C. V. Raman Polytechnic, Bhubaneswar

Department of Mechanical Engineering

LECTURES NOTE

Subject- Advance Manufacturing Processes

6th SEM MECHANICAL

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Introduction – comparison with traditional machining

Modern Manufacturing processes is defined as a group of processes that remove excess material by various techniques involving mechanical, thermal, electrical or chemical energy or combinations of these energies but do not use a sharp cutting tools as it needs to be used for traditional manufacturing processes.

Extremely hard and brittle materials are difficult to machine by traditional machining processes such as turning, drilling, shaping and milling. Modern Manufacturing processes, also called Non Traditional OR Advanced Manufacturing processes, are employed where traditional machining processes are not feasible, satisfactory or economical due to special reasons as outlined below.

*Very hard fragile materials difficult to clamp for traditional machining

*When the work piece is too flexible or slender

*When the shape of the part is too complex

Several types of non-traditional machining processes have been developed to meet extra required machining conditions. When these processes are employed properly, they offer many advantages over non- traditional machining processes.

A machining process is called non-traditional (Advance manufacturing) if its material removal mechanism is basically different than those in the traditional processes.

The nontraditional machining process can be classified according to

(a) different form of energy (mechanical, thermal and electro thermal, chemical or electrochemical), (b) mechanism involved in the process (erosion, ionic dissolution, vaporization), (c) source of energy required for material removal (hydrostatic pressure, high current density, high voltage), (d) medium for transform of these energies (high velocity particles, electrolyte, electron, hot gases)

- In thermal or electro thermal method , heat energy is concentrated in small area of workpiece, thus melts and vaporizes a small portion of workpiece. (EDM, LBM, PAM, EBM, IBM)
- In chemical or electrochemical method, the workpiece is submerged in chemical solution is etched by control manner. (ECM, ECG, ECH, ECD)
- In mechanical method, material is removed by mechanical erosion of workpiece material (USM, AJM , WJM)
- Maximum material can be removed by ECM and PAM; where as minimum material is removed by EBM and LBM. Maximum power is consumed in LBM and minimum by PAM. If accuracy is concerned, USM and EBM are best.

Electric-discharge Machining (EDM)

Electric Discharge machining is the process of metal removal from the work surface due to an erosion of metal caused by electric spark discharge between the two electrodes tool (cathode) and the work (Anode). This technique utilizes thermoelectric process to erode undesired materials from the workpiece by a series of discrete electrical sparks between the workpiece and the electrode. The traditional machining processes rely on harder tool or abrasive material to remove the softer material whereas non-traditional machining processes such as EDM uses electrical spark or thermal energy to erode unwanted material in order to create desired shape. So, the hardness of the material is no longer a dominating factor for EDM process.

Parts of EDM

1. DC Pulse Generator: This is a power source for the machining operation. DC power is supplied.
2. Voltmeter: Voltmeter is used to measure the voltage.
3. Ammeter: It measures or checks the flow of the current.
4. Tool: A tool is connected to negative sources of power whereas the workpiece is connected to positive sources. From the filter, the fluid comes to the tool for the operation. When Power supply will increase, between tools and workpiece the spark generates and then machining starts.
5. Dielectric fluid: common dielectric fluids used are transformer oil, paraffin oil, kerosene, lubricating oil or distilled water.
   - It remains non conductive until required breakdown voltage is reached.
   -it should breakdown electrically in shortest possible time once breakdown voltage has been reached.
   - De-ionize the spark gap after the discharge has occurred
   - provide good cooling medium, have good fluidity
   -capable of carrying away debris from eroded area
   -be cheap and easily available

6. Pump: The pump is connected for sending the fluid to the filter. This works like flowing the fluid from one source to another one.
7. **Filter:** It is used to filtrate the different particles like: In this device, if there is dust particles presence the filter will remove that particle and then it will send to the tool for the operation.
8. **Servo controlled feed:** The constant feed will be supplied by the servo for the operation.
9. **Fixture:** To hold the table.
10. **Table:** To hold the workpiece

Working Principle of Electro Discharge Machining

It consists of an electric power supply, the dielectric medium, the tool, workpiece, and servo control.
The workpiece is generally connected to the positive terminal (anode) and the tool is connected to a negative terminal (cathode) of the DC power supply.
A suitable gap 0.01 to 0.5mm is maintained between the tool and the work. The current may vary from 0.5 to 400 Amp.

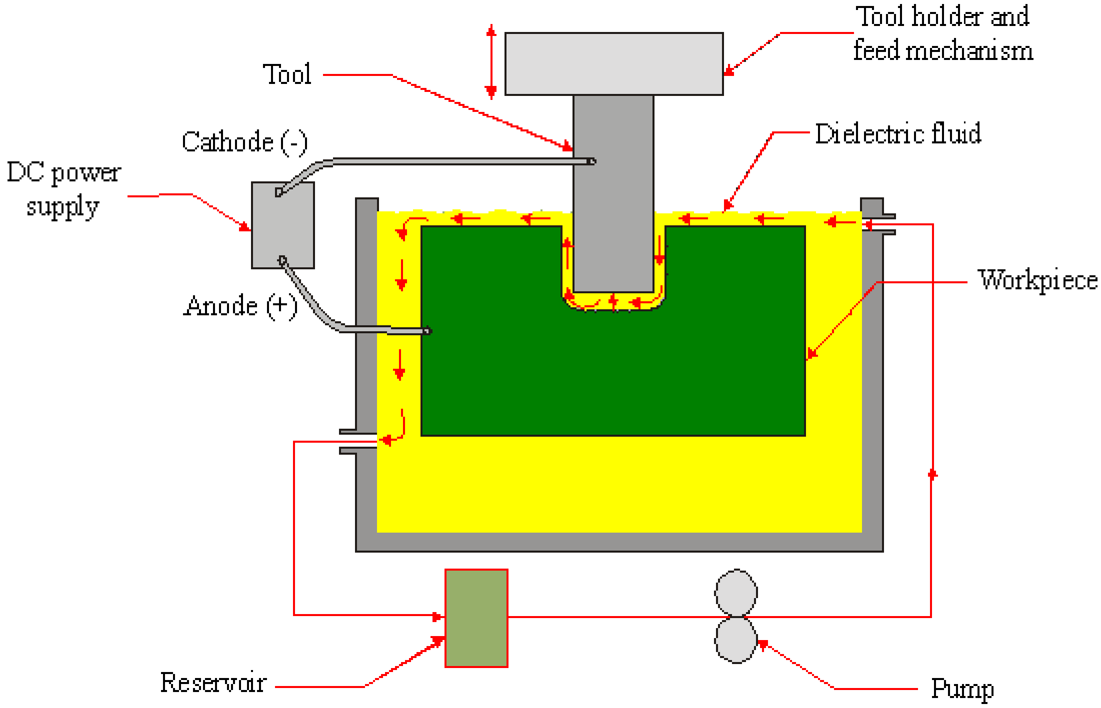
A high voltage (40-300V DC) is applied across the narrow gap between the electrode and the workpiece. This high voltage induces an electric field in the insulating dielectric that is present in narrow gap between electrode and workpiece. This ionizes the fluid between tool and workpiece. When the potential difference between the electrode and the workpiece is sufficiently high, the dielectric breaks down and a transient spark discharges through the dielectric fluid. The moment spark occurs; sufficient pressure is developed between tool and work. The repetitive spark results a local heat of temperature about 10000°C at the spot hit by electrons and at such high temperature and pressure, some metal is melted and eroded. The debris are carried out by dielectric medium from the tool-work gap forming a crater on workpiece. In this a replica of tool is produced in the workpiece. In this the frequency of spark at the rate of 10000 sparks per sec can be achieved. If potential difference decreases, the fluid will de-ionise and discharge will cease. The control of erosion of metal is achieved by rapid recurring spark discharges produced between two electrodes. In this machining, the workpiece and tool must be one electrically conducting body. A servomechanism is used to feed the tool to maintain a constant gap between two electrodes. EDM power supply senses the voltage between the electrodes and sends the signal to the servosystem, where it maintains the desired gap between the electrodes. The accuracy of about 0.05 mm can be achieved in this process.

Mechanism of material removal

When potential difference is applied between the two electrodes, electrons from the cathode tool is released and impelled towards the work anode and that of ions towards the cathode. During movement, the loose electrons collide with the molecules of dielectric present in between the electrodes, detaching electrons from them and causing ionization. Initially the dielectric between the electrode gap is non conductive. After some time, the ionization of dielectric between the inter electrode gap creates a narrow channel of continuous conductivity. When this happens, there is a considerable flow of electrons along the channel is formed creating a momentary current impulse or discharge. The discharge leads to generation of extremely high temperature creating melting and vaporization of local material of workpiece. This results in the formation of tiny craters at the point of discharge. To have machined cavity as replica of tool, the tool wear should be zero. To minimize tool wear, the operating parameter and polarity should be chosen carefully. Amount of material removed from tool and workpiece depends upon the polarity of tool and work. For straight polarity, tool is –ve and work is +ve, while in reverse polarity, it is opposite.

Comparatively less metal is eroded at the tool because in straight polarity:

- The momentum of positive ions striking the work piece is less compared to the momentum of negative electrons
- Compressive force is generated at the tool due to spark generation reduces the tool wear.



Power supply:

EDM power supply senses the voltage between the electrodes and sends the signal to the servo system, where it maintains the desired gap between the electrodes. Power supply controls the parameters like voltage, current, duration and frequency of a pulse, duty cycle and electrode polarity. Duty cycle controls the amount of time the energy is on during each pulse.

Dielectric fluid:

The dielectric fluids generally used are transformer oil, white spirit or kerosene or paraffin. These dielectric fluids have essential characteristics. They de-ionise rapidly and don't vaporize excessively. The choice of dielectric depends upon the workpiece size, shape, tolerance, surface finish and MMR.

It has following functions

- Helps in initiating discharge by serving as a conducting medium when ionized
- It maintains the value of voltage gradient between tool and workpiece.
- Quench the spark, cools the tool and workpiece
- Carries away the eroded material along with it

  It should have following properties

  -it should not evolve toxic gases during operation
  -inflammable, chemically inert with respect to tool and work material
  - it should take minimum time to breakdown when the breakdown voltage is reached
  -should be able to de-ionise quickly
  High dielectric strength to serve as an insulated medium
- Optimum viscosity

Tool material
Commercially EDM tool electrodes are of 3 types i.e, metallic (copper-tungsten, brass, tungsten carbide, aluminium etc.), non-metallic (graphite) and combination of both (copper-graphite). Selection of proper electrode depends on size of electrode, MRR, surface finish, tolerance, dielectric etc.

Flushing
Flushing in EDM is important aspect for machining. It is defined as the correct circulation of dielectric between the tool and workpiece. The eroded particles should be flushed periodically as this will reduce the further material removal rate. when the dielectric is fresh and free from eroded work materials, it is non conductive. With successive discharge, the dielectric gets contaminated reducing its insulation strength. Thus, flushing is important.

Injection flushing: dielectric is injected into the inter electrode gap through a hole made in either the workpiece or tool.
Suction flushing: dielectric is sucked from the inter electrode gap through a hole made in either the workpiece or tool.
Side flushing: when flushing holes cannot be drilled, side flushing is used.

Servo system
It is used to maintain a predetermined gap between the tool and work. There is a gap voltage sensor in power supply. When it senses the presence of conductive material between the gap of two electrodes, a signal will be sent to the servo system to reverse its direction. The servosystem keeps the tool reciprocating towards the workpiece until the dielectric fluid flushes the gap.

Process parameters

The EDM process parameters which drive this process are divided into two types, namely, electrical and non-electrical parameters.

The major electrical parameters are discharge voltage, peak current, pulse duration and interval (pulse-on and pulse-off times), electrode gap, polarity, and pulse wave form. Important non-electrical parameters include flushing of the dielectric fluid, workpiece rotation, electrode rotation, etc. These parameters are discussed below.

The discharge or machining voltage is the average voltage across the spark gap during machining. The discharge voltage directly influences the regulation of the size spark gap and overcut.

Increasing the current in spark increases the MRR and decreases the Surface roughness.. however, decreasing the current in the spark and increasing its frequency will improve its surface finish.

In contrast, higher voltage is considered with materials of low conductivity. This parameter has a direct effect on the material removal rate (MRR), tool wear rate (TWR), and machining accuracy. An increase in current increases MRR and TWR and adversely affects the accuracy. The pulse-on time is the time during which the discharge is applied. The amount of energy generated during pulse-on time has a direct influence on the MRR .

Accordingly, increasing the discharge energy by applying longer pulse-on time also increases the MRR . The pulse-off time is the time during which there is no discharge. During this time, the debris as a result of sparking and erosion is flushed out of the gap between the workpiece and the electrode. Flushing improves the ionization conditions and avoids the formation of an insulating layer; thus, proper selection of pulse-off time provides stable machining. A shorter period of this time increases MRR as long as enough flushing of debris takes place. Otherwise, it may result in unsuitable conditions during the next pulse-on time period. The polarity in EDM depends on many factors, including electrode and workpiece materials, current density, and pulse length. Either the electrode or the workpiece has a positive charge polarity and the other has a negative charge polarity. Negative electrode polarity is recommended for high-precision machining when the MRR is high. The function of the dielectric fluid is to provide insulation against premature discharging, reduce the temperature during machining, and clean away the debris from the machining area. Good dielectric fluids should have characteristics such as high dielectric strength, flushing ability, fast recovery after breakdown, etc.

Output characteristics

Material removal rate; it is the volume of metal removed per unit time. It is proportional to the diameter of crater and depth of which melting temperature is reached. MRR increases with increase in discharge time upto certain limit, and then it drops to zero. High MRR leads to poor surface finish.

Tool wear rate : it is the metal removed from tool per unit time. It depends on electrode polarity, tool material etc.

Surface roughness: The deviation of a surface from its ideal level is defined in terms of surface roughness. The average roughness is calculated by the deviations, i.e., deviation of surface from a theoretical centre line. If the deviations are large, the surface roughness is high, whereas the surface is considered to be smooth for small deviations.

Advantages of EDM

The main advantages of EDM are:

- By this process, materials of any hardness can be machined;
- No burrs are left in machined surface;
- thin and fragile/brittle components can be machined without distortion;
- Complex internal shapes can be machined
- No mechanical stresses are developed in this process

Limitations of EDM

The main limitations of this process are:

- This process can only be employed in electrically conductive materials;
- Material removal rate is low and the process overall is slow compared to conventional machining processes;
- Unwanted erosion and over cutting of material can occur;
- Rough surface finish when at high rates of material removal
- High heat developing causing the change in metallurgical properties of materials.

Application

- Drilling for micro holes in the nozzle.
- This is used in thread cutting.
- Used in wire cutting.
- Rotary form cutting.
- Helical profile milling.
- Curved hole drilling.
- Engraving operation on harder materials.
- Cutting off operation.
- The shaping of alloy steel and tungsten carbide dies.

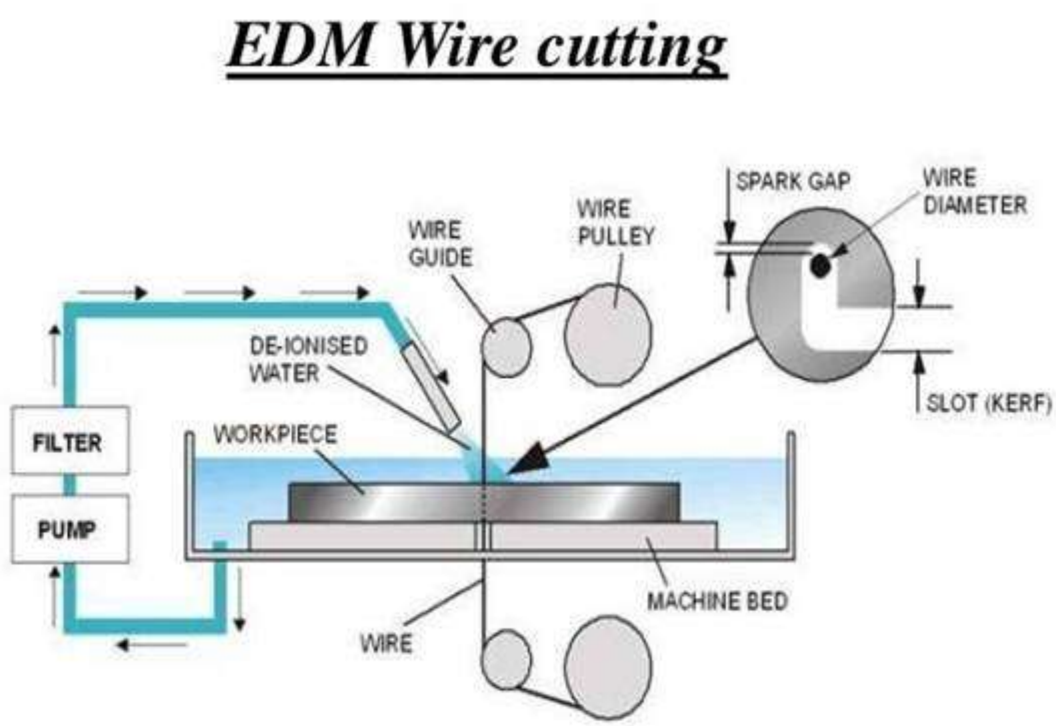
Wire-cut EDM

Working principle

In wire electric discharge machining, a wire (about 0.05 to 0.3 mm diameter) is used as an electrode and deionised water as dielectric. A nozzle is employed to inject the dielectric in the machining area in wire EDM. Electrodes are connected to a pulsed DC supply. Heat generated due to sparking results in melting of workpiece and wire material. Wire EDM usesbelectro-thermal mechanisms to cut electrically conductive materials. The material is removed by a series of discrete discharges between the wire electrode and the workpiece in the presence of dielectric fluid, which creates a path for each discharge as the fluid becomes ionized in the gap. The area where discharge takes place is heated to extremely high temperature, so that the surface is melted and removed. The removed particles are flushed away by the flowing dielectric fluids. A constant gap between tool wire and workpiece is maintained with the help of computer controlled positioning system. The process gives high accuracy and good surface finish.

The wire EDM process can cut intricate components for the electric and aerospace industries. This non-traditional machining process is widely used to pattern tool steel for die manufacturing. The wires for wire EDM is made of brass, copper, tungsten, molybdenum. Zinc or brass coated wires are also used extensively in this process. The wire used in this process should possess high tensile strength and good electrical conductivity.

Wire EDM machine



There are 4 basic elements of this machine

1. Power supply: Wire EDM power supply differ from conventional EDM in terms of frequency which is about 1 MHz. it results in reduced crater size or better surface finish. The wire usually carry around 20 A current because of the small wire size.
2. Dielectric system: Deionised water is generally used in WEDM because of its availability, desirable thermal properties, low viscosity, no fire hazard, high cooling rate and pollution free working. It gives high MRR and better surface finish. Low viscosity helps in efficient flow of dielectric. Tool wear rate is high if water is used. But the wire is not reused so high TWR does not affect the performance.
3. Positioning system: The positioning system is a computerized numerical control (CNC) two axes table. It operates in a control mode so that when wire approaches very near to the workpiece or the gap is bridged with conductive material, it should sense it to avoid short circuit. It should instantly move back to re-establish the proper cutting condition in the gap.
4. Wire drive system: it delivers fresh wire and always keeps the wire under tension so that it moves in the machining zone as a straight wire.

The melting temperature of the parts to be machined is an important parameter for this process rather than strength or hardness. The surface quality and MRR of the machined surface by wire EDM will depend on different machining parameters such as applied peak current, voltage, frequency, wire materials etc. wire speed may be high as 40 mm/s.

Process characteristics:

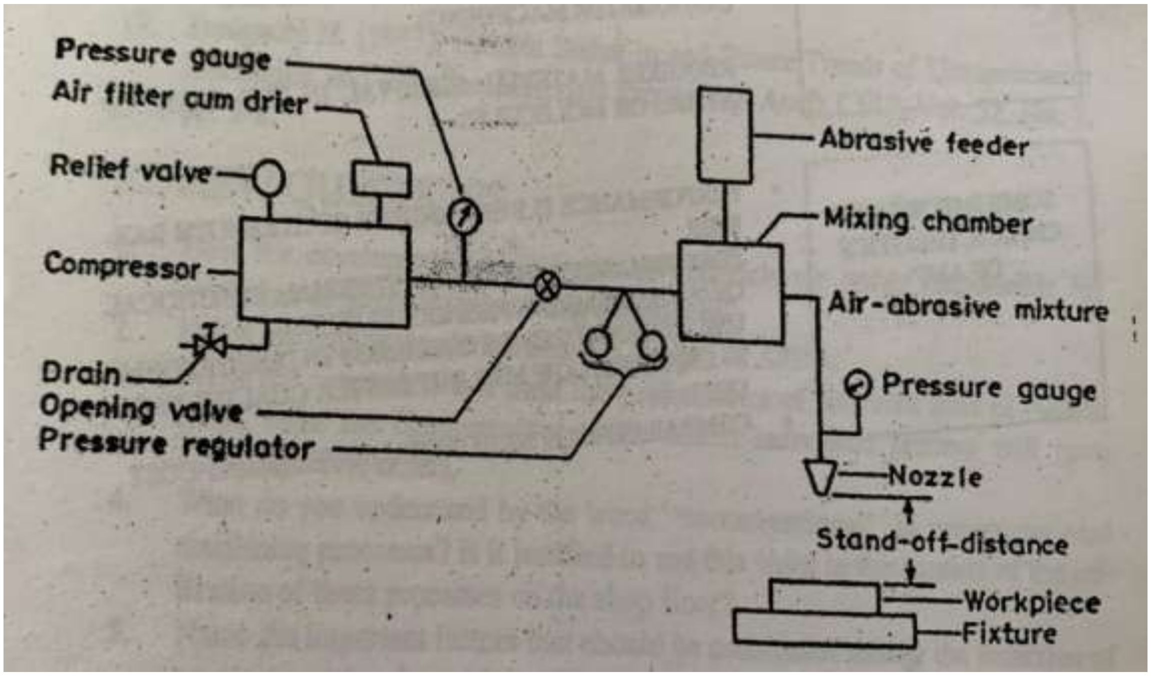
1. Forming electrode adapted to product shape is not required.
2. Machined surfaces are smooth as a new portion of wire electrode is constantly supplied.
3. It provides good tolerance
4. Straight holes can be produced to close tolerance
5. Machine can be operated unattended
6. No skilled labor is required.

Application

Making dies of various types with close tolerance, fabrication of press tools and electrodes for use in EDM.

<u>**Abrasive Jet Machining (AJM)**</u>

A jet of high pressure gas or air consisting of very fine abrasive particles (10 to 40 micron) strikes at the workpiece at very high velocity (200-400 m/s) resulting in material removal through chipping/ erosive action. The inside diameter of nozzle through which abrasives flow is about 0.04mm and stand off distance is kept about 0.7 mm to 1 mm. the process is best suited on hard and brittle materials, super alloys and refractory materials. Also machining of thin section of hard materials and making intricate holes is possible through this method.



Gas propulsion system supplies clean and dry gas (air, N2, CO2) to propel the abrasive particles under pressure (2 to 8 Kg/cm2). After filter and dryer it is passed to a mixing chamber containing abrasive particles and vibrating at 50 c/s. the gas along with abrasive particles (size 10 to 40 micron) passed on to nozzle of tip diameter around 0.45 mm, with a velocity of 200-400 m/sec. A standoff distance is kept about 0.7 mm to 1 mm. when the irregular sized abrasives at high velocity impinge on the work piece; work material is removed by erosion.

The gas used should be non toxic, cheap and easily available. It should not easily spread when discharged from nozzle into atmosphere. One abrasive feeder is used to send required amount of abrasive particle to the mixture chamber. The nozzle is usually made of tungsten carbide or sapphire. Sapphire has a life of 300 hr. the nozzle pressure is generally maintained between 2-8 kgf/cm2. With increase in wear of nozzle , the divergence of jet stream increases resulting in more stray cutting and inaccuracy. Aluminium oxide, silicon carbide, glass beads, crushed glass are some abrasives used in AJM. Its selection depends on work material, MRR and accuracy.

Process parameters

Stand-off distance: SOD is generally varies from 0.75 to 1 mm. a decrease in SOD improves accuracy, decreases kerf width and reduces tapper. However, operations like cleaning, frosting are conducted with large SOD.

Abrasive flow rate: with increase in flow rate, the number of abrasive cutting the workpiece increases increasing MRR. However, further increases in abrasive flow rate , the abrasive flow velocity goes down causing reduction in MRR.

Nozzle pressure: KE of abrasive particles is responsible for removal of material by erosion process. the abrasive must impinge work piece with certain velocity. The range is about 200- 400 m/s.

Mixing ratio: it is the ratio of volume flow rate of abrasive to volume flow rate of carrier gas. An increase in mixing ratio, MRR increases, but large M may decrease jet velocity and block the nozzle. Thus, optimum mixing ratio need to be maintained.

Advantages:

This process can be used to cut intricate holes in hard, brittle, fragile and heat sensitive materials without damage. Its initial cost is low.

Disadvantages:

MRR is low, poor accuracy, soft materials cannot be machined.

Application:

Abrasive jet machining can be advantageously utilized for multifarious purposes including surface cleaning, deburring, abrading and even making holes. Common applications of abrasive jet machining process are provided below. It is to be noted that, irrespective of the purpose, abrasive jet machining (AJM) is beneficial only for hard and brittle materials. AJM should be avoided if work material is soft and ductile; otherwise quality of machined surface will be poor.

- Work surface cl**eaning**—AJM can be advantageously used for cleaning metallic or ceramic surfaces (substrate must be hard). Such cleaning processes include removal of oxide, paint, coating, stain, glue, loose sand particles, etc.

- **Engraving**—As an alternative to laser beam machining, abrasive jet machining can also be applied for incising purposes irrespective of chemical and electrical properties of work material.

- **Ceramic abrading and glass frosting**—Very hard materials including glass, refractory, stone, etc. can be easily abraded by AJM in order to get finished surface having tight tolerance.

- **Deburring**—Abrasive jet machining is one of the efficient methods for deburring (process for removal of burr) of milled features and drilled holes, especially when work material is hard.

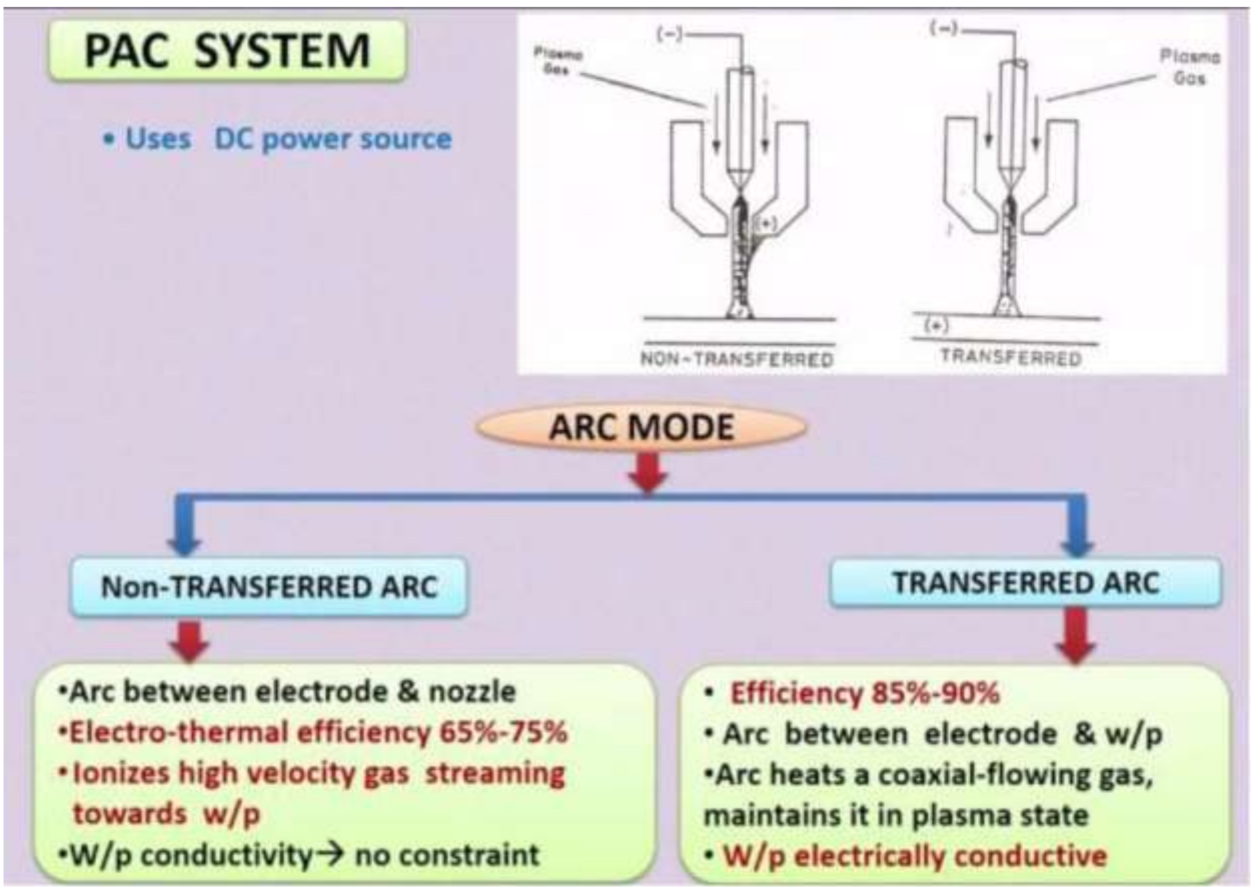
- **Cutting and drilling hole**—AJM can also be utilized for cutting various shapes as well as for drilling holes. However, holes, slots or pockets may lack accuracy as sharp corners cannot be obtained by this process.

Plasma Arc Machining (PAM)

Working principle

A gas molecule at room temperature consists of two or more atoms. When such gas is heated to a high temperature of the order 2000°C, the molecules separate out as atoms. If the temperature rose to 3000°C, the electrons from some atoms dissociate and the gas becomes ionized consisting of ions and electrons. The state of gas is known as plasma. A gas in plasma state becomes electrically conductive. The source of heat generation in plasma is the recombination of electrons and ions into atoms or recombination of atoms into molecules. The liberated bonding energy is responsible for increased KE of atoms or molecules formed by recombination. The temperature of plasma can be up to 33000°C. when such a high temperature source hits the work material, the work material melts and vaporizes and finally cut into pieces.

PAM uses DC power source. It either operates on non transferred arc mode or transferred arc mode. In non transferred arc mode power is transferred between electrode and nozzle. In this case the work may be conductive or non conductive. In case of transferred arc mode , the arc is maintained between electrode and workpiece. When a voltage about 200V and 1000A is applied, an arc is formed between anode and cathode. This arc heats the flowing gas and maintains it in plasma mode. The higher the flow rate, more will be the momentum of plasma.



Elements of PAM

Air plasma torch: Gases are used to create plasma-like, nitrogen, argon, hydrogen, or a mixture of these gases. The plasma gun consists of a tungsten electrode fitted in the chamber. The electrode is given negative polarity and the nozzle of the gun or work piece is given positive polarity. The supply of gases is maintained into the gun. A strong arc is established between the two terminals anode and cathode. There is a collision between molecules of gas and electrons of the established arc. As a result of this collision, gas molecules get ionized and heat is evolved. This hot and ionized gas called plasma is directed to the workpiece with high velocity. The established arc is controlled by the supply rate of gases. Zirconium or hafnium is also used as electrode material because of higher resistance to oxidation.

To avoid oxidation of electrode, oxygen injected torch uses nitrogen as plasma gas. Oxygen is injected downstream of the electrode. Dual gas system uses N_2 as plasma gas while another gas as the shielding gas (O_2, CO_2, argon etc.). Shielding gas is chosen according to material to cut.

Cooling Mechanism : As we know that hot gases continuously come out of nozzle so there are chances of its overheating. A water jacket is used to surround the nozzle to avoid its overheating.

Process performance

Parameters that govern the performance of PAM can be divided into three categories:

1. Those associated with the design and operation of the torch –

electrical power delivered , the gases used to form the plasma, the flow rate of the gases through the torch, the orifice diameter through the nozzle duct.

2. Those associated with the physical configuration of the set up – torch standoff, angle to the work, depth of cut, feed into the work and speed of the work toward the torch.

3. Environment in which the work is performed – any protective type of atmosphere used to reduce oxidation for the exposed high temperature machined surface

PAM has been applied to cut materials as thick as 150 mm.

Advantages

- The main advantage of PAM is speed. For example, mild steel of 6mm thick can be cut at 3m/min

- The plasma arc can be used to cut any metal or even to non conducting materials like concrete etc., since it is primarily a melting process

- Due to high speed of cutting the deformation of sheet metals is reduced while the width of the cut is minimum

- Owing to the high productivity of the plasma arc cutting coupled with the tendency to use cheap and easily available plasma-forming media (air, water, ammonia etc.,), PAC is finding ever increasing

application.

- Smooth cuts free from contaminants are obtained in the process

- Operating costs are less when compared to oxy-fuel torch

- Can be automated

Limitations

 The main disadvantage of PAC is the high initial cost of the equipment. However, it can be made economical, if the quantity involved is large and the thickness is up to 150mm.

 heat affected zone (HAZ). The depth of HAZ depends on the material and its thickness

 Smoke and noise

 Sharp corners are difficult to produce because of the wide diameter of the plasma stream

 Burr is often produced

 Taper on the work-piece may occur

Material removal rate

The values of the material removal rates in Plasma beam machining will be nearly 150 cm3/min.

APPLICATIONS

1. It is used for cutting alloy steels, stainless steel, cast iron, copper, nickel, titanium, aluminum, and alloy of copper and nickel, etc.

2. It is used for profile cutting.

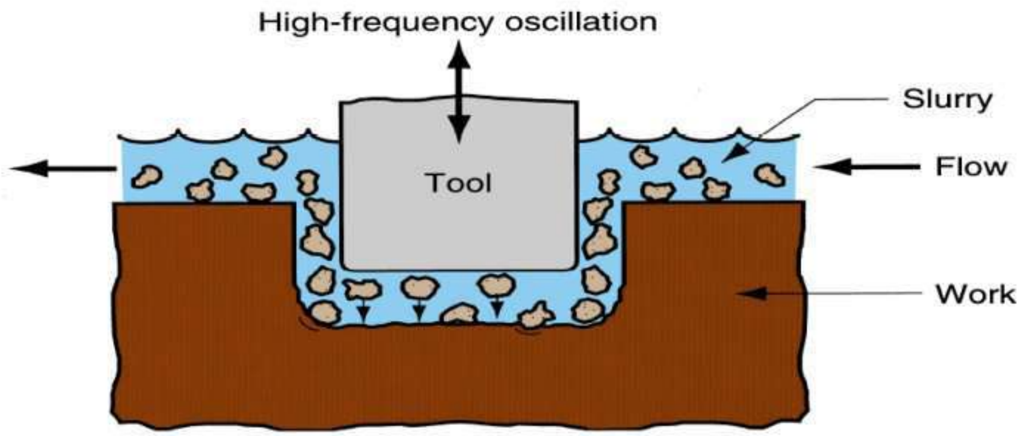
3. It is successfully used for turning and milling of hard to machine materials.

4. It can be used for stack cutting, shape cutting, piercing, and underwater cutting.

5. Uniform thin film spraying of refractory materials on different metals, plastics, ceramics are also done by plasma arcs

Ultrasonic Machining (USM)

USM is mechanical type nontraditional machining process used to erode holes or cavities on hard or brittle workpiece by using a shaped tools, high frequency mechanical motion and an abrasive slurry. In USM material is removed by abrasive grains which are driven into work surface by a tool oscillating normal to work surface. The particles are of different sizes and they are thrown many times per second.It is used extensively in machining hard and brittle materials that are difficult to machine by traditional manufacturing processes.

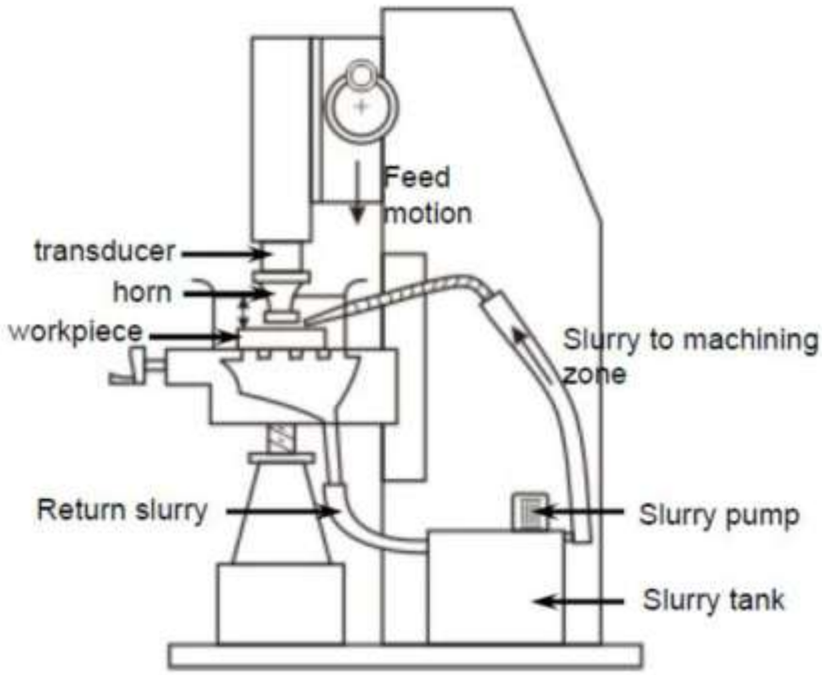


In USM the principle of longitudinal magnetostriction is used. When an object made of ferromagnetic material is placed continuously changing magnetic field, a change in its length takes place. This kind of transducer is known as magnetostriction transducer. A device that converts any form of energy into ultrasonic waves is called ultrasonic transducer. In USM, a transducer converts high frequency electrical signal into high frequency linear mechanical motion (vibration). The vibrations are transmitted to tool via tool holder.

The tool shape is made according to desired cavity. It is placed near to the work surface and the gap is flooded with abrasive slurry. When the tool vibrates, it strikes the abrasive particles. These particles attain KE and strike the work surface with a high force which is sufficient to remove material from brittle workpiece. The process gives very low MRR. There is no contact between tool and Work piece, so thin and fragile components can be machined easily.

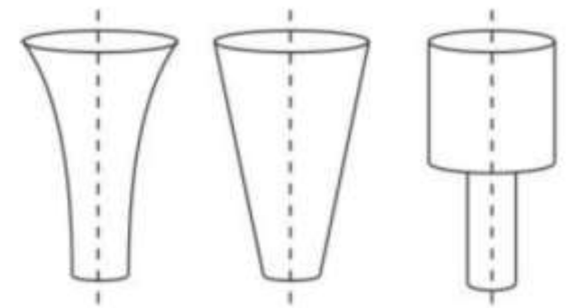
Principle Of Ultrasonic Machining

Material removal in USM primarily occurs due to the indentation of the hard abrasive grits on the brittle work material. As the tool vibrates, it leads to indentation of the abrasive grits. During indentation, cracks would develop just below the contact site, then as indentation progresses the cracks would propagate and ultimately lead to brittle fracture of the work material under each individual interaction site between the abrasive grits and the workpiece. The gap between tool and workpiece is of order of 0.02 to 0.1 mm. the material removed from workpiece in the form of small grains by shear deformation, brittle fracture, cavitations and chemical reaction. The tool material should be such that indentation by the abrasive grits does not lead to brittle failure. Thus the tools are made of tough, strong and ductile materials like steel, stainless steel and other ductile metallic alloys. Hence, USM is mainly used for machining brittle materials which are poor conductors of electricity and thus cannot be processed by Electrochemical and Electro-discharge machining.



In USM high power sine wave generator converts low frequency(60 HZ) electric power to high frequency (above 20 KHZ) electrical power. This high frequency electrical signal is transmitted to the transducer which converts it into high frequency low amplitude mechanical vibration. There are two type of transducer; piezoelectric and magnetostrictive. Tool holder holds and connects the tool to the transducer. It transfers the energy and amplifies the amplitude of vibration. Commonly used tool holder materials are monel, titanium and stainless steel. The horn/ concentrator can be of different sizes like tapered, stepped or exponential type. It is a vibration focusing device which focuses the mechanical vibration transferred from transducer. They are made of materials like brass having high fatigue resistance and low energy loss. It increases the amplitude of vibration. Tools are usually made up of ductile materials (brass, stainless steel, mild steel etc.) so that the tool wear rate can be minimized. TWR and MRR depend on the kind of abrasive, workpiece material and tool material.

Hardness, particle size, cost are some of the criteria to choose suitable abrasive material. Commonly used abrasives are Al2O3, SiC, B4C and diamond dust. Courser abrasive grains results in high MRR and poor surface finish. Abrasive slurry consists of water with 30-60% of abrasives. The abrasive slurry circulated by a pump is cooled by a refrigeration system. It should able to remove the heat to prevent it from boiling in the gap and causing undesirable cavitations. For finer surface finish, finer grit size are chosen. Feeding of the tool is provided by applying a working force between the tool and work piece.



Magnetostriction transducer has solenoid type winding of wire over a stack of nickel (ferromagnetic) lamination and fed with an A.C supply with frequencies of 25 KHZ. Under such magnetic field, it experiences change in its dimension.

Process parameters

MRR and surface finish are greatly influenced by grit size ob abrasive. For roughing operation grit size of 200-400 is used and 800- 1000 grit size abrasives are used for finishing. MRR also depends on the tool size area, vibration, abrasive type and size and concentration of slurry. Accuracy of this process is ±0.007 mm and surface finish upto 0.02 to 0.8 micron RMS. MRR is slow. Surface finish directly depends on the abrasive grain size.

Advantage of USM

USM process is a non-thermal, non-chemical, creates no changes in the microstructures, chemical or physical properties of the workpiece and offers virtually stress free machined surfaces.

 Any materials can be machined regardless of their electrical conductivity

 Especially suitable for machining of brittle materials

 Machined parts by USM possess better surface finish and higher structural integrity.

 USM does not produce thermal, electrical and chemical abnormal surface

Disadvantages of USM

 USM has higher power consumption and lower material-removal rates than traditional fabrication processes.

 Tool wears fast in USM.

 Machining area and depth is restraint in USM.

Applications

Used for machining hard and brittle metallic alloys, semiconductors, glass, ceramics, carbides etc. Used for machining round, square, irregular shaped holes and surface impressions.

Machining, wire drawing, punching or small blanking dies.

Machining of very precise and intricate shapes.

LBM: Laser beam Machining

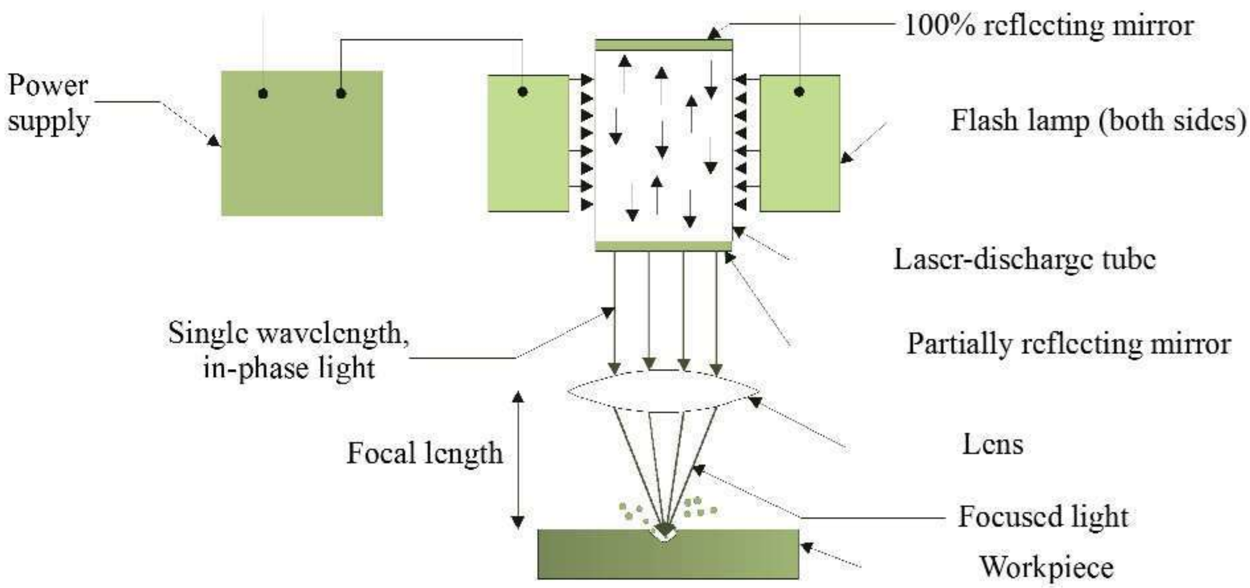
Laser (Light amplification by stimulated emission of radiation) beam machining used the energy from coherent light beams called laser. Under proper condition, light energy of a particular frequency is used to stimulate the electrons in an atom to emit additional light with exactly same characteristics as the original light source.

Laser-beam machining is a thermal material-removal process that utilizes a high-energy, coherent light beam to melt and vaporize particles on the surface of metallic and non-metallic workpieces. Lasers can be used to cut, drill, weld and mark. LBM is particularly suitable for making accurately placed holes.

Different types of lasers are available for manufacturing operations which are as follows:

- Solid State laser: Nd-YAG (Neodymium-doped Yttrium-Aluminum-Garnet ($Y_3Al_5O_{12}$), Ruby (Aluminium oxide with chromium ion impurities (Al_2O_3+ Cr_2(0.05%)
- Gas Laser: Co_2, He, N_2
- Semiconductor Laser
- Excimer Laser

Working Principle



Laser light is monochromatic i.e, its wavelength occupies a very narrow portion of spectrum. Hence a simple lens is able to focus and concentrate laser light to a spot of much smaller diameter and much higher intensity than other type of light. Laser light is coherent in nature (it travels in phases). Hence it gives higher focused intensities than normal light which is incoherent in nature. The low divergent rate of laser is also responsible for high intensity of light.

LBM has three important elements of laser device, a laser medium (collection of atoms, molecules or ions), a pumping energy source required to excite these atoms to higher energy level, and a optical system.

Consider a gas laser consisting of thin tube filled with gas at low pressure. Electric current when passed through provides sufficient energy to stimulate the atoms of the gas in the tube. The optical system consists of two mirrors at both ends; one of these is fully reflective while other one is partially transparent to provide laser output. It allows a beam of radiation to either pass through or bounce back and forth repeatedly through laser medium. When high intensity beam falls on the workpiece through lens, its surface temperature rises to above melting point which melts and vaporizes the workpiece.

Principle of Laser beam production

Electrons are arranged in different cells of an atom and each cell has a set of number of electrons. When we provide external energy to atoms (either by heat or by bombarding photons), the electrons jump to the higher energy level. Einstein proposed that when an atom at low energy level has light of right frequency acting on it, it absorbs photons of that light and moves to higher energy level. This phenomenon is called absorption. The higher energy level is an unstable state, so the electrons of atom moves back to its original state by emitting energy. The emission can be two type; one is spontaneous, another is stimulated emission. The stimulated emission occurs when any photon bombards an atom at the excited state.

Let an atom at energy level (E0) be brought to high energy level (E3) by an outside energy source. The high energy level is an unstable state, when it move back to its ground state it emits a photon. If this photon comes in contact with another atom at higher energy state, it emits two photons to come back to ground state. This chain event will produce photons with same characteristic. This is called Stimulated emission. Further to produce working laser, the energy source should be so powerful that most of the atoms of lasing material are at higher energy level. This is called population inversion. Feedback mechanism captures and redirects a part of coherent photons back into the active medium. These photons further stimulate the emission of some more photons of same characteristics. This mechanism also permits a small percentage of coherent photons to exit the system in the form of laser light.

For laser beam production using Ruby rod, flash lamps are used to continuously bombard the chromium atoms of ruby rod. Chromium atom is present in ruby rod up to 0.05%. when chromium atoms are bombarded it jumps to higher energy level and instantaneously drops down to intermediate energy level as the upper position is most unstable. The intermediate energy level is a metastable phase where the cr atom remains for 3/1000 th sec. it then comes back to ground level by radiating energy absorbed by it. At intermediate level, if photons hit the chromium atom, it instantly emits two photons. This is called stimulation effect. The radiated photon will reflect back to lasing medium by fully reflected mirror. The partial reflected mirror allows some photon to pass through it, and this is used to cut the material by passing through a lens.

Parts

Power Supply:

It provides the energy for excitation of electron from lower energy level to higher energy level. This gives power to xenon flash lamps, which produce light energy. The laser material are exposed in light energy to keep storing energy.

Laser Discharge Tube:

The laser material filled in lased discharge tube. The excitation of electron and come back to its original state process takes place in it. It's one side is partially transparent for laser opening and other side is 100% reflected. It is situated between flash lamp.

Laser Material:

There are many different type of laser material available but in later machining mostly CO2(Pulsed or continuous waves) and Nd: YAG is Used. Carbon die oxide is a laser material that emits light in infrared region. It can provide up to 25 KW power in continuous wave mode. The other one is called Neodymium doped Yttrium Aluminum Garnet is a solid state laser which can delivery light through optical fiber. It can generate about 50 KW power in pulsed mode and 1 KW power in continuous mode.

Focusing Lens:

A focusing lens is used in laser machining operation. It is a convex lens which focus is at work piece. The focused beam radius is directly proportional to the laser Wavelength and lens focal length and inversely proportional to the unfocused radius.

Capacitor: Capacitor is used to operate the laser beam machine at pulse mode.

CHARACTERISCTICS of LBM

Material removal technique - Heating, melting and vaporization.

Tool - Laser beams in wavelength range of 0.4-0.6 μm.

Power density - As high as 107 W/mm^2

Output energy of laser and its pulse duration -20 J , 1 milli second.

Peak power - 20Kw

Medium - normal atmosphere

Material removal rate - 5 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%

Advantages

- No limit to cutting path as the laser point can move any path.
- The process is stress less allowing very fragile materials to be laser cut without any support.
- Very hard and abrasive material can be cut.
- Sticky materials are also can be cut by this process.
- It is a cost effective and flexible process.
- High accuracy parts can be machined.
- No cutting lubricants required
- No tool wear
- Narrow heat effected zone
- Micro holes can be produces

Limitations –

Taper of 0.05 mm when work thickness is more than 0.25 mm.

Very large power consumption

High initial cost, short life of flash lamp, low MRR

High maintenance cost

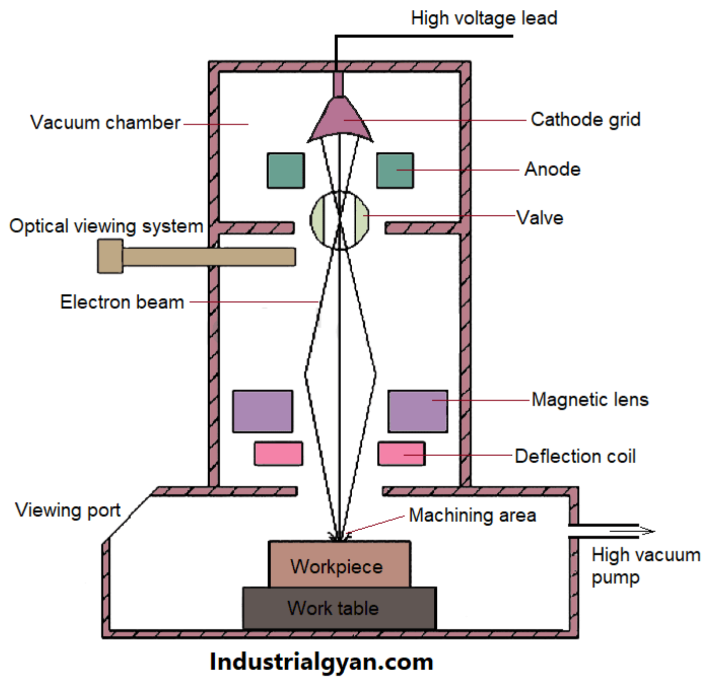
Applications

- LBM can make very accurate holes as small as 0.005 mm in refractory metals ceramics, and composite material without warping the workpieces.
- This process is used widely for drilling and cutting of metallic and non-metallic materials.
- Laser beam machining is being used extensively in the electronic and automotive industries.
- To produce fine and minute holes

Electron Beam Machining

Electron beam machining (EBM) is a thermal machining process in which high-velocity electrons concentrated into a narrow beam are used for instantly heating, melting, or vaporizing the material. In electron beam machining process there is a bombardment of high velocity stream (around 50% -60% velocity of the sunlight) of electrons on the work-piece surface. Because of this bombardment of electrons on the work piece, the KE of electrons convert into heat energy which melts and vaporizes the material from workpiece. The whole process takes place in vacuum. It is used to prevent contamination and avoid collision of electrons with air molecule which may cause loss of KE from electrons. Workpiece material may be both electrically conductive and electrically nonconductive.

Electron Beam Machining Diagram:



Electron beam gun is the heart of any electron beam machining facility. The basic functions of any electron beam gun are to generate free electrons at the cathode, accelerate them to a sufficiently high velocity and to focus them over a small spot size. The cathode as can be seen in is generally made of tungsten. When cathode filaments are heated to a temperature of around 2500°C, emission of electrons takes place. A potential difference of 150 KV is created between the anode and cathode in EBM. Due to force of repulsion from cathode, electrons move at very high velocity towards anode. On the path of electrons, there is a kind of switch (bias grid) which generates the pulses. After the anode, the electron beam passes through the magnetic lenses. The magnetic lenses reduce the divergence of electron beam and shape them. It allows only convergent electrons to pass and captures the low energy divergent electrons from fringes. It improves the quality of the beam. Then the electron beam passes through the final section of the electromagnetic lens and deflection coil. The electromagnetic lens focuses the electron beam to a desired spot. The deflector coil carefully guides the high velocity electron beam to a desired location on the workpiece and improves the shape of the holes.

In this process, production of high vacuum (10 mmHg) is essential to ensure free movement of electron, to prevent cathode from chemical contamination and heat loss, to prevent possibility of arc discharge between the electrodes. An optical viewing system is required in order to allow the operator to see the work, in order to position the beam. In EBM, a tolerance up to 0.005 mm is possible.

Material removal rate: The values of the material removal rates in the process of electron beam machining are about **10 mm3/min**.

Process parameters

The process parameters of EBM are as follows.

- Beam current: It is related to the emission of electrons by the cathode in the beam whose value is as low as 1μA.
- Duration of Pulse: It can be varied from 50 μs to 15 ms.
- Accelerating voltage (Va) is 150 Kv.
- Energy per pulse is 100 J/Pulse.

Advantages

- EBM provides very high drilling rates when small holes with large aspect ratio are to be drilled.
- Moreover it can machine almost any material irrespective of their mechanical properties. As it applies no mechanical cutting force,
- work holding and fixturing cost is very less
- Fragile and brittle materials can also be processed.
- The heat affected zone in EBM is rather less due to shorter pulses.
- EBM can provide holes of any shape by combining beam deflection using electromagnetic coils and the CNC table with high accuracy.

Limitation

- The primary limitations are the high capital cost of the equipment and necessary regular maintenance applicable for any equipment using vacuum system.
- Moreover in EBM there is significant amount of non-productive pump down period for attaining desired vacuum.
- However this can be reduced to some extent using vacuum load locks.
- Though heat affected zone is rather less in EBM but recast layer formation cannot be avoided
- Not suitable for large workpieces

The applications of Electron Beam Machining Process are as follows.

- Mainly used for producing holes in the **diesel injection nozzles.**
- Also used for producing blind holes, narrow slots, etc. in the workpieces.
- In electron beam machining, if the voltage given to the electron gun is about 60 to 70000 volts, the velocity of electrons produced is reducing, heat generation at the workpiece is reducing. Therefore, the heat generated is sufficient to melt and join the workpiece called an electron beam welding operation.

Chapter-2

Plastic processing

Plastic processing can be defined as the process of converting the plastics raw material into semi-finished products. Examples: Buckets, Automobile Parts, Crates, Tanks, Pipes, Bottles, Carry bags, Ropes, Profiles etc.

Plastics can be machined, cast, formed, and joined with requiring little post-processing or surface- finish operations

• Plastics melt or cure at relative low temperatures

• Plastics require less energy to process than metals

• Raw materials most commonly are pellets, powders

• Also available as sheet, plate, rod, and tubing (produced by extrusion, etc.)

• Liquid plastics used to make reinforced plastic parts (composite materials)

Processes;

Extrusion : Long, uniform, solid or hollow complex cross-sections; high production rates; low tooling costs; wide tolerances.

Injection molding : Complex shapes of various sizes, eliminating assembly; high production rates;

costly tooling; good dimensional accuracy.

Blow molding :Hollow thin-walled parts of various sizes; high production rates and low cost for

making containers.

Rotational molding : Large hollow shapes of relatively simple shape; low tooling cost; low production

rates.

Thermoforming : Shallow or relatively deep cavities; low tooling costs; medium production rates.

Compression molding :Parts similar to impression-die forging; relatively inexpensive tooling; medium

production rates.

Transfer molding : More complex parts than compression molding and higher production rates; some

scrap loss; medium tooling cost.

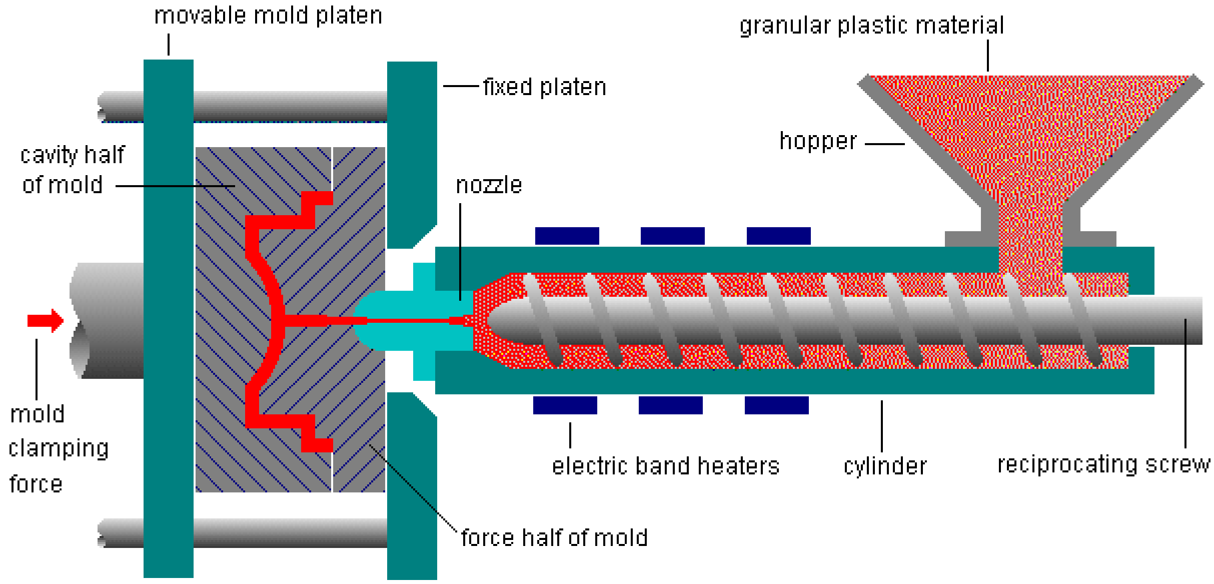
Casting: Simple or intricate shapes made with flexible molds; low production rates.

1. **Injection Molding**

Injection molding is a forming process using molds. Materials such as synthetic resins (plastics) are heated and melted, and then sent to the mold where they are cooled to form the designed shape.

Injection Molding Process

- Injection molding begins with resin pellets (granules) being poured into the hopper, the entry point for the material. The injection ram pushes the material into the heating cylinder.
- The pellets are then heated and melted inside the cylinder in preparation for injection.
- The material is then forced through the nozzle of the injection unit before being delivered through a channel in the mold called a sprue and then through branched runners into the mold cavity.
- After the material cools and hardens, the mold opens, and the molded part is ejected from the mold.
- To finish the molded part, the sprue and runner are trimmed from the part.
- It is important that the melted material is evenly delivered throughout the mold as often times there is more than one cavity within the mold allowing for the production of more than one part at a time. Therefore, the mold shape should be designed in a way that ensures this.
- While injection molding is suitable for mass production, it is essential to have a good knowledge about the various conditions required to produce high-precision products, which include the selection of resin material, the processing precision of the mold, and the temperature and speed of the melt injection
- 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 easily can be pushed into the die. Pressures used from 70-200 MPa. Cool molds used for thermoplastics. Heated molds for thermosets.



injection molding process

Advantages and limitations:

High production rate

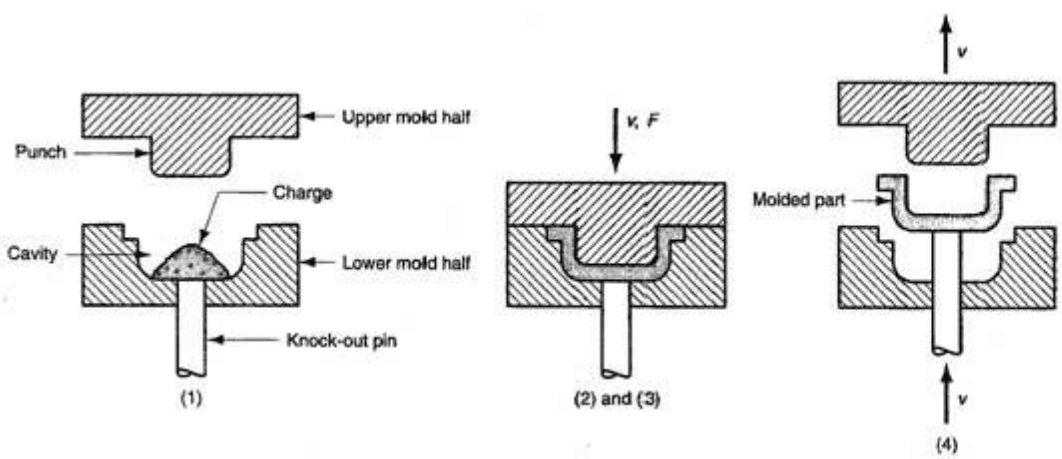
Good dimensional accuracy

Multiple cavities can be formed

Mostly used for thermoplastic as in case of thermosetting , the sprue and runner material is wasted as recycling of this product is not possible.

2. Compression Molding and transfer molding:

It is mostly used for thermosetting polymers. In compression molding the monomers are partially polymerized in a separate operation and polymerization is completed in the mold. The partially polymerized materials are placed in a heated mold. After the compound is softened, the upper die comes downward, compressing the material to the required shape. Continuous heat and pressure produce the chemical reaction leading to cross linking between the molecules chain which hardens the thermosetting material. Excess material may leak out from the parting lines creating flash, which must be trimmed away. Excess material may leak out from the parting lines creating flash, which must be trimmed away. The molding temperature of thermosetting material ranges from 150-180°C and pressure ranges from 135-535 kgf/cm2.

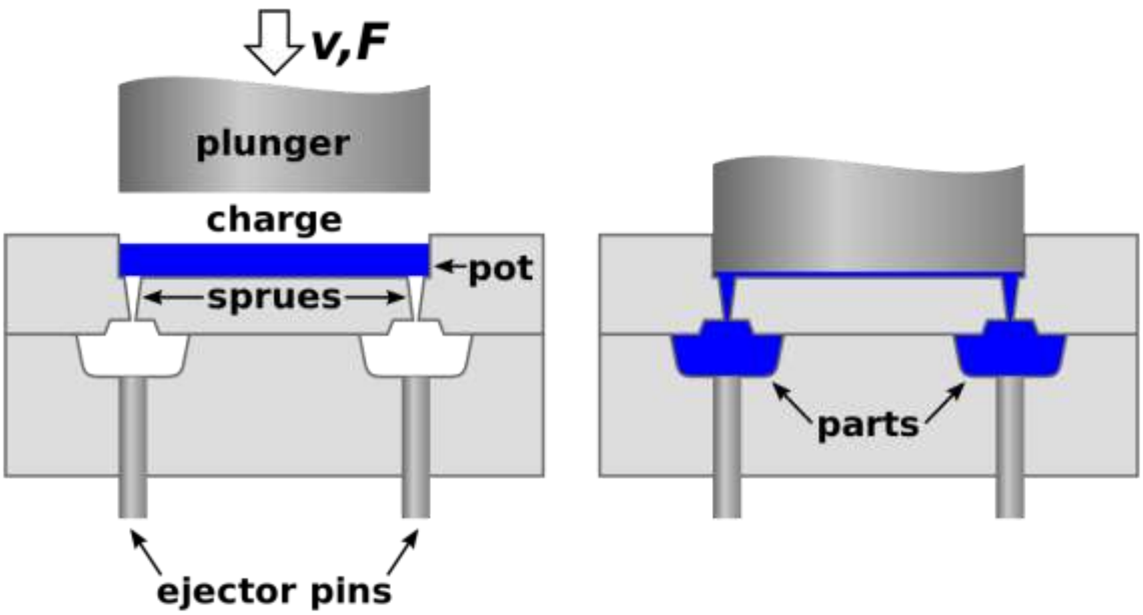


Transfer molding is a process of forming components in a closed mold from a thermosetting material that is conveyed under pressure, in a hot, plastic state, from an auxiliary chamber, called the transfer pot, through runners and gates into the closed cavity or cavities. If the part shape is more complex, transfer molding may be used. Here, the charge (thermoset grains) are placed in a heated cylinder till they are soft; a hole at the bottom of the cylinder is connected to the die cavity by a sprue. A plunger pushes the semi-solid plastic into the die through the sprue, using high pressure.

Transfer molding is a manufacturing process that combines the features of both injection molding and compression molding. It involves the use of a pre-measured amount of raw material. It is heated and loaded into a chamber known as the pot situated at the top of the mold. The material contained in the pot, which is typically a heated reservoir, is used for a single cycle and can be utilized to fill multiple mold cavities simultaneously. A piston is then employed to drive the polymer into a preheated mold through a channel referred to as a sprue. The mold remains in a closed position until the material contained within has fully cured.

The mold used in the transfer molding process is a hollow space, or cavity, which has an inside surface that defines the shape of the desired part. This method offers several advantages over other molding techniques, such as compression molding. These advantages include: shorter production cycle times, higher cavity count, and greater design flexibility.

Transfer molding is primarily used to encase electronic components in rubber or plastic. It enables the fabrication of plastic parts with metal inserts, such as prongs or semiconductor chips. Pins, studs, connectors, and molded terminals can all be produced using this method. These methods are used to make dishes, handles for cooking pots, skis, housing for high-voltage switches, some rubber parts like shoe soles, and even composites such as fiber-reinforced parts.



Advantages

1. Allows for intricate designs with sharper edges, providing greater design flexibility compared to other molding methods
2. Produces parts with minimal or no flash, eliminating the need for additional deflashing processes
3. Typically involves simpler pot and plunger designs, resulting in lower tooling and equipment costs compared to other molding techniques

Disadvantages

1. Generally has a slower production rate compared to injection molding due to the additional steps involved in material preparation and transfer
2. Air can get trapped in the mold during the transfer process. This can lead to defects in the final product and require additional measures to ensure air is properly evacuated

How Does Transfer Molding Differ From Compression Molding?

Transfer molding and **compression molding** are similar processes, but they differ in how the molding material is pressurized. In transfer molding, the material is preheated and pressurized in a separate chamber before being forced through an opening into a closed mold cavity. In compression molding, the material is directly placed into the mold cavity, and pressure is applied to the entire mold to shape the material.

How Does Transfer Molding Differ From Injection Molding?

Transfer molding and injection molding are both popular techniques for manufacturing plastic parts, but they differ in several ways.

- In transfer molding, the material is typically fed into a heated chamber through a screw, and then a plunger forces it into a mold cavity. Injection molding, on the other hand, uses a reciprocating screw to melt and inject the material directly into the mold cavity.

- Transfer molding is commonly employed for encasements and low-volume production of simpler molds, while injection molding is well-suited for larger, thin-walled parts.

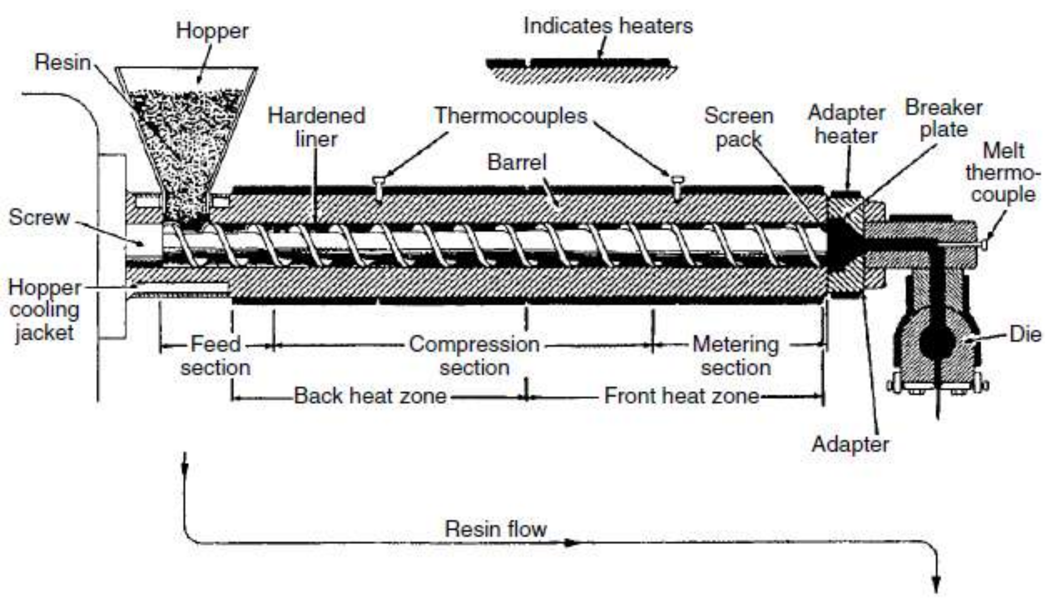
- Injection molding offers higher production rates and better precision, while transfer molding offers lower tooling complexity.

- Transfer molding necessitates preparing the raw material before it is forced into the mold, increasing processing time and raising costs. In contrast, injection molding instantaneously mixes and readies the material, allowing for immediate production.

3. Extrusion Moulding

It is a continuous operation in which powdered polymer or monomer is fed by a screw along a cylindrical chamber. As the powder moves towards the die, it is heated and melts. The molten plastic is forced through the die opening to the desired shape. The extruded product is referred to as the extrudate. The process is used for compounding plastics and for the production of tubes, pipes, sheet, film, wire coating, and profiles. the most common types of extruders are single-screw extruders, intermeshing twin-screw extruders, and ram extruders for special processes.

A single-screw extruder consists of a screw in a metal cylinder or barrel. One end of the barrel is attached to the feed throat while the other end is open. A hopper is located above the feed throat and the barrel is surrounded by heating and cooling elements. The screw itself is coupled through a thrust bearing and gear box, or reducer, to a drive motor that rotates the screw in the barrel. A die is connected to the "open" end of the extruder with a breaker plate. During extrusion, resin particles are fed from the hopper, through the feed throat of the extruder, and into the extruder barrel. The resin falls onto the rotating screw and is packed in the first section or feed zone of the screw. The packed particles are melted as they travel through the middle section (transition or compression zone) of the screw, and the melt is mixed in the final section or metering zone. Pressure generated in the extruder forces the molten polymer through the die. Extruder drive motors must turn the screw, minimize the variation in screw speed, permit variable speed control (typically 50 to 150 r/min), and maintain constant torque.



The feed throat fits around the first few flights of the screw and is usually separate from the barrel of the extruder. It is insulated from the barrel and cooled with water to prevent bridging and premature melting of the resin particles. **The feed hopper** feeds material to the extruder. **The barrel** is a metal cylinder that surrounds the screw. One end fastens to the feed throat and the opposite end connects directly to the die adapter. Extruder barrels typically have length-to-diameter (*L/D*) ratios of 24:1 to 36:1, but they can be larger. Since melting occurs over a longer transition zone, longer barrels provide increased output. **The screen pack** is a wire meshed filters that the melt must pass through. It is placed at the end of the screw and serves to filter contaminates from the melt**. The breaker plate** acts as a seal between the extruder barrel and the die adapter, thus preventing leakage of the melt. It converts the rotational motion of the melt to axial motion. Barrels, dies, and die adapters are heated to bring them to operating temperatures and to maintain set temperatures during operation. To maintain constant temperatures, barrels must usually be cooled by fans (blowers) or water. Although fans remove heat slowly, they are inexpensive, and, thus, are the most commonly used. **Extruder screws** fit into the barrel and are supported by the thrust bearing. Extruder screws are specified by their outside diameter (*D*) and the *L/D.* In metering screws, the flighted section is divided into three zones: feed, transition or compression, and metering.

Working of a single screw extruder

During extrusion, plastic particles flow from the hopper and into the feed throat of an extruder. Gravity is usually the driving force for solids conveying in hoppers. With pellets and some granules, this produces mass or hopper flow in which all the particles flow down the hopper to the feed throat. The feed throat is cooled to prevent plastic particles from melting at the base of the hopper and forming a bridge. The cylinder is heated by electricity, steam or oil along its length. The rotating screw carries and mixes the material through the cylinder and forces it through the die of required shape. The screw has three zones i.e, feed zone, compression zone and metering zone. The screw diameter gradually increases or the pitch of screw decreases in the compression zone. The rotation of screw conveys the plastics forward through the heated barrel. As the plastic moves forward along the screw, the channel depth decreases forcing the plastic through a smaller area. The combination of compression and screw rotation causes friction generating the shear heat. This heat along with the barrel heating section melts the plastic. The extruded shape coming from the die is carried through a cooling medium by conveyor. When it is cooled to retain its shape, it is cut into required lengths or coils. Too rapid cooling must be avoided as it can cause internal strains in the finished pieces.

Advantages
Low initial cost
Continuous production

Chapter-3

Additive manufacturing

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

Common to AM technologies is the use of a computer, 3D modeling software (Computer Aided Design or CAD), machine equipment and layering material.

Once a CAD sketch is produced, the AM equipment reads in data from the CAD file and lays downs or adds successive layers of liquid, powder, sheet material or other, in a layer-upon-layer fashion to fabricate a 3D object.

The term **AM** encompasses many technologies including subsets like 3D Printing, Rapid Prototyping (RP), Direct Digital Manufacturing (DDM), layered manufacturing and additive fabrication.

Applications of Am includes

- Aerospace. Aerospace companies were some of the first to adopt additive manufacturing.
- Medical.
- Transportation.
- Energy.
- Consumer Products.

Need for additive manufacturing

1. Create parts with greater complexity

Additive manufacturing can overcome the limitations of traditional manufacturing methods to create highly complex parts with improved functionality.

2. Minimal material waste

3. Simplified assembly

With traditional manufacturing, multiple components must be produced and then subsequently assembled to create the final part.

However, with 3D printing, several smaller components can be integrated into a single custom part during the design stage, allowing you to print the entire part at once. This significantly simplifies the assembly process, and can even eliminate the need for assembly at times.

4. Material innovation
5. Cost-effective customization

3D printing enables quick and multiple design iterations at no extra cost, taking customisation possibilities to new heights. And as additive manufacturing creates parts directly from digital files, the manufacturing process is significantly accelerated. This means that companies can produce customised products much faster and cost-effectively.

Fundamentals of additive manufacturing /AM process chain

1. Conceptualization:
   A model or component is modelled 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. This mean that the data must specify the inside, outside and boundary of the model. This requirement will become redundant if the modelling technique used is solid modelling. This is by virtue of the technique used, as a valid solid model will automatically be enclosed volume.
2. The solid or surface model to be built is next converted into a format dubbed the “STL” (Stereolithography) file format which originates from 3D systems. The STL file format approximates the surfaces of model by polygons.

The term STL was derived from STereoLithograhy. STL is a simple way of describing a CAD model in terms of its geometry alone.

It works by removing any construction data, modeling history, etc., and approximating the surfaces of the model with a series of triangular facets.

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.

The process of converting to STL is automatic within most CAD systems.

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.

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.

The first few stages of the AM process are semi-automated tasks that may require considerable manual control, interaction, and decision-making.

Once these steps are completed, the process switches to the computer- controlled building phase.

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

3. Post processing

Post-processing refers to the (usually manual) stages of finishing the parts for application purposes.

This may involve abrasive finishing, like polishing and sandpapering, or application of coatings.

ADVANTAGES

- AM can print complex 3D geometries with internal features without any tooling.
- Reduced waste compared to machining.

- Part can be printed directly from the 3D model without the need for a drawing.
- Prototypes can be made quicker, allowing designers to check different iterations resulting in a quicker design cycle phase.
- No or less tooling for smaller batches compared to traditional machining.
- Production tooling can be printed.
- Different materials can be mixed during the printing process to create a unique alloy.
- Different sections of the part can be different variants of the same alloy.

DISADVANTAGES

- High production costs because of the equipment cost
- Various post-processing required depending on the type of additive manufacturing used.
- Small build volume compared to other manufacturing part sizes such as sand casting.
- Poor mechanical properties hence need post-processing.
- Poor surface finish and texture compared to manufacturing processes like CNC and investment casting.
- The strength of the parts is comparably weaker compared to manufacturing processes such as Die casting, Investment casting and CNC machining.

Classification of AM process

Additive manufacturing may be classified into

1. Material extrusion -(fused filament fabrication)
2. VAT polymerization -(Sterio lithography, Direct laser printer)
3. Powder bed fusion (polymer)- (selective laser sintering)
4. Material jetting
5. Binder jetting
6. Powder bed fusion (metal)- (direct metal laser sintering, selective laser melting, electron beam melting)

Difference between AM and CNC

CNC (Computer Numerical Control) and AM (Additive Manufacturing) machines are two types of manufacturing technologies that are widely used in various industries, such as aerospace, automotive, medical, and consumer goods. While both technologies are used to create complex parts and components, they operate on different principles and have distinct advantages and disadvantages.

CNC

- CNC machines are subtractive manufacturing devices that use computer-controlled cutting tools to remove material from a block or sheet of material to create a desired shape.
- The process begins with a 3D model of the part, which is created using computer-aided design (CAD) software.
- The CNC machine reads the CAD file and uses it to control the movement of a cutting tool along multiple axes, such as X, Y, and Z, to precisely remove material from the work piece until the desired shape is achieved.
- CNC machines can produce parts with high accuracy, surface finish, and repeatability, making them ideal for the mass production of parts with tight tolerances.
- CNC machines are versatile and can work with a variety of materials, such as metals, plastics, composites, and wood.
- They can produce parts with complex geometries and features, such as holes, pockets, threads, and chamfers.
- CNC machines can also perform multiple operations, such as drilling, milling, turning, and grinding, on a single workpiece, reducing the need for manual labor and increasing productivity

Limitations

- CNC machines have some limitations, such as material wastage, long setup times, and limited flexibility.
- Since CNC machines remove material from the workpiece, they generate a significant amount of scrap material, which can increase the production cost and environmental impact.
- CNC machines also require significant setup time to load and align the workpiece and cutting tools, which can reduce the throughput and increase the lead time. Additionally, CNC machines are designed to produce parts in large quantities and may not be suitable for low-volume or customized production.

AM

- AM machines, also known as 3D printers, are additive manufacturing devices that use computer-controlled deposition of material to build up a part layer by layer from a 3D model.
- The process begins with a 3D model of the part, which is created using CAD software or obtained from a 3D scanner. The AM machine reads the CAD file and uses it to control the deposition of material, such as polymers, metals, ceramics, or composites, through a nozzle or a laser beam.
- The material is deposited layer by layer, following the shape of the part, until the final part is complete. AM machines can produce parts with high complexity, customization, and functionality, making them ideal for prototyping, low-volume production, and highly customized parts.
- AM machines have several advantages, such as material efficiency, short setup time, and high flexibility. Since AM machines add material only where it is needed, they generate little to no waste, reducing the production cost and environmental impact.
- AM machines also require minimal setup time and can switch between different parts and geometries quickly, reducing the lead time .

- Additionally, AM machines can produce parts with complex internal structures, overhangs, and undercuts that are difficult or impossible to achieve with CNC machines.

Limitations

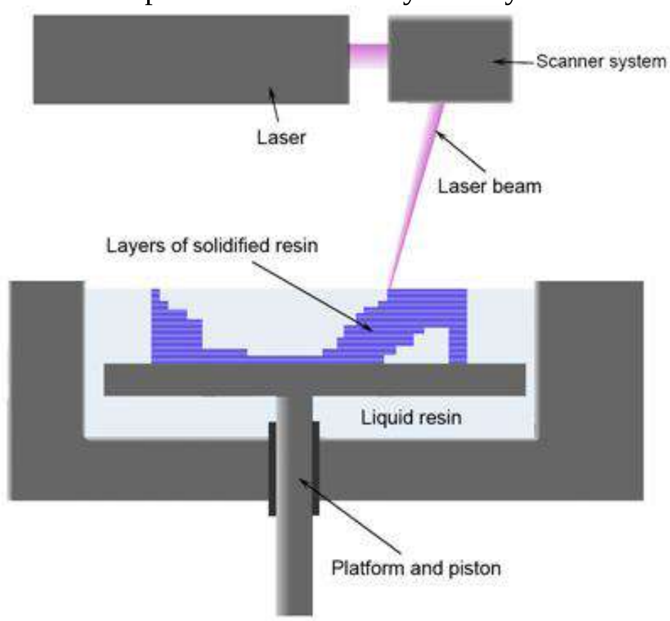
- However, AM machines also have some limitations, such as lower accuracy, lower surface finish, and limited scalability.
- Since AM machines build up parts layer by layer, the surface finish of the part may be rougher than that of a CNC-machined part.
- AM machines also have lower accuracy and repeatability than CNC machines, which can affect the quality and consistency of the parts.
- Finally, AM machines may not be suitable for mass production or high-volume production due to their slower build speed

<u>Types of AM process</u>

Vat Photopolymerization / steriolithography (SLA):-

This fast and affordable technique was the first successful method of commercial 3D printing. It uses a bath of photosensitive liquid which is solidified layer-by-layer using a computer-controlled ultra violet (UV) light.

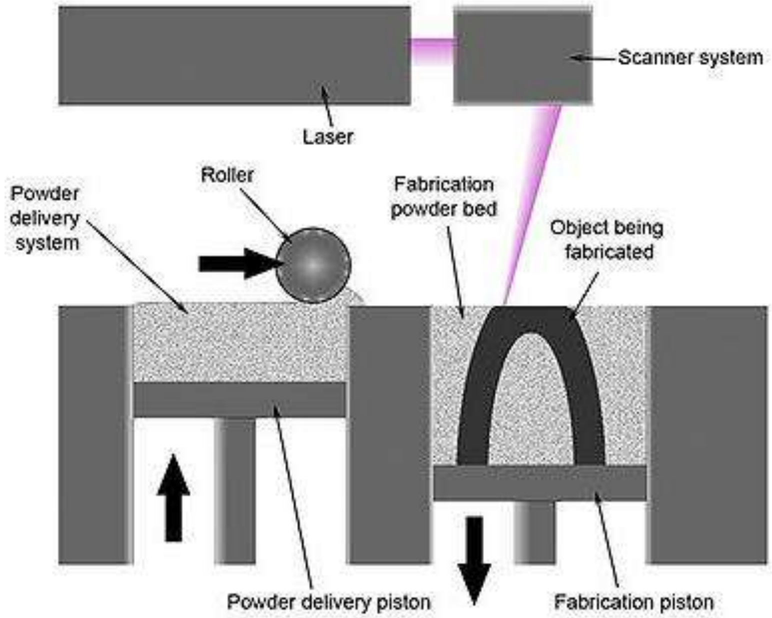
- Laser beam traces one layer on the surface of the resin
- Laser light cures and solidifies parts it hits
- The platform descends by one layer



2) Selective Laser Sintering (SLS):

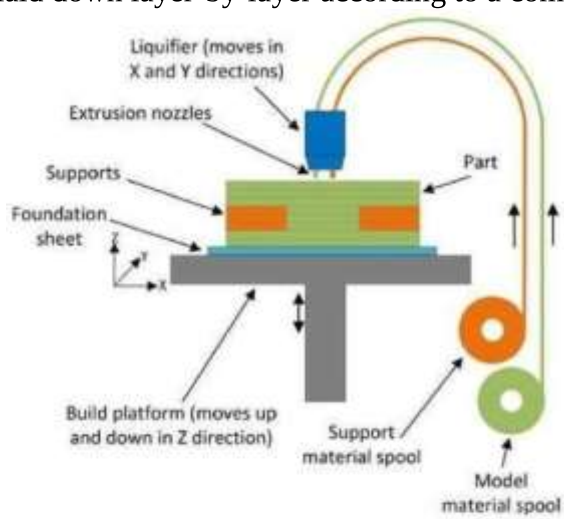
Used for both metal and plastic prototyping, SLS uses a powder bed to build a prototype one layer at a time using a laser to heat and sinter the powdered material. However, the strength of the parts is not as good as with steriolithography, while the surface of the finished product is usually rough and may require secondary work to finish it.

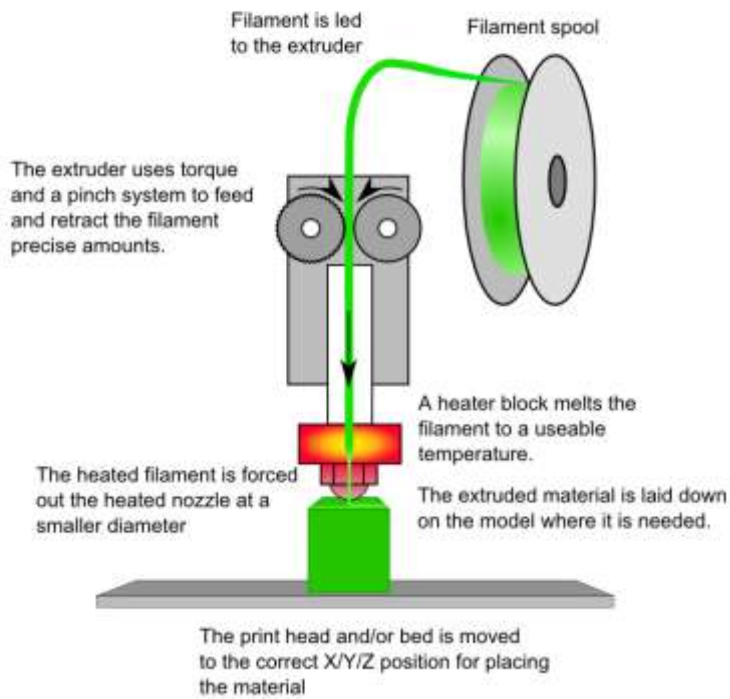
•SLS and DMLS use a bed of small particles (made of plastic, metal, ceramic, or glass)
•High-power laser traces one layer on the surface of the powder bed fusing the particles
•The platform descends by one layer and more material is added



3. Fused Deposition Modelling (FDM) or Material Jetting:

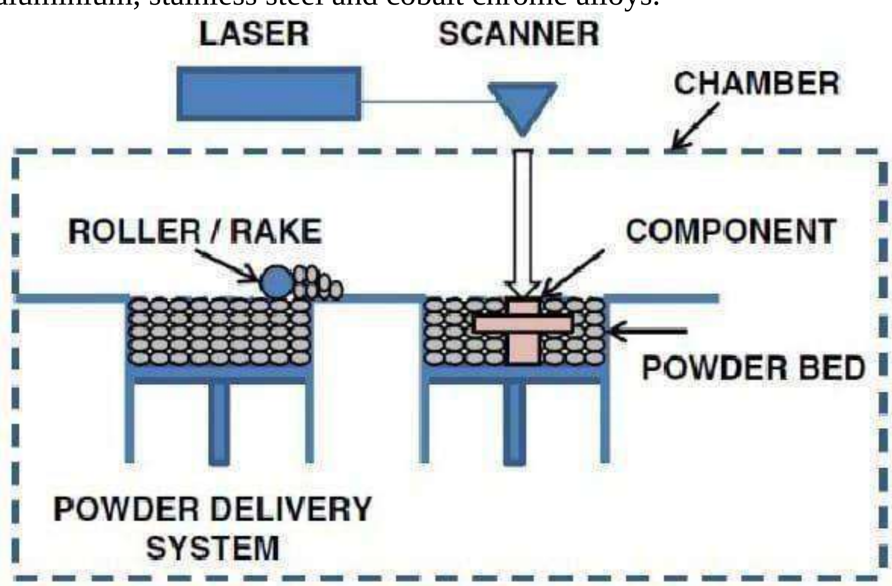
This inexpensive, easy-to-use process can be found in most non-industrial desktop 3D printers. It uses a spool of thermoplastic filament which is melted inside a printing nozzle barrel before the resulting liquid plastic is laid down layer-by-layer according to a computer deposition program.





4. Selective Laser Melting (SLM) or Powder Bed Fusion:

Often known as powder bed fusion, this process is favoured for making high-strength, complex parts. Selective Laser Melting is frequently used by the aerospace, automotive, defence and medical industries. This powder bed based fusion process uses a fine metal powder which is melted in a layer by layer manner to build either prototype or production parts using a high-powered laser or electron beam. Common SLM materials used in RP include titanium, aluminium, stainless steel and cobalt chrome alloys.

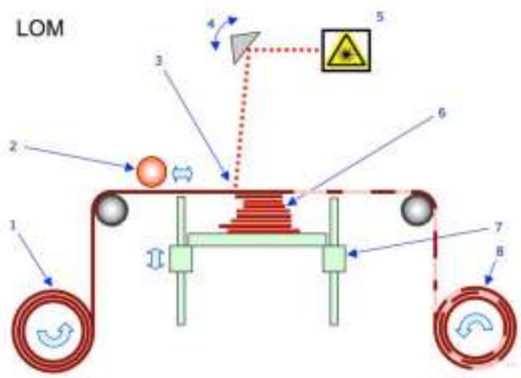


Powder bed fusion is an Additive Manufacturing technique that uses either a laser or electron beam to melt and fuse the material to form a 3D geometry part.

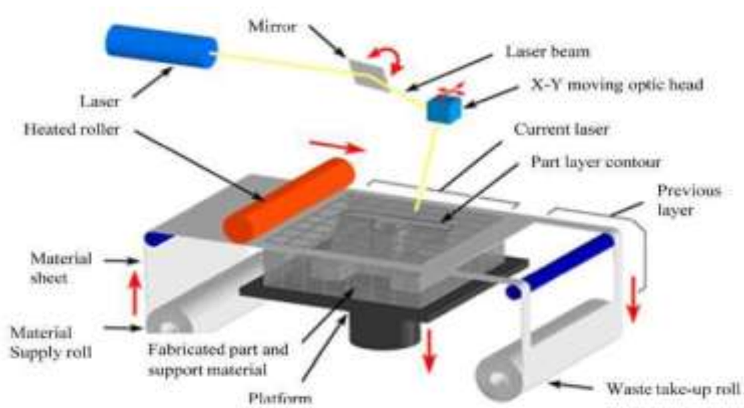
5. Laminated Object Manufacturing (LOM) or Sheet Lamination:

This inexpensive process is less sophisticated than SLM or SLS, but it does not require specially controlled conditions. LOM builds up a series of thin laminates that have been accurately cut with laser beams or another cutting device to create the CAD pattern design. Each layer is delivered and bonded on top of the previous one until the part is complete.

•Sheet is adhered to a substrate with a heated roller
•Laser traces desired dimensions of prototype
•Laser cross hatches non-part area to facilitate waste removal
•Platform with completed layer moves down out of the way
•Fresh sheet of material is rolled into position
•Platform moves down into position to receive next layer



1 Foil supply. 2 Heated roller. 3 Laser beam. 4. Scanning prism. 5 Laser unit. 6 Layers. 7 Moving platform. 8 Waste.



6.

BINDER JETTING PROCESS:

Binder Jetting selectively deposits the bonding agent, a binding liquid, to join the powder material to form a 3D part. This process is different to any other AM technology as it does not employ heat during the process like others to fuse the material.

The print head and a powder spreader deposit alternating layers of bonding agent and build material to form a 3d object.

7.

MATERIAL EXTRUSION:

Material Extrusion is an additive manufacturing technique that uses a continuous filament of thermoplastic or composite material to construct 3D parts

In this additive manufacturing technique, the continuous filament of thermoplastic is fed through a heated nozzle before being deposited layer by layer onto the build platform to create the object.

8. Digital Light Processing (DLP):

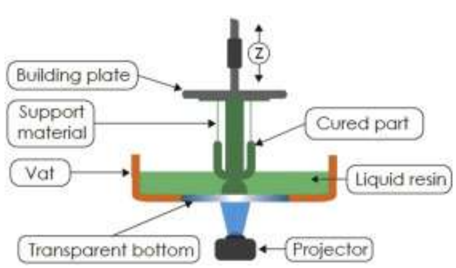
Similar to SLA, this technique also uses the polymerisation of resins which are cured using a more conventional light source than with SLA. While faster and cheaper than SLA, DLP often requires the use of support structures and post-build curing.

An alternative version of this is Continuous Liquid Interface Production (CLIP), whereby the part is continuously pulled from a vat, without the use of layers. As the part is pulled from the vat it crosses a light barrier that alters its configuration to create the desired cross-sectional pattern on the plastic.

Working Process:

The digital light projector is the light source of a DLP 3D printer. The DMD (Digital Micromirror Device) is a component which is made of thousands of micromirrors used for navigating the light beam projected by the digital light projector. Next up the line is the vat, which is basically a tank for the resin.

However, the vat needs to have a transparent bottom so that the light projected by the digital light projector reaches the resin and cures it. The build platform is simply the surface the printed objects stick to during printing. The z-axis is also a self-explanatory component, used for slowly lifting the build platform during the printing process. Again next layer is formed until complete model gets ready.



Application of AM

1. Medical

   Orthopedic implants, pre surgery models from CT scan, dental devices
2. Energy

rotors, turbine nozzles, stators, down-hole tool components and models, flow meter parts, mud motor models, fluid/water flow analysis, pressure gauge pieces, pump manifolds, and control-valve components.

3. Aerospace
4. Consumer product
5. Transportation

Rapid Prototyping

Rapid prototyping (RP) is a new manufacturing technique that allows for fast fabrication of computer models designed with three-dimension (3D) computer aided design (CAD) software. Rapid Prototyping (RP) can be defined as a group of techniques used to quickly fabricate a scale model of a part or assembly using three-dimensional computer aided design (CAD) data. RP is used in a wide variety of industries, from shoe to car manufacturers. This technique allows for fast realizations of ideas into functioning prototypes, shortening the design time, leading towards successful final products.

The reasons of Rapid Prototyping are
• To increase effective communication.
• To decrease development time.
• To decrease costly mistakes.
• To minimize sustaining engineering changes.
• To extend product lifetime by adding necessary features and eliminating redundant features early in the design.

RP technique comprise of two general types: additive and subtractive

Subtractive type RP or traditional tooling manufacturing process is a technique in which material is removed from a solid piece of material until the desired design remains. Examples of this type of RP includes traditional milling, turning/lathing or drilling to more advanced versions computer numerical control (CNC), electric discharge machining (EDM). Additive type RP is the opposite of subtractive type RP. Instead of removing material, material is added layer upon layer to build up the desired design such as stereolithography, fused deposition modeling (FDM), and 3D printing.

Rapid Prototyping uses a standard data interface, implemented as the STL file format, to translate from the CAD software to the 3D prototyping machine. The STL file approximates the shape of a part or assembly using triangular facets. 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.

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.

APPLICATION:

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.

Applications of Rapid Prototyping

RAPID TOOLING
• Patterns for Sand Casting
• Patterns for Investment Casting
• Pattern for Injection mouldings

RAPID MANUFACTURING
• Short productions run
• Custom made parts
• On-Demand Manufacturing
• Manufacturing of very complex shapes

AEROSPACE & MARINE
• Wind tunnel models
• Functional prototypes

BIOMEDICAL APPLICATIONS - I
• Prosthetic parts
• Use of data from MRI and CT scan to build 3D parts
• 3D visualization for education and training
• Customized surgical implants
• Mechanical bone replicas
• Anthropology
• Forensics

ARCHITECTURE
• 3D visualization of design space

FASHION & JEWELRY
• Shoe Design
• Jewellery

Web based Rapid prototyping

A web-based rapid prototyping and manufacturing (RP&M) system offers a collaborative production environment among users and RP&M providers to implement the remote service and manufacturing for rapid prototyping, to enhance the availability of RP&M facilities, and to improve the capability of rapid product development.

• 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 (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
A flexible manufacturing system (FMS) is a production method that is designed to easily adapt to changes in the type and quantity of the product being manufactured. Machines and computerized systems can be configured to manufacture a variety of parts and handle changing levels of production.
A FMS integrates all major elements of manufacturing into a highly automated system. The flexibility of FMS is such that it can handle a variety of part configurations and produce them in any order. The basic elements of FMS are a) works station b) automated material handling and automated storage and retrieval systems c) control systems. Because of major capital investment; efficient machine utilization is essential. Consequently, proper scheduling and process planning are crucial, that are complex in nature. Because of the flexibility in FMS, no setup time is wasted in switching between manufacturing operations; the system is capable of different operations in different orders and on different machines.

Advantages:
- Parts can be produced randomly in batch sizes, as small as one, and at lower cost.
- The lead times required for product changes are shorter
- Labour and inventories are reduced
- Production is more reliable, because the system is self-correcting and so product quality is uniform.
- Increased machine utilization

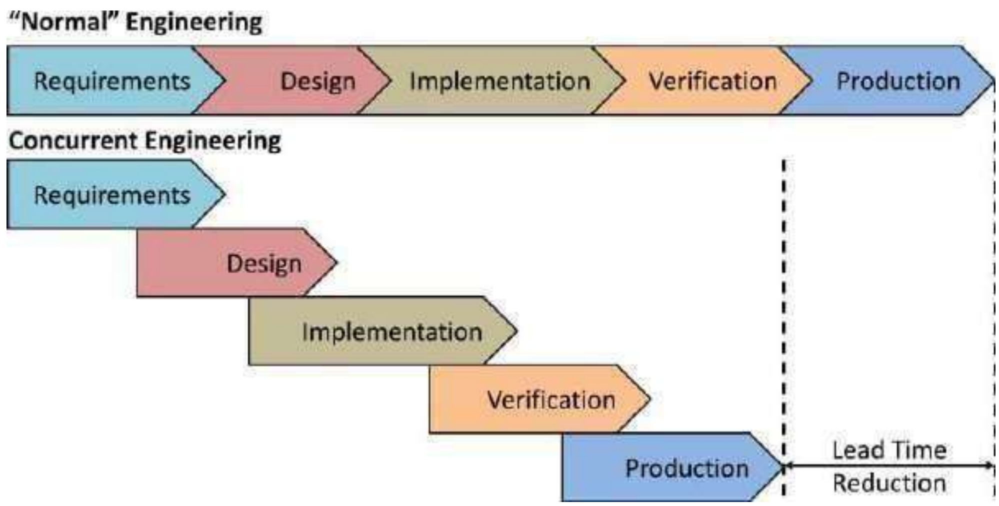
 Fewer machines required
 Reduced factory floor space
 Greater responsiveness to change

Three capabilities that a manufacturing system must possess to be a flexible.

1.The ability to identify and distinguish among the different part styles processed by the system.
2.Quick changeover of operating instructions, and
3.Quick changeover of physical setup.

Concurrent Engineering

It is also known as simultaneous engineering. It 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.



Chapter -4

SPECIAL PURPOSE MACHINE

Any machine which is used for mass production of particular component is called Special Purpose machine. SPM tools are developed for performing specific operation in mass production environment. SPM intended for manufacture of a special type of product. The machine will not have much variation but will have a small within that vicinity. Ex.
Hexagonal nuts, springs are some of the examples of product which are manufactured with the help of special purpose machines.

Advantage of Special Purpose Machines

- High accuracy
- Comprehensive tooling solutions
- Uniform quality
- Large production quantities.
- Repeatability
- Minimum possible time. Uncomplicated service or repair
- Short batch production

Elements of Special Purpose Machine
The elements that are used only in the specific type of machine are called as special purpose elements. For instance piston and connecting rods are used in the engines and compressors, while blades are used in the turbines and blowers. Some other examples are cam shafts push roads, crankshaft, cylinder etc.

The Elements of Special Purpose Machine are classified into two types: fasteners and elements of rotary motion drive.

1) Fasteners

The fasteners are the machine elements that connect or join various parts of the machine. The joints can be of permanent type or temporary type. The permanent joints are the ones that cannot be separated or disassembled into individual elements without destroying or damaging them. The examples of permanent joints are welded joints, riveted joints etc. The temporary joints are the ones in which the individual elements of the assembly can be separated easily without destroying or damaging them. The joints obtained by nut and bolt, and the cotter joints are common and widely used examples of the temporary joints.

2) Elements of rotary motion drive

These are the elements that help transmit the motion or power to or from the machines. For example belt connected to the motor and pump helps running them. The gear box helps transmit the motion and power from the engine to the wheels of the vehicles. Other examples of elements of the rotary motion drive are rope, chain, gear, worm drives, shafts, axles, couplings, bearings etc.

Principle of SPM design

Machine design and drawing are very important subjects of mechanical engineering No product can be manufactured without designing it. The knowledge of machine design helps the designers as follows:

1) To select proper materials and best suited shapes,

2) To calculate the dimensions based on the loads on machines and strength of the material,

3) Specify the manufacturing process for the manufacture of the designed component of the machine or the whole machine.

Machine Design is the application of mathematics, kinematics, statics, dynamics, mechanics of materials, engineering materials, mechanical technology of metals and engineering drawing. It also involves application of other subjects like thermodynamics, electrical theory, hydraulics, engines, turbines, pumps etc. Machine drawing is the integral part of the machine design, since all the components or the machines that have been designed should be drawn to manufacture them as per the specifications. Without machine drawing the subject of machine design is Incomplete.

Here are some guidelines as to how the machine design engineer can proceed with the design

1) Making the written statement : Make the written statement of what exactly is the problem for which the machine design has to be done. This statement should be very clear and as detailed as possible. If you want to develop the new product, write down the details about the project. This statement is sort of the list of the components that are to be achieved from machine design.

2) Consider the possible mechanism

When we are designing the machine, we have to consider all the possible mechanisms which involve for desired motion of the proposed machine. From the various options the best can be selected whenever required.

3) Transmitted forces

Machine is made up of various machine elements on which various forces are applied. Calculate the forces acting on each of the element and energy transmitted by them.

4) Material selection

Select the appropriate materials for each element of the machine so that they can sustain all the forces. Also we have to consider the cost of the material during design.

5) Find allowable stress

All the machine elements are subjected to stress whether small or large. Considering the various forces acting on the machine elements, their material and other factors that affect the strength of the machine, we have to calculate the allowable or design stress for the machine elements.
6) Dimension of the machine elements

Find out the appropriate diameters for the machine elements considering the forces acting on it, its material, and design stress. The size of the machine elements should be such that they should not distort or break when loads are applied.
7) Consider the past experience

If you have the past experience of designing the machine element or the previous records of the company, consider them and make the necessary changes in the design. Further, designer can also consider the personal judgment so as to facilitate the production of the machine and machine elements.

8) Make drawings:

After designing the machine and machine elements make the assembly drawings of the whole machines and detailed drawings of all the elements of the machine. In the drawings clearly specify the dimensions of the assembly and the machine elements, total number, material and method of their production. The designer should also specify the accuracy, surface finish and other related parameters for the machine.

Productivity Improvement by SPM:

The special purpose machine are designed and manufactured to improve productivity. Productivity is generally defined as the ratio of aggregate output and aggregate input. In any firm or industry, productivity is a concept that measures the efficiency with which inputs are transformed into valuable output in a production process. Similarly, it can be defined as the combination of efficiency and effectiveness of a production process that aims to maximize output while minimizing the use of inputs. Productivity measures the relationship between outputs such as goods and services produced, and inputs that include labor, capital, material and other resources.
Some major considerations in developing a special purpose machine
Specific operations on the job and produce components at shortest possible time

Work automatically, to the extent possible Involve

Involve only the barest minimum of operator's involvement

Should set up and run machine in the shortest time.

Special purpose machine are aimed at reducing the cycle times and control unnecessary costs thus increasing the profits. Special purpose machine should work automatically, to the extend possible. Special purpose machine are designed and manufactured keeping in focus that it must have minimum operator's involvement.
In addition to technology, there are also other means for improving productivity like, re-organization of resources, effective management of human resources, Improving the quality

work, reducing the amount of maintenance needed, making sure that delays do not occur etc are only some examples.

Some of the Improvement by SPM are given below:
1. New developed machine saves a considerable amount of time which ultimately results in production of more components
2. Reduced cycle time helps the company in manufacturing components at a higher rate
Previously the component was machined on conventional set up which were associated with more cycle time, skilled labor, inspection of components. In newly SPM manufactured machine the component is machined and finished to required dimensional accuracies with an unskilled labor.
3. The direct labor cost for component has been reduced with saving the machining time
2. Loading and unloading of the component on the machine does not require skill. An unskilled labor can do the loading and unloading of component.

Chapter 5

MAINTENANCE OF MACHINE TOOLS

Machine maintenance can include regularly scheduled service, routine checks, and both scheduled and emergency repairs. It also includes replacement or realignment of parts that are worn, damaged, or misaligned. Machine maintenance can be done either in advance of failure or after failure occurs. Machine maintenance is critical at any plant or facility that uses mechanical assets. It helps organizations meet production schedules, minimize costly downtime, and lower the risk of workplace accidents and injuries.

Types of machine maintenance:

There are different types of machine maintenance. Each one has its pros and cons (except reactive maintenance, which is all cons), and can be mixed and matched with assets to create a balanced maintenance program.

Reactive maintenance/ breakdown maintenance:

Reactive maintenance refers to repairs done when a machine has already reached failure. Since it's unexpected, unplanned, and usually leads to rushed, emergency repairs, It's often called "fighting fires." Repairs or replacements performed after a machine has failed to return to its functional state following a malfunction or shutdown. e.g., an electric motor of a machine tool will not start, a belt is broken, etc.

Run to fail maintenance:

Run to fail maintenance is very similar to reactive maintenance. It involves letting a piece of equipment run until it breaks down. However, run to fail is a deliberate choice, whereas reactive maintenance is not. A plan is in place to ensure parts and labor is available to get the asset up and running, or replaced, as soon as possible.

Routine maintenance:

Routine maintenance consists of basic maintenance tasks, such as checking, testing, lubricating, and replacing worn or damaged parts on a planned and ongoing basis.

Corrective maintenance:

Corrective maintenance is any work that gets assets back into proper working order, although it's most commonly associated with smaller, non-invasive tasks that fix a problem before a complete failure occurs. For example- re-aligning a part during a routine inspection.

Preventive maintenance:

Preventive maintenance refers to any regularly scheduled machine maintenance intended to identify problems and repair them before failure occurs. Preventive maintenance can be split up into two predominant types:

Time-based preventive maintenance and usage-based preventive maintenance. Time-based preventive maintenance is tasks scheduled at a certain time interval, such as the last day of every month. Usage-based preventive maintenance is when work is scheduled based on the operation of equipment, such as after 30 production cycles.

Condition-based maintenance:

Condition-based maintenance depends on monitoring the actual condition of assets in order to perform maintenance when there is evidence of decreased performance or upcoming failure. This evidence can be obtained through inspection, performance data, or scheduled tests, and it can be gathered either on a regular basis or continuously, through the use of internal sensors.

Predictive maintenance:

Predictive maintenance builds on condition-based maintenance, using tools and sensors to track machinery performance in real-time. This enables the identification of potential problems so they can be corrected before failure occurs.

Prescriptive maintenance:

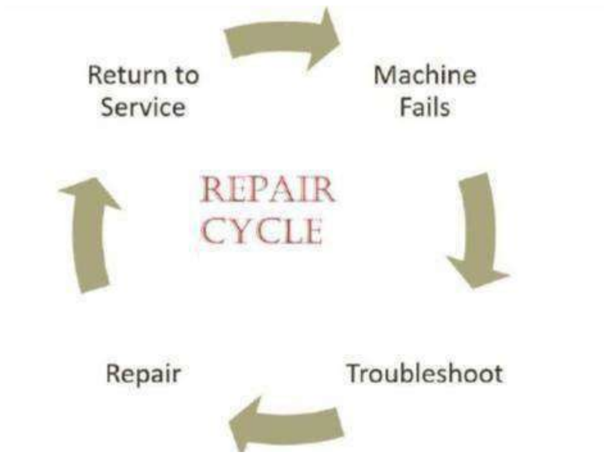
Prescriptive maintenance automates the maintenance process even further through the use of machine learning and artificial intelligence (AI). With a prescriptive maintenance strategy in place, sensors track machinery performance in real-time and uses AI to let you know what maintenance work needs to be done and when.

REPAIR CYCLE ANALYSIS

The stages through which a reparable item passes from the time of its removal or replacement until it is reinstalled or placed in stock in a serviceable condition. Level of repair analysis (LORA) is a process used to determine when and where an asset should be repaired. Level of repair analysis is intended to optimize repair decisions in order to minimize the overall life cycle costs of assets. The Level of repair analysis process takes into account numerous factors, including:

- The costs of different types of repairs, including diagnostics, parts, and labor The impact asset failure could have on operations
- The skills and equipment needed to complete specific repairs

After assessing what it would take to repair specific issues and how necessary those repairs would be, Level of repair analysis determines the type of repair work that should be done and who should do it.



Maintenance manual;

It is a comprehensive document that provides all the details necessary about a physical plant as well as individual pieces of equipment to help the maintenance staff to keep everything run smoothly.

Components of maintenance manual:

A comprehensive operations and maintenance manual have several common parts:

Overview: This section provides a general overview of the physical plant being discussed as well as the components covered in the manual. It includes personnel information, organizational charts, company history, or other background information.

Physical building: This section details important information about one specific facility. Ideally, this information is collected during the construction of the facility itself and contains floor plans, building materials, finish data, building code and specification information, and site survey.

Operating procedures: A comprehensive, detailed explanation of all major operating procedures should be documented so that a new employee can learn quickly and a seasoned technician can double-check work.

Maintenance procedures: The preventive and corrective maintenance programs should be explained thoroughly including schedules, procedures, responsibilities, trouble-shooting and test requirements.

Emergency procedures: It's important to think through emergency situations before they happen because it can be difficult to remember details in the middle of a chaotic situation. This section outlines all the people, steps, agencies, and other organizations that need to be notified as well as a primer on how to handle crisis communications internally and externally.

Maintenance records:

It is a document that includes information regarding each repair and maintenance work that is done on asset or equipment. In simple words, it keeps tracks of assets failures and repairs. It is one of best way to maintain health and safety management.

HOUSEKEEPING

Lubrication: Regular lubrication, as part of your regular machine tool maintenance routine, will ensure moving parts are protected reducing wear and tear. This includes greasing internal and external moving parts and visual inspection.

Cleanliness: Cleanliness is a simple, but often overlooked maintenance step. However, it can go a long way in reducing grime accumulation and rust.

Proper maintenance of machine tool accessories and parts: Routine inspection can sharpen operators' ability to detect developing issues beforehand. Keeping a checklist and a detailed log of all machine tool maintenance procedures can also help catch possible problems.

TOTAL PRODUCTIVE MAINTENANCE

It is the process of using machines, equipment, employees and supporting processes to maintain and improve the integrity of production and the quality of systems.

In other word it is the process of maximizing equipment effectiveness through the active involvement of all supporting departments. The goal of Total Productive Maintenance (TPM) is to improve overall productivity by optimizing equipment availability.

The 8 Pillars of Total Productive Maintenance (TPM): Traditional total productive maintenance was developed by Seiichi Nakajima of Japan. The results of his work on the subject led to the TPM process in the late 1960s and early 1970s.

Nippon Denso a company that created parts for Toyota, was one of the first organizations to implement a TPM program.

TPM is built on eight pillars based on the 5-S system. The 5-S system is an organizational method based around five Japanese words and their meaning.

1) Seiri (organize): eliminating clutter from the workspace

2) Seiton (orderliness): ensure order by following "a place for everything and everything in its place"

3) Seiso (cleanliness): clean the workspace and keep it that way

4) Seiketsu (standardize): standardize all work processes, making them consistent

5) Shitsuke (sustain): constantly reinforcing the first four steps

- **Sort** tools, equipment, and materials to identify which of these can be discarded. A red tag is placed on all items not required to complete your job. These items are then moved to a central holding area

- Straighten and **set things in the proper order** to reduce unnecessary motion and efficiently travel between working groups and locations. Strategies for effective Set In Order are painting floors, outlining work areas and locations, shadow boards, and modular shelving and cabinets for needed items such as trash cans, brooms, mop and buckets.

- **Shine** refers to performing necessary housekeeping to clean up the work area. Workers will also begin to notice changes in equipment and facility location such as air, oil, coolant leaks, fatigue, breakage, and misalignment.

- **Standardize** and schedule activities to systematically form a habit to keep the workplace organized. Allow your employees to participate in the development of such standards.

- **Sustain** the process and principles for long-term applications. Maintain through empowerment, commitment, and discipline.

Objective of TPM

1. To create a collective culture to the attainment of maximum efficiency in all the production process.

2. To prevent production losses and to attain zero accident, zero defect and zero breakdowns in the manufacturing process.

3. To involve all the employees from bottom to top in the TPM programs.

4. To obtain zero production losses through integration of the activities of the teams with the production team.

5. To manufacture products with good quality

Benefits

♦ Simplifies work environment ♦ reduces waste ♦ Improves quality ♦ Improves safety ♦ Provide self esteem for everyone in the organization.