CBCS SCHEME

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18ME641

Sixth Semester B.E. Degree Examination, July/August 2022
Non-Traditional Machining

Time: 3 hrs. Max. Marks: 100

Note: Answer any FIVE full questions, choosing ONE full question from each module.

Module-1

1 a. Define Non-Traditional Machining Process. Explain the need for non-traditional machining process. **(06 Marks)**

b. Discuss briefly the classification of Non-Traditional Machining process based on different sources of energy. **(06 Marks)**

c. What are the specific advantages, limitations and applications of Non-Traditional machining process? **(08 Marks)**

OR

2 a. Differentiate between conventional (traditional) and Non-Traditional machining process. **(08 Marks)**

b. Write in brief note on the selection of Non-Traditional Machining process. **(08 Marks)**

c. Write history about Non-Traditional Machining. **(04 Marks)**

Module-2

3 a. With the help of neat sketch, explain working principle of ultrasonic machining process. **(08 Marks)**

b. Discuss the effects of the following parameters on the rate and material removal and surface finish obtained in ultrasonic machining:
i) Amplitude and frequency of vibration
ii) Static load
iii) Abrasive grid size. **(06 Marks)**

c. List the advantages and disadvantages of ultrasonic machining process. **(06 Marks)**

OR

4 a. Explain the working principle of abrasive jet machining process with the help of neat diagram. Mention its advantages. **(10 Marks)**

b. With a neat sketch, explain the following variables that influence the MRR in AJM.
i) Standoff distance
ii) Types of abrasive
iii) Carrier gas
iv) Velocity of the abrasive jet
v) Work material. **(10 Marks)**

Module-3

5 a. Explain the working principle of electro chemical machining with the help of neat sketch. **(08 Marks)**

b. Explain with a neat sketch, Electro Chemical Grinding (ECG). **(06 Marks)**

c. Explain the following ECM process characteristics:
i) Material removal rate
ii) Accuracy
iii) Surface finish. **(06 Marks)**

OR

6 a. Explain with neat sketches of chemical blanking process and chemical milling process. **(08 Marks)**

b. Explain the following in chemical machining process:
i) Maskants ii) Etchants. **(06 Marks)**

c. What are the advantages, disadvantages and applications of chemical machining process? **(06 Marks)**

Module-4

7 a. With the help of a neat diagram, working principle of electrical discharge machining process. **(08 Marks)**

b. Explain the different methods of dielectric flushing in electrical discharge machining. **(06 Marks)**

c. Sketch and explain travelling wire EDM process. **(06 Marks)**

OR

8 a. Explain with neat diagram, construction and working principle of Plasma Arc Machining (PAM). **(08 Marks)**

b. What are the safety precautions in PAM? Explain. **(06 Marks)**

c. What are the advantages and disadvantages of PAM. **(06 Marks)**

Module-5

9 a. Explain with neat sketch, working principle of Laser Beam Machining (LBM) process. **(08 Marks)**

b. What are characteristics and process parameters of LBM? **(06 Marks)**

c. What are the advantages and limitations of LBM process? **(06 Marks)**

OR

10 a. Explain working of electron beam machining process with the help of neat sketch. **(08 Marks)**

b. Explain the equipments used in the Electron Beam Machining (EBM). **(06 Marks)**

c. Write the advantages and applications of Electron beam machining process. **(06 Marks)**

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1.a. Non-traditional machining, also known as the modern machining method, is a machining method that uses electricity, heat energy, light energy, electrochemical energy, energy, chemical energy, sound energy, and special mechanical energy to remove, deform, change properties, or plate materials.

Need for NTM

Extremely hard and brittle materials are difficult to machine by traditional machining processes such as turning, drilling, shaping and milling. Nontraditional machining processes, also called advanced manufacturing processes, are employed where traditional machining processes are not feasible, satisfactory or economical due to special reasons as outlined below. a) Very hard fragile materials difficult to clamp for traditional machining b) When the workpiece is too flexible or slender c) When the shape of the part is too complex.

1. b. Classification of NTM processes is carried out depending on the nature of energy used for material removal.

1. Mechanical Processes: In this case mechanism the material removal is by Erosion/Shear process, the high velocity particles are made to hit the work piece under the influence of pneumatic or hydraulic pressure.
    - Abrasive Jet Machining (AJM)
    - Ultrasonic Machining (USM)
    - Water Jet Machining (WJM)
    - Abrasive Water Jet Machining (AWJM)
2. Electrochemical Processes: In this case mechanism the material removal is by Ion displacement process with the help of electrolytes.
    - Electrochemical Machining (ECM)
    - Electro Chemical Grinding (ECG)
    - Electro Jet Drilling (EJD)
3. Electro-Thermal Processes: In this case mechanism the material removal is by fusion / vaporization process with the help of hot gases, radiation, ion stream etc.
    - Electro-discharge machining (EDM)
    - Laser Jet Machining (LJM)
    - Electron Beam Machining (EBM)
4. Chemical Processes: In this case mechanism the material removal is by ablative reaction process with the help of suitable chemicals like corrosive agents.
    - Chemical Milling (CHM)
    - Photochemical Milling (PCM)

1.c Advantages and Disadvantages:

Advantages:

- It provides high accuracy and surface finish.
- No physical tool is used hence, no tool wear occur.
- They do not generate chips or generate microscopic chips.
- These are quieter in operation.
- It can be easily automated.
- It can machine any complex shape.

Disadvantages:

- High initial or setup cost.
- High skilled labor is required.
- Lower metal removal rate.
- More power required for machining.
- It is not economical for bulk production.
-

Applications

Non-traditional machining (NTM) processes are now being widely used to generate intricate and accurate shapes in materials, like titanium, stainless steel, high strength temperature resistant (HSTR) alloys, fiber-reinforced composites, ceramics, refractories and other difficult-to- machine alloys.

2 a.

Sl. No	Conventional Machining	Nontraditional Machining
1.	The cutting tool and work piece are always in physical contact with relative motion with each other, which results in friction and tool wear.	There is no physical contact between the tool and work piece, In some nontraditional process tool wear exists.
2.	Material removal rate is limited by mechanical properties of work material.	NTM can machine difficult to cut and hard to cut materials like titanium, ceramics, SST, composites, semiconducting materials.
3.	Relative motion between the tool and work is typically rotary or reciprocating. Thus the shape of work is limited to circular or flat shapes. In spite of CNC systems, production of 3D surfaces is still a difficult task.	Many NTM are capable of producing complex 3D shapes and cavities.
4.	Machining of small cavities , slits , blind holes or through holes are difficult	Machining of small cavities, slits and Production of non-circular, micro sized, large aspect ratio, shall entry angle holes are easy using NTM
5.	Use relative simple and inexpensive machinery and readily available cutting tools	Non traditional processes requires expensive tools and equipment as well as skilled labour, which increase the production cost significantly
6.	Capital cost and maintenance cost is low	Capital cost and maintenance cost is high
7.	Traditional processes are well established and physics of process is well understood	Mechanics of Material removal of Some of NTM process are still under research
8.	Conventional process mostly uses mechanical energy	Most NTM uses energy in direct form For example: laser, Electron beam in its direct forms are used in LBM and EBM respectively.
9.	Surface finish and tolerances are limited by machining inaccuracies	High surface finish(up to 0.1 micron) and tolerances (25 Microns)can be achieved
10.	High metal removal rate.	Low material removal rate.

- 2. b. The selection of non-traditional machining process is based on three parameters, which include: workpiece material, machining operation, process characteristics.

DIFFERENT MACHINING OPERATIONS IN NTM:

Many complex designed products can be generated on the work piece material by the application of appropriate NTM processes.

- Deep cutting: The machining operations are carried out to generate the desired design on the work piece material with more depth of cut.
- Shallow cutting: In this operation the depth of cut is comparatively low.
- Drilling operation: This operation is used to cut or to machine a hole of circular cross section in a solid.

- Precision cavity: A cavity with close dimensional tolerances is produced for its internal application.
- Standard cavity: a cavity with clear set of dimensions is produced, but it cannot be employed for intrinsic applications.
- Double contouring: The shape feature obtained is demarcated into two separate and different, top and bottom contours of the work piece material.
- Surface of revolution: This operation is done to obtain good surface finish on the work-piece by rotating the work piece in two dimensional curve about its axis.
- Finishing: This machining operation is done to attain mirror finish on the surface of the work piece with high accuracy and superior surface finish.

PROCESS CHARACTERISTICS:

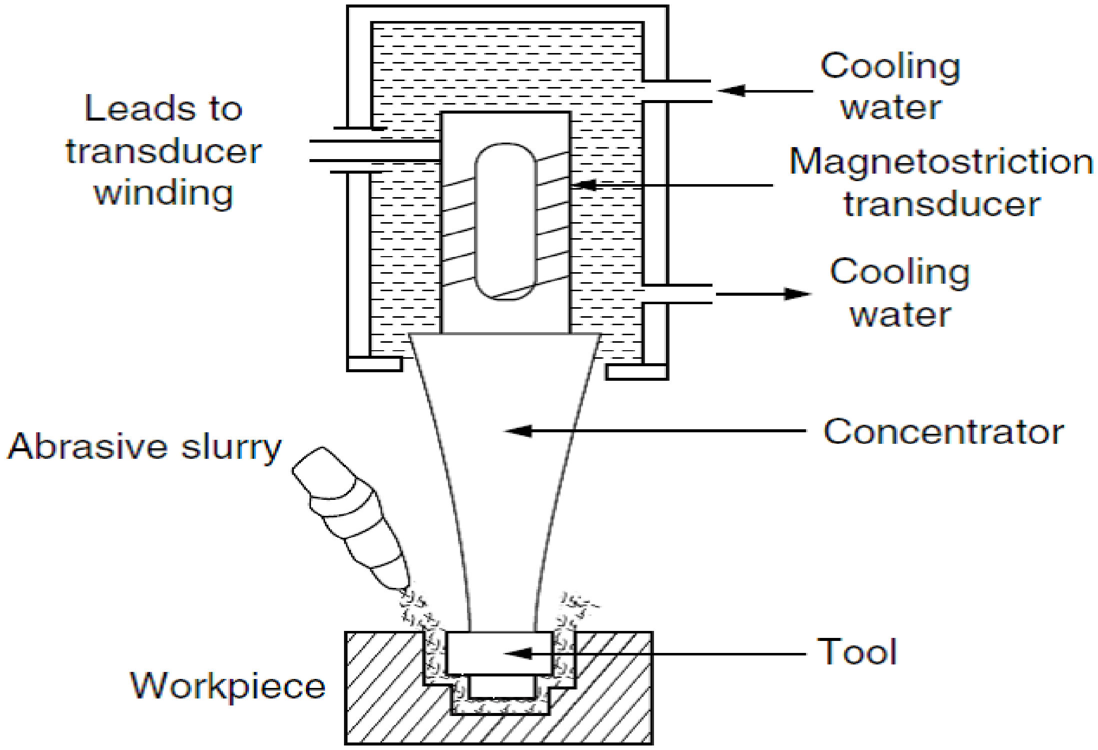
Some process characteristics have a direct influence on the productivity and effectiveness of the NTM process, which include:

- Voltage characteristics- A potential difference is applied to operate the non-traditional machining setup.
- Corner radius (in mm)- The radius of a circle that is generated if the corner arc of a rectangle is extended to form a complete circle.
- Total cost Total cost of NTM setup includes the cost of tooling, fixture, power consumption, and tool wear cost.
- Current characteristic (in A) – To initiate the material removal process in NTM processes there should be flow of electrons or ions inside the electronic circuits.
- Volumetric material removal rate(in mm3/min) The volume of material removed from the work piece per unit machine time.
- Power rating (in W) The power rating of a NTM setup.
- Safety (in R scale) The safety refers to the safety of the operators while performing a machining operation in an NTM equipment.
- Surface damage(in micro meter)- The damage caused on the work-piece surface due to the imperfect machining and the impact forces acting on the work-piece during machining or due to ion beam bombardment.
- Surface finish (in micro meter) It is the allowable deviation from an absolutely flat surface which can be accomplished through the machining action and is measured in terms of center line average or roughness average value.
- Taper (in mm/mm)- A gradual narrowing of the work-piece from the reference towards one end of the work piece.
- Tolerance (in micro meter)- The dimensional closeness of the end product when compared with the given specifications .
- Toxicity Toxicity is the environmental hazards caused due to the machining medium contamination.

2.c. History of NTM

The development of Science and Technology especially since 1950s as well as product development as well as need for scientific experiments in many industrial sectors, especially the defense industry, requires that the edge cutting science and technology products should be developed.

3. a. . It works on the same principle of ultrasonic welding. This machining uses ultrasonic waves to produce high frequency force of low amplitude, which act as driving force of abrasive. Ultrasonic machine generates high frequency vibrating wave of frequency about 20000 to 30000 Hz and amplitude about 25-50 micron. This high frequency vibration transfer to abrasive particle contains in abrasive slurry. This leads indentation of abrasive particle to brittle work piece and removes metal from the contact surface.



In ultrasonic machining, tool of desired shape vibrates at ultrasonic frequency (19 to 25 kHz.) with an amplitude of 15-50 Microns over work piece. Generally tool is pressed down with a feed force F. Between the tool and work, machining zone is flooded with hard abrasive particles generally in the form of water based slurry. As the tool vibrates over the work piece, abrasive particles acts as indenter and indent both work and tool material . Abrasive particles , as they indent , the work material would remove the material from both tool and work piece. In Ultrasonic machining material removal is due to crack initiation, propagation and brittle fracture of material. USM is used for machining hard and brittle materials, which are poor conductors of electricity and thus cannot be processed by Electrochemical machining (ECM) or Electro discharge machining (EDM). The tool in USM is made to vibrate with high frequency on to the work surface in the midst of the flowing slurry. The main reason for using ultrasonic frequency is to provide better performance. Audible frequencies of required intensities would be heard as extremely loud sound and would cause fatigue and even permanent damage to the auditory apparatus.

Power Source:

As we know, this machining process requires high frequency ultrasonic wave. So a high frequency high voltage power supply require for this process. This unit converts low frequency electric voltage (60 Hz) into high frequency electric voltage (20k Hz).

Magnetostrictive transducer:

As we know, transducer is a device which converts electric single into mechanical vibration. In ultrasonic machining magnetostrictive type transducer is used to generate mechanical vibration. This transducer is made by nickel or nickel alloy.

Booster:

The mechanical vibration generated by transducer is passes through booster which amplify it and supply to the horn.

Tool:

The tool used in ultrasonic machining should be such that indentation by abrasive particle, does not leads to brittle fracture of it. Thus the tool is made by tough, strong and ductile materials like steel, stainless steel etc.

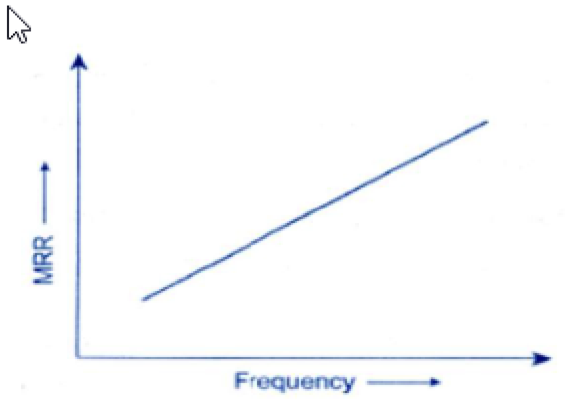
Tool holder or Horn:

As the name implies this unit connects the tool to the transducer. It transfers amplified vibration from booster to the tool. It should have high endurance limit.

Abrasive Slurry:

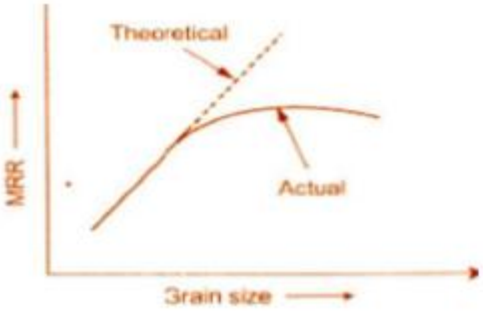
A water based slurry of abrasive particle used as abrasive slurry in ultrasonic machining. Silicon carbide, aluminum oxide, boron carbide are used as abrasive particle in this slurry. A slurry delivery and return mechanism is also used in USM.

- First the low frequency electric current passes through electric supply. This low frequency current converts into high frequency current through some electrical equipment.
- This high frequency current passes through transducer. The transducer converts this high frequency electric single into high frequency mechanical vibration.
- This mechanical vibration passes through booster. The booster amplify this high frequency vibration and send to horn.
- Horn which is also known as tool holder, transfer this amplified vibration to tool which makes tool vibrate at ultrasonic frequency.
- As the tool vibrates, it makes abrasive particle to vibrate at this high frequency. This abrasive particle strikes to the work piece and remove metal form it.
- 3.b. Ultrasonic wave frequency is directly proportional to the metal removal rate as shown in the fig.



Grain size of the abrasive

- MRR and surface finish are greatly influenced by the grain size of the abrasive
- Maximum rate in machining is attained when the grain size of the abrasive is bigger.
- For rough work operation grit size of 200-400 is used and for finishing operation the grit size of 800-1000 is used

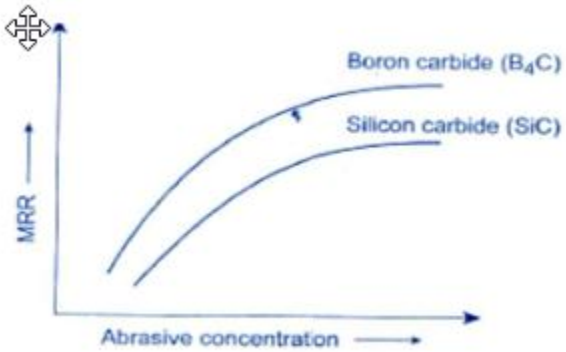


(b) Abrasive Materials

- The proper selection of the abrasive particles depends on the type of material to be machined, hardness of the material and metal removal rate and the surface finish required.
- The most commonly used abrasive materials are boron carbide and silicon carbide used for machining tungsten carbide and die steel.
- Aluminum oxide is the softest abrasive used for machining glass and ceramics

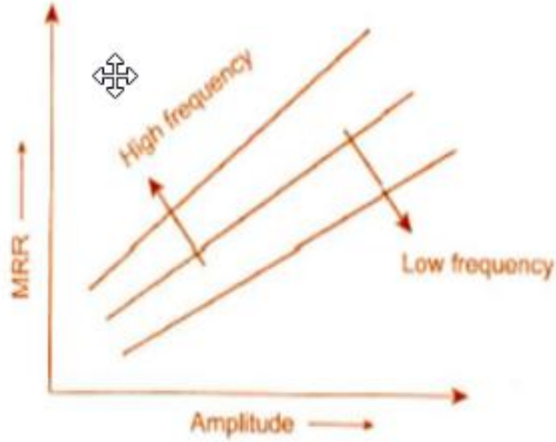
(c) Concentration of slurry:

- Abrasive slurry usually a mixture of abrasive grains and water of definite proportion 20-30% is made to flow flow under pressure.
- The fig shows how the metal removal rate varies with slurry concentration



d) Amplitude of Vibration

- Metal removal rate in ultrasonic machining process increases with increasing amplitude of vibration



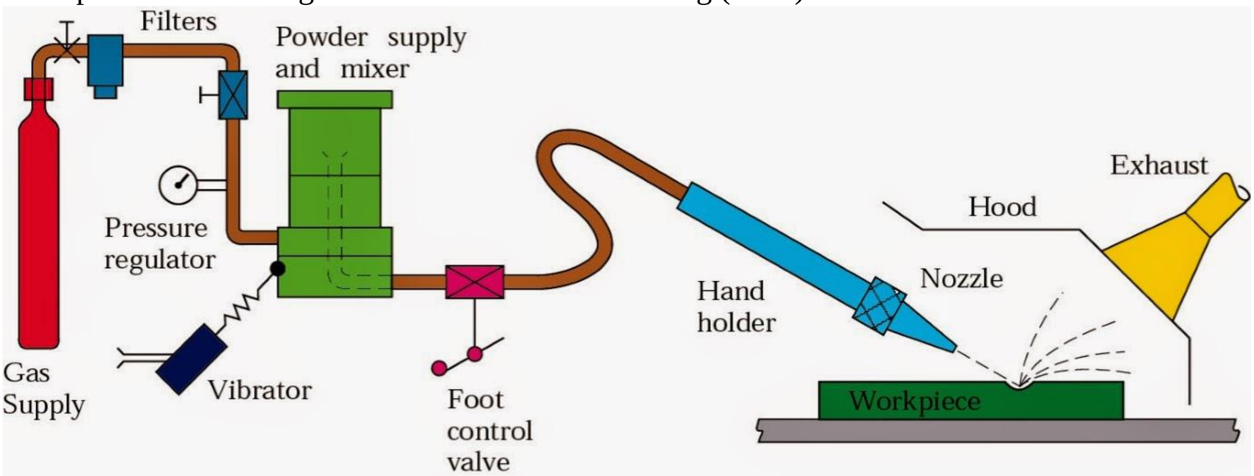
3.c. Advantages:

- Hard material can be easily machined by this method.
- No heat generated in work so there is no problem of work hardening or change in structure of work piece.
- Non-conductive metals or non-metals, which cannot be machined by ECM of EDM can be machined by it.
- It does not form chips of significant size.

Disadvantages:

- It is quite slower than other mechanical process.
- Tool wear is high because abrasive particle affect both work-piece and tool.
- It can machine only hard material. Ductile metal cannot be machine by this method.
- It cannot used to drill deep hole.

4.a. The gap between nozzle tip and work surface has great influence on the diameter of cut, its shape and size and also rate of material removal. It is clear that the SOD or stand-off distance, changes the spread of abrasive particles on the working surface and increases the diameter of the cut.
The process makes use of an abrasive jet with high velocity, to remove material and provide smooth surface finish to hard metallic work pieces. It is similar to Water Jet Machining (WJM).
A simple schematic diagram of Abrasive Jet Machining (AJM) is shown below:



Construction of Abrasive Jet Machining (AJM):
The constructional requirements of Abrasive Jet Machining (AJM) are listed and described below:
1. **Abrasive jet:** It is a mixture of a gas (or air) and abrasive particles. Gas used is carbon-di-oxide or nitrogen or compressed air. The selection of abrasive particles depends on the hardness and Metal Removal Rate (MRR) of the workpiece. Most commonly, aluminium oxide or silicon carbide particles are used.
2. **Mixing chamber:** It is used to mix the gas and abrasive particles.
3. **Filter:** It filters the gas before entering the compressor and mixing chamber.
4. **Compressor:** It pressurizes the gas.
5. **Hopper:** Hopper is used for feeding the abrasive powder.
6. **Pressure gauges and flow regulators:** They are used to control the pressure and regulate the flow rate of abrasive jet.
7. **Vibrator:** It is provided below the mixing chamber. It controls the abrasive powder feed rate in the mixing chamber.
8. **Nozzle:** It forces the abrasive jet over the workpiece. Nozzle is made of hard and resistant material like tungsten carbide.

Working:
Dry air or gas is filtered and compressed by passing it through the filter and compressor.
A pressure gauge and a flow regulator are used to control the pressure and regulate the flow rate of the compressed air.
Compressed air is then passed into the mixing chamber. In the mixing chamber, abrasive powder is fed. A vibrator is used to control the feed of the abrasive powder. The abrasive powder and the compressed air are thoroughly mixed in the chamber. The pressure of this mixture is regulated and sent to nozzle.
The nozzle increases the velocity of the mixture at the expense of its pressure. A fine abrasive jet is rendered by the nozzle. This jet is used to remove unwanted material from the workpiece.
For a good understanding of construction and working of AJM, refer the schematic diagram above.
Operations that can be performed using Abrasive Jet Machining (AJM):
The following are some of the operations that can be performed using Abrasive Jet Machining:
1. Drilling
2. Boring
3. Surface finishing
4. Cutting

5. Cleaning
6. Deburring
7. Etching
8. Trimming
9. Milling

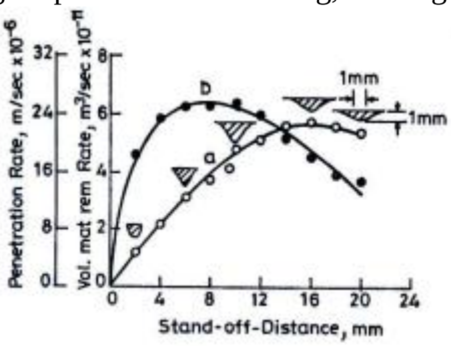
Advantages of Abrasive Jet Machining:

- Surface of the workpiece is cleaned automatically.
- Smooth surface finish can be obtained.
- Equipment cost is low.
- Hard materials and materials of high strength can be easily machined.
- A process quite suitable for machining brittle, heat resistant and fragile materials like, ceramic, glass, germanium, etc.
- It could be used to cut, drill, polish, debur, clean the materials.

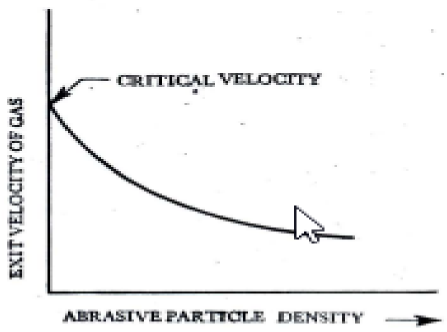
Disadvantages of Abrasive Jet Machining:

- Metal removal rate is low
- In certain circumstances, abrasive particles might settle over the work piece.
- Nozzle life is less. Nozzle should be maintained periodically.
- Abrasive Jet Machining cannot be used to machine soft materials.
- The tapering of hole mainly when the depth of the hole is more, becomes inevitable.
- It needs a dust collecting chamber to prevent air pollution.
- The abrasive particles might remain embedded into work surface.
- Abrasive particles are not reusable.

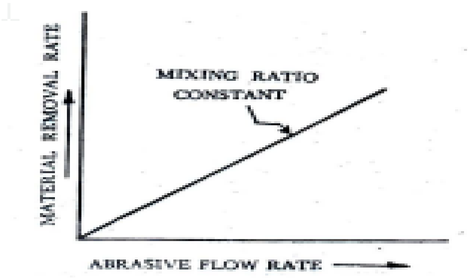
4.b. Nozzle tip distance: Stand-off distance is defined as the distance between the face of the nozzle and the work surface of the work. SOD has been found to have considerable effect on the work material and accuracy. A large SOD results in flaring of jet which leads to poor accuracy. It is clear from figure that MRR increase with nozzle tip distance or Stand-off distance up to certain distance and then decreases. Penetration rate also increases with SOD and then decreases. Decrease in SOD improves accuracy, decreases width, and reduces taper in machined groove. However light operation like cleaning, frosting etc are conducted with large SOD.(say 12.5 to 75mm)



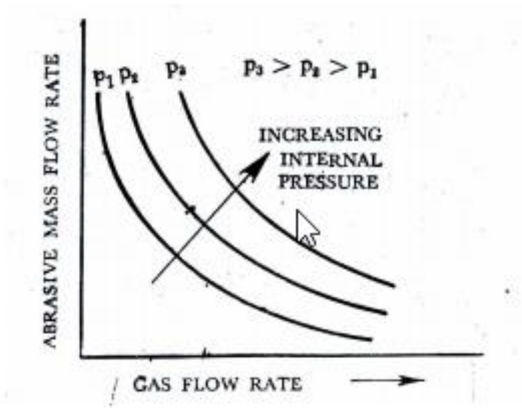
- Effect of exit gas velocity and abrasive particle density: The velocity of carrier gas conveying the abrasive particles changes considerably with the change of abrasive particle density as indicated in figure. The exit velocity of gas can be increased to critical velocity when the internal gas pressure is nearly twice the pressure at exit of nozzle for the abrasive particle density is zero. If the density of abrasive particles is gradually increased exit velocity will go on decreasing for the same pressure condition. It is due to fact that Kinetic energy of gas is utilized for transporting the abrasive particle.



- Effect of abrasive flow rate and grain size on MRR It is clear from the figure that at a particular pressure MRR increase with increase of abrasive flow rate and is influenced by size of abrasive particles. But after reaching optimum value, MRR decreases with further increase of abrasive flow rate. This is owing to the fact that Mass flow rate of gas decreases with increase of abrasive flow rate and hence mixing ratio increases causing a decrease in material removal rate because of decreasing energy available for erosion.



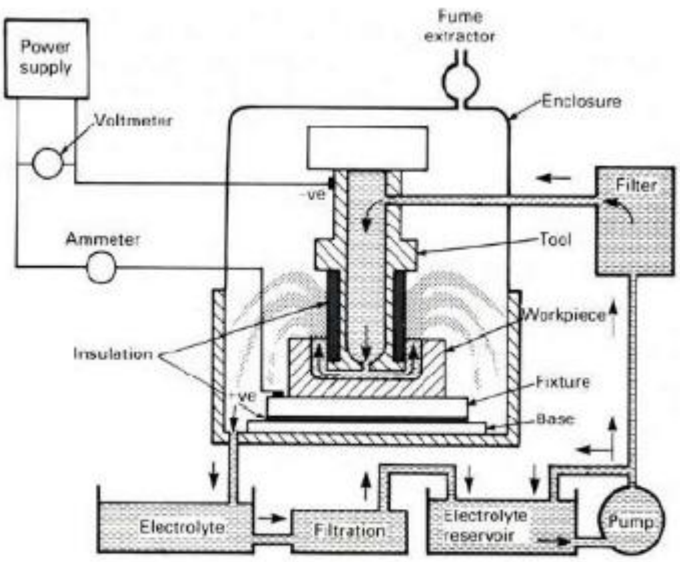
- Effect of gas pressure on MRR : The abrasive flow rate can be increased by increasing the flow rate of the carrier gas. This is only possible by increasing the internal gas pressure as shown in the figure. As the internal gas pressure increases abrasive mass flow rate increase and thus MRR increases. As a matter of fact, the material removal rate will increase with the increase in gas pressure Kinetic energy of the abrasive particles is responsible for the removal of material by erosion process. The abrasive must impinge on the work surface with minimum velocity for machining glass by SIC particle is found to be around 150m/s.



1. 5.a. **Electrochemical Machining**

Electrochemical machining works on the Faraday law of electrolysis which state that if two electrode are placed in a container which is filled with a conductive liquid or electrolyte and high ampere DC voltage applied across them, metal can be depleted form the anode (Positive terminal) and plated on the cathode (Negative terminal). This is the basic principle of electrochemical machining. In this machining process, tool is connected with the negative terminal of battery (work as cathode) and work-piece is connected with the positive terminal of battery (work as anode). They both are placed in a electrolyte solution with a small distance. When the DC current supplied to the electrode, metal removed from work-piece. This is basic fundamental of electrochemical machining.

ECM



Working of Electrochemical Machining:

Electrochemical machining works inverse as electroplating process. Metal is removed from anode into electrolyte and convert into slag form by reacting opposite ions available in electrolyte. This process works as follow.

- In ECM, the electrolyte is so chosen that there is no plating on tool and shape of tool remain unchanged. Generally NaCl into water takes as electrolyte.
- The tool is connected to negative terminal and work is connected to positive terminal.
- When the current passes through electrode, reaction occur at anode or work piece and at the cathode or tool. To understand proper working let's take an example or machining low carbon steel.
- Due to potential difference ionic dissociation take place in electrolyte.
- When the potential difference applied between the work piece and tool, positive ions move towards the tool and negative ions towards the work piece.
- Thus the hydrogen ion moves towards tool. As the hydrogen reaches to the tool, it takes some electron from it and converts into gas form. This gas goes into environment.
- When the hydrogen ions take electron from tool, it creates lack of electron in mixture. To compensate it, ferrous ions created at the work piece (anode) which gives equal amount of electron in mixture.
- These Ferrous ions react with opposite chlorine ions or hydroxyl ions and get precipitate in form of sludge.
- This will give ferrous or iron into electrolyte and complete the machining process. This machining process gives higher surface finish because machining is done atom by atom.

Application:

- ECM is used to machining disk or turbine rotor blade.
- It can be used for slotting very thin walled collets.
- ECM can be used to generate internal profile of internal cam.
- Production of satellite rings and connecting rod, machining of gears and long profile etc.

Advantages:

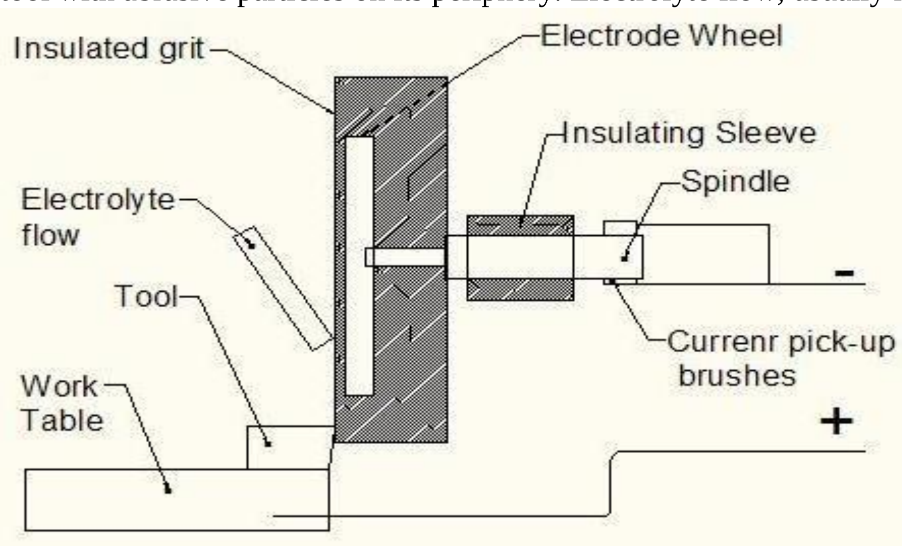
- It can machine very complicated surface.
- A single tool can be used to machining large number of work-piece. Theoretically no tool wear occur.
- Machining of metal is independent on strength and hardness of tool.
- ECM gives very high surface finish.

Disadvantages:

- High initial cost of machine.
- Design and tooling system is complex.
- Fatigue property of machined surface may reduce.
- Nonconductive material cannot be machined.
- Blind hole cannot be machined form ECM.
- Space and floor area requirement is high compare to conventional machining.

5.b. Electrochemical grinding (ECG) -

The process is similar to cathode is a specially constructed grinding wheel instead of a cathodic shaped. The insulating abrasive material (diamond or aluminum oxide) of the grinding wheel is set in conductive bonding, the wheel is a rotating cathodic tool with abrasive particles on its periphery. Electrolyte flow, usually NaNO3, is provided for ECD (Electro chemical dissolution). Similar to ECM except that the cathode is a specially constructed grinding of a cathodic shaped tool. The insulating abrasive material (diamond or the grinding wheel is set in a conductive bonding material. the wheel is a rotating cathodic tool with abrasive particles on its periphery. Electrolyte flow, usually NaNO3, is provided for ECD.



Working Principle

The wheel rotates at a surface m/s, while current ratings when a gap voltage of between the cathodic anodic work piece, a current to 240 A/cm2 is created. The current density depends on the material being machined, the gap width, and the applied voltage surface speed of 20 to 35 ratings are from 50 to 300 A. of 4 to 40 V is applied grinding wheel and the current density of about 120. The current density depends on the material, the gap width, and the applied voltage.

Applications

- Machining parts made from difficult such as sintered carbides, creep-resisting (Inconel titanium alloys, and metallic composites. • Applications similar to milling, grinding, cutting off, sawing, and tool and cutter sharpening.
- Production of tungsten carbide cutting tools, fragile parts, and thin walled tubes.
- Producing specimens for metal fatigue and tensile tests.
- Machining of carbides and a variety of high alloys.

Advantages

- Absence of work hardening
- Elimination of grinding burrs
- Absence of distortion of thin fragile or thermosensitive parts
- Good surface quality • Production of narrow tolerances

- Longer grinding wheel

Disadvantages

- Higher capital cost than conventional machines.
- Process limited to electrically conductive materials.
- Corrosive nature of electrolyte.
- Requires disposal and filtering of electrolyte
- Higher capital cost than conventional
- Process limited to electrically conductive
- Corrosive nature of electrolyte

5.c. Material removal rate

- It is a function of feed rate which dictates the current passed between the work and the tool.
- As the tool advances towards work, gap decreases and current increases which increases more metal at a rate corresponding to tool advance.
- A stable spacing between tool and work is thus established (known as equilibrium machining gap).
- It may be mentioned that high feed rate not only is productive but also produces best quality of surface finish.
- However feed rate is limited by removal of hydrogen gas and products of machining.
- Metal removal rate is lower with low voltage, low electrolyte concentration and low temperature.

Surface Finish

- ECM can produce surface finish of the order of 0.4 pm by rotation of tool/work. Any defect on the tool face produces replica on work piece.
- Tool surface should therefore be polished.
- The finish is better on harder materials.
- Cobalt alloys give mirror like finish and copper and aluminium give a matty finish.
- For optimum surface finish, careful electrode design, maximum feed rate, and surface improving additives in electrolyte are selected.
- Low voltage decreases the equilibrium machining gap and results in better surface finish and tolerance control.
- Low electrolytic concentration decreases the equilibrium machining gap and thus better surface finish and tolerance.
- Low electrolyte temperature also promotes better surface finish.

Accuracy

- Under ideal conditions & with properly designed tooling, **ECM** is capable of holding tolerance of the order of . 02 mm & less.
- Repeatability of the **ECM** process is also very good.

6.a. Chemical blanking is the controlled chemical dissolution (CD) of the work piece material by contact with a strong reagent Used to produce pockets & contours. Chemical blanking is used to etch entirely through a metal part. In chemical blanking, holes and slots that penetrate entirely through the material are produced, usually in thin sheet materials.

Chemical blanking consists of following steps-

- Preparing and pre cleaning the work piece surface.
- Masking using readily strippable mask
- Scribing of the mask, guided by templates
- The work piece Is then etched and rinsed

Etchants are acid or alkaline solutions maintained within a controlled range of chemical composition and temperature. Main technical goals of etchants are- Good surface finish, Uniformity of metal removal, Maintenance of air quality and avoid the environmental problems and ability to regenerate the etchant solution.

Chemical blanking is used for parts that are otherwise typically produced by mechanical blanking presses from thin plates and foil material. With mechanical presses, vibrations, backlash, and part distortion will make smaller parts difficult to produce. Chemical blanking becomes a favorable solution in such a case.

(1) Process steps

Chemical blanking employs the following four steps.

a) Pre-process

Material cleaning - Metal surface is cleaned by degreasing, pickling and grinding.

b) Masking

Metal portion not to be removed by etching is covered with chemical resistant coating. For extra precise applications, photo-resist material is used.

c) Through-material etching

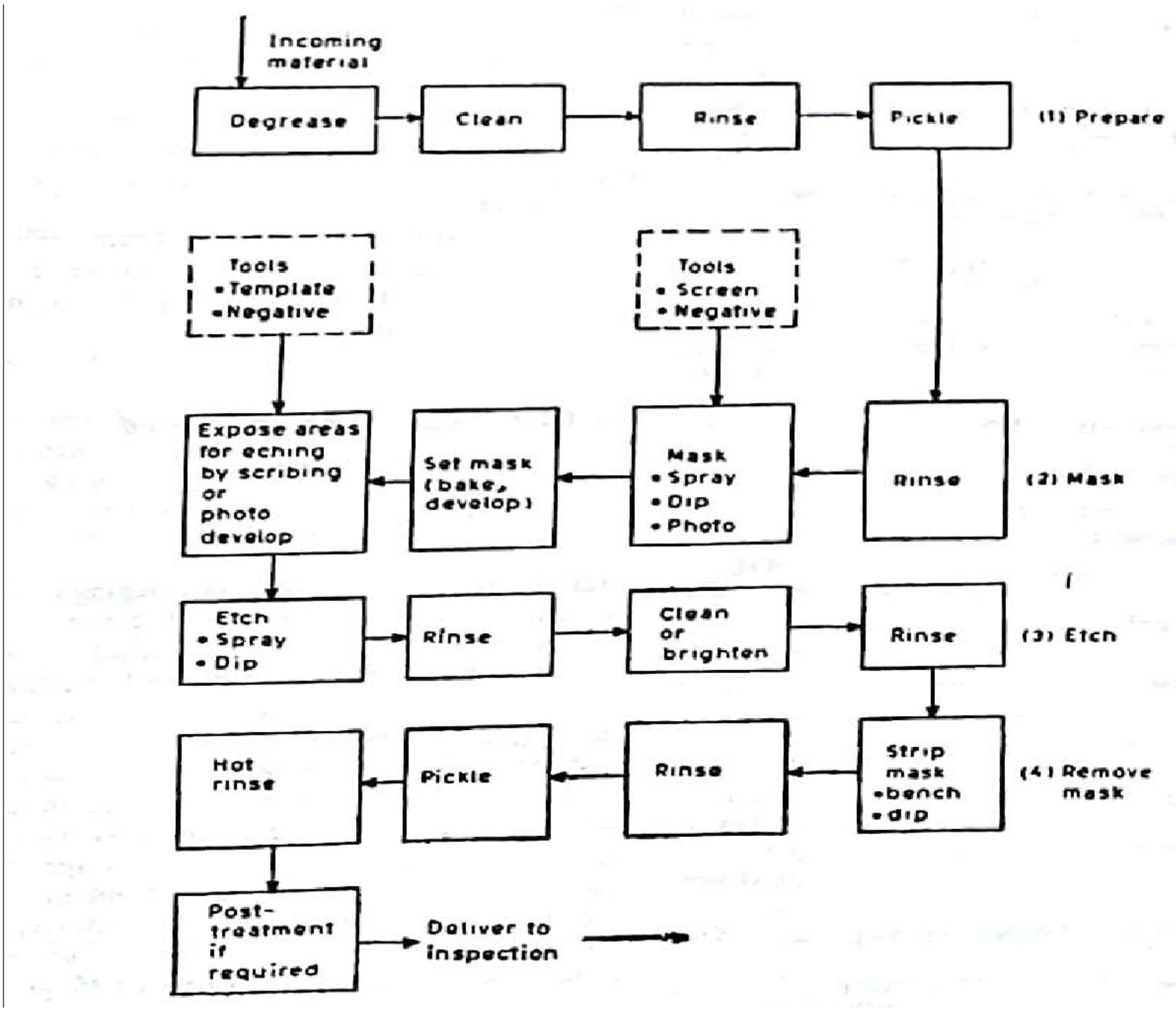
Since the material is to be penetrated through, etching is applied from both sides simultaneously.

d) Post-process

Removal of the resist material, and washing off etchant. If the resist material is non water soluble, organic solvents are used.

(2) Through-material etching

There are two application methods: Immersion type and Spray type. With the immersion type, the part is immersed in the corrosive liquid, and the liquid is constantly stirred. Air injection is the widely used stirring method.



<u>Advantages</u>

- Weight reduction is possible on complex contours that are difficult to machine using conventional methods.
- No burrs are found.
- Design changes can be implemented quickly.
- A less skilled operator is needed.
- Simultaneous material removal, from all surfaces, improves productivity and reduces wrapping.

<u>Limitations</u>

- Handling and disposal of chemicals can be troublesome.
- Surface imperfections are reproduced in the machined parts.
- Deep narrow cuts are difficult to produce.
- Porous castings yield uneven etched surfaces.
- Material removal from one side of residually stressed material can result in a considerable distortion. Welded areas frequently etch at rates that differ from base metal.

Applications

- CHB applications range from large aluminum alloy airplane wing parts to minute integrates chips.
- CHB is used to thin out walls, webs, and ribs of parts that have been produced by forging, casting, or sheet metal forming
- Shallow cuts in large thin sheets are the most popular application especially for weight reduction of aerospace components
- Removal of sharp burrs from conventionally machined parts of complex shapes.
- Elimination of the decarburized layer from low alloy steel forgings.

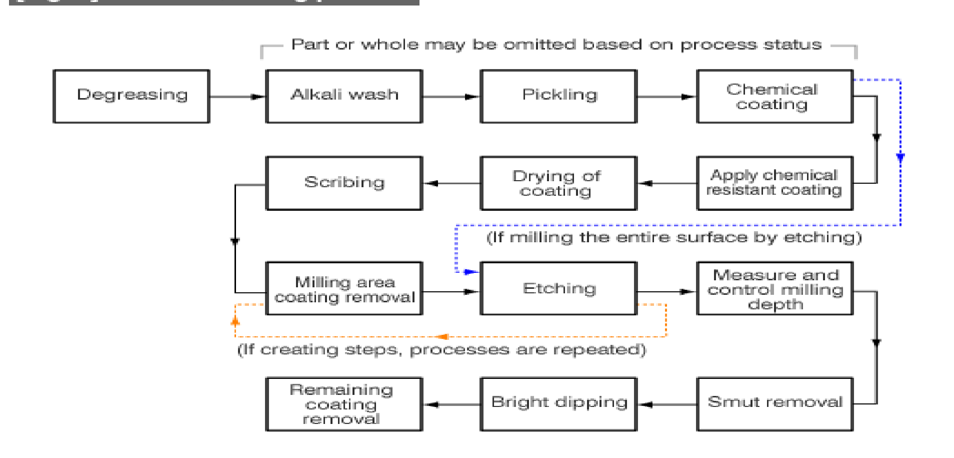
2. Chemical Milling (CHM) is the controlled chemical dissolution(CD) of the work piece material by contact with a strong reagent Used to produce pockets & contours.

CHM consists of following steps-

- Preparing and pre cleaning the work piece surface.
- Masking using readily strippable mask
- Scribing of the mask, guided by templates
- The work piece Is then etched and rinsed

Etchants are acid or alkaline solutions maintained within a controlled range of chemical composition and temperature. Main technical goals of etchants are- Good surface finish, Uniformity of metal removal, Maintenance of air quality and avoid the environmental problems and ability to regenerate the etchant solution.

[Fig. 1] Chemical milling process



Advantages

- Weight reduction is possible on complex contours that are difficult to machine using conventional methods.
- No burrs are found.
- Design changes can be implemented quickly.
- A less skilled operator is needed.
- Simultaneous material removal, from all surfaces, improves productivity and reduces wrapping.

Limitations

- Handling and disposal of chemicals can be troublesome.
- Surface imperfections are reproduced in the machined parts.
- Deep narrow cuts are difficult to produce.
- Porous castings yield uneven etched surfaces.

6.b. i)Maskants are generally used to protect parts of the workpiece where Chemical Dissolution action is not needed. Synthetic or rubber base materials are frequently used.

Maskants should possess the following properties:

1. Be tough enough to withstand handling
2. Adhere well to the workpiece surface
3. Scribe easily
4. Be inert to the chemical reagent used
5. Be able to withstand the heat generated by etching
6. Be removed easily and inexpensively after etching

ii) Etchants are acid or alkaline solutions maintained within a controlled range of chemical composition and temperature. Their main technical goals are to achieve the following:

1. Good surface finish
2. Uniformity of metal removal
3. Control of selective and intergranular attack
4. Maintenance of personal safety
5. Best price and reliability for the materials to be used in the construction of the process tank
6. Maintenance of air quality and avoidance of possible environmental problems
7. Low cost per unit weight dissolved
8. Ability to regenerate the etchant solution and/or readily neutralize and dispose of its waste products

6.c. Advantages

1. No effect of work piece materials properties such as hardness
2. Simultaneous material removal operation
3. No burr formation
4. No stress introduction to the work piece
5. Low capital cost of equipment
6. Easy and quick design changes
7. Requirement of less skilled worker
8. Low tooling costs
9. The good surface quality
10. Using decorative part production
11. Low scrap rates (3%)

Disdvantages

- Difficult to get sharp corner.
- Difficult to chemically machine thick material (limit is depended on
- work piece material, but the thickness should be around maximum 10 mm).
- Scribing accuracy is very limited, causes less dimensional accuracy.
- Etchants are very dangerous for workers.
- Etchant disposals are very expensive

Applications

- High Precision Parts and Decorative Items
- Gaskets
- Washers
- Sensors
- Nameplate
- Jewelry

- Microprocessor Chips

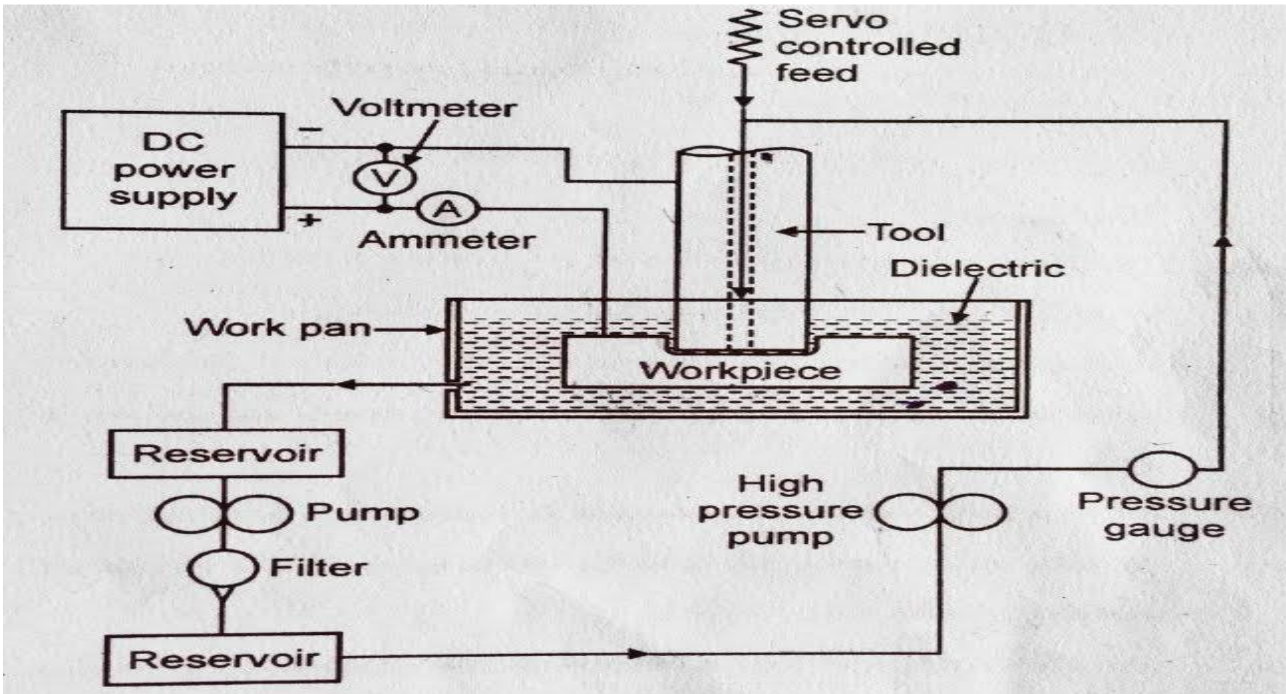
7.a. **Working principle of EDM**

The principle behind this process is the ability of controlled electric sparks to erode material. The workpiece and electrode do not touch during this process. In between is a gap that is roughly as thick as a human hair. The amount of removed material with a single spark is small, yet the discharge occurs roughly several 100,000 times a second.

While the electrode is moved closer to the workpiece, the electric field in the gap, also known as **spark gap**, increases until it reaches the breakdown volume. For this process, it is necessary that the fluid in which this discharge occurs is not conductive, or dielectric. The discharge causes strong heating of the material, melting away small amounts of material. This excess material is removed with the steady flow of the dielectric fluid. The liquid is also useful for cooling during the machining. Moreover, it is necessary for controlling the sparks.

At the beginning of EDM operation, a high voltage 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 cause conducting particles suspended in the dielectric to concentrate at the points of strongest electrical field. 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, removing small amount of material from the workpiece surface. The volume of the material removed per spark discharge is typically in the range of 10^{-6} to 10^{-6} mm^3.

EDM removes material by discharging an electrical current, normally stored in a capacitor bank, across a small gap between the tool (cathode) and the workpiece (anode) typically in the order of 50 volts/10amps.



Advantages of EDM

- By this process, materials of any hardness can be machined;
- No burrs are left in machined surface
- One of the main advantages of this process is that thin and fragile/brittle components can be machined without distortion.
- Complex internal shapes can be machined.

Limitations of EDM

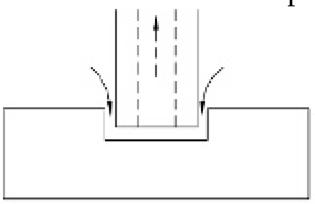
- The main limitations of this process are:
- This process can only be employed in electrically conductive materials.
- Material removal rate is low and the process overall is slow compared to conventional machining processes.
- Unwanted erosion and over cutting of material can occur.

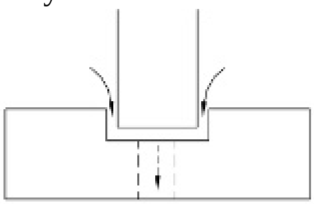
7.b. Flushing Techniques in EDM

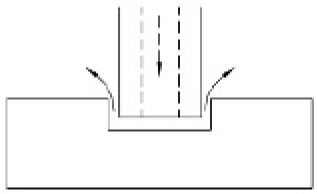
One of the important factors in a successful EDM operation is the removal of debris (chips) from the working gap. Flushing these particles out of the working gap is very important, to prevent them from forming bridges that cause short circuits. EDMs have a built-in power adaptive control system that increases the pulse spacing as soon as this happens and reduces or shuts off the power supply. Flushing – process of introducing clean filtered dielectric fluid into spark gap. If flushing is applied incorrectly, it can result in erratic cutting and poor machining conditions. Flushing of dielectric plays a major role in the maintenance of stable machining and the achievement of close tolerance and high surface quality. Inadequate flushing can result in arcing, decreased electrode life, and increased production time.

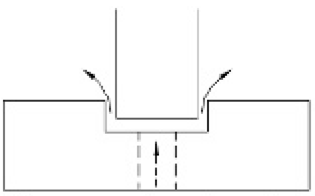
Flushing Four methods: 1. Normal flow 2. Reverse flow 3. Jet flushing 4. Immersion flushing

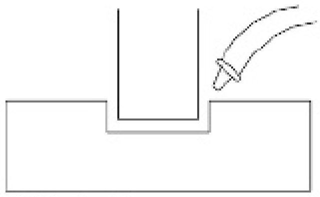
1. Normal flow (Majority): Dielectric is introduced, under pressure, through one or more passages in the tool and is forced to flow through the gap between tool and work. Flushing holes are generally placed in areas where the cuts are deepest. Normal flow is sometimes undesirable because it produces a tapered opening in the workpiece.
2. Reverse flow: Particularly useful in machining deep cavity dies, where the taper produced using the normal flow mode can be reduced. The gap is submerged in filtered dielectric, and instead of pressure being applied at the source a vacuum is used. With clean fluid flowing between the workpiece and the tool, there is no side sparking and, therefore, no taper is produced.
3. Jet flushing: In many instances, the desired machining can be achieved by using a spray or jet of fluid directed against the machining gap. Machining time is always longer with jet flushing than with the normal and reverse flow modes.
4. Immersion flushing: For many shallow cuts or perforations of thin sections, simple immersion of the discharge gap is sufficient. Cooling and debris removal can be enhanced during immersion cutting by providing relative motion between the tool and workpiece. Vibration or cycle interruption comprises periodic reciprocation of the tool relative to the workpiece to effect a pumping action of the dielectric.
5. Synchronized, pulsed flushing is also available on some machines. With this method, flushing occurs only during the non-machining time as the electrode is retracted slightly to enlarge the gap. Increased electrode life has been reported with this system.

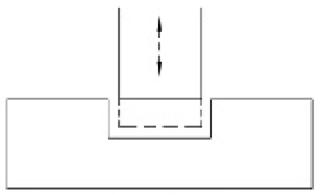

(a) Suction through electrodes


(b) Suction through work piece

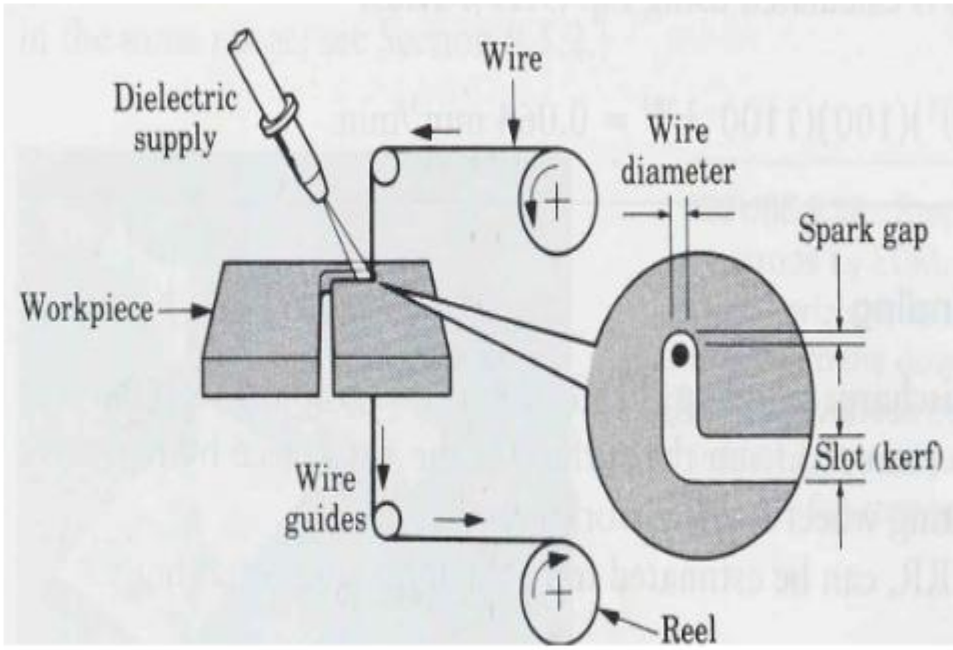

(c) pressure through electrode


(d) pressure through work piece


(e) jet flushing


(f) periodic cycling of electrode

7.c. Travelling wire EDM



Wire electrical discharge machining (EDM) is a non-traditional machining process that uses electricity to cut any conductive material precisely and accurately with a thin, electrically charged copper or brass wire as an electrode.During the wire EDM process, the wire carries one side of an electrical charge and the workpiece carries the other side of the charge. When the wire gets close to the part, the attraction of electrical charges creates a controlled spark, melting and vaporizing microscopic particles of material. The spark also removes a miniscule chunk of the wire, so after the wire travels through the workpiece one time, the machine discards the used wire and automatically advances new wire. The process takes place quickly—hundreds of thousands of sparks per second—but the wire never touches the workpiece. The spark erosion occurs along the entire length of the wire adjacent to the workpiece, so the result is a part with an excellent surface finish and no burrs regardless of how large or small the cut.Wire EDM machines use a dielectric solution of deionized water to continuously cool and flush the machining area while EDM is taking place. In many cases the entire part is submerged in the dielectric fluid, while high-pressure upper and lower flushing nozzles clear out microscopic debris from the surrounding area of the wire during the cutting process. The fluid also acts as a non-conductive barrier, preventing the formation of electrically conductive channels in the machining area. When the wire gets close to the part, the intensity of the electric field overcomes the barrier and dielectric breakdown occurs, allowing current to flow between the wire and the workpiece, resulting in an electrical spark.

On most wire EDM machines, the path of the wire is controlled by computer numerically-controlled (CNC) diamond guides, which can move independently of each other on multiple axes for tapered cuts and complex shapes such as small-radius inside corners and narrow slots. Additionally, wire sizes vary from 0.012” diameter down to 0.004” for high-precision work. Wire EDM is capable of holding tolerances as tight as +/-0.0001”.Wire EDM provides a solution to the problems encountered when trying to machine materials that are normally difficult to work with, such as hardened steel, aerospace-grade titanium, high-alloy steel, tungsten carbide, Inconel, and even certain conductive ceramics.

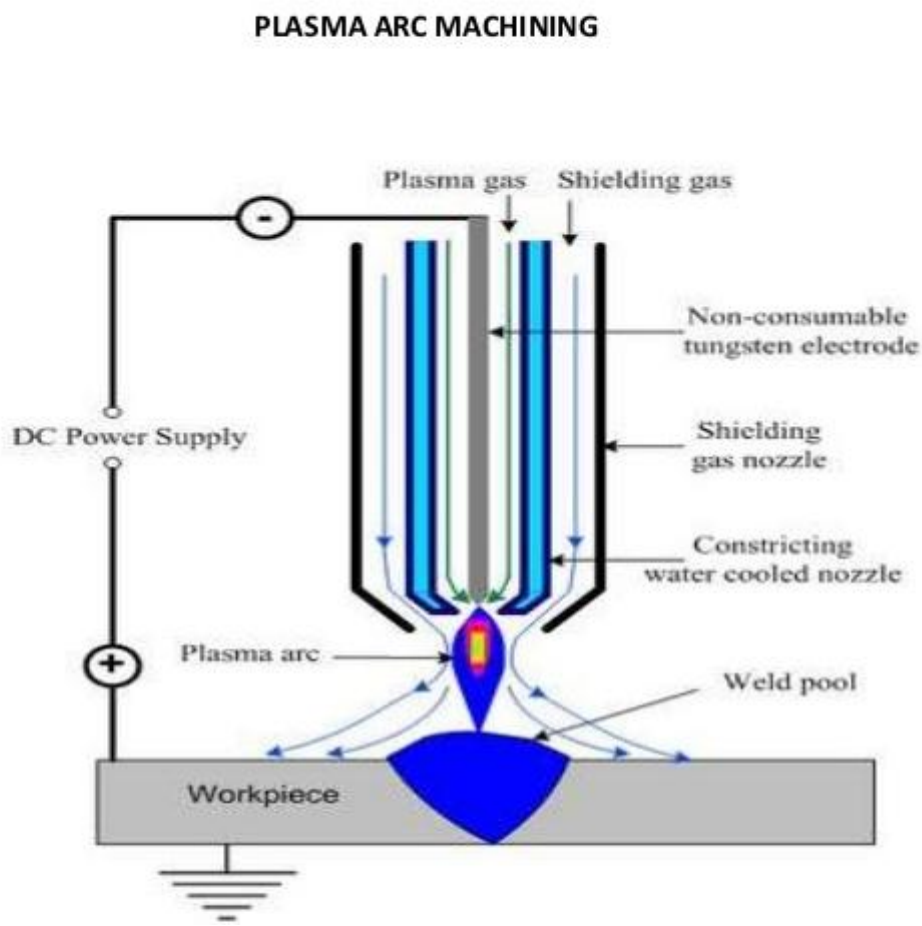
One requirement of the wire EDM process is a start hole for threading the wire if the part's features do not allow you to cut an edge. Wire EDM can only machine through features; however, we can quickly drill a hole in any conductive material using another type of EDM, small hole drilling or "hole pop" EDM.

8.a. Principle of Plasma Arc Machining

- A high frequency spark is used to initiate a pilot arc between the tungsten electrode (cathode) and the copper nozzle (anode) both of which are water cooled.
- Pilot arc is then cut off and the external arc generates a plasma jet which exists from the nozzle at high velocity.
- Plasma jet heats the workpiece by striking with electrons and by transfer of energy from high temperature, high energy gas.
- The heat is effective in cutting the workpiece upto thickness of 50mm.

Construction

- The equipment can be used to machine a wide range of materials and thickness by suitable adjustments of power level, gas tight, gas flow rate, speed.
- The direct current is supplied to the tungsten electrode (cathode) from the power supply.
- The tungsten electrode is heated to a very high temperature and generates high frequency spark.
- A high frequency spark initiates a pilot arc between the tungsten electrode (cathode) and the copper nozzle (anode).
- Gas is supplied to the ceramic chamber through plasma gas inlet at high velocity. Due to the heat liberated from the tungsten electrode gas is heated to a very high temperature. The collision between atoms increases and results with ionization.
- Increase in collision causes pilot arc to cut off and the external arc generates a plasma jet which exit from the nozzle at high velocity. Plasma jet strikes the work piece and heats the surface. The heat produced melts the workpiece and the velocity gas stream blows the molten metal away.



Mechanism of Material removal

- The metal removal in plasma arc machining is basically due to the high temperature produced.
- The heating of workpiece is as a result of anode heating, due to direct electron bombardment plus convection heating from the high temperature plasma that accompanies the arc.
- The heat produced is sufficient to raise the workpiece temperature above its melting point and the high velocity gas stream effectively blows the molten metal away.
- Under optimum conditions, upto approximately 45% of the electrical power delivered to the torch is used to remove metal from the workpiece.
- Plasma arc cutting was primarily employed to cut metals that form a refractory oxide outer skin.
- The arc heat is concentrated on a localized area of the workpiece and it raises it to its melting point.
- The quality of cut is affected by the heat flow distribution; uniform heat supply throughout the thickness of the material produces a cut of excellent quality.

8.b. Safety Precautions in PAM

- Do not use faulty equipment. ...
- Do not weld or cut containers that have held combustible liquids or gases.
- Do not heat or cut metals coated with or containing materials that emit toxic fumes, unless coating is removed from the work surface.
- Never leave the machine running unattended.
- **Noise, air quality, and electrocution** are three of the most dangerous risks when working with a plasma cutter. Each of these risks can result in long-lasting health consequences. Sparks, flames, and heat hazards are some of the dangers that MCR Safety directly addresses with personal protective equipment

8.c. Advantages:

- Any material, regardless of its hardness and refractory nature can be efficiently and economically machined.
- Faster cutting speeds due to high velocity and high temperature of cutting gas.
- Requires minimal operator training.
- Process variables such as type of gas, power, cutting speed, etc, can be adjusted for each metal type.
- As there is no contact between tool and work piece a simply supported workpiece is adequate.

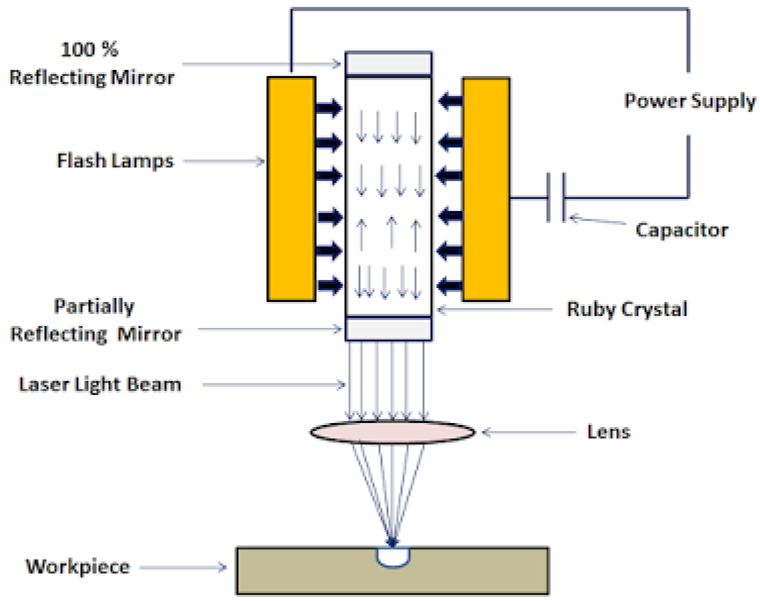
Disadvantages:

- High equipment cost.
- The high temperature, high velocity impinging gas causes metallurgical alterations in the workpiece material.
- Shielding and noise protection adds additional equipments and also burden on the operator's precautions.

9.a. **Laser Beam Machining (LBM)** is a form of machining process in which laser beam is used for the machining of metallic and non-metallic materials. In this process, a laser beam of high energy is made to strike on the workpiece; the thermal energy of the laser gets transferred to the surface of the workpiece. The heat so produced at the surface heats melts and vaporizes the materials from the workpiece. Light amplification by stimulated emission of radiation is called **LASER**.

It works on the principle that when a high energy laser beam strikes the surface of the workpiece. The heat energy contained by the laser beam gets transferred to the surface of the workpiece. This heat energy absorbed by the surface heat melts and vaporizes the material from the workpiece. In this way the machining of material takes place by the use of laser beam.

The various main parts used in the laser beam machining are



1. A pumping Medium: A medium is needed that contains a large number of atoms. The atoms of the media are used to produce lasers.
2. Flash Tube/Flash Lamp: The flash tube or flash lamp is used to provide the necessary energy to the atoms to excite their electrons.
3. Power Supply: A high voltage power source is used to produce light in flashlight tubes.
4. Capacitor: Capacitor is used to operate the laser beam machine at pulse mode.
5. Reflecting Mirror: Two types of mirror are used, first one is 100 % reflecting and other is partially reflecting. 100 % reflecting mirror is kept at one end and partially reflecting mirror is at the other end. The laser beams comes out from that side where partially reflecting mirror is kept.

Working of Laser Beam Machining

A very high energy laser beam is produced by the laser machines. This laser beam produced is focused on the workpiece to be machined.

When the laser beam strikes the surface of the workpiece, the thermal energy of the laser beam is transferred to the surface of the w/p. this heats, melts, vaporizes and finally removes the material from the workpiece. In this way laser beam machining works.

9.b. Characteristics and Parameters of LBM

<u>Process Parameters of LBM</u>

- *Power density* and *laser beam-work piece* interaction time are the most important variables determining whether the beam will weld, cut, mark or heat treat.
- For rapid heating of a surface without melting, a highly focused beam producing power densities of only $1.5x10^2$- $1.5xl0^4$ w/ cm^2 is used.
- If melting is desired, as in the case of welding or cladding applications, power densities ranging from 1.5×10^4 - 1.5×10^5 $W\,cm^2$ is used.
- Cutting and drilling action will occur for power densities ranging from 1.5×10^6 - 1.5×10^8 $W\,cm^2$.

Characteristics of LBM

- Laser beam have two great characteristics, these are **monochromatic and parallel** so it can be directly focused to a micron size diameter and can produce high energy (like

100MW) for micro size area. It is best for making a precise micro size hole. Also, it can be used for other micro machining on all types of materials.

- Any material, including non-metals, and irrespective of their hardness and brittleness can be machined by laser.

- Apart from cutting, drilling and welding materials, lasers can also be used for marking, scribing, heat- treating of surfaces and selectively clad materials.

9.c. Advantages

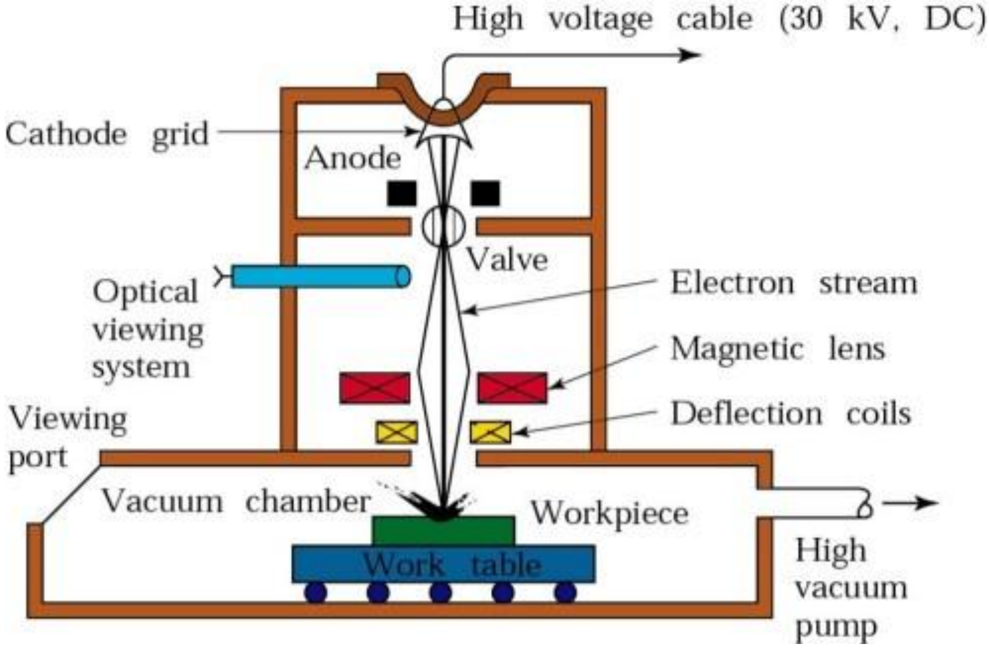
- It can be focused to a very small diameter.
- It produces a very high amount of energy, about 100 MW per square mm of area.
- It is capable of producing very accurately placed holes.
- Laser beam machining has the ability to cut or engrave almost all types of materials, when traditional machining process fails to cut or engrave any material.
- Since there is no physical contact between the tool and workpiece. The wear and tear in this machining process is very low and hence it requires low maintenance cost
- This machining process produces object of very high precision. And most of the object does not require additional finishing
- It can be paired with gases that help to make cutting process more efficient. It helps to minimize the oxidation of w/p surface and keep it free from melted of vaporized materials. Produces a very high energy of about 100 MW per square mm of area.
- It has the ability to engrave or cut almost all types of materials. But it is best suited for the brittle materials with low conductivity.

Disadvantages

- High initial cost. This is because it requires many accessories which are important for the machining process by laser.
- Highly trained worker is required to operate laser beam machining machine.
- Low production rate since it is not designed for the mass production.
- It requires a lot of energy for machining process.
- It is not easy to produce deep cuts with the w/p that has high melting points and usually cause a taper.
- High maintenance cost.

10.a. **Electron Beam Machining (EBM)**

The source of energy in electron beam machining is high-velocity electrons, which strikes the surface of the workpiece and generate heat. Electrons escape from the hot surface and a voltage of 50 to 200 kV helps to accelerate them. These high energy electrons possess high energy density generally in the order of 10ˆ4 kW/mm². Thin and high energy stream strikes the workpiece. As a result, the kinetic energy of the electrons is converted to heat energy. This heat energy is more than sufficient to melt and even vaporize any material. Electrons can penetrate only a few atomic layers of the metals and can melt metal up to a depth of 25 mm. The electron beam traveling at a speed of ¾ of the velocity of the sound is focused on the material to be machined. To focus the electron beams electro-static or electromagnetic lenses are used. Generally, electron beam machining is done in a high vacuum chamber to avoid the unnecessary scattering of the electrons. The following figure shows the schematic diagram of the electron beam machining process.



Schematic illustration of the electron-beam machining process. Unlike LBM, this process requires a vacuum, so workpiece size is limited to the size of the vacuum chamber.

For observing the process of machining an optical viewing system consisting of lens and prism is also incorporated. The beam can be controlled very accurately and focused on width as small as 0.002 mm. The electrons on impingement over the workpiece heat it up and raise its temperature to a value as high as 5000°C. Due to this the material melts and vaporizes locally.

Recent developments have made it possible to machine outside the vacuum chamber. In this arrangement, the necessary vacuum is maintained within the electron gun proper by removing gases as soon as they enter. The full vacuum system is more costly, but it has the advantage that no contaminating gases are present and the electron gun can be located at a considerable distance from the workpiece.

10.b. **Equipment:**

There are 3 important elements of electron beam machining system i.e.,

1) Electron beam gun.

2) Power supply.

3) Vacuum system.

1) **Electron beam gun:**

- It is used to produce electron beam of desired shape and focus at the predetermined location. A super heated cathode made of tungsten generates the electrons. Due to force of repulsion from cathode electrons move at a very high speed towards the anode. The speed of the electrons passing towards the anode is 70% of the speed of light.

- A magnetic lens is used to shape the electron beam into converging beam.

This beam is focused and directed on the work surface. Magnetic lens are used to point the location of beam and make it circular beam falling on the workpiece.

2) **Power Supply:**

- The power supply generates a voltage as high as 150 Kw to accelerate

electrons.

- Electron beam gun is usually operates at about 12 Kw. This power density

developed at work. Surface is too high and thus it is capable to melt and vaporize the workpiece. Thus metal removal in EBM is basically due to vaporization.

3) **Vacuum system:**

- The electron beam generation and machining operation takes place in a

vacuum chamber. The vacuum does not allow rapid oxidation of filament.

- There is no loss of energy of electrons as a result of collision with air molecules.

10.c. Advantages of EBM

- Very hard, heat resistant materials could be machined or welded easily
- No physical or metallurgical damage results in the workpiece.
- Close dimensional tolerance could be achieved since there is no cutting tool wear.
- In electron beam welding there is virtually no contamination and close control of penetration is possible.
- Holes as small as 0.002 mm diameter could be drilled.

Applications:

- Used for producing very small size holes like holes in diesel injection nozzles, Air brakes etc.
- Used only for circular holes.
- Electron beam machining is more popular in aerospace, food processing, chemical clothing etc.
- It is suitable for drilling of holes on metals such as tungsten, molybdenum.
- It is also used for drilling 1000’s of holes (diameter less than 1mm) in very thin plates.
- Micro machining operations on workpieces of thin sections.
- Micro drilling operations (upto 0.002mm) for thin orifices, dies for wire drawing parts of electron microscopes, fibre spinners, injector holes for diesel engines etc.
- Very effective for machinng of metals of low heat conductivity and high melting point.