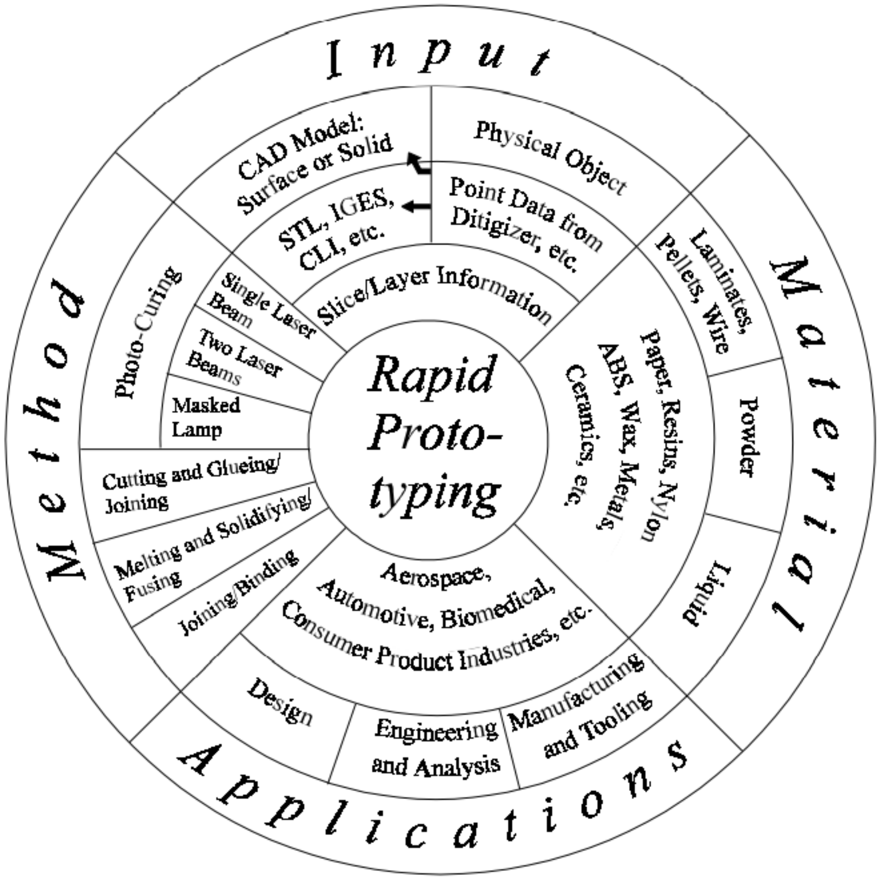
FUNDAMENTALS OF RAPID PROTOTYPING

1. Design of a model or component on a Computer-Aided Design/ Computer-Aided Manufacturing (CAD/CAM) system.
   - The model which represents the physical part to be built must be represented as closed surfaces which define an enclosed volume. This means that the data must specify the inside, outside and boundary of the model.
   - This is not necessary if the modeling technique used is solid modeling. This is by virtue of the technique used, as a valid solid model will automatically be an enclosed volume.
   - This requirement ensures that all horizontal cross sections that are essential to RP are closed curves to create the solid object.

2. The solid or surface model to be built is next converted into a format i.e. the “STL” (STereoLithography) file format which originates from 3D Systems.
   - The STL file format approximates the surfaces of the model by polygons.
   - Highly curved surfaces must employ many polygons, which mean that STL files for curved parts can be very large.
3. A computer program analyzes a STL file that defines the model to be fabricated and “slices” the model into cross sections.
   - The cross sections are systematically recreated through the solidification of either liquids or powders and then combined to form a 3D model.
   - Another possibility is that the cross sections are already thin, solid laminations and these thin laminations are glued together with adhesives to form a 3D model. Other similar methods may also be employed to build the model.

CAD image of a teacup with further images showing the effects of building using different layer thicknesses

THE RAPID PROTOTYPING WHEEL



1. **Input:** Input refers to the electronic information required to describe the physical object with 3D data. There are two possible starting points — a computer model or a physical model. The computer model created by a CAD system can be either a surface model or a solid model. On the other hand, 3D data from the physical model is not at all straightforward. It requires data acquisition through a method known as **reverse engineering.** (In reverse engineering, a wide range of equipment can be used, such as CMM (coordinate measuring machine) or a laser digitizer, to capture data points of the physical model and "reconstruct" it in a CAD system.)

2. **Method:** While they are currently more than 20 vendors for RP systems, the method employed by each vendor can be generally classified into the following categories: photo-curing, cutting and glueing/joining, melting and solidifying/fusing and joining/binding. Photo-curing can be further divided into categories of single laser beam, double laser beams and masked lamp.
3. **Material:** The initial state of material can come in either solid, liquid or powder state. In solid state, it can come in various forms such as pellets, wire or laminates. The current range materials include paper, nylon, wax, resins, metals and ceramics.
4. **Applications:** Most of the RP parts are finished or touched up before they are used for their intended applications. Applications can be grouped into (1) Design (2) Engineering, Analysis, and Planning and (3) Tooling and Manufacturing. A wide range of industries can benefit from RP and these include, but are not limited to, aerospace, automotive, biomedical, consumer, electrical and electronics products.

ADVANTAGES OF RAPID PROTOTYPING

- Today's automated; toolless, patternless RP systems can directly produce functional parts in small production quantities.
- Parts produced in this way usually have an accuracy and surface finish inferior to those made by machining. However, some advanced systems are able to produce near tooling quality parts that are close to or are the final shape.
- The parts produced, with appropriate post processing, will have material qualities and properties close to the final product.
- More fundamentally, the time to produce any part — once the design data are available — will be fast, and can be in a matter of hours.

- The benefits to the company using RP systems are many. One would be the ability to experiment with physical objects of any complexity in a relatively short period of time.
- The product designers can increase part complexity with little significant effects on lead time and cost. They can optimize part design to meet customer requirements.
- The manufacturing engineer can minimize design, manufacturing and verification of tooling. He can also reduce parts count and, therefore, assembly, purchasing and inventory expenses.
- The manufacturer can reduce the labor content of manufacturing, since part-specific setting up and programming are eliminated, machining/casting labor is reduced, and inspection and assembly are also consequently reduced as well.
- Reducing material waste, waste disposal costs, material transportation costs, inventory cost for raw stock and finished parts (making only as many as required, therefore, reducing storage requirements)
- The consumer can buy products which meet more closely individual needs and wants. Firstly, there is a much wider diversity of offerings to choose from. Secondly, one can buy (and even contribute to the design of) affordable products built-to-order. Furthermore, the consumer can buy products at lower prices, since the manufacturers' savings will ultimately be passed on.

COMMONLY USED TERMS

- Worldwide, the most commonly used term is Rapid Prototyping. The term is apt as the key benefit of RP is its rapid creation of a physical model. However, prototyping is slowly growing to include other areas. Soon, Rapid Prototyping, Tooling and

Manufacturing (RPTM) should be used to include the utilization of the prototype as a master pattern for tooling and manufacturing.

- Some of the less commonly used terms include Direct CAD Manufacturing, Desktop Manufacturing and Instant Manufacturing. The rationales behind these terms are also speed and ease, though not exactly direct or instant!
- CAD Oriented Manufacturing is another term and provides an insight into the issue of orientation, often a key factor influencing the output of a prototype made by RP methods like SLA.
- Another group of terms emphasizes on the unique characteristic of RP — layer by layer addition as opposed to traditional manufacturing methods such as machining which is material removal from a block. This group includes Layer Manufacturing, Material Deposit Manufacturing, Material Addition Manufacturing and Material Incress Manufacturing.
- There is yet another group which chooses to focus on the words "solid" and "freeform" — Solid Freeform Manufacturing and Solid Freeform Fabrication. Solid is used because while the initial state may be liquid, powder, individual pellets or laminates, the end result is a solid, 3D object, while freeform stresses on the ability of RP to build complex shapes with little constraint on its form.

CLASSIFICATION OF RAPID PROTOTYPING SYSTEMS

While there are many ways in which one can classify the numerous RP systems in the market, one of the better ways is to classify RP systems broadly by the initial form of its material, i.e. the material that the prototype or part is built with. In this manner, all RP systems can be easily categorized into (1) liquid-based (2) solid-based and (3) powderbased.

Liquid-Based

Liquid-based RP systems have the initial form of its material in liquid state. Through a process commonly known as curing, the liquid is converted into the solid state. The following RP systems fall into this category:

(1) 3D Systems' Stereolithography Apparatus (SLA)

(2) Cubital's Solid Ground Curing (SGC)

(3) Sony's Solid Creation System (SCS)

(4) CMET's Solid Object Ultraviolet-Laser Printer (SOUP)

(5) Autostrade's E-Darts

(6) Teijin Seiki's Soliform System

(7) Meiko's Rapid Prototyping System for the Jewelry Industry

(8) Denken's SLP

(9) Mitsui's COLAMM

(10) Fockele & Schwarze's LMS

(11) Light Sculpting

(12) Aaroflex

(13) Rapid Freeze

(14) Two Laser Beams

(15) Microfabrication

As is illustrated in the RP Wheel in Figure, three methods are possible under the "Photo-curing" method. The single laser beam method is most widely used and include all the above RP systems with the exception of (2), (11), (13) and (14) Cubital (2) and Light Sculpting (11) use the masked lamp method, while the two laser beam method is still not commercialized. Rapid Freeze (13) involves the freezing of water droplets and deposit in a manner much like FDM to create the prototype.

Solid-Based

Except for powder, solid-based RP systems are meant to encompass all forms of material in the solid state. In this context, the solid form can include the shape in the form of a wire, a roll, laminates and pellets. The following RP systems fall into this definition:

(1) Cubic Technologies' Laminated Object Manufacturing (LOM)

(2) Stratasys' Fused Deposition Modeling (FDM)

(3) Kira Corporation's Paper Lamination Technology (PLT)

(4) 3D Systems' Multi-Jet Modeling System (MJM)

(5) Solidscape's ModelMaker and PatternMaster

(6) Beijing Yinhua's Slicing Solid Manufacturing (SSM), Melted Extrusion Modeling (MEM) and Multi-Functional RPM Systems (M-RPM)

(7) CAM-LEM's CL 100

(8) Ennex Corporation's Offset Fabbers

(9) Quick cast

Referring to the RP Wheel in Figure two methods are possible for solid-based RP systems. RP systems (1), (3), (4) and (9) belong to the Cutting and Glueing/Joining method, while the Melting and Solidifying/Fusing method used RP systems (2), (5), (6), (7) and (8).

Powder-Based

In a strict sense, powder is by-and-large in the solid state. However, it is intentionally created as a category outside the solid-based RP systems to mean powder in grain-like form. The following RP systems fall into this definition:

(1) 3D Systems's Selective Laser Sintering (SLS)

(2) EOS's EOSINT Systems

(3) Z Corporation's Three-Dimensional Printing (3DP)

(4) Optomec's Laser Engineered Net Shaping (LENS)

(5) Soligen's Direct Shell Production Casting (DSPC)

(6) Fraunhofer's Multiphase Jet Solidification (MJS)

(7) Acram's Electron Beam Melting (EBM)

(8) Aeromet Corporation's Lasform Technology

(9) Precision Optical Manufacturing's Direct Metal Deposition (DMDTM)

(10) Generis' RP Systems (GS)

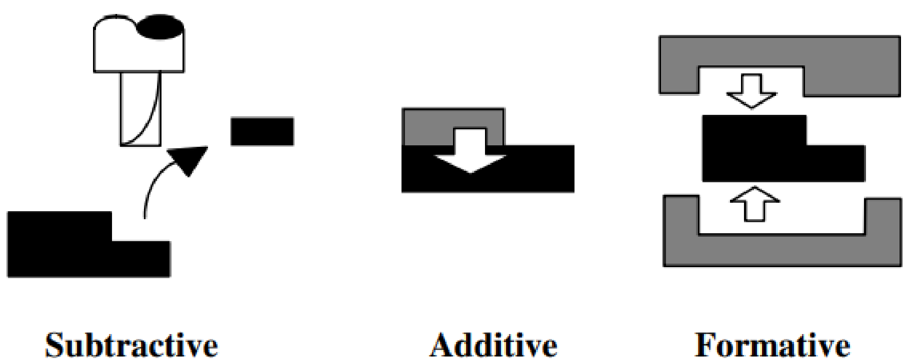
(11) Therics Inc.'s Theriform Technology

(12) Extrude Hone's Prometal TM 3D Printing Process

All the above RP systems employ the Joining/Binding method. The method of joining/binding differs for the above systems in that some employ a laser while others use a binder/glue to achieve the joining effect.

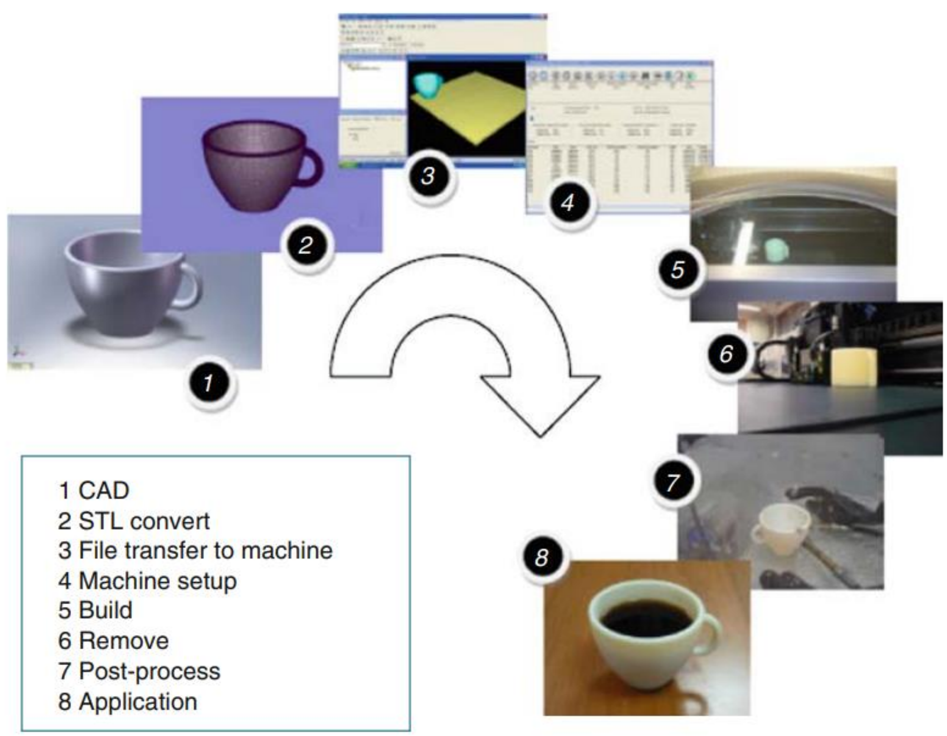
FUNDAMENTAL AUTOMATED PROCESSES

There are three fundamental fabrication processes as shown in Figure. They are Subtractive, Additive and Formative processes.



In the subtractive process, one starts with a single block of solid material larger than the final size of the desired object and material is removed until the desired shape is reached. In contrast, an additive process is the exact reverse in that the end product is much larger than the material when it started. A material is manipulated so that successive portions of it combine to form the desired object. Lastly, the formative process is one where mechanical forces or restricting forms are applied on a material so as to form it into the desired shape. There are many examples for each of these fundamental fabrication processes. Subtractive fabrication processes include most forms of machining processes — CNC or otherwise. These include milling, turning, drilling, planning, sawing, grinding, EDM, laser cutting, waterjet cutting and the likes. Most forms of rapid prototyping processes such as Stereolithography and Selective Laser Sintering fall into the additive fabrication processes category. Examples of formative fabrication processes are: Bending, forging, electromagnetic forming and plastic injection molding. These include both bending of sheet materials and molding of molten or curable liquids. The examples given are not exhaustive but indicative of the range of processes. Hybrid machines combining two or more fabrication processes are also possible. For example, in progressive pressworking, it is common to see a hybrid of subtractive (as in blanking or punching) and formative (as in bending and forming) processes.

PROCESS CHAIN



The above-mentioned sequence of steps is generally appropriate to all AM technologies. There will be some variations dependent on which technology is being used and also on the design of the particular part.

Step 1: Conceptualization and CAD

The first step in any product development process is to come up with some idea as to how the product will look and function. Conceptualization can take many forms, from textual and narrative descriptions to sketches and representative models.

If AM is to be used, the product description must be in a physical mode. For complex products there are likely to be many stages in the development process where models can be used.

For these purposes it is therefore important that the model description be entered into a computer. AM technology would not exist if it were not for 3D CAD. Only after we gained the ability to represent solid objects in computers were we able to develop technology to physically reproduce such objects.

All AM parts must start from a software model that fully describes the external geometry. This can involve the use of almost any professional CAD solid modeling software, but the output must be a 3D solid or surface representation. Reverse engineering equipment (e.g., laser scanning) can also be used to create this representation.

It is most important that such 3D geometric models can be shared by the entire design team for many different purposes, such as interference studies, stress analyses, FEM analysis, detail design and drafting, planning for manufacturing, including NC programming, etc.

Step 2: Conversion to STL

Nearly every AM technology uses the STL file format. The term STL was derived from STereoLithograhy, which was the first commercial AM technology from 3D Systems in the 1990s.

The STL file format approximates the surfaces of the model using tiny triangles. Highly curved surfaces must employ many more triangles, which mean that STL files for curved parts can be very large.

The minimum size of these triangles can be set within most CAD software and the objective is to ensure the models created do not show any obvious triangles on the surface. Basic thumb rule is to ensure that the minimum triangle offset is smaller than the resolution of the AM machine.

A CAD model on the left converted into STL format on the right

The process of converting to STL is automatic within most CAD systems, but there is a possibility of errors occurring during this phase. There have therefore been a number of software tools developed to detect such errors and to rectify them if possible. (STL file repair software, like the MAGICS software from the Belgian company. Such software may therefore be applied as a checking stage to ensure that there are no problem with the STL file data before the build is performed.)

Nearly every AM machine accepts the STL file format, which has become a de facto standard, and nearly every CAD system can output such a file format. This file describes the external closed surfaces of the original CAD model and forms the basis for calculation of the slices.

Almost, if not all, major CAD/CAM vendors supply the CAD-STL interface. Since 1990, almost all major CAD/CAM vendors have developed and integrated this interface into their systems. This conversion step is probably the simplest and shortest of the entire process chain. However, for a highly complex model coupled with an extremely low performance workstation or PC, the conversion can take several hours. Otherwise, the conversion to STL file should take only several minutes.

Step 3: Transfer to AM Machine and STL File Manipulation

Once the STL file has been created, it can be sent directly to the target AM machine. Data transmission via agreed data formats such as STL or IGES may be carried out through a diskette, email (electronic mail) or LAN (local area network).

Once the STL files are verified to be error-free, the RP system's computer analyzes the STL files that define the model to be fabricated and slices the model into cross-sections. The cross-sections are systematically recreated through the solidification of liquids or binding of powders, or fusing of solids, to form a 3D model.

AM system software normally has a visualization tool that allows the user to view and manipulate the part. The user may wish to reposition the part or even change the orientation to allow it to be built at a specific location within the machine. It is quite common to build more than one part in an AM machine at a time. This may be multiples of the same part (thus requiring a copy function) or completely different STL files.

Some applications may require the AM part to be slightly larger or slightly smaller than the original to account for process shrinkage or coatings; and so scaling may be required prior to building.

Applications may also require adding text and simple features to STL formatted data. This would be done in the form of adding 3D embossed characters.

Step 4: Machine Setup

The AM machine must be properly set up prior to the build process. Such settings would relate to the build parameters like the material constraints, energy source, layer thickness, timings, etc.

All AM machines will have at least some setup parameters that are specific to that machine or process.

Some machines are only designed to run one or two different materials and with no variation in layer thickness or other build parameters. These types of machine will have very few setup changes.

Other machines are designed to run with a variety of materials and permit parts to be built quicker but with poorer layer resolution, for example. Such machines can have numerous setup options available.

Normally, an incorrect setup procedure will still result in a part being built. The final quality of that part may, however, be unacceptable.

Step 5: Build

This is where the previously mentioned layer-based manufacturing takes place and is fully automated. The building process may take up to several hours to build depending on the size and number of parts required.

All AM machines will have a similar sequence of layer control, using a height adjustable platform, material deposition, and layer cross-section formation.

Some machines will combine the material deposition and layer formation simultaneously while others will separate them. All machines will repeat the process until either the build is complete or there is no source material remaining. In either case, the machine will alert the user to take action.

Building the part is mainly an automated process and the machine can largely carry on without supervision. Only superficial monitoring of the machine needs to take place at this time to ensure no errors have taken place like running out of material, power or software glitches, etc.

Step 6: Removal and Cleanup

Once the AM machine has completed the build, the parts must be removed. This may require interaction with the machine, which may have safety interlocks to ensure for example that the operating temperatures are sufficiently low or that there are no actively moving parts.

Ideally, by this stage the output from the AM machine should be ready for use. The part must be either separated from the build platform on which the part was produced or removed from excess build material surrounding the part.

Some AM processes use additional material. This material will be used as support structures to help keep the part from collapsing or warping during the building.

There is also a degree of manual skill required since mishandling of parts and poor technique in support removal can result in a low quality output. The cleanup stage may also be considered as the initial part of the post-processing stage.

Step 7: Postprocessing

Once removed from the machine, parts may require an amount of additional cleaning up before they are ready for use. Parts may be weak at this stage or they may have supporting features that must be removed. This therefore often requires time and careful, experienced manual manipulation.

The cleaning task refers to the removal of excess parts which may have remained on the part. Thus, for SLA parts, this refers to excess resin residing in entrapped portion such as a blind hole of a part, as well as the removal of supports. Similarly, for SLS parts, the excess powder has to be removed. Likewise for LOM, pieces of excess woodlike blocks of paper which acted as supports have to be removed.

Step 8: Application

Parts may now be ready to be used. However, they may also require additional treatment before they are acceptable for use. For example, they may require priming and painting to give an acceptable surface texture and finish. Treatments may be laborious and lengthy if the finishing requirements are very demanding. They may also be required to be assembled together with other mechanical or electronic components to form a final model or product.

DISTINCTION BETWEEN AM AND CNC MACHINING

CNC differs mainly in that it is primarily a subtractive rather than additive process, requiring a block of material that must be at least as big as the part that is to be made.

Material

- AM technology was originally developed around polymeric materials, waxes and paper laminates. Subsequently, there has been introduction of composites, metals, and ceramics. CNC machining can be used for soft materials, like medium-density fiberboard (MDF), machineable foams, machineable waxes, and even some polymers. However, use of CNC to shape softer materials is focused on preparing these parts for use in a multistage process like casting.
- When using CNC machining to make final products, it works particularly well for hard, relatively brittle materials like steels and other metal alloys to produce high accuracy parts with welldefined properties.
- Some AM parts, in contrast, may have voids or anisotropy that are a function of part orientation, process parameters or how the design was input to the machine, whereas CNC parts will normally be more homogeneous and predictable in quality.

Speed

- High speed CNC machining can generally remove material much faster than AM machines can add a similar volume of material.
- However, this is only part of the picture, as AM technology can be used to produce a part in a single stage. CNC machines require considerable setup and process planning, particularly as parts become more complex in their geometry.

- Speed must therefore be considered in terms of the whole process rather than just the physical interaction of the part material. CNC is likely to be a multistage manufacturing process, requiring repositioning or relocation of parts within one machine or use of more than one machine.
- To make a part in an AM machine, it may only take a few hours; and in fact multiple parts are often batched together inside a single AM build. Finishing may take a few days if the requirement is for high quality. Using CNC machining, this same process may take weeks.

Complexity

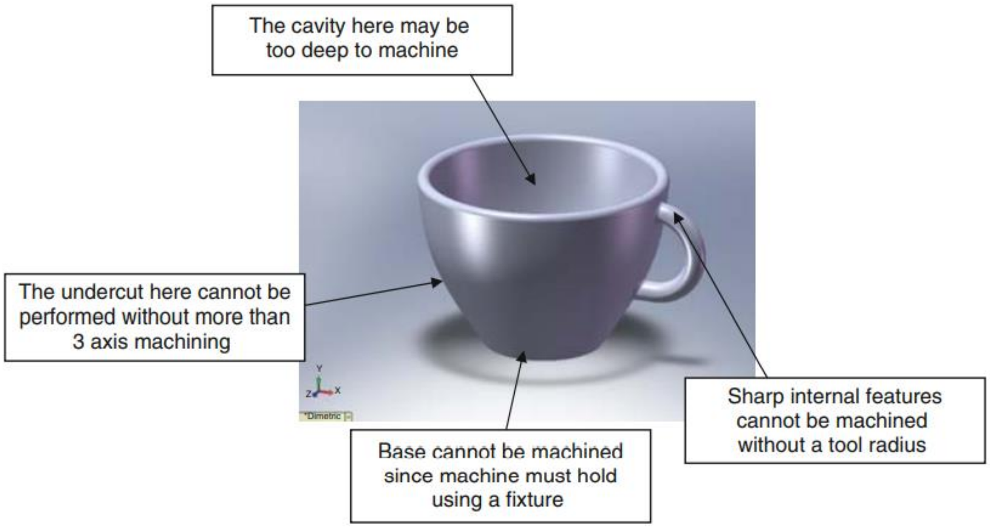
- As mentioned above, the higher the geometric complexity, the greater the advantage AM has over CNC.
- If CNC is being used to create a part directly in a single piece, then there are some geometric features that cannot be fabricated. Since a machining tool must be carried in a spindle, there may be certain accessibility constraints or clashes preventing the tool from being located on the machining surface of a part.
- AM processes are not constrained in the same way and undercuts and internal features can be easily built without specific process planning. Certain parts cannot be fabricated by CNC unless they are broken up into components and reassembled at a later stage.
- Consider, for example, the possibility of machining a ship inside a bottle. How would you machine the ship while it is still inside the bottle? Most likely you would machine both elements separately and work out a way to combine them together as an assembly process. With AM you can build the ship and the bottle all at once.

Accuracy

- AM machines generally operate with a resolution of a few tens of microns. It is common for AM machines to also have variable resolution along different orthogonal axes. Typically, the vertical build axis corresponds to layer thickness and this would be of a lower resolution compared with the two axes in the build plane.
- The accuracy of CNC machines on the other hand is mainly determined by a similar positioning resolution along all three orthogonal axes and by the diameter of the rotary cutting tools. There are factors that are defined by the tool geometry, like the radius of internal corners, but wall thickness can be thinner than the tool diameter since it is a subtractive process. In both cases very fine detail will also be a function of the properties of the build material.

Geometry

AM machines essentially break up a complex, 3D problem into a series of simple 2D cross-sections with a nominal thickness. In this way, the connection of surfaces in 3D is removed and continuity is determined by how close the proximity of one cross-section is with an adjacent one. Since this cannot be easily done in CNC.



Features that represent problems using CNC machining

Complex geometry can become extremely difficult to produce with CNC, even with 5-axis control or greater. Undercuts, enclosures, sharp internal corners and other features can all fail if these features are beyond a certain limit. Consider, for example, the features represented in the part in Fig. Many of them would be very difficult to machine without manipulation of the part at various stages.

Programming

Determining the program sequence for a CNC machine can be very involved, including tool selection, machine speed settings, approach position, and angle, etc. Many AM machines also have options that must be selected, but the range, complexity and implications surrounding their choice are minimal in comparison. The worst that is likely to happen in most AM machines is that the part will not be built very well if the programming is not done properly. Incorrect programming of a CNC machine could result in severe damage to the machine and may even be a safety risk.

OTHER RELATED TECHNOLOGIES

There are, however, other ways in which the STL files can be generated and other technologies that can be used in conjunction with AM technology.

REVERSE ENGINEERING TECHNOLOGY

- RE is the process of capturing geometric data from another object. This data is usually initially available in what is termed "point cloud" form, meaning an unconnected set of points representing the object surfaces.
- These points need to be connected together using RE software like **Geomagic,** which may also be used to combine point clouds from different scans and to perform other functions like hole-filling and smoothing.
- In many cases, the data will not be entirely complete. Samples may, for example, need to be placed in a holding fixture and thus the surfaces adjacent to this fixture may not be scanned. So the representation may not turn out exactly how the object is in reality.
- Engineered objects would normally be scanned using **laser-scanning or touch probe technology**.
- Objects that have complex internal features or anatomical models may make use of Computerized Tomography (CT), which was initially developed for medical imaging but is also available for scanning industrially produced objects. This technique essentially works in a similar way to AM, by scanning layer by layer and using software to join these layers and identify the surface boundaries. Boundaries from adjacent layers are then connected together to form surfaces. The advantage of CT technology is that internal

features can also be generated. High energy X-rays are used in industrial technology to create high resolution images of around 1 μm.

COMPUTER-AIDED ENGINEERING

- 3D CAD is an extremely valuable resource for product design and development. One major benefit to using software-based design is the ability to implement change easily and cheaply. If we are able to keep the design primarily in a software format for a larger proportion of the product development cycle, we can ensure that any design changes are performed virtually on the software description rather than physically on the product itself.
- The more we know about how the product is going to perform before it is built, the more effective that product is going to be. This is also the most cost-effective way to deal with product development. If problems are only noticed after parts are physically manufactured, this can be very costly.
- However, 3D CAD is also commonly linked to other software packages, often using techniques like finite element method (FEM) to calculate the mechanical properties of a design, collectively known as Computer-Aided Engineering (CAE) software. Forces, dynamics, stresses, flow, and other properties can be calculated to determine how well a design will perform under certain conditions. While such software cannot easily predict the exact behavior of a part, for analysis of critical parts a combination of CAE, backed up with AM-based experimental analysis, may be a useful solution.

Rapid prototyping and manufacturing (RP&M) technique has shown a high potential to reduce the cycle and cost of product development, and has been considered as one of crucial enabling tools in digital manufacturing to effectively aid rapid product development. Manufacturing industry is evolving toward digitalization, network and globalization. The Internet, incorporating computers and multimedia, has provided tremendous potential for remote integration and collaboration in business and manufacturing applications. RP&M technique using the Internet can further enhance the design and manufacturing productivity, speed, and economy, as well as share the RP machines. Web-based RP&M systems have been developed and employed to implement remote service and manufacturing for rapid prototyping, enhance the availability of RP&M facilities and improve the capability of rapid product development for a large number of small and medium sized enterprises.

Since the mid-1990s, the research and development of web-based RP&M systems have received much attention. Substantial investments have been made to support the research and practice of web-based RP&M systems from both the academic community and industrial bodies all over the world. A number of studies have been performed to explore the architecture, key issues and enabling tools for developing web-based RP&M systems.

Various Architectures for Web-based RP&M Systems

A variety of frameworks for developing web-based RP&M systems have been proposed. The Tele-Manufacturing Facility (TMF) is probably the first system that provides users with direct access to a rapid prototyping facility over the Internet. TMF allows users to easily submit jobs and have the system automatically maintain a queue. It can also automatically check many flaws in .STL (Stereo Lithography) files, and in many cases, fix them. A laminated object manufacturing (LOM) machine was first connected with network, and then the .STL file of a part to be built could be submitted to this machine via a command-line.

Luo and Tzou et al. presented an e-manufacturing application framework of a web-based RP system that mainly includes five parts for: (1) opening .STL file and displaying it using Open GL technology, (2) product quotation, (3) selecting a suitable RP system, (4) joint alliance, and (5) order scheduling.

Concurrent engineering (**CE**) is a work methodology emphasizing the parallelization of tasks (i.e. performing tasks concurrently), which is sometimes called **simultaneous engineering** or **integrated product development** (**IPD**) using an integrated product team approach. It refers to an approach used in product development in which functions of design engineering, manufacturing engineering, and other functions are integrated to reduce the time required to bring a new product to market.

Concurrent engineering, also known as simultaneous engineering, is a method of designing and developing products, in which the different stages run simultaneously, rather than consecutively. It decreases product development time and also the time to market, leading to improved productivity and reduced costs.

This **streamlined** approach towards an engineering product forces several teams such as **product design**, **manufacturing**, **production, marketing**, product **support**, **finance,** etc., within the organization to work simultaneously on new product development.

For instance, while engineering product designers begin to design the product, the sales team can start working on the marketing and the product support department can start thinking about the after-sale support. While the mechanical designers work on the packaging design to incorporate the PCB being developed by the electrical engineering team, the software engineers can start looking at the software code.

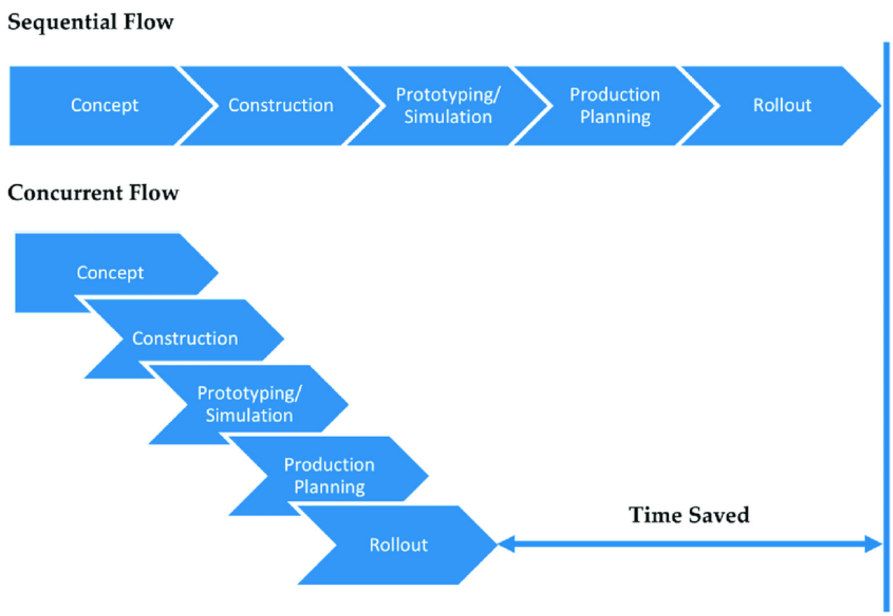
Advantages of concurrent engineering

- It encourages multi-disciplinary collaboration
- Reduces product cycle time
- Reduces cost
- Increases quality by supporting the entire project cycle – enhanced quality
- Increases productivity by stopping mistakes in their tracks
- Gives a competitive edge over the competitors

Disadvantages of concurrent engineering

- Complex to manage
- Relies on everyone working together hence communication is critical

- Room for mistakes is small as it impacts all the departments or disciplines involved



APPLICATIONS OF AM

Applications		
Design	***Engineering, Analysis and Planning***	***Manufacturing and Tooling***
• CAD-model verification (design specification) • Visualizing objects • Proof of concept • Marketing and presentation model	• Form and fit-models • Flow analysis • Analysis of stress distribution • Pre-series parts • Diagnostic and pre-surgical operation planning • Design and fabrication of custom protheses and implants	• Tooling mold parts — direct soft tools — indirect soft tools — direct hard tools — indirect hard tools • Casting — sand-casting — investment casting — evaporative pattern casting — die casting • EDM electrodes • Master models

Industries		
• Aerospace	• Automotive	• Biomedical
• Jewelry	• Coin	• Tableware
• Consumer electronics	• Home appliances	• etc.

Typical application areas of RP

APPLICATION IN DESIGN

1. CAD Model Verification

This is the initial objective and strength of RP systems, in that designers often need the physical part to confirm the design that they have created in the CAD system. This is especially important for parts or products designed to fulfill aesthetic functions or that are intricately designed to fulfill functional requirements.

2. Visualizing Objects

Designs created on CAD systems need to be communicated not only amongst designers within the same team, but also to other departments, like manufacturing, and marketing.

Thus, there is a need to create objects from the CAD designs for visualization so that all these people will be referring to the same object in any communications.

3. Proof of Concept

Proof of concept relates to the adaptation, of specific details to an object environment or aesthetic aspects (such as car telephone in a specific car), or of specific details of the design on the functional performance of a desired task or purpose.

4. Marketing and Commercial Applications

Frequently, the marketing or commercial departments require a physical model for presentation and evaluation purposes, especially for assessment of the project as a whole. The mock-up or presentation model can even be used to produce promotional brochures and related materials for marketing and advertising even before the actual product becomes available.

AEROSPACE INDUSTRY

There are abundant examples of the use of RP technology in the aerospace industry. The following are a few examples.

1. Design Verification of an Airline Electrical Generator

Sundstrand Aerospace, which manufactures electrical generators for military and commercial aircraft, needed to verify its design of an integrated drive generator for a large jetliner. It decided to use Helisys's LOM to create the design-verification model. The generator is made up of an external housing and about 1200 internal parts. Each half of the housing measures about 610 mm in diameter and 300 mm tall and has many intricate internal cavities into which the sub-assemblies must fit.

Such complex designs are difficult to visualize from twodimensional drawings. A physical model of the generator housing and many of its internal components is a good way to identify design problems. But the time and expense needed to construct the models by traditional means are quite impossible.

Thus Sundstrand decided to turn to RP technologies. Initial designs for the generator housing and internal sub-assemblies were completed on a CAD system and the subsequent STL files were sent to a service bureau. Within two weeks, Sundstrand was able to receive the parts from the service bureau and began its own design verification. Sundstrand assembled the various parts and examined them for form, fit, and limit function. Clearances and interferences between the housing and the many sub-assemblies were checked. After the initial inspection, several problematic areas were found which would have otherwise been missed. These were corrected and incorporated into the CAD design, and in some cases, new RP models were made.

Though the approximate cost for the RP models was US$16 500, the savings realized from removing engineering and design changes were immeasurable, and the time saved (estimated to be about eight to ten weeks) was significant.

2. Engine Components for Fanjet Engine

In an effort to reduce the developmental time of a new engine, AlliedSignal Aerospace used 3D Systems' QuickCast™ to help to produce a turbofan jet engine for a business aviation jet.

Basically, RP is used for the generation of the casting pattern of an impeller compressor shroud engine component. This part is the static component that provides the seal for the high-pressure compressor in the engine.

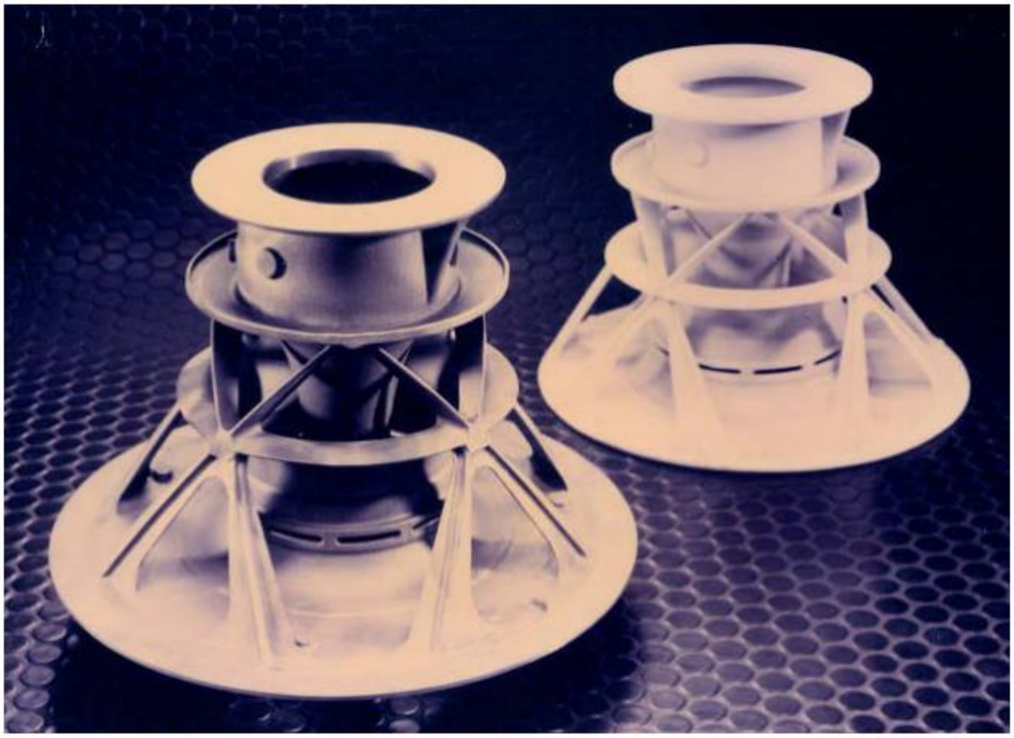
Using QuickCast, the 3D Technology Center was able to directly produce patterns for investment castings using the stereolithography technology. The patterns produced were durable, had improved accuracy, good surface finish and were single large piece patterns.

With the use of these RP techniques, production time was slashed by eight to ten weeks, and a savings of US$50 000 was realized.

3. Prototyping Air Inlet Housing for Gas Turbine Engine

Sundstrand Power Systems, a manufacturer of engines for military and commercial aircraft, needed prototypes of air inlet housing for a new gas turbine engine. The part, which is very complex in design, would have been difficult and costly to build using traditional methods.

To realize the part, Sundstrand used DTM's SLS system to build the evaluation models of the housing and then generate the necessary patterns for investment casting, ultimately the method used for the manufacture of inlet housing.



Polycarbonate investment-casting pattern (right) and the steel air inlet housing (right) for a jet turbine engine (Courtesy DTM Corporation)

4. Fabrication of Flight-Certified Production Castings

Bell Helicopter has successfully used stereolithography, first to verify parts design, then to aid with fit and functional testing, and finally to produce investment casting patterns for the manufacture of Federal Aviation Authority (FAA)-certifiable production parts. About 50 of the parts that made up the new helicopter's flight control system were developed with stereolithography.

AUTOMOTIVE INDUSTRY

1. Prototyping Complex Gearbox Housing for Design Verification

Volkswagen has utilized Helysis's LOM to speed up the development of large, complex gearbox housing for its Golf and Passat cars.

The CAD model for the housing was extremely complex and difficult to visualize. VW wanted to build a LOM part to check the design of the CAD model. Using traditional methods, such a prototype would be costly and time consuming to build and it may not be always possible to include all fine details of the design. All these difficulties were avoided by using RP technology as the fabrication of the model was based entirely on the CAD model created.

The gearbox housing was too large for the build volume of the LOM machine. The CAD model was thus split into five sections and reassembled after fabrication. It took about ten days to make and finish all five sections, and once they were completed, patternmakers glued them together to complete the final model.

The LOM model was first used for verifying the design, and subsequently, to develop sand-casting tooling for the creation of metal prototypes. The RP process had shrunk the prototype development time from eight weeks to less than two, and considerable time and cost savings were achieved.

2. Prototyping Advanced Driver Control System with Stereolithography

At General Motors, in many of its divisions, RP is becoming a necessary tool in the critical race to be first to market. For example, Delco Electronics, its automotive electronics subsidiary, was involved in the development of the Maestro project. Designed to blend an advanced Audio

System, a hands-free cellular phone, Global Positioning System (GPS) navigation, Radio Data System (RDS) information, and climate control into a completely integrated driver control system. With many uniquely-shaped push-buttons (as many as 108) the time needed to develop the system was the most critical factor.

The models for each button face were manually machined. Once the designs were confirmed, the machined models were laser scanned, generating the CAD data needed for the creation of SLA models. The final prototype buttons needed to be accurate enough to ensure proper fit and function, as well as be translucent, so that they could be back-lit.

Then the SLA models were generated on 3D Systems' SLA machine installed in the actual prototype vehicle, eliminating the need for rubber molds. The result was that in less than four months, Delco Electronics was able to complete the functional instrument panel, with all 108 buttons built using the SLA.

3. Creating Cast Metal Engine Block with RP Process

As new engine design and development is an expensive and time consuming process, the ability to test a new engine and all its auxiliary components before actual manufacturing is important in ensuring costs and time savings. The Mercedes-Benz initiated a program of physical design verification on prototype engines using SLA parts for initial form and fit testing. After initial design reviews, metal components were produced rapidly using the QuickCast process.

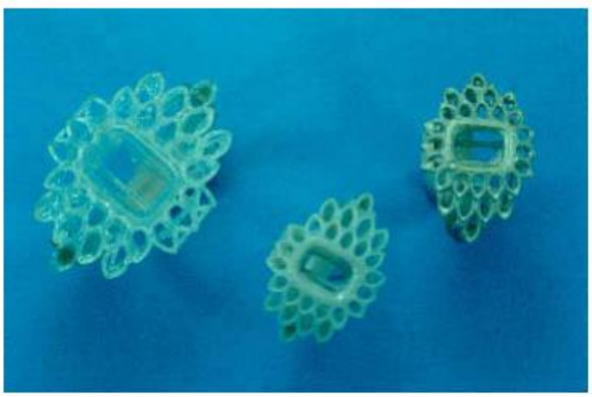
Their first project was the design and prototyping of a four-cylinder engine block for the new Mercedes-Benz "A-Class" car. The aim was to cast the engine block directly from a stereolithography Quick Cast pattern. The engine block was designed on Mercedes-Benz own

CAD system, and the data were transferred to 3D Systems Technology Center at Darmstadt, where the one-piece pattern of the block was built on the SLA machine.

JEWELRY INDUSTRY

The jewelry industry has traditionally been regarded as one which is heavily craft-based, and automation is generally restricted to the use of machines in the various individual stages of jewelry manufacturing.

The use of RP technology in jewelry design and manufacture offers a significant breakthrough in this industry. In an experimental computeraided jewelry design and manufacturing system jointly developed by Nanyang Technological University and Gintic Institute of Manufacturing Technology in Singapore, the SLA process was used successfully to create fine jewelry models. These models were used as master patterns to create precious metal end product.



An investment cast silver alloy prototype of a broach (right), the full-scale wax pattern produced from the silicon rubber molding (center), and the two-time scaled SLA model to aid visualization (left)

In an experiment with the design of rings, the overall quality of the SLA models were found to be promising, especially in the generation of intricate details in the design. However, due to the nature of the step-wise building of the model, steps at the slope of the model were visible. With the use of better resin and finer layer thickness, this problem was reduced but not fully eliminated.

Though post-processing of SLA models is necessary in the manufacture of jewelry, the ability to create models quickly (a few hours compared to days or even weeks, depending on the complexity of the design) and its suitability for use in the manufacturing process offer great promise in improving design and manufacture in the jewelry industry.

BIOMEDICAL INDUSTRY

1. Operation Planning for Cancerous Brain Tumor Surgery

In one case study, a patient had a cancerous bone tumor in his temple area and because of that the surgeon would have to access the growth via the front through the right eye socket. The operation was highly dangerous as damage to the brain was likely which would result in the impairment of some motor functions. In any which way, the patient would have lost the function of the right eye. However, before proceeding with the surgery, the surgeon wanted another examination of the tumor location, but this time using a three-dimensional plastic replica of the patient's skull. By studying the model, the surgeon realized that he could re-route his entry through the patient's jawbone, thus avoiding the risk of harming the eye and motor functions. Eventually, the patient lost only one tooth and of course, the tumor. The plastic RP model used by the surgeon was fabricated by the SLA from a series of 2D CT scans of the patient's skull.

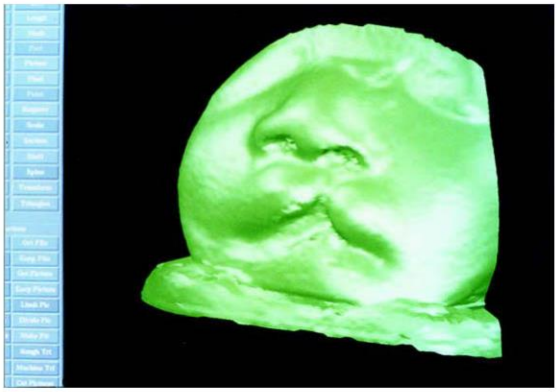
2. Planning Reconstructive Surgery with RP Technology

Due to a traffic accident, a patient had a serious bone fracture on the upper and lateral orbital rim in the skull. In the first reconstructive surgery, the damaged part of the skull was transplanted with the shoulder bone, but shortly after the surgery, the transplanted bone had dissolved. Thus, it was necessary to perform another surgery to transplant an artificial bone that would not dissolve.

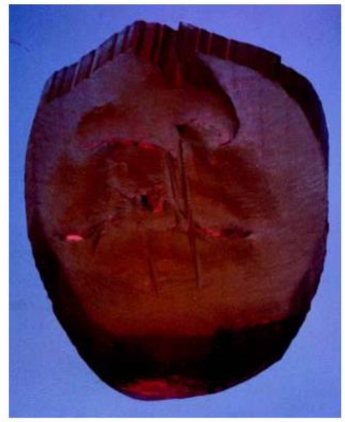
The conventional procedure of such a surgery would be for surgeons to manually carve the transplanted bone during the operation until it fitted properly. This operation would have required a lot of time, due to the difficulty in carving bone, let alone during the surgery. Using rapid prototyping, a SLA prototype of the patient's skull was made and then used to prepare an artificial bone that would fit the hole caused by the dissolution. This preparation not only greatly reduced the time required for the surgery, but also improved its accuracy.

3. Craniofacial Reconstructive Surgery Planning

Restoration of facial anatomy is required in cases of congenital abnormalities, trauma or post cancer reconstruction. In one case, the patient had a deformed jaw by birth, and a surgical operation was necessary to amputate the shorter side of the jaw and change its position. The difficult part of the operation was the evasion of the nerve canal that runs inside the jawbone. Such an operation was impossible in the conventional procedure because there was no way to visualize the inner nerve canal. Using a CAD model reconstructed from the CT images, it clearly showed the position of the canal and simulation of the amputating process on workstations was a good support for surgeons to determine the actual amputation line.



CAD model from laser scanner data of a patient's facial details



SLA model of a patient's facial details

4. Knee Implants

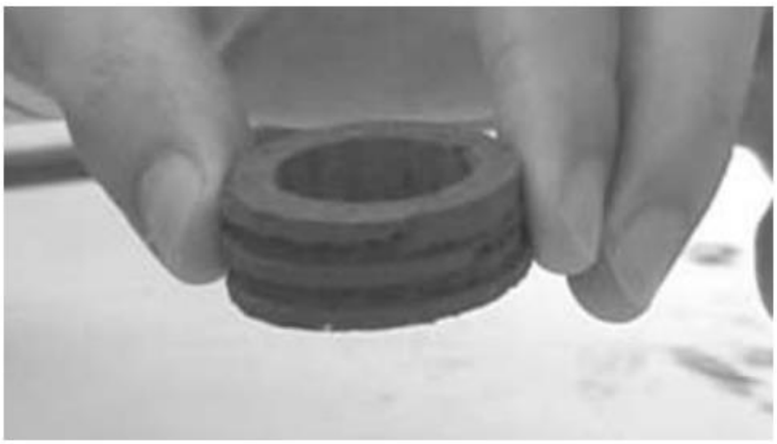
Engineers at DePuy Inc., a supplier of orthopedic implants, have integrated CAD and RP into their design environment, using it to analyze the potential fit of implants in a specific patient and then modifying the implant design appropriately. At DePuy, SLA plays a major role in the production process of all the company's products, standard and custom. The prototypes are also used as masters for casting patterns to launch a product or to do clinical releases of a product.

5. Scaffolds for Tissue Engineering

Tissue engineering has been used to replace failing or malfunctioning organs such as skin, liver, pancreas, heart valve leaflet, ligaments, cartilage and bone. This has given rise to the interests in applying RP techniques to build scaffolds either to induce surrounding tissue and cell in-growth or serve as temporary scaffolds for transplanted cells to attach and grow onto. These scaffolds can be designed in threedimensions on CAD taking into consideration the porosity and good interconnectivity for tissue induction to occur. RP has been able to lend itself to producing complex geometry scaffolds.

6. Inter-Vertebral Spacers

Human spinal vertebras can disintegrate due to conditions such as osteoporosis or extreme forces acting on the spine. In the management of such situations, a spacer is usually required as part of the spinal fixation process. RP has been investigated for the production of such spacers as it is an ideal process to fabricate 3D structures with good interconnecting pores for the promotion of tissue in-growth. Other considerations for producing such an implant are that the material is biocompatible, and that the mechanical compressive strength of the spacer is able to withstand spinal loads.



Spacer

WEB BASED RAPID PROTOTYPING SYSTEMS

- Rapid prototyping and manufacturing (RP&M) technique has shown a high potential to reduce the cycle and cost of product development.
- It has been considered as one of crucial enabling tools in digital manufacturing.
- Manufacturing industry is evolving toward digitalization, network and globalization. The Internet, incorporating computers and multimedia, has provided tremendous potential for remote integration and collaboration in business and manufacturing applications.

- With the rapid development of the Internet technologies, they have been widely employed in many developing manufacturing systems to associate with various product development activities, such as marketing, design, process planning, production, customer service, etc., distributed at different locations into an integrated environment.
- It has now been widely accepted that the future patterns of manufacturing organizations will be information oriented, knowledge driven and many of their daily operations will be automated around a global information network that connects everyone together.
- The integration and collaboration among different partners of the product development team can largely improve the product quality; reduce the product development cost and lead-time.
- RP&M technique using the Internet can further enhance the design and manufacturing productivity, speed, and economy, as well as share the RP machines.
- Web-based RP&M systems have been developed and employed to implement remote service and manufacturing for rapid prototyping.
- It enhances the availability of RP&M facilities and improves the capability of rapid product development for a large number of small and medium sized enterprises.

Web-based RP&M Systems: a Comprehensive Review

- Since the mid-1990s, the research and development of web-based RP&M systems have received much attention. Substantial investments have been made to support the research and practice of web-based RP&M systems from both the academic community and industrial bodies all over the world.
- A number of studies have been performed to explore the architecture, key issues and enabling tools for developing web-based RP&M systems.

- A variety of frameworks for developing web-based RP&M systems have been proposed. The Tele-Manufacturing Facility (TMF) is probably the first system that provides users with direct access to a rapid prototyping facility over the Internet. TMF allows users to easily submit jobs and have the system automatically maintain a queue. It can also automatically check many flaws in STL (StereoLithography) files, and in many cases, fix them. A laminated object manufacturing (LOM) machine was first connected with network, and then the .STL file of a part to be built could be submitted to this machine via a command-line.

FLEXIBLE MANUFACTURING SYSTEM (FMS)

Flexibility can have different interpretations; but it generally refers to the system's responsiveness to changing demand patterns, so that the mix of part styles in the system and the production volume that can be adjusted rapidly to meet changing requirements.

So FMS is the production with machine systems capable of making a different product without retooling or similar changeover.

In today's competitive global market, manufactures have to modify their operations to ensure a better and faster response to needs of customers, higher quality of products and faster response in introduction of new products. In conventional manufacturing change cannot be tolerated as it relied on economics of scale.

FMS not only improves productivity but also provides the required flexibility enabling the factories to become more reactive to market demand.

COMPONENTS OF FMS:

a. **WORKSTATIONS/PROCESSING STATIONS:** The workstations are typically CNC machine tools that perform machining operations on families of parts.

The various workstations are:

i) Machining centre: are usually CNC machine tools with appropriate automatic tool changing and tool Storage features to facilitate quick physical changeover as necessary.

ii) Load and unload stations: is the physical interface between the FMS and the rest of the factory where raw parts enter the system and completely processed parts exit the system.

iii) Assembly workstations: consists of a number of workstations with industrial robots that sequentially assemble components of the base parts to create the overall assembly.

iv) Inspection stations: the parts manufactured are inspected here for quality purpose.

v) Others: sheet metal fabrication which has station for press working operations, such as punching, shearing, forging stations. |

vi) Supporting: may include inspection stations where CAM, special inspection probes and machine vision may be used, other stations may include part washing stations and temporary storage stations.

b. MATERIAL HANDLING AND STORAGE SYSTEMS:

- The primary material handling system establishes the FMS layout and is responsible for moving parts between stations in the system.

- The secondary handling system consists of transfer devices, automatic pallet changers and other mechanisms to transfer parts from the primary material handling system to the work head of the processing station or to a supporting station. It is also responsible for the accurate positioning of the part of the workstation, so that the machining process may be performed upon the part in the correct manner.
- Other purposes include re-orientation of the part if necessary to present the surface that is to be processed and to act as buffer storage as the workstation.

The functions of the material handling and storage system in FMS are:

- Allows random and independent movement of the work parts between stations
- Enables handling of a variety of work part configurations by means of pallet fixtures for prismatic parts and industrial robots for rotational parts.
- Provide temporary storage.
- Provides convenient access for loading and unloading work parts at load and unload stations. Creates compatibility with computer control so that the computer system can direct it to the various workstations, load/unload stations and storage areas.

c. COMPUTER CONTROL SYSTEM:

FMS uses a distributed computer system that interfaces with all work stations in the system, as well as with the material handling system and other hardware components.

It consists of a central computer and series of microcomputers that control individual machines in FMS.

The central computer co-ordinates the activities of the components to achieve smooth operational control of the System.

The various functions are:

Control of each workstation: often in the form of a CNC control.

Distribution of control instructions: to workstations by means of a central computer to handle the processing occurring at different workstations.

Production control: management of the mix and rate at which various parts are launched into the system is important,

Traffic control: so that parts arrive at right location at the right time and night condition.

Shuttle control: to ensure the correct delivery of the work part to the station's work head.

Workpiece monitoring: to ensure that we know the location of every element in the system.

Tool control: is connected with managing tool location and tool life.

Performance monitoring: and reporting: the computer must collect the data on the various operations ongoing in the FMS and present performance findings based on this.

Diagnostics: the computer must be able to diagnose, to 4 high degree of accuracy, where a problem may be occurring in the FMS.

OPERATION OF FMS

Workparts are loaded and unloaded at a central location in the FMS. Pallets are used to transfer workparts between machines. Once a part is loaded onto the handling system, it is automatically routed to the particular workstations required in its processing. For each different workpart type, the routing may be different, and the operations and tooling required at each workstation will also differ. The coordination and control of the parts handling and processing activities is accomplished under command of the computer, One or more computers can be used to control a single FMS. To computer system is used to control the machine tools and material handling system, to monitor the performance of the system and to schedule production.

Flexible manufacturing systems provide the ability economically to manufacturing small volumes of many different parts. This

(i) Reduces work-in-process inventory,

(ii) provides increased capacity due to reductions in set-up times,

(iii) Better predictability and control of operations and scheduling,

(iv) Reduction in material-handling costs, and

(v) Greater sensitivity to market requirement.

SPECIAL PURPOSE MACHINES

Special purpose machines (SPM) are those machines which are not available off the shelf and these are not covered in standard manufacturing process; these are designed and tailored made as per the customer specific requirements.

Different layouts of special purpose machines

There are two layouts for SPMs:

1. Single-station
2. Multi-station

In single station the workpiece is held in a fixed position where machining and sliding units are situated around it with the end goal that they can handle the part from various headings.

On account of different machining units, they may deal with the part at the same time or in grouping relying upon the math of the workpiece and machining highlights

Different types of special purpose machines include - (a) Single-station, (b) Special application, (c) Transfer machine, (d) Rotary machine, and (e) In-line operation machine.

Various types of special purpose machines

- SPM for metal cutting
- Special purpose computer numerical control machine
- SPM for vertical turning machine
- Rotary indexing drilling and tapping SPM
- SPMs for multi and simultaneous operations such as drilling, milling, boring etc

Introduction to Special Purpose Machine Tools:

Special purpose machine tools are designed and manufactured for specific jobs and as such never produced in bulk. Such machines are finding increasing use in industries. The techniques for designing such machines would obviously be quite different from those used for mass produced machines. A very keen judgment is essential for success of such machines.

Broadly the special purpose machine tools could be classified as those in which job remains fixed in one position and those in which job moves from one station to other (transfer machines). In first case the machine may perform either only one operation or more.

In the second case, the product may be either moving continuously (as in the case of spraying, polishing, sanding etc.) or intermittently (the most usual case in machining operation). Rotary intermittent motion transfer machine is very popular production machine and is described in brief below.

Such a machine comprises a turret, on whose periphery several heads are mounted to receive and locate the components for working. The turret rotates intermittently about its central axis and is provided with fine and sophisticated mechanisms to control its motion so that before stopping, it is properly decelerated and desired positioning accuracy is attained.

At stationary positions around the turret, usually mounted on a table, are the several tools and units which perform the machining operation. It is essential that all movements be completely synchronized in order to obtain desired product.

All tools and units must have completed their operation and be withdrawn clear of the turret before it starts to index. Similarly the turret must index precisely and accurately and come to rest, before tools and units begin their work.

Index Mechanisms of Special Purpose Machine Tools:

There are a variety of index mechanisms and these needs to be selected properly to suit the given requirements. A versatile indexing unit used in presses, drilling machines and other special purpose machines is described below. Number of indexes, speed of index and dwell time, etc. can be readily changed in this mechanism.

It operates by fluid power and uses ratchet and pawl mechanisms. One cylinder moves a gear rack assembly which is in mesh with a pinion gear keyed to a shaft on which the turret is mounted. Thus the linear movement of cylinder rotates the turret by a predetermined amount to the next indexing position.

The rack assembly is arranged in a pair, parallel to each other on either side of the pinion. Only one rack contacts the pinion. By another power cylinder mounted at right angle to the previous power cylinder, it is possible to make one of the two racks engage the pinion. Thus both forward and backward stroke of main cylinder can be utilized to rotate the turret in same direction. Arrangements are also made to govern the feed rate of the main cylinder.

Along with turret a dividing wheel having indexing holes on its periphery is also mounted. Second cylinder which changes position of lock also operates a moving stop which engages the dividing wheel. During dwell, the turret is locked in position because first cylinder clamps the dividing wheal against the stop.

In a simple indexing mechanism used in lamp industry, a number of follower rollers (ground to close tolerances and to accurate concentricities) are mounted on the underside of the turret on a common pitch circle diameter.

A cross-over cam engages the follower rollers and is mounted on the main camshaft of the machine and driven by a motor through reduction gearing. The cam consists of a ridge perpendicular to the cam shaft and this ridge fits precisely in the space between two adjacent follower rollers, thus locking the turret to the cam.

The two ends of the ridge are curved outward and away from each other so that when the cam rotates the curved portions interact against the follower rollers causing a positive transference of movement to the turret.

The sides of the follower rollers are ground conical in order to give true running conditions without scuffing. The straight portion of the ridge does not interact against the rollers and this represents the dwell portion of the cam.

Types of Special Purpose Machine Tools:

In general, rotary index types of machine tools are used for smaller size of component. The components are usually located into jig against fixed stop. Components are clamped and un-damped hydraulically. Sometimes for safety reasons, machine can be started only by depressing two push buttons spaced well apart. The un-machining movements are designed to be quite fast, and feed during machining operation is judiciously selected with some dwell at the end.

Some manufacturers produce modular units of machine which can be assembled to produce a variety of machine tools as per requirement. Multi-spindle heads are used to perform parallel operations of similar size and depth.

Various standard attachments which can be used in construction of machine tools are coolant distributor, anti-friction rotary bushing centre for drilling unit to guide tools or tool holders, angular feed head, recessing head, milling head, planetary speed reducer, hydraulic slide for longer strokes, rotary index table, etc.

For larger components, in line transfer machine is used. Such a machine consists of a series of machining units with their respective work-holding fixtures linked with work piece skid rails. All units are designed to be electrically interlocked to perform their functions in a predetermined sequence.

All machine motions and fixture clamps and locators are operated hydraulically. Machining operations are carried out at several working stations and several idle stations are provided to give adequate access for tool changing and maintenance.

Parts Handling Equipment for Special Purpose Machine Tools:

Handling and storage of parts have become a functioning part of the manufacturing system. There are no universal parts handling equipment which can be used for all feeding jobs at all rates of feed. A variety of feeders and orienting devices are available for handling parts.

It is important to understand how the performance of these devices is affected by configuration of the parts to be handled. Every part to be fed mechanically demands special consideration. Automatically feeding/orienting individual parts from a bulk supply depends upon some type of part agitation or mass part movement.

In the process, some parts assume the desired orientation and are separated from the others. Automatic feeder is not always the solution, particularly when the parts are not rugged enough to withstand agitation, or have a surface finish that can be marred, or tend to tangle with each other, or do not have some shape or weight characteristic that allows those with a desired orientation to be selected. In some cases it may be desirable to use magazine or a container to hold parts in a desired orientation for feeding into processing equipment.

A brief description of several types of feeders with their characteristics is given below:

(i) Rotary Disc Hopper Feeder:

It consists of disc which can rotate within a stationary hopper. Multiple profiles are machined or cast into face of this disc (to suit the component fed) so that parts can be picked up by these profiles and these parts are then guided by a cam into a discharge chute. Such feeders are especially suitable for headed parts and cylindrical parts requiring no end selection.

(ii) Centre Board Hopper Feeder:

In this feeder, a blade made of hardened steel, with a shaped top/groove is oscillated up and down (by a crank mechanism and a geared reduction unit) through a mass of parts. In the process, some properly oriented parts are picked up by the blade and discharged by gravity into a track. The form of the groove and the shape of the top edge are evolved by trial.

This type of feeder is suitable for parts having simple shape like balls, cylinders, short lengths of tube headed parts, nuts and bolts, rivets etc. where high feeding rate is desirable. They are very robust and have long working life. They can’t be used for fragile components and the degree to which they can orient is rather limited. The capacity of centre board hopper is large.

(iii) Tumbling Barrel Hopper Feeder:

In this hopper the parts are continuously agitated by the vanes in the rotating barrel. As a result some parts drop into a shaped track and are captured for discharge into a track which can move parts by gravity or vibration force. This type of feeder is suitable for handling irregular shapes and a wide variety of part sizes.

(iv) Horizontal Belt Feeder:

In this type of feeder, horizontal belts move side-by-side in opposite directions. Several deflector blocks are mounted to orient the parts and to circulate parts between belts or guide parts to a discharge track, and one blade contains a profile to pass correctly oriented parts. It is suitable for delicate parts which are likely to be chipped or scratched.

(v) Reciprocating Tube Hopper Feeder:

In this feeder, parts are picked up as a tube reciprocates to present the tube opening to a mass of products. The parts picked up are discharged into a track for further feeding. It is suitable for simple forms like balls or other regular shapes where random orientation is satisfactory.

(vi) Oscillating Box-Feeder:

In this feeder, the parts are tumbled as the box hopper oscillates about a pivot at one end. The properly oriented parts pass through a selection gate at the pivot end onto holding tracks. It is possible to incorporate dividers into the box so that several types and sizes of parts can be sorted and fed simultaneously.

(vii) Elevator Hopper Feeder:

In this type of feeder a blade flights on an elevating mechanism to pick up some parts from a mass in a storage hopper. Parts picked up are discharged into a delivery chute where these are further oriented and selected. It can handle large part size and the feed rate is very high. It is used for large hopper capacities.

(viii) Vibratory Feeder:

In this feeder a supporting surface is vibrated at a predetermined rate (to control feed) to make the parts move. The parts are then oriented by a series of devices mounted along the line of travel. In it, different parts can be handled simultaneously. Feeders may be circular bowls, or straight line, horizontal type.

Operating efficiency of vibratory feeders is sensitive to total weight of parts being vibrated, weight of individual parts, contact area and coefficient of friction between part and surface. Parts discharged from a feeder move via a track to an escapement mechanism that regulates parts flow according to the needs of processing equipment. Special measures are taken to avoid jamming of parts.

Escapements may be reciprocating, oscillating, or rotary mechanisms built around jaws, ratchets, gates, wheels shuttles or drum. Final part handing may require some type of placement mechanism—usually a push-and-guide or pick- and-place type.

The following points must be thoroughly considered in designing a parts handling problem:

(i) Part design should permit efficient feeding. Often it is found that part redesign might solve some of the problems associated with parts handling. For example, parts that tend to become interlocked with one another when agitated can be suitably redesigned to eliminate tangling tendency. The soft and thin parts require special consideration to avoid their damage and buckling.

(ii) Since feeder problems may be experienced with burrs on metal parts, or oil on them (which would collect dust and foul feeder tracks), or other foreign material along with parts, these should be properly inspected before feeding.

(iii) The feeder should have adequate feed rate to match with the cycle time of product on equipment. Time necessary to feed, orient and place an individual part must be properly evaluated. Other factors to be considered in hopper design are space requirement and availability of feeder, hopper load for optimum feeder performance, access to hopper, frequency of hopper refill.

(iv) The desired orientation of parts is an important condition which is dictated by machine served by the feeder. The proper feeder capable of providing preferred orientation is selected after studying the preferred orientation of part shape and profile. The preferred orientation is then changed to required orientation by track and escapement design or pick-and-place mechanism.

(v) Auxiliary controls, devices, mechanisms also deserve full attention. Arrangements to detect feeder malfunctions, for fall out of dirt or foreign material on track, removable track covers at points of likely jams etc. need to be provided.

Input/Output Control Equipment:

Input/output equipment for any machine tool provides communication mechanism. With increase in automation, electro-mechanical limit switches constitute most important communication mechanism. These switches usually have single-pole contact block with one normally open (NO) and one normally closed (NC) contacts. Time delayed contact limit switches are used for detecting machine jam-up by causing switch to remain actuated beyond a predetermined time interval.

Maintained contact switches are used where a second definite reset motion is desired. Push-in roller limit switch is used for linear or rotary cam actuation. Forked roller lever limit switch is used for reversing operations. Wobble stick limit switch is used for actuation in variety of directions. In addition, a very wide variety of limit switches are available.

Proximity Switches are also essential with increase in automation. These sense presence or absence of a target without touching it. The various types are magnetic, capacitive, ultrasonic, inductive and photoelectric. Magnetic switch is made of a magnetically-activated reed and a stationary contact. When a magnet is brought towards the switch an induced magnet field causes the movable reed to close upon the stationary contact.

It is the simplest device, low in cost, can be operated on AC or DC supply and can operate in dusty environment. However, it is sensitive to shocks and can't be mounted on ferrous base. Capacitive type proximity switch consists of a sensing plate forming one side of a resonating capacitor which forms part of a tuned oscillator circuit.

When an object is brought close to the sensing plate, the oscillator produces a signal which is rectified to trigger output circuitry. It can sense metallic and non-metallic targets but is sensitive to temperature change and is affected by humidity changes.

In ultrasonic type of proximity switch, a transmitter directs an ultrasonic signal to a receiver mounted in a remote location. When an object interrupts the beam, the output device is tripped. Wide range of distance sensing is possible and this device can operate satisfactorily in dirty or wet environments.

However, targets must be non- porous. Its working is affected by rapid air movement and its accuracy is relatively low. Radio frequency inductive proximity switch consists of an oscillator that produces a radio frequency signal.

When a conductive object is introduced in the field, eddy current losses are induced on the target's surface, absorbing energy and decreasing the amplitude of radio frequency signal. It is very fast in operation and can sense all conductive materials and has high repeatability.

Photoelectric proximity switches consist of light-emitting-diode (LED) emitting light in the infrared region, and a pulsed or modulated signal prevents most ambient-light interference. It can detect all materials in sizes upto fine wires. Dirty atmosphere can clog the lens and hence affect performance.

Fibre Optic Scanners are also finding wide applications in machine tools. These are resistant to shock, vibration, moisture, corrosion, environment temperature, electrical noise. The sensing tips are extremely small and available in a number of shapes.

For counting parts, electric scales are used. Sophisticated input/output controls like voice data entry and machine vision technology are also finding application in machine tools.

Control Systems:

Control systems for machine tools range from relay panels, programmable controllers, computerised numerical controllers and drive systems to highly complex computers. An automated factory consists of any of these in combination with robots, distributed control, and data communications networks.

Programmable controllers have been very effective in improving production line uptime, lower maintenance cost, increasing production volume and product uniformity, optimum space utilisation etc. The programmable controllers used should be compatible with the communications network. In deciding the extent of automation, the cost/value ratios should be determined.

Electric Power Supply:

Most of the drives of machine tools and controls require electric power supply. Uninterrupted power supply obtained by batteries or back up engine generators is essential for computer systems. High production rates and high costs of idle time and materials demand that no part of a plant should be shut down unnecessarily.

Nuisance tripping of branch and feeder circuits needs to be avoided by using better protective devices such as breakers and ground fault protection and better coordination of such devices among main branch, and feeder circuits.

Microprocessor technology is being used to achieve circuit protective devices to obtain precise co-ordination. Power supply for microprocessor based equipment should be clean, i.e. contain no voltage spike from any disturbances in the system or by external influence.

Drives and Drive Controls:

The rotary shafts and linear motion members are most important for any machine tool. The use of high efficiency motors is desirable. Since drive efficiency is the product of all drive component efficiencies, all drive line components should be efficient.

This also reduces heat dissipation, thereby extending equipment life. Adjustable speed drives play a greater role in energy conservation. Both AC and DC motors are available with adjustable speeds. DC motors with no brushes and easily replaceable modular components are available.

Hydraulic and mechanical adjustable speed drives are also available. Electric motors with soft-start devices (fluid or mechanical, with coupling in the drive line, or solid state electrical soft start) devices and injection brakes (injecting DC into starter) are also available. Other good tips in improving drives are use of high ratio helical-gear drives for large speed reductions instead or worm-gear drive, efficient V-belts, high water based fluids for hydraulic systems etc.

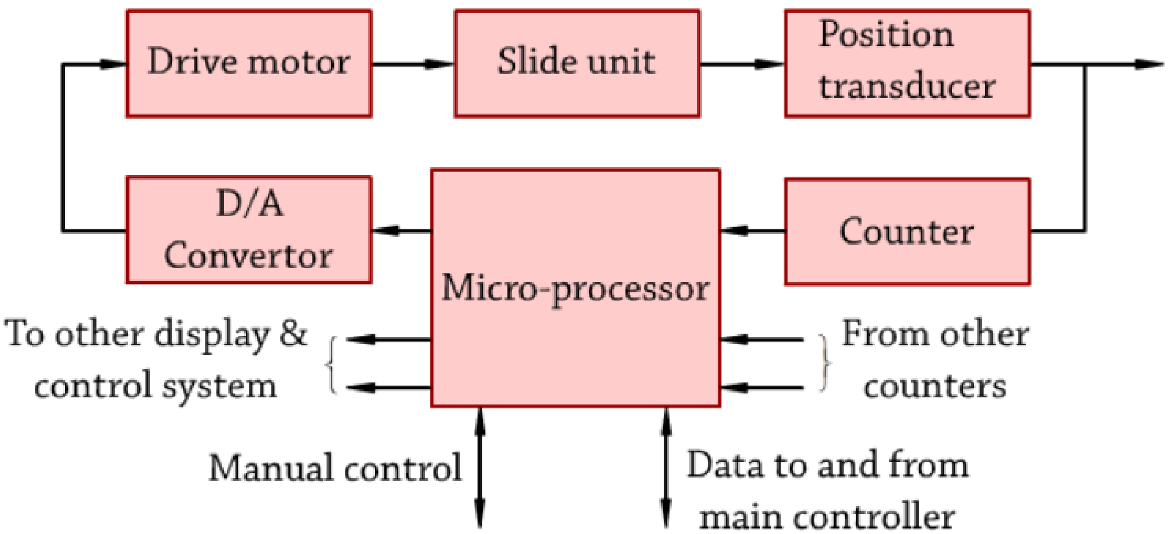
Control of Special Purpose Machine Tools:

Special purpose machines are not produced in large quantities since these are specially tailored for each application. These are basically multi-way, multi-spindle machines. Many tools work on the same work piece from different directions. It is essential that each tool be controlled independently, and as the number of units to be controlled are many the control of these machines is different from other NC and CNC machines.

Slides are controlled by independent position and speed controllers which in turn interface with main controller. The main controller also provides interface between the user and machine. The control system for such machines must employ modular control and programming system so that these could be easily tailored for each application.

Provision for adjusting position commands and spindle and slide-speeds is made after the programming is done in order to optimize the machining. Programming can be done by push buttons on the control unit. Specially made fixed subprograms are used to make programming easier.

Work piece handling systems such as robots capable of being interfaced with the control system are used. A controller block diagram for a slide unit is shown in Fig. The slide position is sensed by a rotating or linear incremental transducer like resolver.



The pulses from transducers are fed to counter. Every slide unit has its own counter. The counter is read by the microprocessor and slide position is compared with the command value and the error signal is used to calculate the output signal to D/A (Digital to analog) convertor. D/A converter also act as a buffer memory.

When the controller is in auto mode, it gets new position and speed values from main controller. In accordance with speed value, a position increment is calculated and every time the position command value is executed that position command value is increased or decreased with this increment until the desired position is reached. After the command is executed, the main controller is informed and slide remains in last position till fresh command is received.

Special Purpose Machines range from dedicated production milling machines, through rotary multi-station machines right upto full scale linear transfer machines.

The Transfer Line optimises the application of production engineering to achieve the lowest possible unit cost. Each line is a unique combination of machining stations which can encompass milling, drilling, reaming, tapping and boring operations. All these stations plus the transfer system between stations has to be integrated into one control system.

Special Purpose Machines and Transfer Lines are designed to satisfy specific production requirements, taking into account complexity of component and production rate required.

G.P JAJPUR

MECHANICAL DEPARTMENT

QUESTION BANK

ADVANCE MANUFACTURING PROCESSES, 6^{TH} SEMESTER

MODULE 1

Modern Machining Processes

SHORT ANSWER TYPE QUESTIONS (2 MARKS AND 5 MARKS)

1. Explain the need for the use of unconventional machining processes compared to the conventional ones.
2. Explain the reasons why the unconventional machining processes are used.
3. Explain why the tool shape in EDM should be complementary to the final form.
4. What are the functions served by the dielectric fluid in EDM?
5. Give examples of dielectric fluid used in EDM.
6. What are the characteristics required for a good electrode material in EDM?
7. State various electrode materials for EDM.
8. Explain the application of the following electrode materials in EDM: (a) Copper (b) Graphite
9. What are the important parameters that control the material-removal rate in EDM? Briefly explain any two factors.
10. Explain the advantages and disadvantages of EDM.
11. Write a short note on wire-EDM process.
12. Write down various application areas of EDM.
13. Explain the principle of ECM with a neat sketch.
14. What are the functions served by the electrolyte in ECM?
15. Give examples of electrolytes used for ECM.
16. Describe the factors that should be considered in selecting an electrolyte in ECM.

17. What factors should be considered in selecting the tool materials in ECM?
18. What are the various tool materials used in ECM?
19. Briefly explain the various process parameters that affect the material-removal rate in ECM.
20. Explain the advantages and disadvantages of ECM.
21. Write down various application areas of ECM.
22. Explain how material is removed in USM.
23. Briefly explain about the functions of transducer and tool cone in USM.
24. What is the function of abrasive slurry in USM? Explain how the abrasive selection is made.
25. State about MRR and factors affecting it in USM.
26. Explain the advantages and disadvantages of USM.
27. Write down various application areas of USM.
28. Give a short note on LBM.
29. What are the types of lasers that are generally used in LBM? Explain their significance.
30. State about MRR and factors affecting it in LBM.
31. Write down various application areas of LBM.
32. Explain the advantages and disadvantages of A]M.
33. Describe the factors that should be considered in selecting the abrasive in AJM.
34. Give examples of abrasives used in AJM.
35. Explain how material is removed in AJM.
36. State about MRR and factors affecting it in AJM.
37. Write down various application areas of AJM.
38. Explain the advantages and limitations of electron-beam machining.
39. State about MRR and factors affecting it in EBM.
40. Give the applications of plasma-arc machining.
41. Explain the advantages and limitations of plasma-are machining.
42. State about MRR and factors affecting it in PAM.

LONG QUESTIONS (8 MARKS)

1. Give a comparison of the unconventional processes in terms of process, material-removal rate and applications.
2. Explain the working principle of EDM with a neat sketch.
3. Briefly explain the working of an EDM machine showing important elements.
4. Briefly explain the working of an ECM machine showing important elements.
5. Briefly explain the working of an USM machine showing important elements.
6. Briefly explain the working of an LBM machine showing important elements.
7. Explain the working principle of AJM with a neat sketch. State its advantages and disadvantages.
8. Briefly explain the equipment and working principle used for electron beam machining. Give the applications of electron-beam machining.
9. Briefly explain the working principle plasma-arc machining process with neat sketch.

MODULE 2

Plastic Processing

SHORT ANSWER TYPE QUESTIONS (2 MARKS AND 5 MARKS)

1. Differentiate between thermoplastic and thermosetting polymers with suitable examples.
2. Write down common properties of plastics.
3. List out the basic moulding methods for plastics.
4. Briefly mention the criteria for selecting plastic processing methods.
5. Write a short note on casting processing method.
6. Explain the process calendaring.
7. Briefly explain blow moulding method for making a plastic water bottle.
8. What do you mean by vacuum forming?
9. Explain pressure bag moulding process.
10. Write down the methods for laminating plastics.

11. Write a short note on low pressure laminates.
12. Write down the applications of plastics in engineering fields.

LONG QUESTIONS (8 MARKS)

1. What are the various materials added to polymers during polymerization? Briefly mention their roles with examples.
2. What is compression moulding? Briefly explain the process with a neat sketch. Write down the advantages and applications of compression moulding.
3. Explain (i) flash type (ii) positive type (iii) landed positive type (iv) semi positive type compression moulding.
4. What is transfer moulding? Briefly explain the process with a neat sketch. Write down the advantages and applications of transfer moulding.
5. What is injection moulding? Briefly explain the process with a neat sketch. Write down the advantages, limitations and applications of injection moulding.
6. What is extrusion moulding? Briefly explain the process with a neat sketch. Write down the advantages and applications of extrusion moulding.
7. Explain the methods for manufacturing plastic laminating sheets, plastic rods and tubes.

MODULE 3

Additive Manufacturing Process

SHORT ANSWER TYPE QUESTIONS (2 MARKS AND 5 MARKS)

1. How would you define prototype in the context of modern product development?
2. What are the main roles and functions for prototypes? How do you think rapid prototyping satisfies these roles?
3. What are the fundamentals of additive manufacturing?
4. What is the *Rapid Prototyping Wheel?* Describe its four primary aspects.
5. Write down the limitations of additive manufacturing.
6. What are the other terms used in place of additive manufacturing? Justify.

7. What is your favorite term (AM, Freeform Fabrication, RP, etc.) for describing this technology and why?
8. How do you classify rapid prototyping systems?
9. Name three Rapid Prototyping Systems that are liquid-based.
10. How can the liquid form be converted to the solid form as in these liquid-based Rapid Prototyping Systems?
11. In what form of material can Rapid Prototyping Systems be classified as solid-based? Name three such systems.
12. What is the method used in powder-based Rapid Prototyping Systems?
13. Briefly explain various fundamental automated processes.
14. Briefly explain other technologies that are related to AM.
15. Which step in the entire process chain is, in your opinion, the shortest? Most tedious? Most automated? Support your choice.
16. What are the finishing processes that are used for RP models and explain why they are necessary?
17. What are the typical RP applications in design?
18. What are the typical RP applications in engineering and analysis?
19. Explain how RP systems can be applied to traditional industries like the jewelry industries.
20. What are the typical RP applications in medicals and bioengineering?
21. What are the typical RP applications in aerospace engineering?
22. What are the typical RP applications in automotive industries?
23. What do you mean by concurrent engineering? Explain briefly.
24. Write a short note on capstan and turret lathe.
25. What do you understand by the term flexible manufacturing system?
26. Explain the needs for flexible manufacturing syatem?
27. Write down the advantages of FMS.
28. List down the various components of FMS.
29. Write a short note on concurrent engineering.

LONG QUESTIONS (8 MARKS)

1. Describe the advantages of Rapid Prototyping in terms of its beneficiaries such as the product designers, tool designer, manufacturing engineer, marketeers and consumers?
2. Differentiate between CNC and AM.
3. Broadly classify rapid prototyping systems.
4. Describe the steps involved in a general RP process chain.
5. Distinguish cleaning, post curing and finishing which are the various tasks of post processing. Name two RP processes that do not require post curing and one that does not require cleaning.
6. Explain the components of FMS: Processing Station, Material handling & storage and Computer Control System.
7. Describe the process flow of Cubic's Laminated Object Manufacturing.
8. Describe the process flow of Stratasys' Fused Deposition Modeling.
9. Describe the process flow of the 3D System Stereolithography Apparatus.