Nontraditional Machining

UNIT 1

Introduction

Parts manufactured by casting, forming, and various shaping processes often require further operations before they are ready for use or assembly In many engineering applications, parts have to be interchangeable in order to function properly and reliably during their expected service lives; thus control of the dimensional accuracy and surface finish of the parts is required during manufacture. Machining involves the removal of some material from the work piece (machining allowance) in order to produce a specific geometry at a definite degree of accuracy and surface quality.

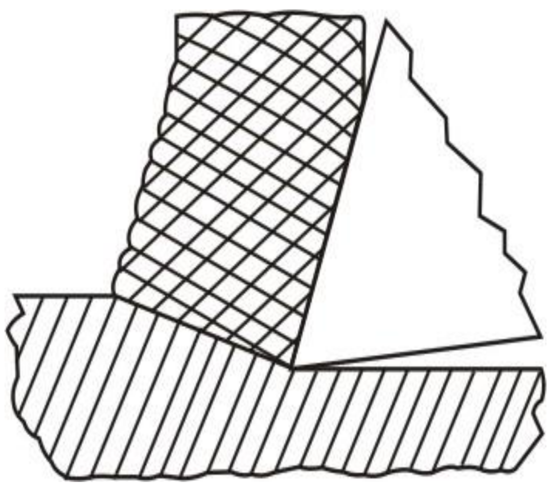
History of Machining

From the earliest of times methods of cutting materials have been adopted using hand tools made from bone, stick, or stone. Later, hand tools made of elementary metals such as bronze and iron were employed over a period of almost one million years. Indeed up to the seventeenth century, tools continued to be either hand operated or mechanically driven by very elementary methods. By such methods, wagons, ships, and furniture, as well as the basic utensils for everyday use, were manufactured. The introduction of water, steam, and, later, electricity as useful sources of energy led to the production of power-driven machine tools which rapidly replaced manually driven tools in many applications. Based on these advances and together with the metallurgical development of alloy steels as cutting tool materials, a new machine tool industry began to arise in the eighteenth and nineteenth centuries. A major original contribution to this new industry came from John Wilkinson in 1774. He constructed a precision machine for boring engine cylinders, thereby overcoming a problem associated with the first machine tools, which were powered by steam. Twenty-three years later, Henry Maudslay made a further advancement in machining when he devised a screw-cutting engine lathe. James Nasmyth invented the second basic machine tool for shaping and planing; these techniques are used to machine flat surfaces, grooves, shoulders, T-slots, and angular surfaces using single-point cutting tools. The familiar drilling machine is the third category of machine tools; it cuts holes with a twist drill. Whitney in about 1818 introduced the first milling machine to cut grooves, dovetails, and T-slots as well as flat surfaces. The first universal milling machine, constructed in 1862 by J. R. Brown, was employed to cut helical flutes of twist drills. In the late nineteenth century, the grinding machine was introduced. An advanced form of this technology is the lapping process used to produce a high-quality surface finish and a very tight tolerance, as small as ±0.00005 millimeters (mm) compared to the ±0.0025 mm achieved during grinding. Band saws and circular disc saws are used for cutting shapes in metal plates, for making external and internal contours, and for making angular cuts. A notable development includes the turret lathe made in the middle of the nineteenth century for the automatic production of screws. Another significant advance came in 1896, when F. W. Fellows built a machine that could produce any kind of gear. An example of the significance of early achievements in grinding technology came from C. N. Norton’s work in reducing the time needed to grind a car crankshaft from 5 hours (h) to 15 minutes (min). Multiple-station vertical lathes, gang drills, production millers, and special-purpose machines (for example, for broaching, honing, and boring) are other noteworthy examples of advances in machine tool technology (McGeough, 1988). In the later part of the nineteenth century and in the twentieth century, machine tools became increasingly powered by electricity rather than steam. The basic machine tools underwent further refinement; for instance, multiple-point cutters for milling machines were introduced. Even with these advances, conventional machine tool practice still relies on the principle whereby the tool must be made of a material that is harder than the work piece that is to be cut. During machining by these conventional methods the operator is given a drawing of the finished part. He or she determines the machining strategy, sets up the machine, and selects tooling, speeds, and feeds. The operator manipulates the machine control to cut the part that passes inspection. Under such circumstances, the product accuracy and surface quality are not satisfactory. Further developments for these conventional machines came by the introduction of copying techniques, cams, and automatic mechanisms that reduced labor and, consequently, raised the product accuracy.

Classification.

Classification of Non Traditional Machining Processes

- To classify Non Traditional Machining Processes (NTM), one needs to understand and analyze the differences and similar characteristics between conventional machining processes and NTM processes.
- Conventional Machining Processes mostly remove material in the form of chips by applying forces on the work material with a wedge shaped cutting
- Such forces induce plastic deformation within the work piece leading to shear deformation along the shear plane and chip formation



- Thus the major characteristics of conventional machining are:
- Generally macroscopic chip formation by shear deformation
- Material removal takes place due to application of cutting forces – energy domain can be classified as mechanical
- Cutting tool is harder than work piece at room temperature as well as under machining conditions
- Non Traditional Machining (NTM) Processes on the other hand are characterized as follows:
- Material removal may occur with chip formation or even no chip formation may take place. For example in AJM, chips are of microscopic size and in case of Electrochemical machining material removal occurs due to electrochemical dissolution at atomic level

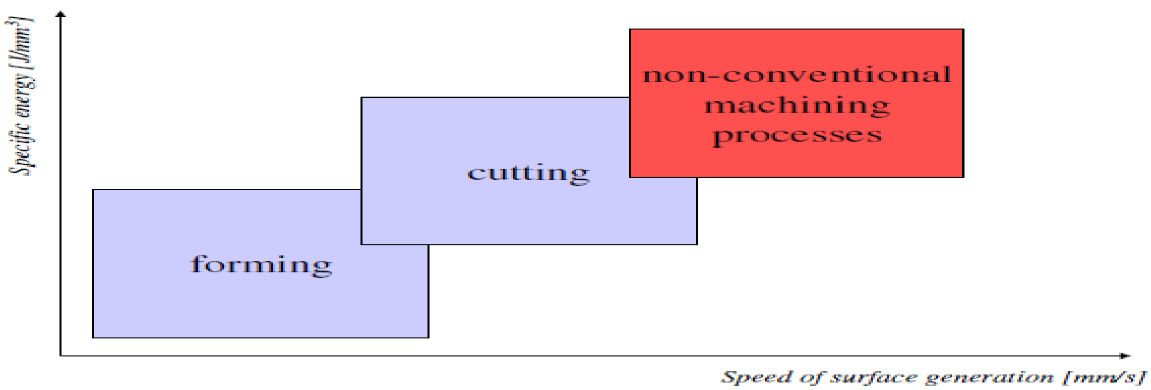
- In NTM, there may not be a physical tool present. For example in laser jet machining, machining is carried out by laser beam. However in Electrochemical Machining there is a physical tool that is very much required for machining

- In NTM, the tool need not be harder than the work piece material. For example, in EDM, copper is used as the tool material to machine hardened steels.

- Mostly NTM processes do not necessarily use mechanical energy to provide material removal. They use different energy domains to provide machining. For example, in USM, AJM, WJM mechanical energy is used to machine material, whereas in ECM electrochemical dissolution constitutes material removal.

Nontraditional Machining
Definition:

- Nontraditional machining refers to a group a processes which removes excess material by various techniques involving mechanical, thermal, electrical or chemical energy



Classification.

Available nontraditional material removal processes

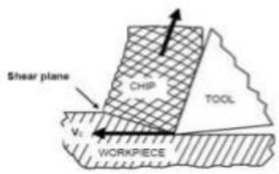
- Mechanical
  - AJM - abrasive jet machining
  - USM - ultrasonic machining
  - WJM - water jet machining
- Electrical/Electrochemical
  - ECM - electrochemical machining
- Thermal
  - EBM - electron beam machining
  - EDM - electrical discharge machining
  - LBM - laser beam machining
  - PBM - plasma beam machining
- Chemical
  - CHM - chemical machining

PROCESS SELECTION:

Before selecting the process to be employed, the following aspects must be studied;

i) Physical parameters
ii) Properties of the work material and the shape to be machined
iii) Process capability
iv) Economic considerations.

Comparison

Conventional Manufacturing Processes	Non-Conventional Manufacturing Processes
1. Generally macroscopic chip formation by shear deformation. 	1. Material removal may occur with chip formation or even no chip formation may take place. For example in AJM, chips are of microscopic size and in case of Electrochemical machining material removal occurs due to electrochemical dissolution at atomic level
2. There may be a physical tool present. for example a cutting tool in a Lathe Machine,	2. There may not be a physical tool present. For example in laser jet machining, machining is carried out by laser beam. However in Electrochemical Machining there is a physical tool that is very much required for machining.
3. Cutting tool is harder than work piece at room temperature as well as under machining conditions	3. There may not be a physical tool present. For example in laser jet machining, machining is carried out by laser beam. However in Electrochemical Machining there is a physical tool that is very much required for machining.
4. Material removal takes place due to application of cutting forces – energy domain can be classified as mechanical	4. Mostly NTM processes do not necessarily use mechanical energy to provide material removal. They use different energy domains to provide machining. For example, in USM,

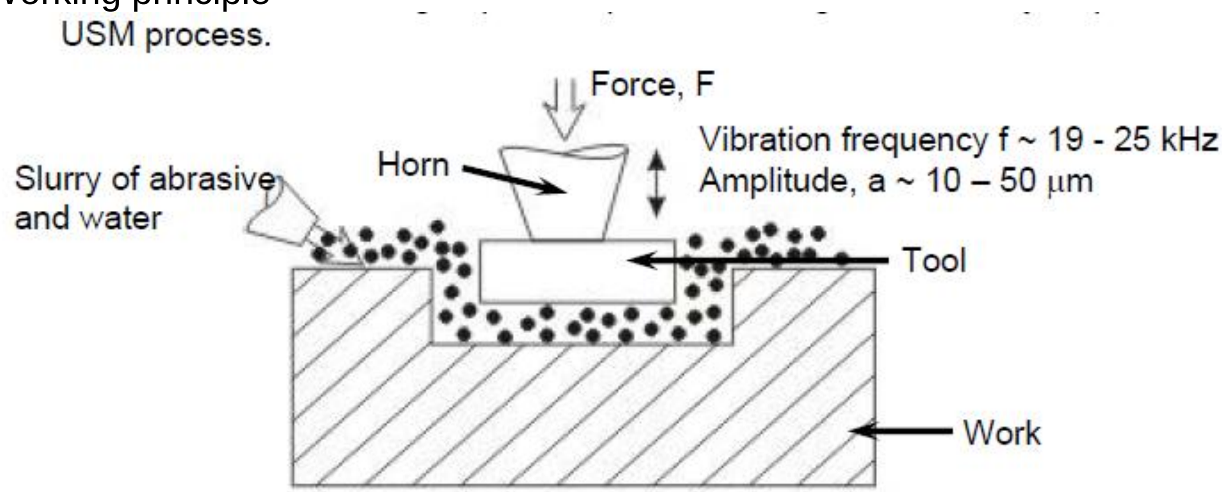
UNIT 2

Ultrasonic Machining (USM)

INTRODUCTION

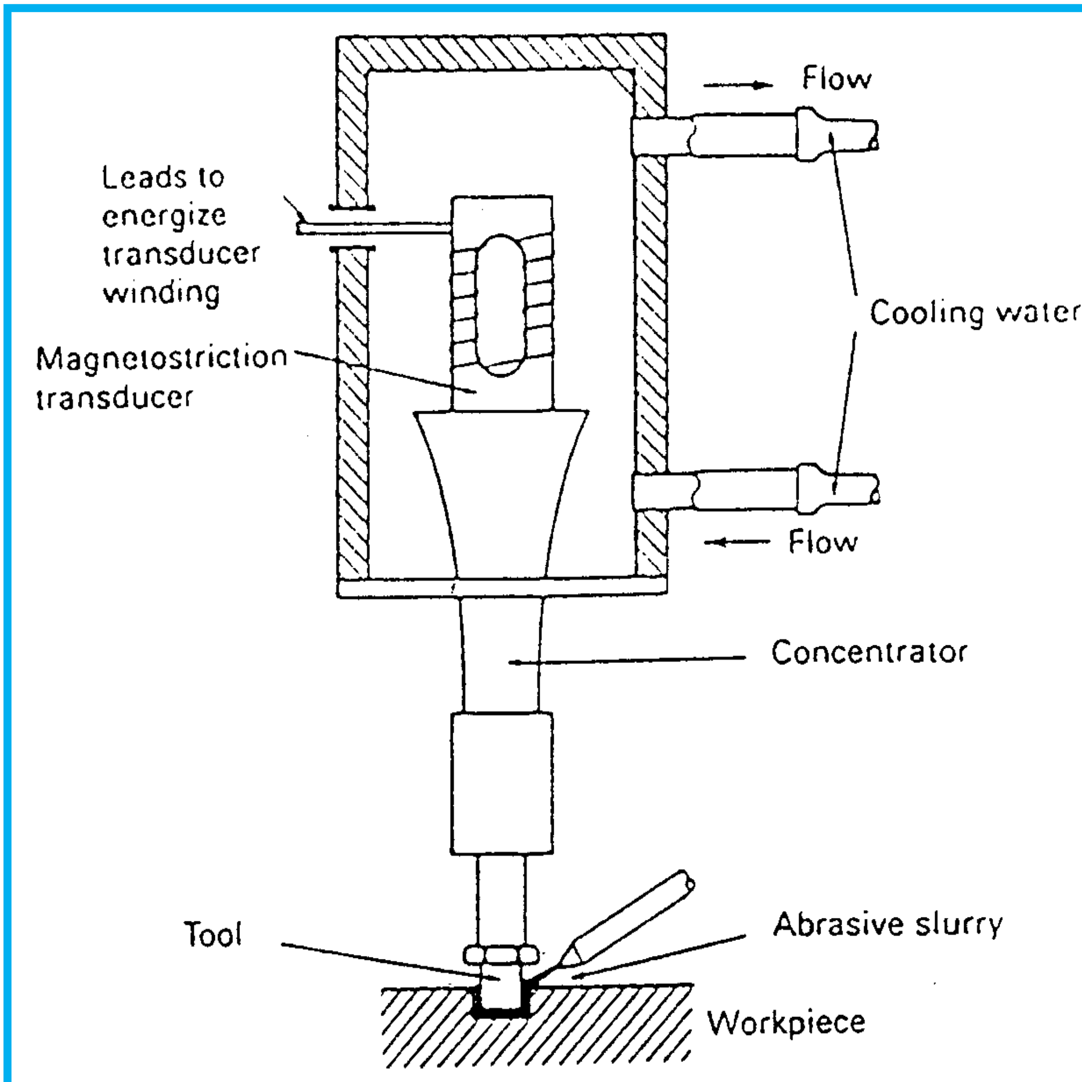
Ultrasonic machining is a non-traditional machining process. USM is grouped under the mechanical group of NTM processes. Material Removing Process. USM is used to erode holes and cavities in hard or brittle work pieces by using shaped tools, high-frequency mechanical motion and an abrasive slurry.USM is able to effectively machine all hard materials whether they are electrically conductive or not.

Working principle



- The process is performed by a cutting tool, which oscillates at high frequency, typically 20-40 kHz, in abrasive slurry.
- The shape of the tool corresponds to the shape to be produced in the work piece.
- The high-speed reciprocations of the tool drive the abrasive grains across a small gap against the work piece (0.02 to 0.1 mm).
- The tool is gradually fed with a uniform force.
- The impact of the abrasive is the energy principally responsible for material removal in the form of small wear particles that are carried away by the abrasive slurry.
- The abrasive particles, as they indent, the work material, would remove the same, particularly if the work material is brittle, due to crack initiation, propagation and brittle fracture of the material. Hence, USM is mainly used for machining brittle materials
- The tool material, being tough and ductile, wears out at a much slower rate.

Equipment



The major components of an USM apparatus are:

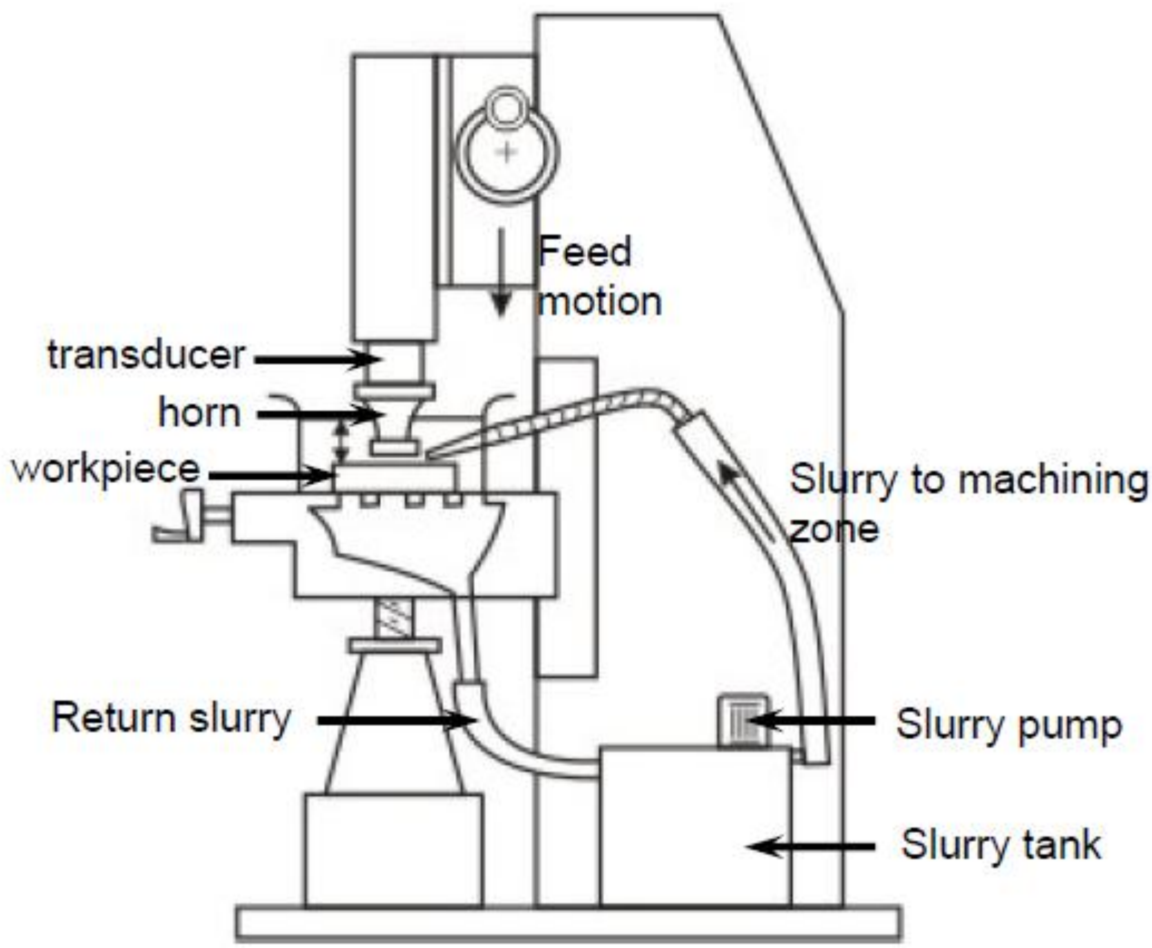
1. The electronic oscillator and amplifier known as generator.
2. The transducer, which operates by magnetostriction. This is connected to The horn or concentrator also known as wave guide, which mechanically amplifies the vibration to the required amplitude of 15 – 50 μm and accommodates the tool at its tip.
3. The abrasive slurry and circulation system.
4. Tool.

1. **The electronic oscillator and amplifier** known as generator converts the available energy of low frequency to high frequency to the transducer

2. **Transducer**

The ultrasonic vibrations are produced by the transducer. The transducer is driven by suitable signal generator followed by power amplifier. The transducer for USM works on the following principle

- Piezoelectric effect
- Magnetostrictive effect
- Electrostrictive effect
- Magnetostriction effect is the change of dimension of a material in response to a magnetic field.
- Magnetostrictive transducers are most popular and robust amongst all. The following figure shows a typical magnetostrictive transducer along with horn.
- The horn or concentrator is a wave-guide, which amplifies and concentrates the vibration to the tool from the transducer.



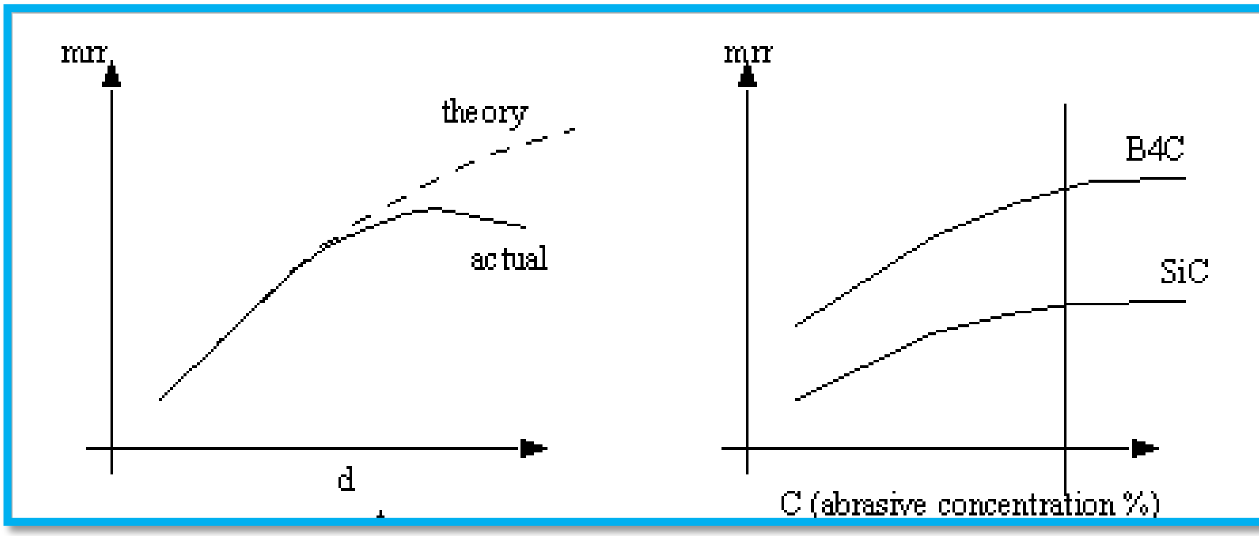
Abrasive slurry

- The criteria for selection of an abrasive for a particular application include hardness, usable life, cost, and particle size.
- Diamond is the fastest abrasive, but is not practical because of its cost.
- Boron carbide is economical and yields good machining rates but 20 times costlier than aluminium oxide.
- Silicon carbide and aluminium oxide are also widely used. Coarse grits exhibit the highest removal rate, when the grain size becomes comparable with the tool amplitude, cut more slowly.

- The larger the grit size, the rougher the machined surface.
- Grit size of 200µm to 400µm are used for roughing and 800µm to 1000µm for finishing.
- With an abrasive concentration of about 30% to 60% by weight in water, but thinner mixtures are used to promote efficient flow when drilling deep holes or when forming complex cavities.

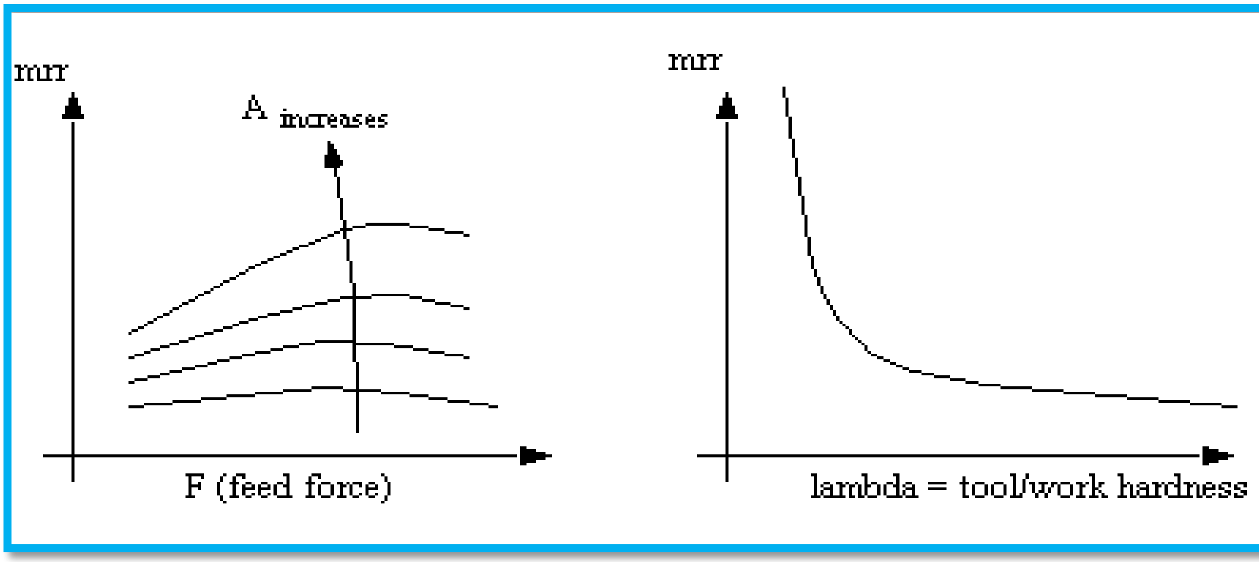
The slurry is circulated by pumping and it has to be cooled continuously to remove the heat during machining.

A refrigeration system is used to cool the slurry to a temperature of 5 to 6 ^{o}C

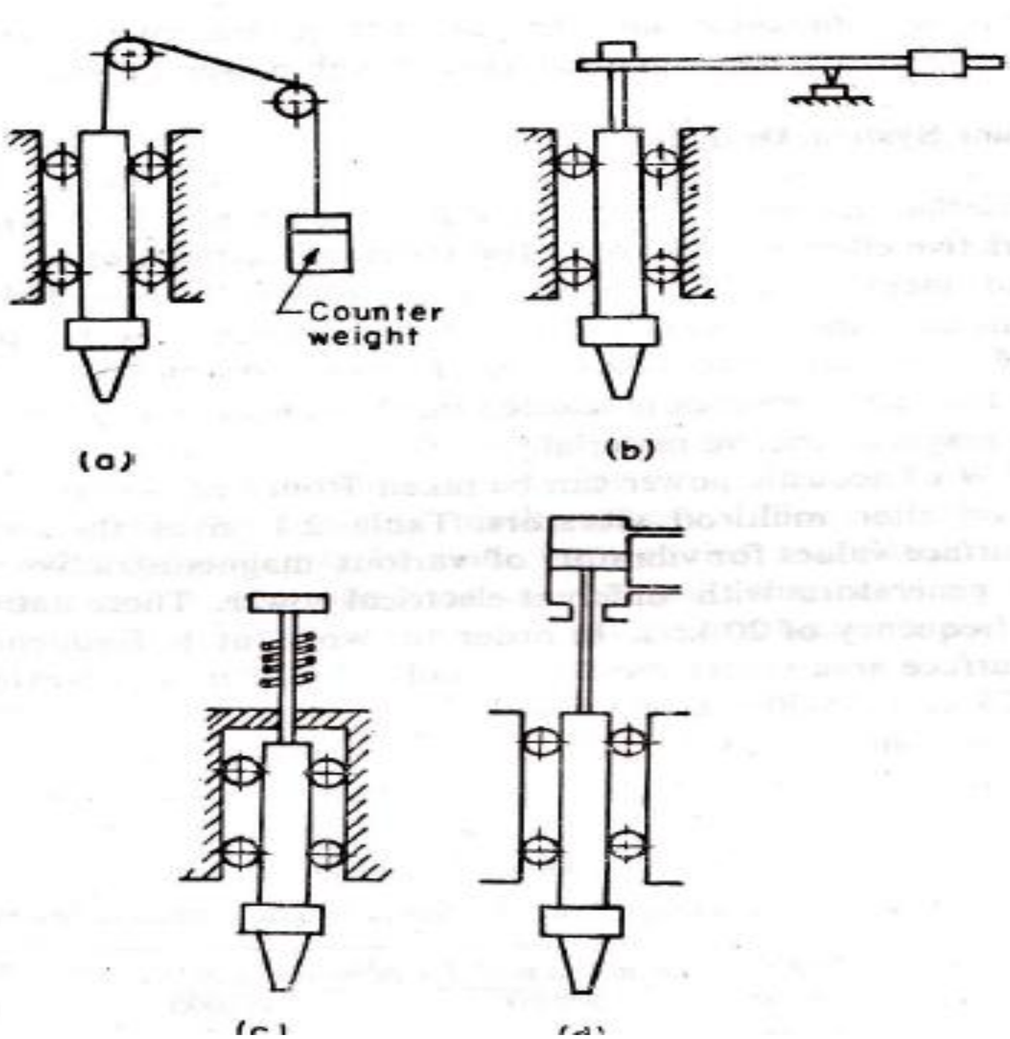


Tool

- Tools should be constructed from relatively tough and ductile materials.
- The harder the tool material, the faster its wear rate will be.
- It is important to realize that finishing or polishing operations on the tools are sometimes necessary because their surface finish will be reproduced in the work piece.
- The geometry of the tool generally corresponds to the geometry of the cut to be made,
- Because of the overcut, tools are slightly smaller than the desired hole or cavity
- Tool and tool holder are often attached by silver brazing and it has to be fed very carefully as shown.

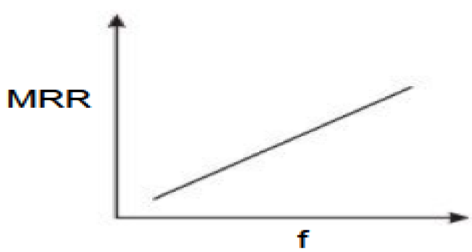


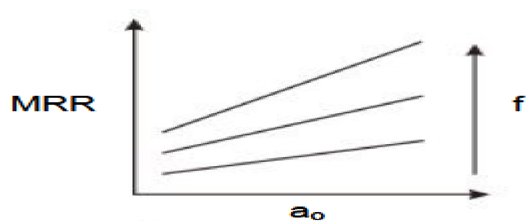
- The mass length of the tool is also very important.
- If the mass is more the energy is absorbed, if the length is more overstressing will occur at tool point
- The appropriate tool will have a slenderness ratio of 20 and diameter will be less than 25mm



Process Parameters and their Effects.

- Amplitude of vibration (a^{o}) – 15 – 50 μm
- Frequency of vibration (f) – 19 – 25 kHz
- Feed force (F) – related to tool dimensions
- Abrasive size – 15 μm – 150 μm
- Volume concentration of abrasive in water slurry – C





Process characteristics

- The following process characteristics are studied

1. Material removal rate
2. Tool wear
3. Accuracy
4. Surface finish

Material removal rate (MRR)

USM can be employed for all materials However it is not recommended for materials less than 50 HRC Generally stainless steel, germanium, glass, ceramic, carbide, quartz and semiconductor materials are machined by USMMRR is inversely proportional to cutting area of the tool.All the process parameters discussed affect the MRR

Tool wear

Tool wear in USM is defined by the ratio of volume of material removed from the work piece to that removed from the tool

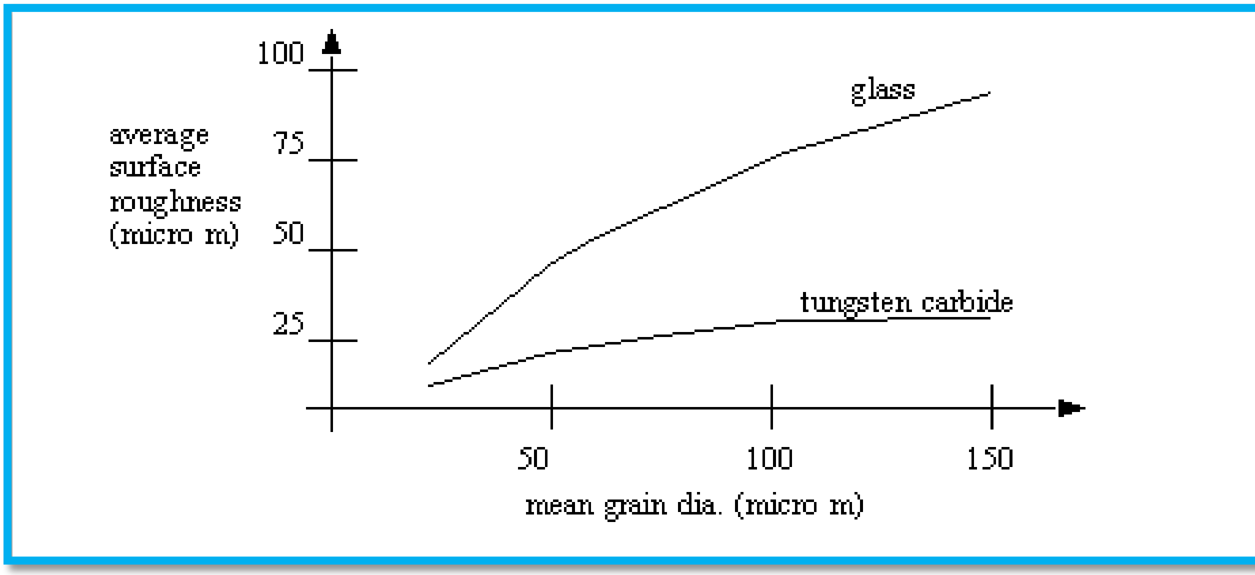
Tool material	**Wear ratio**	
	Glass	Steatite
Stainless steel	100:1	40:1
Carbon steel	100:1	35:1

Accuracy

- The size of the hole produced is influenced by the grit of the abrasive
- The size of the hole produced is equal to the tool size plus an overcut which is about twice the size of the abrasive particles
- Accuracy can be improved by changing the slurry regularly
- Use of different tools for roughing and finishing is essential for better accuracy
- Rotating the workpiece results in better accuracy with a tolerance of +/-0.03mm on diameter and +/-0.06mm on depth

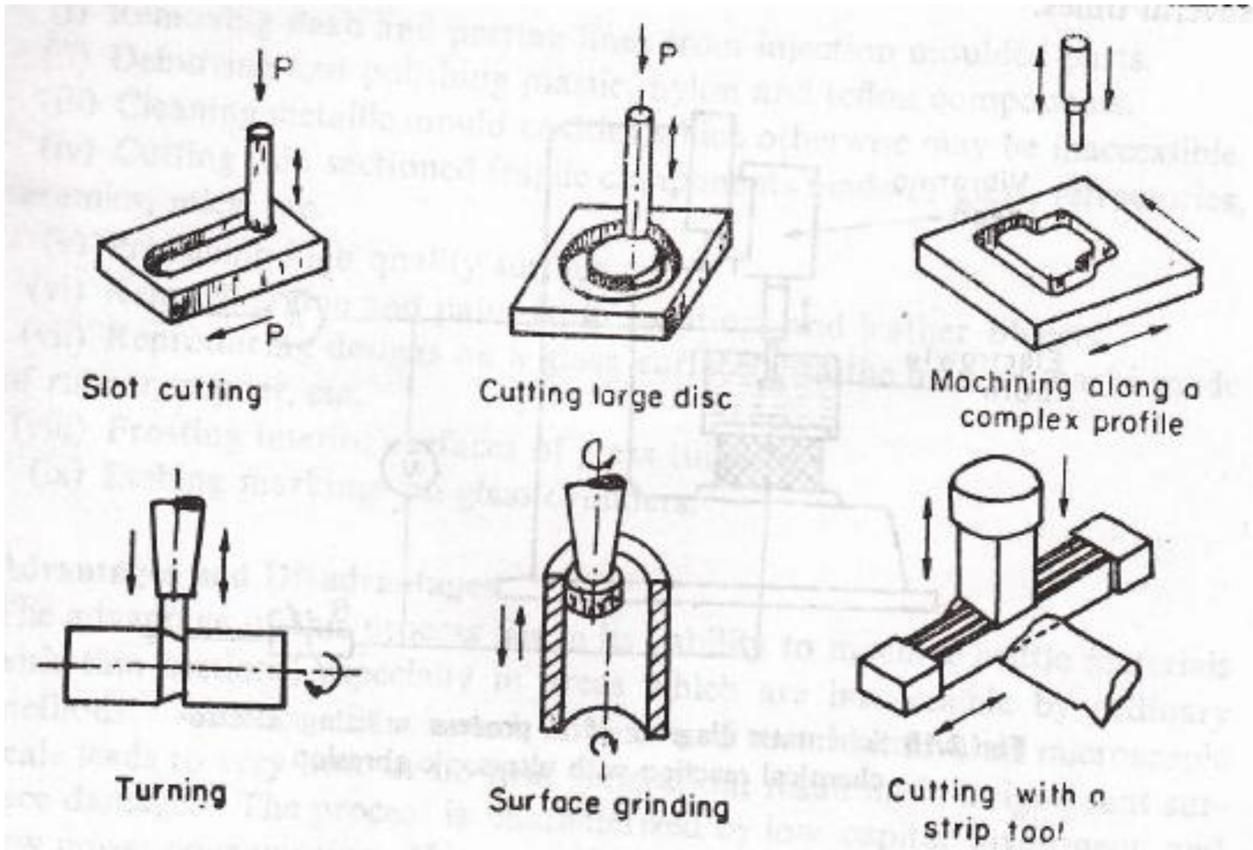
Surface finish

- The surface finish depends on the size of the abrasive particles, work material, tool amplitude and slurry circulation.
- With finer sizes of abrasive a surface finish of 0.2 to 0.8 μm can be obtained



Applications

- Used for machining hard and brittle metallic alloys, semiconductors, glass, ceramics, carbides etc.
- Producing Round holes (0.05mm) and irregular holes
- Coining operations for materials such as glass, ceramics
- Threading micro-holes
- Welding of plastics
- Inserting metals into plastics



Advantages

- Can be used for machining very hard materials
- Micro holes can be produced
- Very useful for machining brittle materials
- Not hazardous provided proper shielding is done to avoid US Waves
- No high speed moving parts

Limitations

- Low MRR
- Rather high tool wear
- Low depth of hole
- Tool has to be machined as preparatory process to match the shape required.

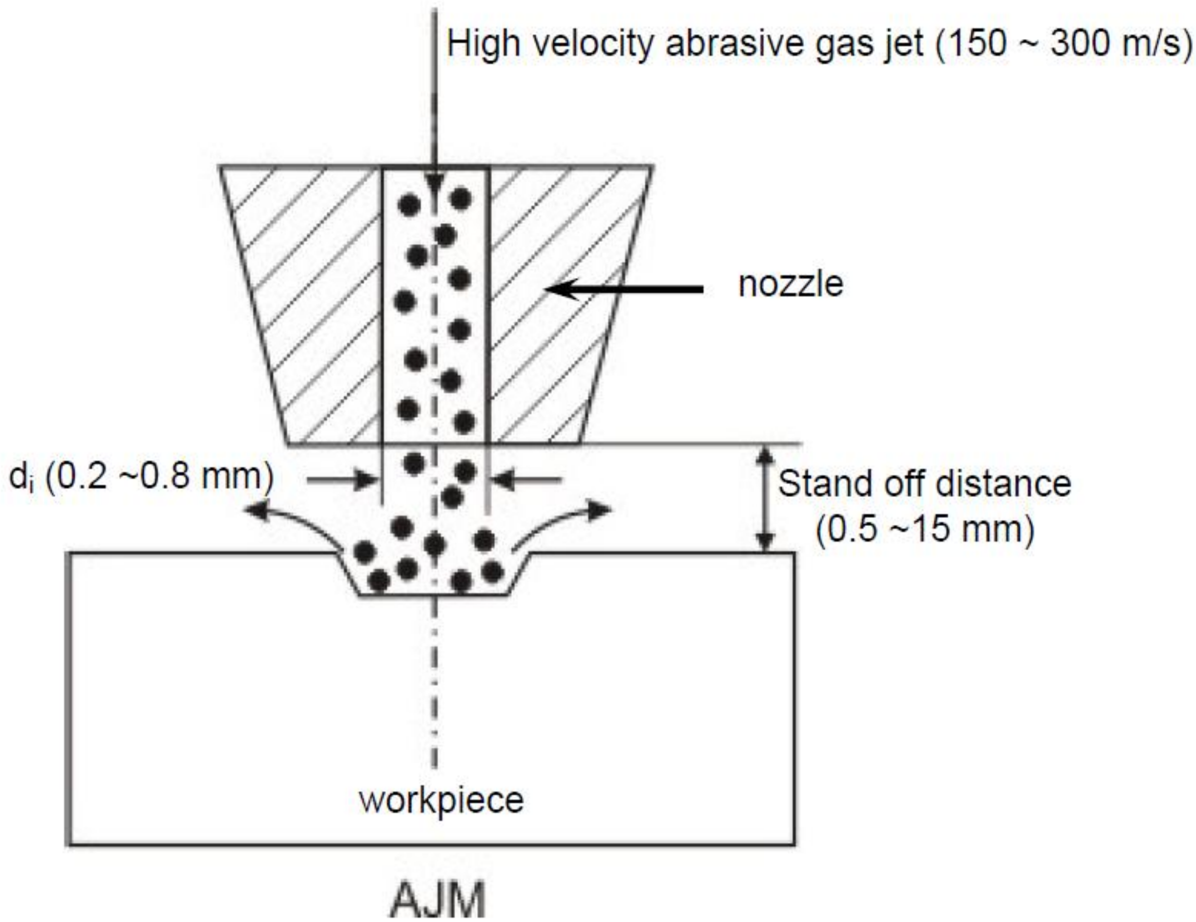
- Tool has to be replaced frequently to overcome rounding of edges and angular holes.
- Tool's center of gravity is a critical factor for proper holes/shapes

UNIT 3

ABRASIVE JET MACHINING (AJM)

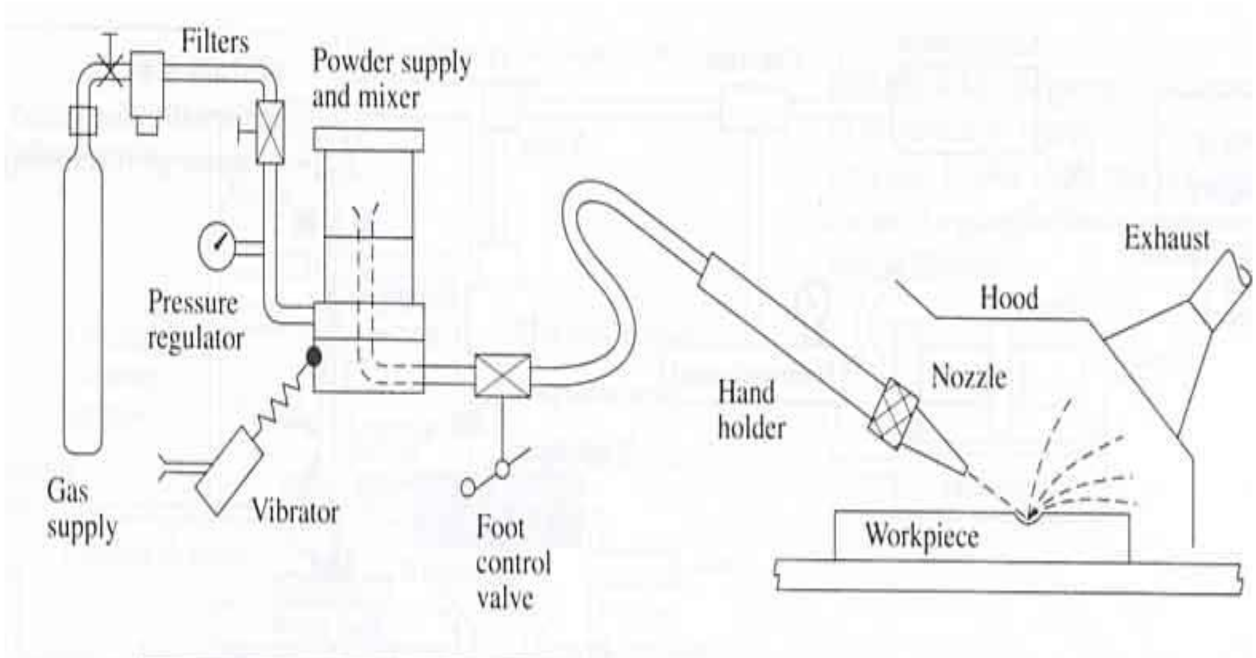
INTRODUCTION

- Abrasive Jet Machining is the removal of material from a work piece by the application of high speed stream of abrasive particles carried in a gas medium through a nozzle
- The high velocity stream of abrasive is generated by converting the pressure energy of the carrier gas or air to its kinetic energy and hence high velocity jet.
- The nozzle directs the abrasive jet in a controlled manner onto the work material, so that the distance between the nozzle and the work piece and the impingement angle can be set desirably
- AJM is different from standard shot or sand blasting, as in AJM, finer abrasive grits are used and the parameters can be controlled more effectively providing better control over product quality.
- In AJM, generally, the abrasive particles of around 50 μm grit size would impinge on the work material at velocity of 200 m/s from a nozzle of I.D. of 0.5 mm with a stand off distance of around 10 mm.
- The kinetic energy of the abrasive particles would be sufficient to provide material removal due to brittle fracture of the work piece or even micro cutting by the abrasives.



AJM

Equipment



- The carrier gas is first passed through a series of filters to remove any oil vapor or particulate contaminant and through a drier to remove any residual water vapor
- Next it is passed through a pressure regulator to obtain the desired working pressure.
- Then the carrier gas enters a closed chamber known as the mixing chamber. The abrasive particles enter the chamber from top through a metallic sieve. The sieve is constantly vibrated by an electromagnetic shaker. The mass flow rate of abrasive (15 gm/min) entering the chamber depends on the amplitude of vibration of the sieve and its frequency.
- The abrasive particles are then carried by the carrier gas to the machining chamber via foot control on-off valve.

  The machining enclosure is essential to contain the abrasive and machined particles in a safe and eco-friendly manner. The machining is carried out as high velocity (200 m/s) abrasive particles are issued from the nozzle onto a work piece traversing under the jet

  Variables of AJM process
- Various process parameter of AJM are characterized by the following elements

1. Nozzle design
2. Abrasives – type and size
3. Carrier gas
4. Velocity of the abrasive jet
5. Mean number of abrasive particles per unit volume of the carrier gas
6. Work material
7. Stand off distance
8. Shape of the cut

   Nozzle
   - Should withstand the erosive action of the abrasive material i.e high resistance to wear
   - The nozzle should be so designed as to minimize the loss due to bends, friction.
   - Material – Tungsten Carbide (for both circular and rectangular c/s / sapphire (only for circular cross section)
   - Diameter – (Internal) 0.2 ~ 0.8 mm

- Life – WC- 8 to 12 hrs, sapphire - 10 ~ 300 hours with 27 µm abrasive powder

Shape of the cut

It may not be possible to machine parts with sharp edges as abrasive particles move in stray direction

Abrasive – type and size

- Selection depends on type of machining, work material and cost
- Should have sharp and irregular shape
- Material – Al_2O_3 / SiC – used for cutting / glass beads / sodium bi carbonate – used for cleaning, etching and deburring.
- Reuse is not recommended as it reduces the quality of cut
- Size – Al_2O_3 - 10 ~ 25 µm, SiC - 25 – 40 µm, sodium bi carbonate - 27 µm, glass beads – 0.635 to 1.27mm
- Mass flow rate – 2 ~ 20 gm/min

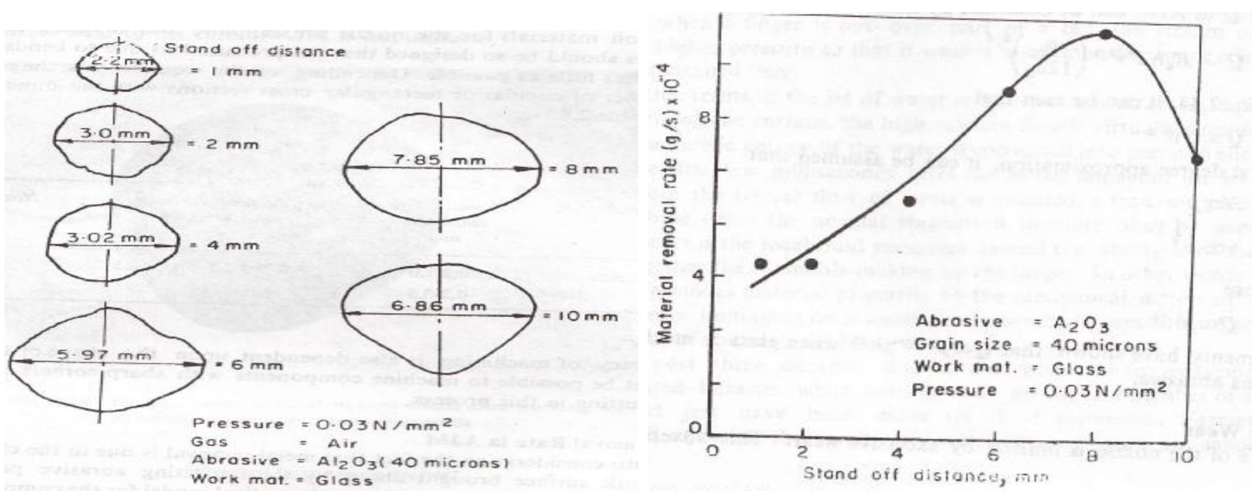
Work material

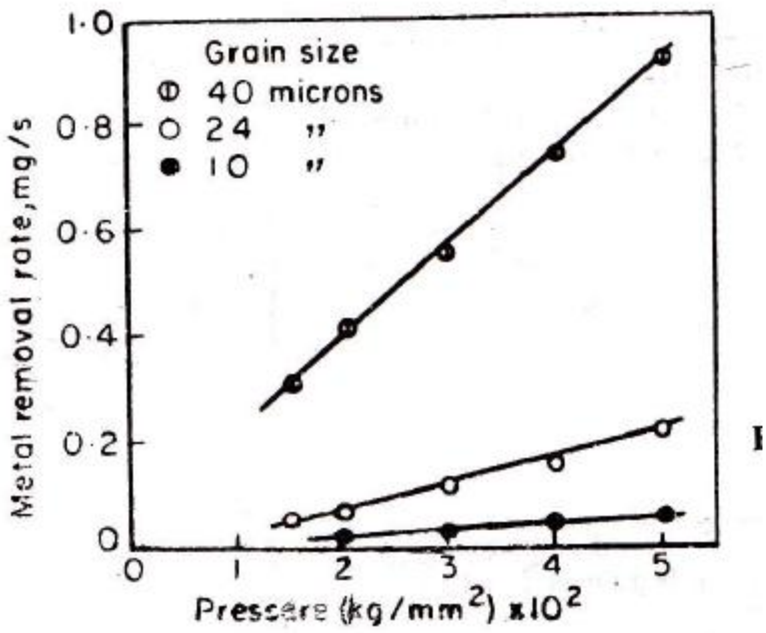
AJM is recommended for hard and brittle materials

Stand off distance

It is the distance between the face of the nozzle and the working surface

A large SOD results in flaring up of the jet and hence poor accuracy





Carrier gas

- Composition – Air, CO_2, N_2
- Density – Air ~ 1.3 kg/m^3
- Velocity – 500 ~ 700 m/s
- Pressure – 2 ~ 10 bar
- Flow rate – 5 ~ 30 lpm
- Must not flare when discharged
- Should be non toxic, cheap, capable of being dried and cleaned easily

Abrasive Jet

- Velocity – 100 ~ 300 m/s
- Mixing ratio – mass flow ratio of abrasive to gas –
- Stand-off distance – 0.5 ~ 10 mm
- The kinetic energy of the abrasive jet is used for material removal
- For the erosion of glass by silicon carbide the minimum jet velocity has been found to be 150m/s
- Impingement Angle – 60^0 ~ 90^0

Mean number of abrasive grains per volume of the carrier gas volume flow rate of the abrasive per unit time volume flow rate of the carrier gas per unit time

Large value of M results in higher MRR, but at very high values, particles clog at the nozzle

Process characteristics

The important machining characteristics in AJM are

- The material removal rate (MRR) mm^3/min or gm/min
- The machining accuracy and surface finish

MRR

- The typical MRR for AJM is 16 mm^3/min in cutting glass

Process characteristics

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MRR

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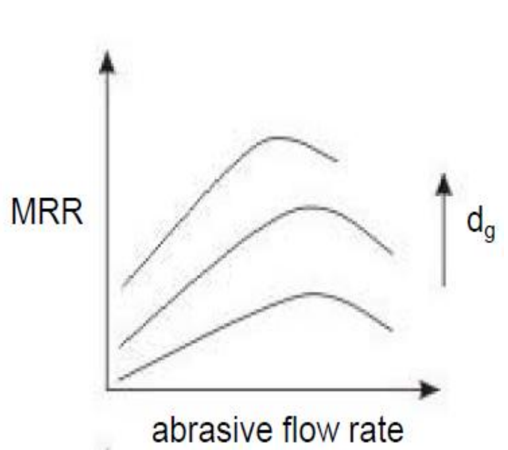
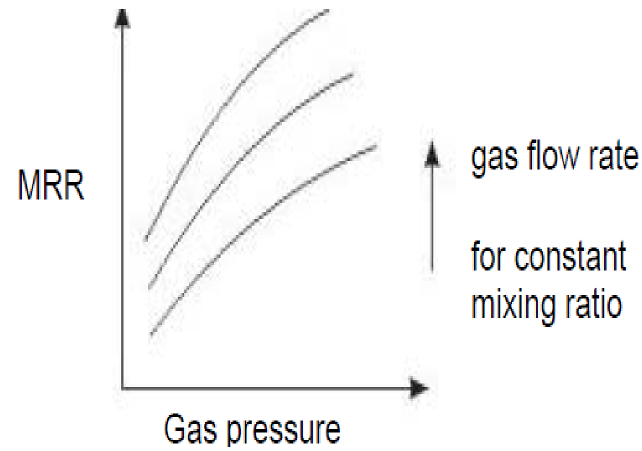
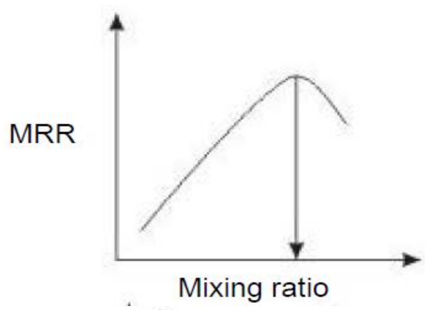
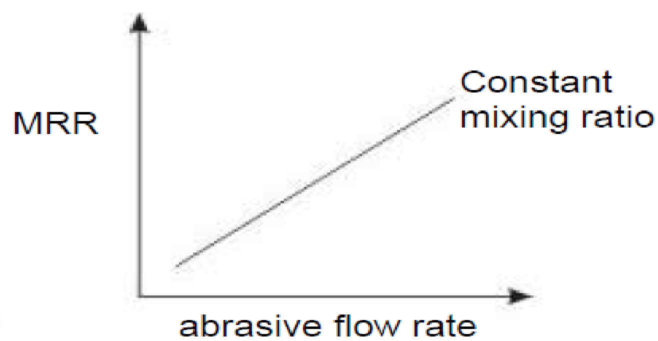
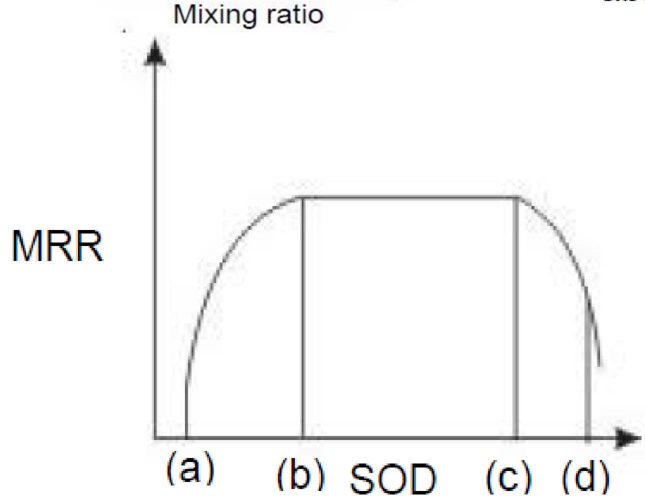
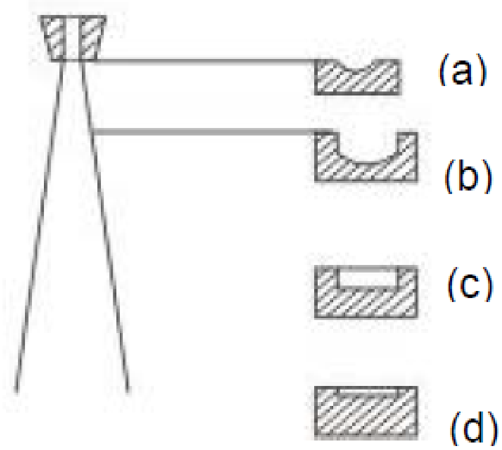












Accuracy and surface finish

With close control of all parameters, a tolerance in the range of +/- 0.05 mm can be obtained

Average particle size in µm	Surface roughness in µm
10	0.15 to 0.2
25	0.4 to 0.8
50	1.0 to 1.5

Advantages

- Ability to cut intricate shape hole in materials of hardness and brittleness
- Ability to cut fragile and heat sensitive materials without damage
- Low capital cost

Limitations

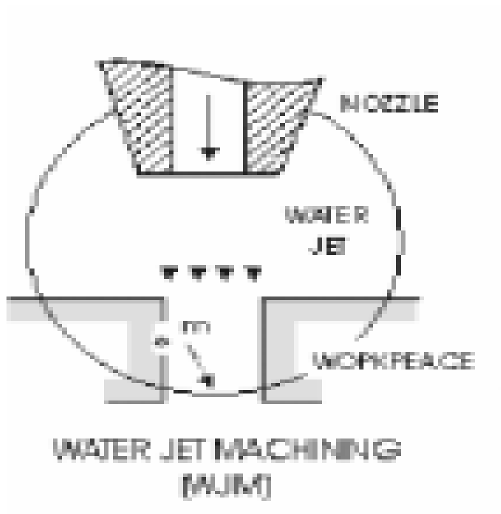
- MRR is rather low (around ~ 15 mm^3/min for machining glass)
- Abrasive particles tend to get embedded particularly if the work material is ductile
- Tapering occurs due to flaring of the jet
- Environmental load is rather high.
- Low accuracy

Applications

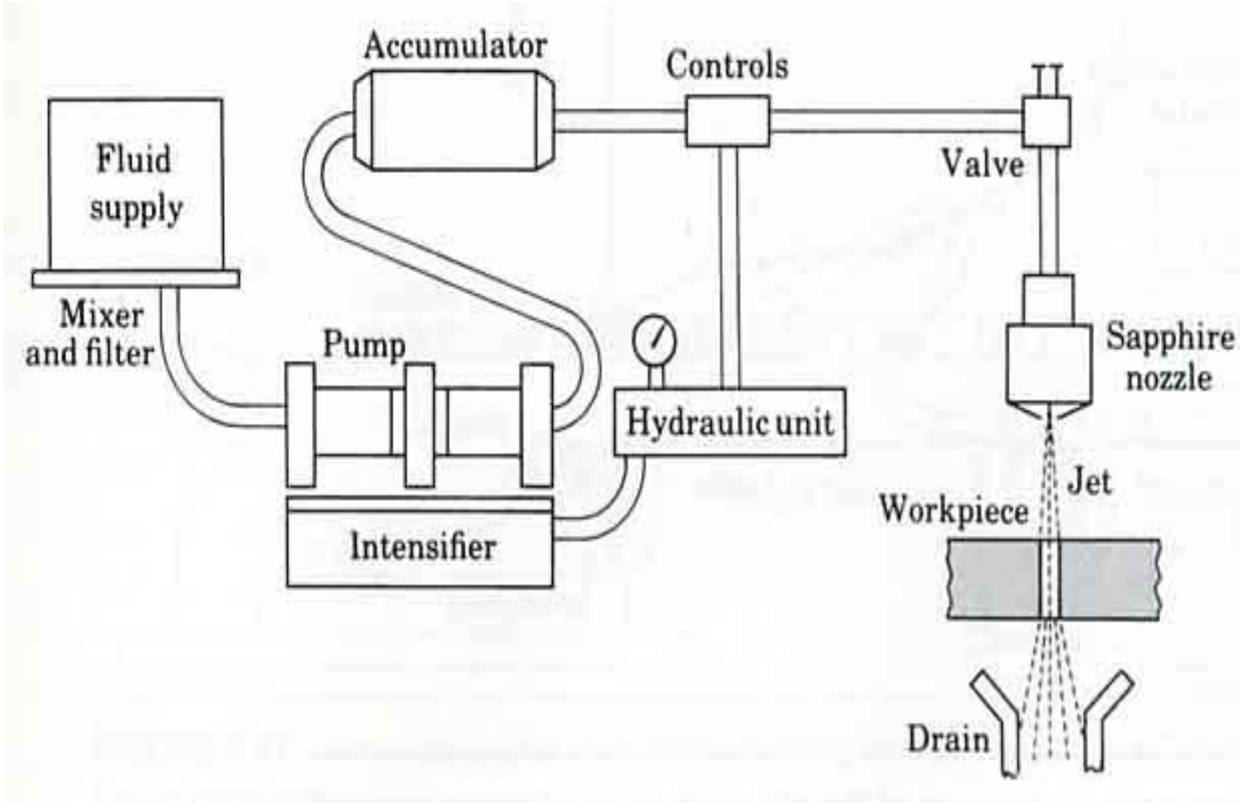
- For drilling holes of intricate shapes in hard and brittle materials
- For machining fragile, brittle and heat sensitive materials
- AJM can be used for drilling, cutting, deburring, cleaning and etching.
  Micro-machining of brittle materials

Water jet machining (WJM)

Water Jet Machining (WJM) and Abrasive Water Jet Machining (AWJM) are two non-traditional ornon-conventional machining processes. They belong to mechanical group of non-conventional processes like Ultrasonic Machining (USM) and Abrasive Jet Machining (AJM). In these processes (WJM and AJWM), the mechanical energy of water and abrasive phases are used to achieve material removal or machining.



- In pure WJM, commercially pure water (tap water) is used for machining purpose. However as the high velocity water jet is discharged from the orifice, the jet tends to entrain atmospheric air and flares out decreasing its cutting ability.
- Hence, quite often stabilizers (long chain polymers) that hinder the fragmentation of water jet are added to the water.
- Very thin stream (0.004-0.010 dia)
- Very little material loss due to cutting
- Can cut thick, soft, light materials like fiberglass insulation up to 24” thick or thin fragile materials
- The cutting ability of water jet machining can be improved drastically by adding hard and sharp abrasive particles into the water jet.
- Thus, WJM is typically used to cut so called “softer” and “easy-to-machine” materials like thin sheets and foils, non-ferrous metallic alloys, wood, textiles, honeycomb, polymers, frozen meat, leather etc,
- The domain of “harder and “difficult-to-machine” materials like thick plates of steels, aluminium and other commercial materials, metal matrix and ceramic matrix composites, reinforced plastics, layered composites etc. are reserved for AWJM.



- Water jet acts like a saw and cuts a narrow groove in the material.
- Pressure level of the jet is about 400MPa.
- Water inlet pressure between 20k-60k psi
- Forced through hole in jewel 0.007-0.020" dia
- Sapphires, Rubies with 50-100 hour life
- Diamond with 800-2,000 hour life, but they are priced high
- The variables that affect machining are velocity of the jet, diameter of the nozzle, pressure of the jet, and work piece material.
- **Advantages**
  - no heat produced
  - cut can be started anywhere without the need for predrilled holes
  - burr produced is minimum
  - environmentally safe and friendly manufacturing.
- **Limitations**
  - not used for high rate machining
  - a limited number of materials can be cut economically.
  - very thick parts can not be cut with water jet cutting and still hold dimensional accuracy

Application	Materials
• Paint removal	Steels
• Cleaning	Non-ferrous alloys
• Cutting soft materials	Ti alloys, Ni- alloys
• Cutting frozen meat	Polymers
• Textile, Leather industry	Honeycombs
• Mass Immunization	Metal Matrix Composite
• Surgery	Ceramic Matrix Composite
• Peening	Concrete

- Cutting
- Pocket Milling
- Drilling
- Turning
- Nuclear Plant Dismantling

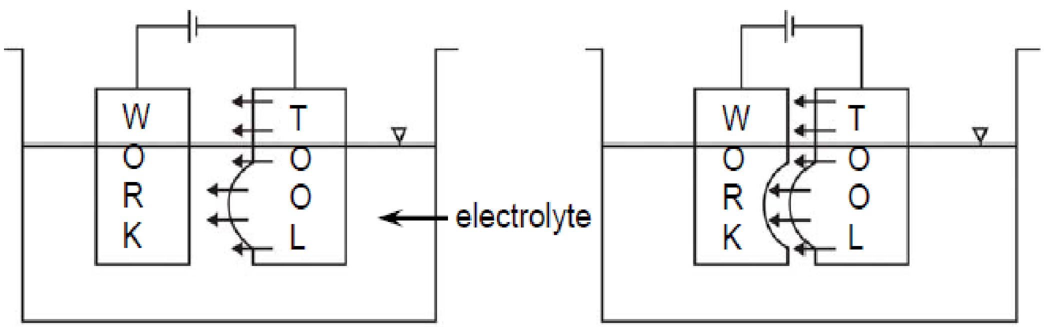
Stone – Granite
Wood
Reinforced plastics
Metal Polymer Laminates
Glass Fiber Metal Laminates

UNIT 4

Electrochemical machining (ECM)

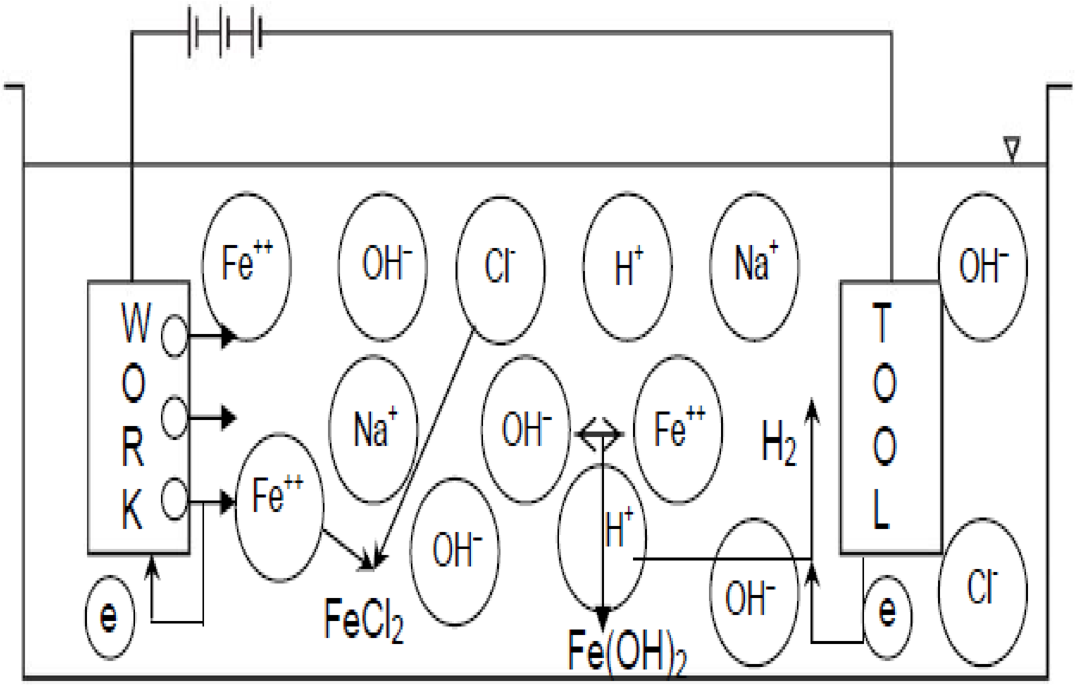
INTRODUCTION

- Electrochemical Machining (ECM) is a non-traditional machining (NTM) process belonging to Electrochemical category.
- ECM is opposite of electrochemical or galvanic coating or deposition process.
  Uses an electrolyte and electrical current to ionize and remove metal atoms
- Thus ECM can be thought of a controlled anodic dissolution at atomic level of the work piece that is electrically conductive by a shaped tool due to flow of high current at relatively low potential difference (20V) through an electrolyte which is water based neutral salt solution.
- Can machine complex cavities in high-strength materials.
- Leaves a burr-free surface.
- Not affected by the strength, hardness or toughness of the material



- During ECM, there will be reactions occurring at the electrodes i.e. at the anode or workpiece and at the cathode or the tool along with within the electrolyte.
- Let us take an example of machining of low carbon steel which is primarily a ferrous alloy mainly containing iron.
- For electrochemical machining of steel, generally a neutral salt solution of sodium chloride (NaCl) is taken as the electrolyte.
- The electrolyte and water undergoes ionic dissociation as shown below as potential difference is applied
- $NaCl \leftrightarrow Na^+ + Cl^-$
- $H_2O \leftrightarrow H^+ + (OH)^-$
- As the potential difference is applied between the work piece (anode) and the tool (cathode), the positive ions move towards the tool and negative ions move towards the workpiece.
- Thus the hydrogen ions will take away electrons from the cathode (tool) and form hydrogen gas as:
- $2H^+ + 2e^- = H_2\uparrow$ at cathode
- Similarly, the iron atoms will come 2of the anode (work piece) as:
- $Fe = Fe^{++} + 2e^-$
- Within the electrolyte iron ions would combine with chloride ions to form iron chloride ($FeCl_2$) and similarly sodium ions would combine with hydroxyl ions to form sodium hydroxide
- $Na^+ + OH^- = NaOH$
- In practice $FeCl_2$ and $Fe(OH)_2$ would form and get precipitated in the form of sludge.

- In this manner the work piece gets gradually machined and gets precipitated as the sludge.
- Moreover there is no coating on the tool, only hydrogen gas evolves at the tool or cathode.
- As the material removal takes place due to atomic level dissociation, the machined surface is of excellent surface finish and stress free.



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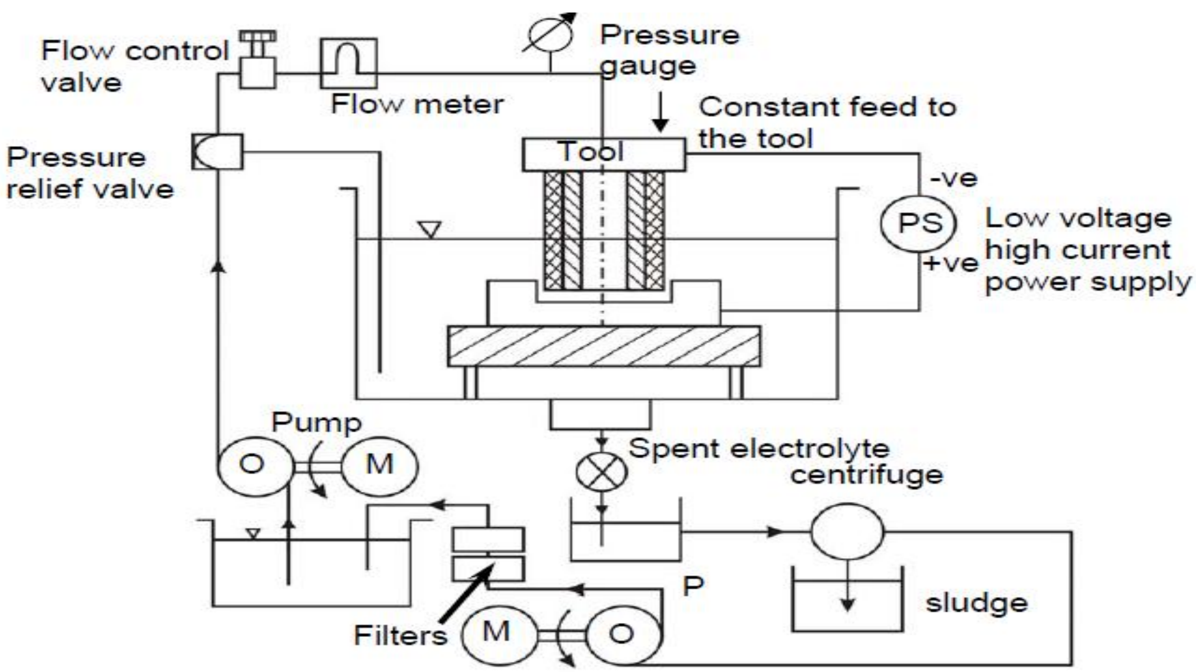
Equipment



- Electric current is in the order of 1000 to 40000 A, at 5 – 30V dc, across a gap of 0.05 – 0.7 mm between tool and workpiece.
- The usual MRR at 10000 A is around 16 cm^3 per min. (As the current increases the amount of electrolyte needed to cool, flush the sludge and inhibit the reaction increases)
- The machine should have the following characteristics

1. Rigidity – should resist hydrostatic and hydrodynamic forces
2. Steady feed drive – should be free of stick –slip motion
3. Accessible work tank – the work area should be accessible for loading and unloading of workpiece, a corrosion resistant enclosure to prevent splashing of electrolyte, a vent system for exhausting fumes.
4. Corrosion resistance

Elements

The electrochemical machining system has the following modules:

- Cathode tool and anode work piece
- Power supply
- Electrolyte filtration and delivery system
- Tool feed system
- Working tank

Cathode tool and anode work piece

The accuracy and surface finish of the tool affects the accuracy of the workpiece.

In ECM, aluminium, brass, bronze, copper, stainless steel are used for tools.

There is no restriction for work piece, but it has to be a good conductor of electricity.

The removal rate is proportional to the atomic weight and inverse of the valency of the material. The material is

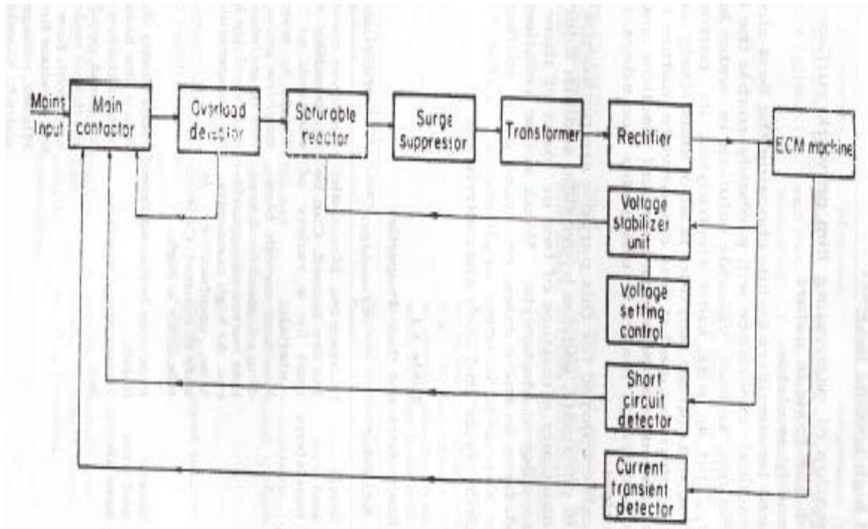
held by an insulator like PVC which has high thermal stability and low moisture absorption properties.

Power supply

The process needs low voltage (2 to 20 V) and high current (800A/cm^2) conditions.

A step down transformer with a rectifier is used to maintain a constant d.c. output at a preset voltage.

Proper care has to be taken to avoid sparking that may damage both tool and workpiece.



Electrolytes

- The electrolyte has four main functions

1. Carries the current from tool to work piece to complete the circuit
2. To allow the desirable reactions to start the machining process.
3. Removes machined parts
4. Dissipates heat

- The electrolyte must be injected in the gap at high speed (between 1500 to 3000 m/min).
- The inlet pressure must be between 0.15-3 MPa.
- The electrolyte system must include a fairly strong pump.
- System also includes a filter, sludge removal system, and treatment units.
- The electrolyte is stored in a tank

It should have following properties:

The electrolyte should have high electrical conductivity, low toxicity, chemical and electrochemical stability, low viscosity and high specific heat and passivating effects. Sodium chloride is the most common electrolyte As sodium chloride is corrosive, titanium, aluminium and copper alloys are machined with sodium nitrate as electrolyte. sodium hydroxide is used for tungsten or molybdenum alloys as they retain the removed metals and hence require less filtering, but has to be chemically controlled as the composition of the electrolyte changes Since electrolyte has to be pumped at a high velocity, single or multi stage centrifugal pumps having a minimum flow rate of 15lts/min are used Filtration of electrolyte is very essential to avoid interference of machined particles during the process. A wire mesh of one third the operating gap is usually used – 75 µm, which need cleaning every 30 hrs.

Electrolytes and their Properties

S. No.	Electrolyte	Material	Advantages	Disadvantages
(i)	NaCl or KCl upto 0.25 kg/litre.	Steels and iron base alloys	Inexpensive. Non-toxic. No fire hazard. Can be used for a variety of materials. Produces smooth blending of machined area into surrounding surfaces. At high concentration, conductivity is easy to control. Current efficiency is high.	Removes material from surrounding finished surfaces. Tends to selectively machine grain boundaries of stainless steels. Conductivity is affected by temperature.
(ii)	$NaNO_3$ upto 0.5 kg/litre.	Steels and iron base alloys.	Produces better surface finish. Lesser stray machining.	More costly than NaCl. It is a fire hazard. High concentration is required for good conductivity. Electrical resistivity can vary with flow velocity to produce flow lines. Higher voltages are required. Conductivity is affected by temperature.

S. No.	Electrolyte	Material	Advantages	Disadvantages
(iii)	$NaClO_3$ 0.2 to 0.5 kg/litre.	Steel and iron base alloys.	Produces very smooth bright surface which is resistant to subsequent corrosion. Conductivity relatively unaffected by temperature. No stray machining or pitting of adjacent surfaces. Applicable for precise machining.	High cost. Toxic. High fire risk if allowed to dry on combustible materials. Requires special handling and storage. Low current efficiency at lower concentration. High voltages (about 20 V) are required for best results. No machining at <9 V.
(iv)	NaCl+0.01 kg/litre citric acid.	Steel and iron base alloys.	Citric acid prevents formation of metal hydroxide precipitates. Suitable for operation at very small gap sizes for definition of intricate work shapes. Lower electrolyte pressures may be employed, e.g. in the operation of slender electrodes as used in deep hole drilling.	Very expensive if used for other than small intricate parts. Electrolyte must be changed frequently.

(v)	NaCl upto 0.20 kg/litre or $NaNO_3$ upto 0.5 kg/litre.	Grey cast iron.	Produces good surface finish.	Large machining gap sizes must be used (0.50-0.80 mm) to allow graphite particles to be swept clear.
(vi)	NaCl upto 0.1 kg/litre+ $NaNO_3$ 0.1 kg/litre.	Nickel and cobalt-base alloys.	Inexpensive mixture. Produces good surface finish.	Produces flow lines on work surface. Machined surface carries lightly adherent grey smut.
(vii)	$NaNO_3$ upto 0.5 kg/litre.	Nickel and cabalt-base alloys.	Produces good surface finish.	Disadvantages same as (vi) electrolyte. Costlier than (vi) electrolyte. It is a fire hazard. Needs higher operating voltage.
(vii)	NaCl upto 0.25 kg/litre.	Nickel and cabalt-base alloys.	Produces smooth surfaces. Surfaces need no after cleaning.	Intergranular corrosion which drastically lowers the fatigue endurance of components machined with this electrolyte. Danger of pitting

High concentration of the electrolyte offers low resistance to the flow of current, however for better surface finish, dilute electrolyte is used.

The composition of the electrolyte changes during use which are listed below.

1. Loss of hydrogen that reduces the electrical conductivity.
2. Loss of water due to evaporation that results in increased viscosity
3. Precipitate formation that absorbs the salt and thereby affects conductivity.

The difference of temperature at the entry and exit of the tool-work gap is very important.

If the temperature is above $45^{o}C$ then the specific resistance decreases that affects the flow characteristics.

However at high temperatures the reaction is speeded up.

Process characteristics

- **Material removal rate**

MRR depends chiefly on feed rates, which determines the current that passes between work and the tool.

As the tool approaches work, the length of the conductive current path decreases, and magnitude of the current increases.

A stable cut is established, when the current is just sufficient to remove the metal at a rate corresponding to the rate of tool advance.

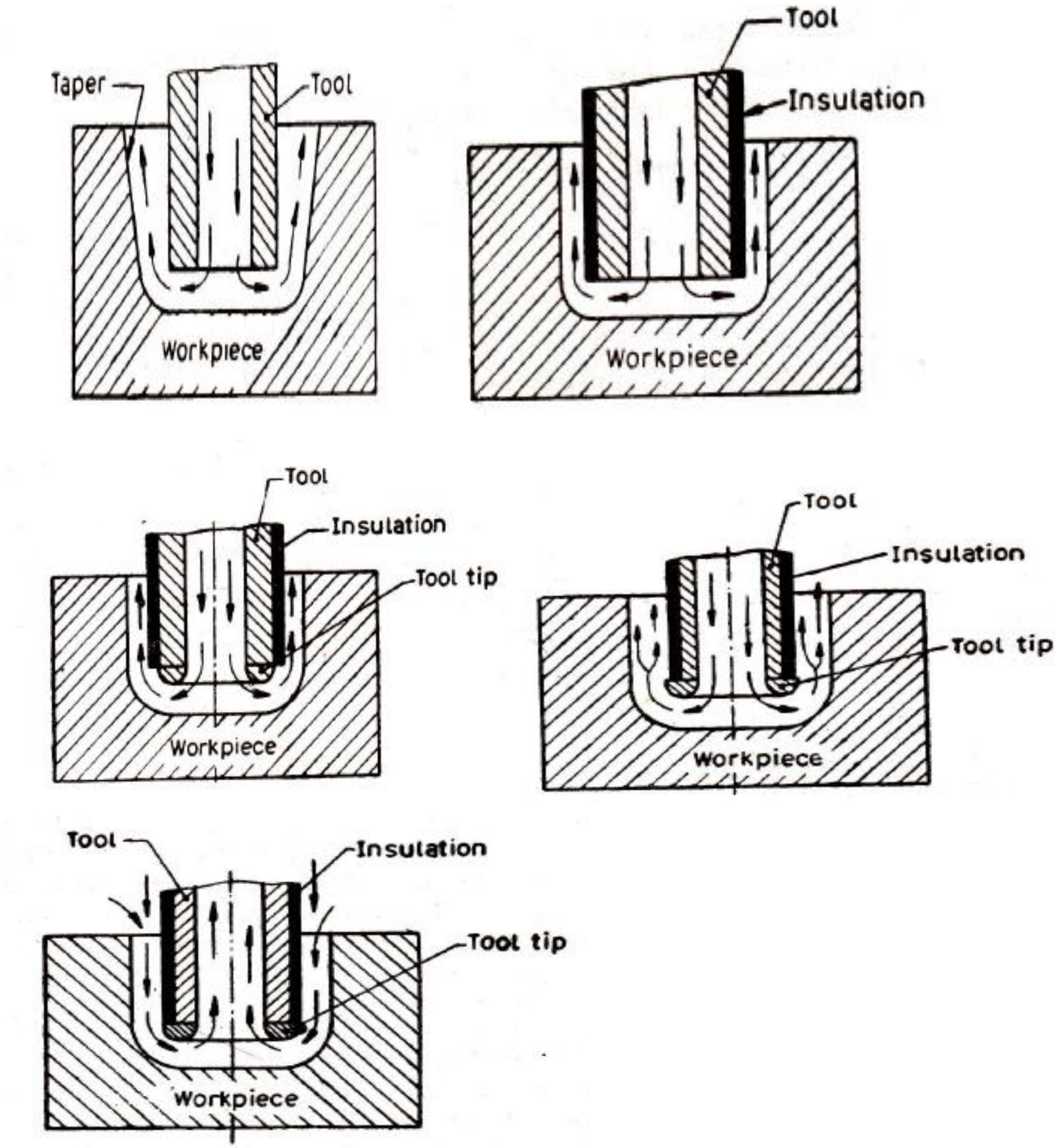
A proper control has to be provided to maintain the fixed spacing to facilitate highest MRR.

Accuracy and surface finish

The following factors govern the accuracy and surface finish

a. Machining voltage – the voltage variation changes the surface texture as higher voltage makes more overcut and vice versa
b. Feed rate of the tool – this also has the same effect as that of the voltage
c. Temperature of the electrolyte
d. Concentration of the electrolyte

ECM tooling techniques



First figure is a simple round tool, due to sharp edge and no insulation, the tapering effect will be more as the complete surface area of the hole produced is being machined

In the next figure the tool is insulated at the sides due to which the tapering effect is reduced. But as the tool has sharp edges, the electrolyte will become turbulent and affects tolerance and accuracy

- The next figure the edges are rounded to allow uniform flow of the electrolyte around the corner, also the tip is brazed to shank for easy replacement
- Next figure has an overlap of the tip that helps the electrolyte flow to break up as it passes around the corner. This avoids any additional machining by the electrolyte on already machined surfaces.
- The last sketch has an arrangement for flow of electrolyte from outside through inside. This is as opposed to divergent flow known as convergent flow. This produces minimum taper and excellent finish of the surface.

Tool and insulation materials

- Any electrically conductive material can be used as tool, but stainless steel and brass are preferred due to corrosive action of the electrolyte.

Properties	Copper	Brass	SS	Titanium	copper
Resistivity	1	4	53	48	8
Stiffness	1.6	1	1.9	1.1	2.2
Machinability	6	8	2.5	1	1.8
Thermal conductivity	25	7.5	1	2.6	10

- For insulation most commonly used materials are porcelain, vinyl, phenolic enamel, teflon, and epoxy.
- These are applied to electrode by dipping or spraying.
- While applying insulation care should be taken to avoid insulator being hit directly from the electrolyte flow.

Tool size

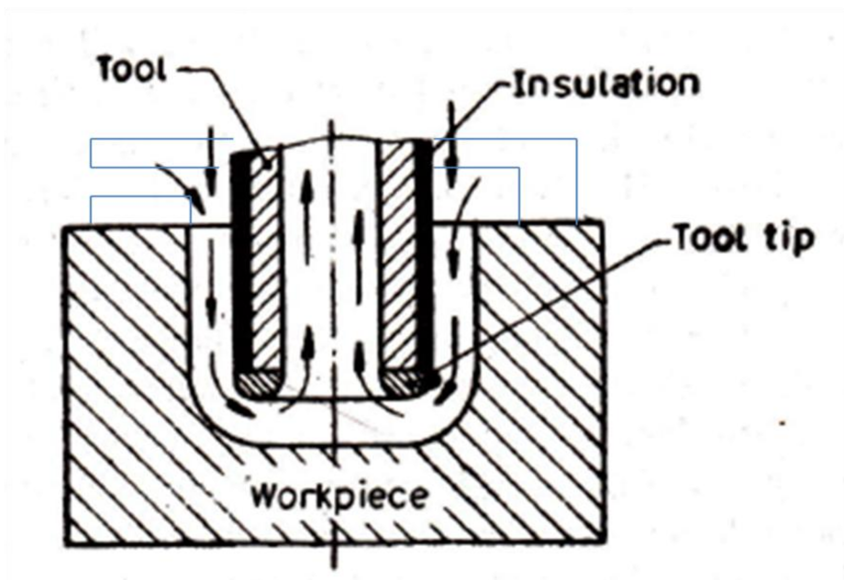
The size of the tool is exactly the mirror image of the part to be produced but with some overcut.

Overcut ranges from 0.025 to 0.5 mm

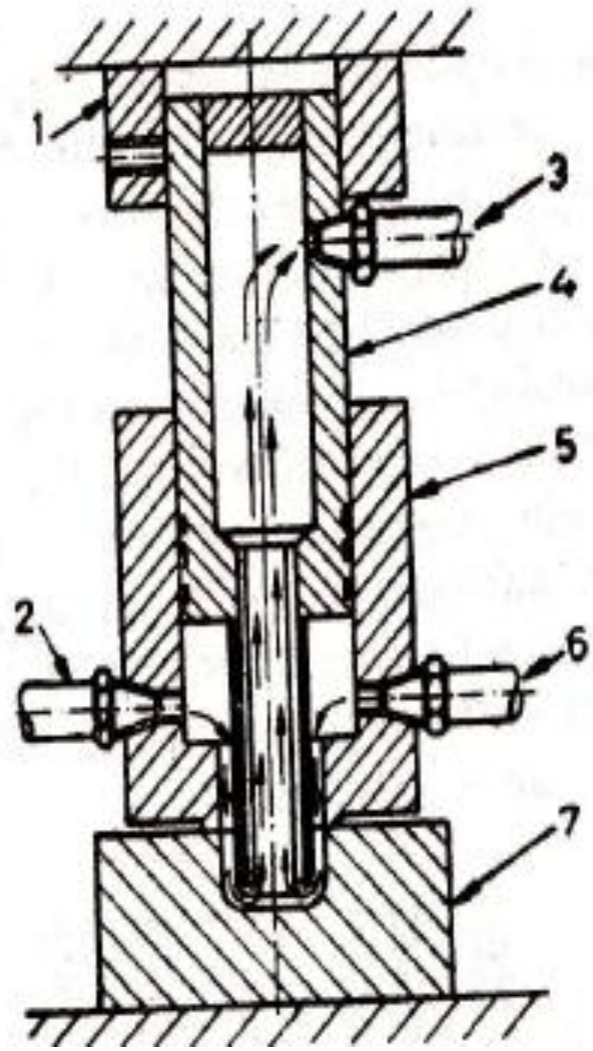
Electrolyte flow arrangement

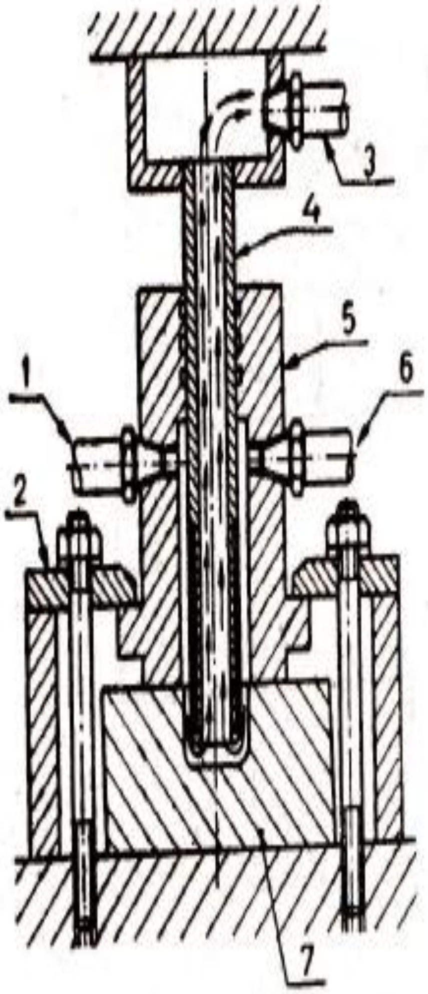
The advantage of this system are:

- More uniform and predictable side overcut and front machinable gap
- Improved surface finish
- Reduced possibility of arcing
- Cleaner operating conditions
- Elimination of undesirable machining due to stray current



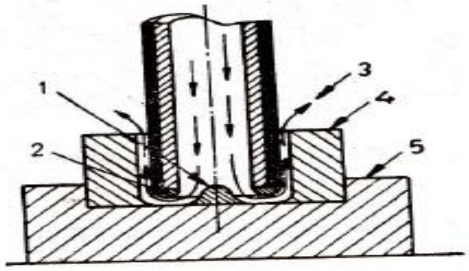
First figure indicates convergent flow with clamping while the second is without clamping

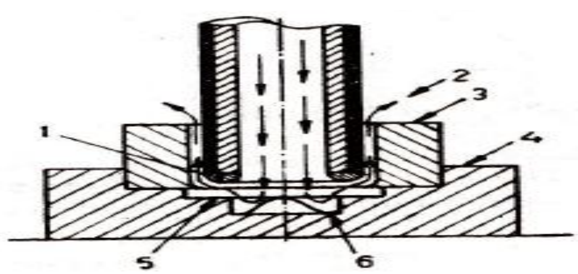




Handling of slugs

- While machining through holes, a slug of material is formed below the hole that may move anywhere causing short circuit or damage the tool. This can be overcome by providing a clearance as shown





Economics of ECM

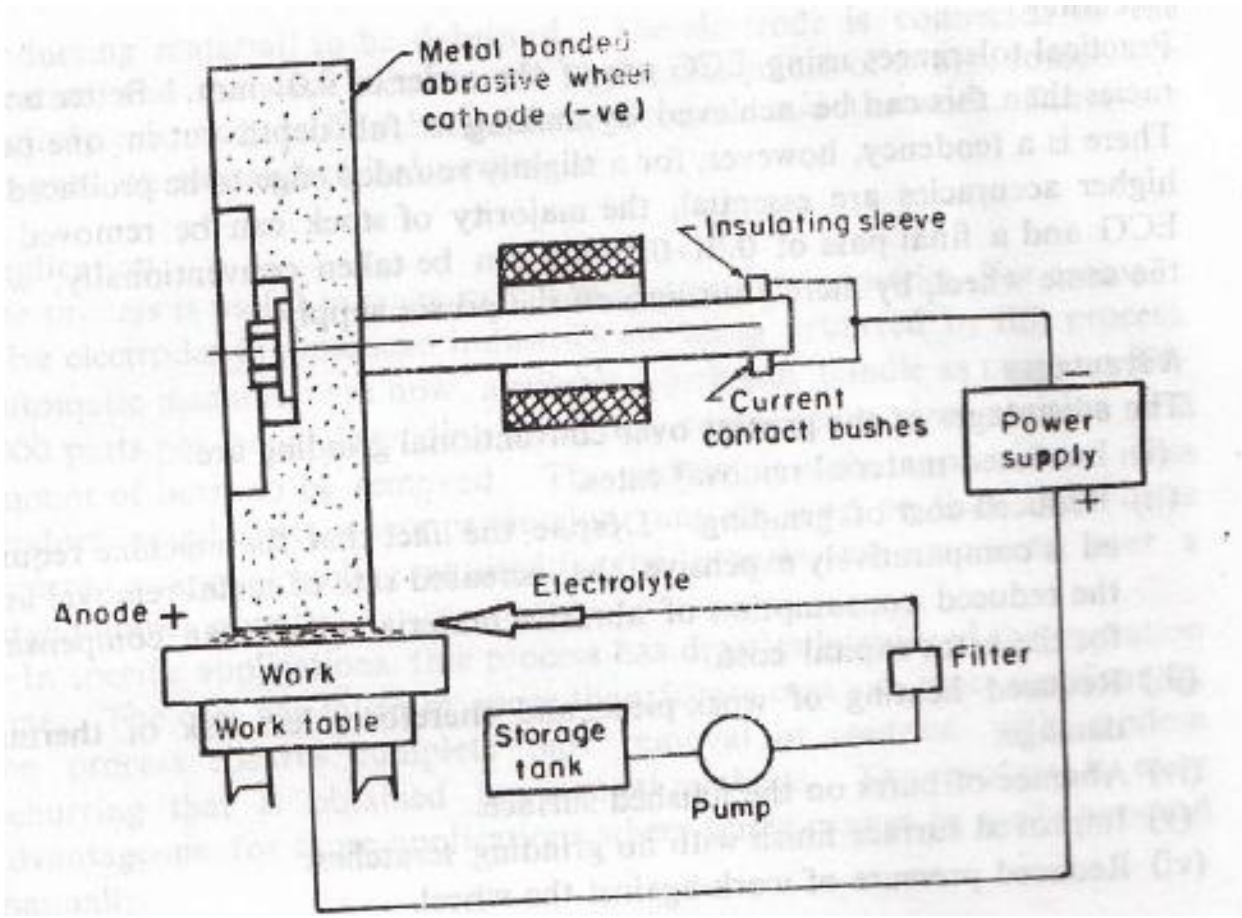
- Fixed costs for ECM are very high as compared to operating costs
- Overhead costs are as same that of any other NTM processes
- The economic choice of the ECM process depends on the choice of the application.
- The process is economical when a large number of complex identical products need to be made (at least 50 units)
- Several tools could be connected to a cassette to make many cavities simultaneously. (i.e. cylinder cavities in engines)
- Large cavities are more economical on ECM and can be processed in 1/10 the time of EDM.

Applications

ECM is used for

- Die sinking
- Profiling and contouring
- Trepanning
- Grinding
- Drilling
- Micro-machining
- The most common application of ECM is high accuracy duplication. Because there is no tool wear, it can be used repeatedly with a high degree of accuracy.
- The two most common products of ECM are turbine / compressor blades and rifle barrels.

Electrochemical grinding



The work piece is in contact with the bed of the machine forming an electrolytic cell.

The work piece is anode and the grinding wheel is the cathode.

The insulating abrasive particles protrude evenly above the wheel surface

When the work is pressed against the wheel, the protrusion of the particles determines the gap between the electrodes. Here the electrolysis takes place.

The MRR is in the order of $1cm^3$/min/100A with an average of $0.5cm^3$/min/100A

With ECG an accuracy of 0.01 to 0.1mm can be obtained.

A surface finish up to 0.4 to 0.6 microns can easily be obtained.

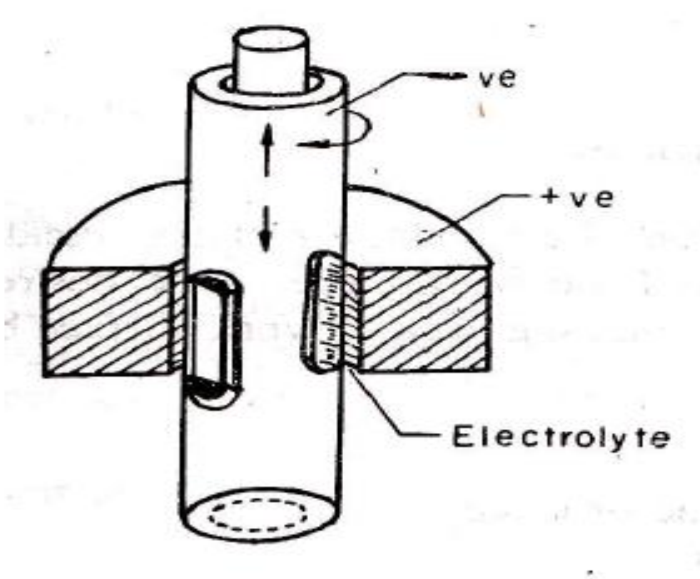
Advantages of ECG over conventional ECG are:

1. Increased MRR
2. Reduced cost of grinding
3. As heat generated is less, less risk of thermal damage
4. Absence of burrs on the finished surfaces and hence better surface finish

Applications

1. For grinding carbide cutting tools
2. For fragile parts such as honey combs, needles, thin walled tubes and any part made with heat sensitive materials

Electrochemical honing



The process consists of a rotating and vibrating tool inside the cylindrical components.

The electrolyte is fed under pressure to ensure the flow of electrolyte is uniform at every point.

The gap between the tool and the workpiece is adjusted by employing an expandable tool.

The accuracy of the process is in the order of 0.01 mm on the diameter

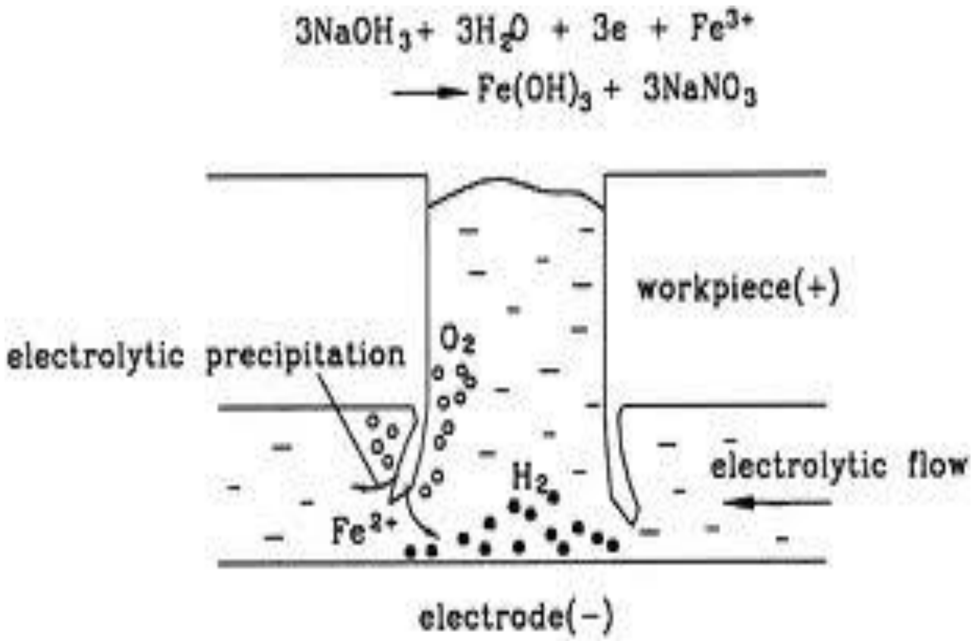
The surface roughness is obtained in the range of 0.1 to 0.5 microns.

For rough surfaces, the process is switched off after few seconds of work.

The advantages of ECH are as same that of ECG.

The applications of the process are exclusively for trueing inside surfaces of the cylinder.

Electrochemical deburring



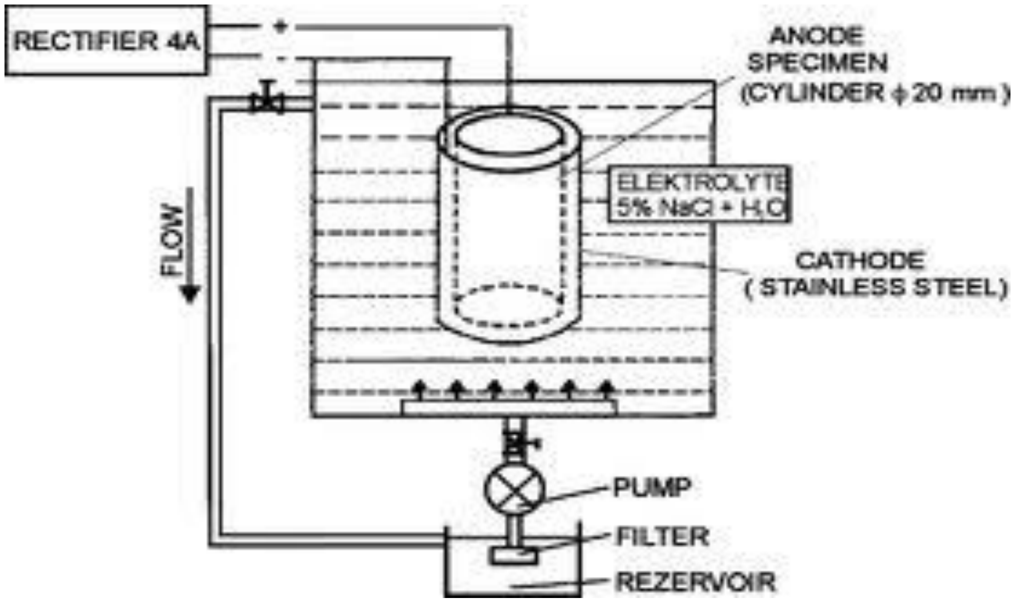
This process is used to remove the burrs after machining. The machined part is kept in the electrolyte bath and normal ECM process is used.

The tool is positioned near the base of the burr.

Due to electrolysis the burrs are removed without affecting the machined surface.

This is most suitable for deburring connecting rods, gear teeth, valve ports, etc.

Electrochemical turning



- In this process the job is kept at the center of the tool. The tool is cylindrical that covers the job.
- The whole setup is kept inside the electrolyte bath as shown.

Advantages of ECM

- There is no cutting forces therefore clamping is not required except for controlled motion of the work piece.
- There is no heat affected zone.
- Very accurate.
- Relatively fast
- Can machine harder metals than the tool.

When compared to ECD the advantages are

- Faster than EDM
- No tool wear at all.
- No heat affected zone.
- Better finish and accuracy

Limitations

- More expensive than conventional machining.

- Need more area for installation.
- Electrolytes may destroy the equipment.
- Not environmentally friendly (sludge and other waste)
- High energy consumption.
- Material has to be electrically conductive.

UNIT 5

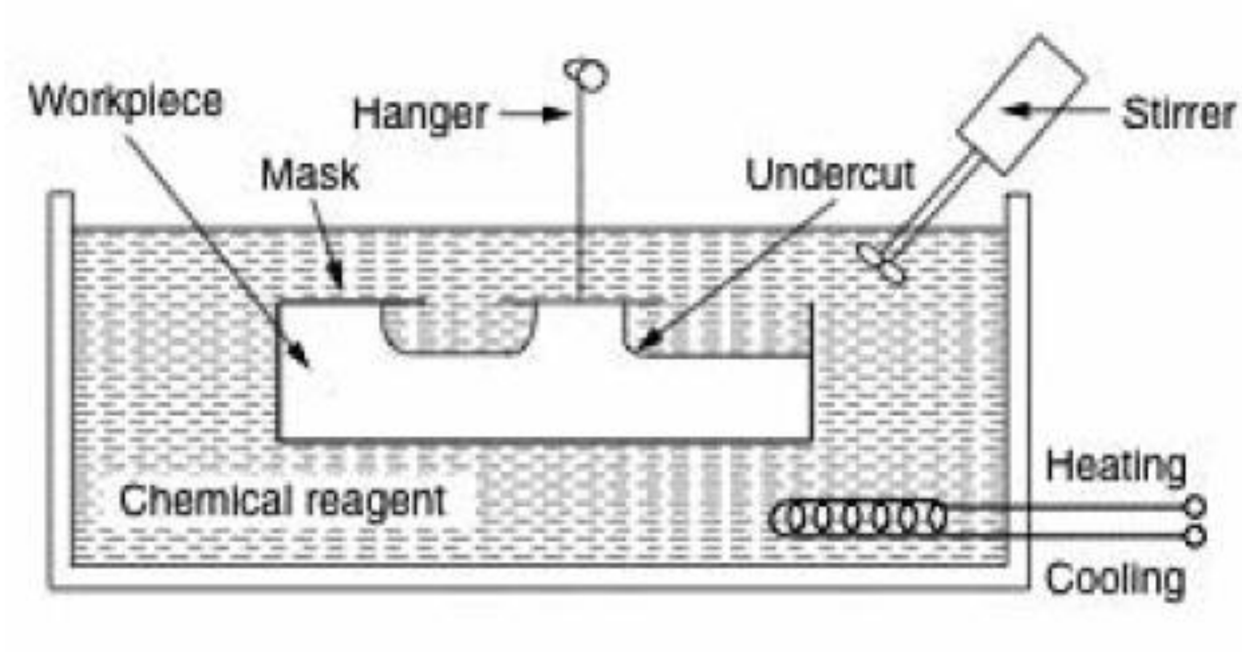
Chemical machining (CM)

INTRODUCTION

- It is observed that chemicals and acids attack the material if contacted and thereby remove small amount of material.
- This is the basic idea behind developing the Chemical Machining process
- Chemical machining (CHM) is a well known nontraditional machining process
- It is the controlled chemical dissolution of the machined workpiece material by contact with a strong acidic or alkaline chemical reagent.
- Chemical machining method may be the oldest nontraditional machining method which is used to shape copper with citric acid in the Ancient Egypt in 2300 BC

Steps of CHM

- Workpiece preparation: The workpiece material has to be cleaned in the beginning of chemical machining process. The cleaning operation is carried out to remove the oil, grease, dust, rust or any substance from the surface of material.
- The most widely used cleaning process is chemical method due to less damages occurred comparing to mechanical.
- Coating with masking material: The next step is the coating cleaned workpiece material with masking material. The selected masking material should be readily strippable mask, which is chemically impregnable and adherent enough to stand chemical abrasion during etching.
- Etching: This step is the most important stage to produce the required component from the sheet material. The workpiece material is immersed into selected etchant to machine the uncovered areas.
- Cleaning masking material: Final step is to remove masking material from etched part.



Elements of the process

Basically there are two elements of the process

1. Resists or Maskant
2. Etchants

Maskant

- Masking material which is called maskant is used to protect workpiece surface from chemical etchant.
- Polymer or rubber based materials are generally used for masking procedure.
- Multiple maskant coatings are used to provide a higher etchant resistance. Long exposure time is needed when thicker and rougher dip or spray coatings are used.
- Various maskant application methods can be used such as dip, brush, spray, roller, and electro-coating as well as adhesive tapes.
- The selected maskant material should have following properties.

  1. Tough enough to withstand handling

  2. Well adhering to the work piece surface

  3. Easy scribing

  4. Inert to the chemical reagent used

5. Able to withstand the heat used during chemical machining

6. Easy and inexpensive removal after chemical machining etching

- When higher machined part dimensional accuracy is needed, spraying the mask on the workpiece through silk screen would provide a better result.
- Thin maskant coating would cause severe problems such as not withstanding rough handling or long exposure times to the etchant.
- The application of photo-resist masks which are generally used in photochemical machining operation, produce high accuracy, ease of repetition for multiple part etching, and ease of modification.

Possible maskant materials for different workpiece materials

Workpiece material	Masking material
Aluminium and alloys	Polymer, Butyl rubber, neoprene
Iron based alloys	Polymer, Polyvinyl chloride, Polyetilien butyl rubber
Nickel	Neoprene
Magnesium	Polymer
Copper and alloys	Polymer
Titanium	Polymer
Silicon	Polymer

Etchants

Etchants are the most influential factor in the chemical machining of any material.

- The best possible etchant should have properties as follows.

a. High etch rate

b. Good surface finish

c. Minimum undercut

d. Compatibility with commonly used maskants

e. High dissolved-material capacity

f. Economic regeneration

g. Etched material recovery

h. Easy control of process.

i. Personal safety and maintenance

Material	Chemical etchant	Concentration	Etching Temperature (°C)	Etch rate (mm/min)
Aluminium and alloys	$FeCl_3$	12-18 ^{0} Bé (*)	49	0.013-0.025
Copper and alloys	$FeCl_3$	42 ^{0} Bé	49	2.0
	$CuCl_2$	35 ^{0} Bé	54	1.0
	Alkaline etchants	---	50	---
Steel	$FeCl_3$	42 ^{0} Bé	54	0.025
Nickel	$FeCl_3$	42 ^{0} Bé	49	0.13-0.38
Titanium	HF	---	--	1.0
Magnesium	HNO_3	% 12-15	32-49	1.0
Glass	HF	---	---	---
	$HF+HNO_3$	---		
Silicon	HNO_3+HF+H_2O	---	38-49	Very slow

- **Factors to be considered while selecting the etchant are**

1. Material to be etched
2. Type of the maskant
3. Depth of etch
4. Surface finish required
5. MRR
6. Damage to the work material

Types of CHM

- Can be classified into:

  Chemical Milling

- Shallow cavities on sheets, plates, etc…
- Selective attack by chemicals on workpiece
- Used in aerospace industry
- Used to fabricate microelectronic devices

- **Chemical Blanking**

- Blanking of sheet metals
- Material removed by chemical dissolution
- Used to produce fine screens, flat springs, etc…
- Very cheap but efficient

Chemical blanking

Photosensitive masking is used to define the location on the workpiece at which the material is to be etched.

I. Preparation of workpiece – workpiece is cleaned and degreased

II. Preparation of the masters

Consists of artwork and negatives used to produce the acid resistant image

Produced at a size four times larger than the actual size and even can go up to 200 times.

This is then reduced photographically and multiple image masters are made

Masking with photo resist

- Photoresists are applied to the workpiece by dipping, whirl coating or spraying.

These are used for

1. Materials up to 0.8mm thick

2. High volume components

3. When the tolerance is tighter than +/-0.1 mm

- Dried at room temperature and baked at 110^{o}C for 15 minutes to remove the residual solvent.
- Exposed to UV light to increase its resistance to organic solvents.
- A vacuum printing frame is used for this purpose to expose both sides of the workpiece simultaneously.
- Next developing is done by immersing the workpiece in a suitable organic solvent then rinsed with water.

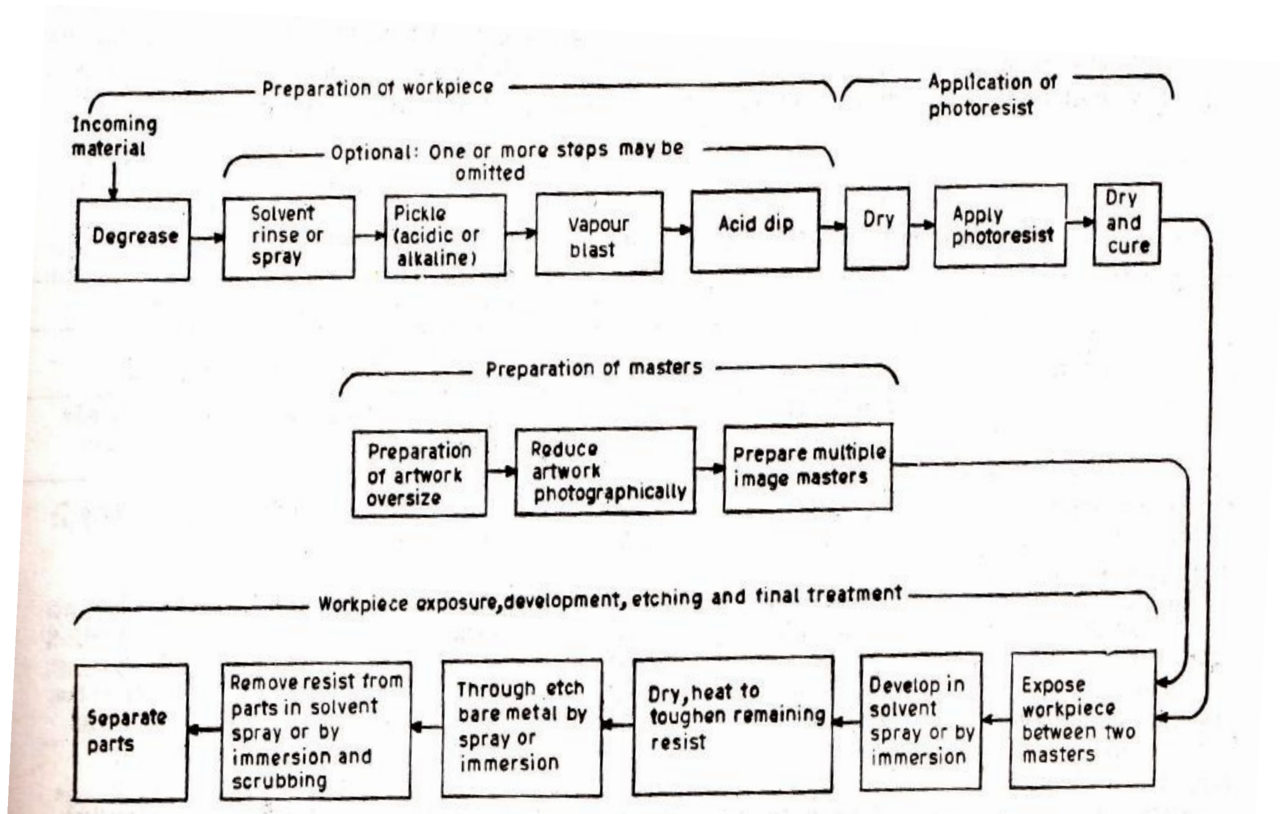


Fig. 14.71 Flow chart of principal process steps for chemical blanking

Now the photoresist is dried at room temperature and baked at 110^{o}C for 15 minutes to improve the hardness and chemical resistance of the photoresist.

Photoresists are classified into two groups: positive resists and negative resists.

- A *positive resist* is a type of photoresist in which the portion of the photoresist that is exposed to light becomes soluble to the photoresist developer (etchant). The portion of the photoresist that is unexposed remains insoluble to the photoresist developer.
- A *negative resist* is a type of photoresist in which the portion of the photoresist that is exposed to light becomes insoluble to the photoresist developer. The unexposed portion of the photoresist is dissolved by the photoresist developer.Ultra-Pro and Rapid-Mask are the common Photoresists Masking techniques other than photoresist are

a. Maskant can be applied over the whole area and with the help of a template, the maskant is peeled off in areas to be etched out

b. Masking material can be applied directly to the work by screening or offset printing

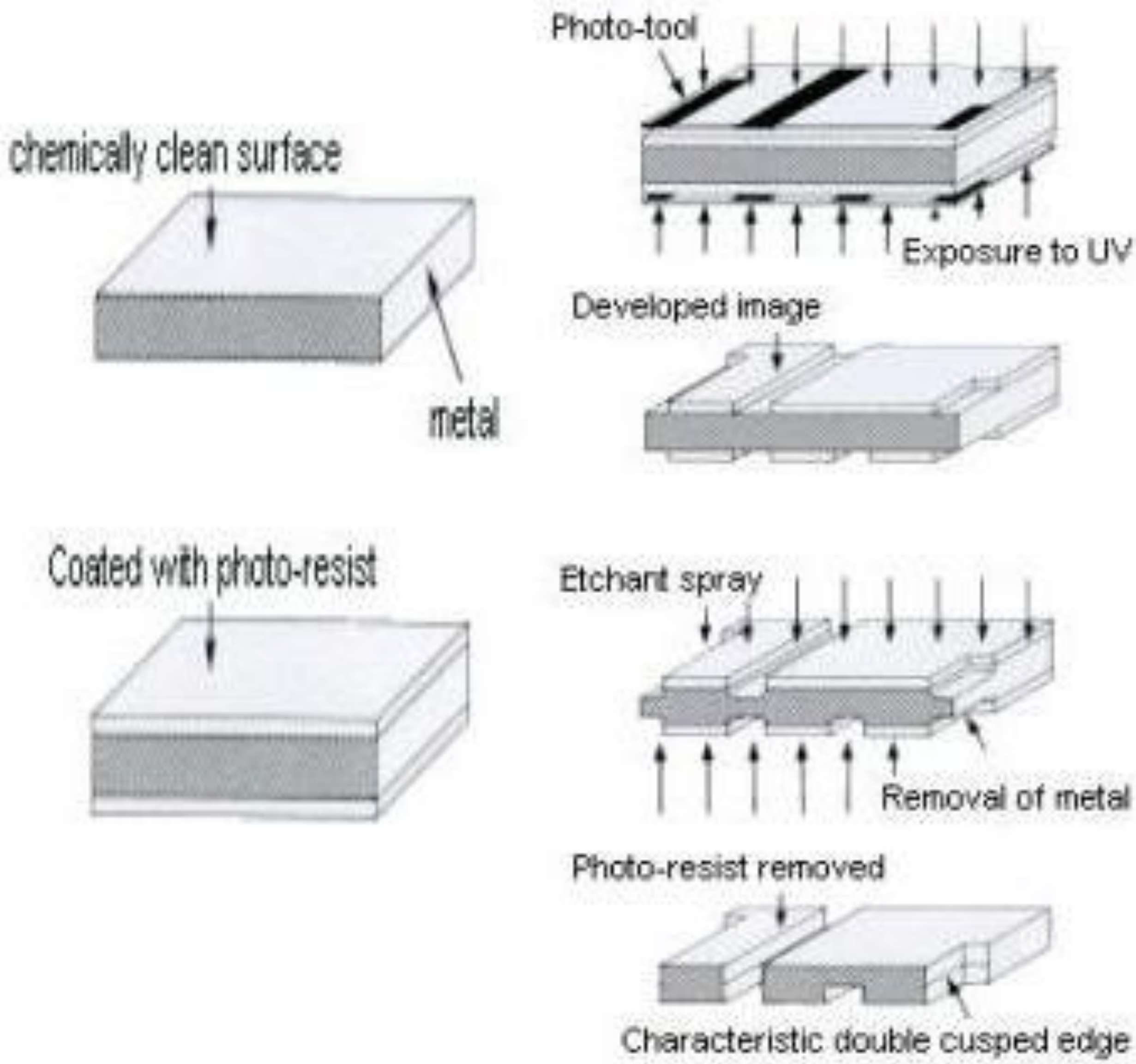
Screen printing is preferred when

1. Parts not larger than 1x1m

2. For flat or simple contours
3. Depth of etch does not exceed 1.5 mm

The selection of a resist depends on following factors

i. Chemical resistance required
ii. Number of parts to be produced
iii. Shape and size of the component
iv. Ease of removal
v. Etching for blanking
vi. The workpiece is immersed in etchant bath, agitated by air or mechanical means.
vii. The etchant converts the metal into metallic solvent that can be dissolved in the etchant.
viii. Normally Sodium Hydroxide or Ferric Chloride is used as etchants.


chemically clean surface
metal
Coated with photo-resist
Photo-tool
Exposure to UV
Developed image
Etchant spray
Removal of metal
Photo-resist removed
Characteristic double cusped edge

Applications

Motor laminations and laminations for magnetic recording heads.

Slotted spring disks and gaskets

Meter parts

Camera parts

Fine screens

Chemical milling

Mainly used for contour shaping in three dimensional objects.

I. Preparation of workpiece – workpiece is cleaned and degreased

II. Masking – done by dipping or spraying or brushing The thickness of a mask is around 0.1 to 0.4 mm, but thicker masks give better bonding strength. Thinner masks may result in low adhesion strength. The masking techniques are as same as that of chemical blanking

III. Etching – generally done by immersion, but spraying is also used. Tapering is produced by withdrawing the specimen at a controlled slow rate. Sometimes the specimen is withdrawn after partial etching to release the trapped gases.

Etchants used are as same that of chemical blanking

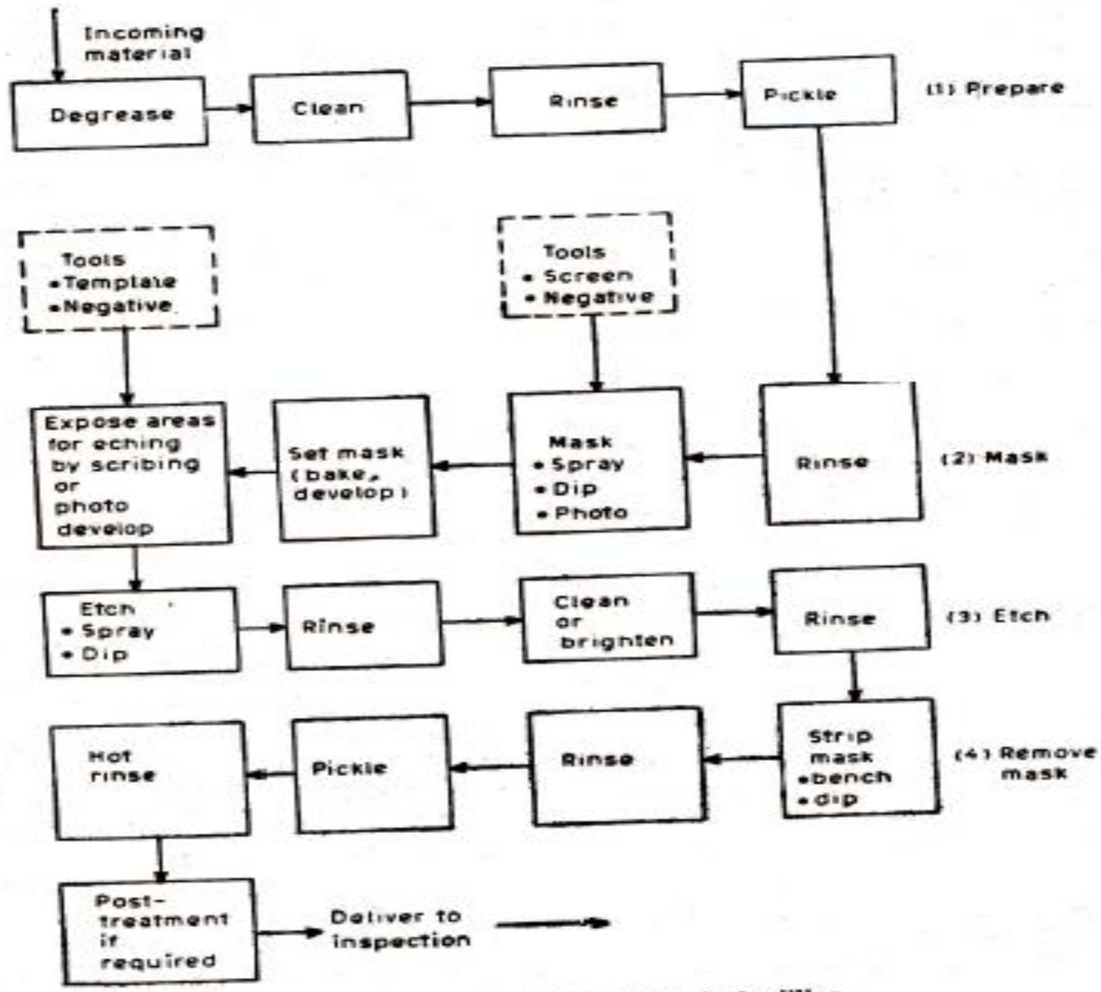


Fig. 14.73 Flow chart of chemical milling

Process characteristics

- **Material removal rate**
  - Depends chiefly on etchant selected.
  - But etchant that has higher MRR, will have the problems like reduced surface finish, increased undercutting, higher heating, attack the maskant.
  - Hence etch rate is generally limited to 0.02 to 0.04 mm/min.
- **Accuracy** – the undercut is one of the most sever problem in CHM.

  accuracies of +/-0.01 mm can be achieved on relatively shallow d.o.c.
- **Surface finish** – the quality of finish is lower in extrusions, forgings and castings.
  - It could be around 5μm however for aluminium alloys it could be 1.6μm

- Hydrogen embrittlement may occur as some metals like steel, stainless steel, nickel, copper alloys, absorb hydrogen during CHM.
- This can be overcome by heating the workpiece to 120^{o}C for 1 to 4 hrs

Hydrogen Embrittlement

- **Hydrogen embrittlement** is the process by which various metals, most importantly high-strength steel, become brittle and fracture following exposure to hydrogen.
- Hydrogen embrittlement is often the result of unintentional introduction of hydrogen into susceptible metals during forming or finishing operations and increases cracking in the material. This phenomenon was first described in 1875.
- Hydrogen embrittlement is also used to describe the formation of zircaloy hydride. Use of the term in this context is common in the nuclear industry.
- The mechanism starts with lone hydrogen atoms diffusing through the metal. At high[*clarification needed*] temperatures, the elevated solubility of hydrogen allows hydrogen to diffuse into the metal (or the hydrogen can diffuse in at a low temperature, assisted by a concentration gradient).
- When these hydrogen atoms re-combine in minuscule voids of the metal matrix to form hydrogen molecules, they create pressure from inside the cavity they are in.
- This pressure can increase to levels where the metal has reduced ductility and tensile strength up to the point where it cracks open (*hydrogen induced cracking*, or HIC).
- High-strength and low-alloy steels, nickel and titanium alloys are most susceptible.
- Ap High Precision Parts and Decorative Items
- Metal removal from forgings, castings
- Reduce web thickness in forged parts
- Engraving on metal pieces

➢ Gaskets

➢ Washers

➢ Sensors

➢ Nameplates

➢ Jewelry

➢ Microprocessor Chips

- Plications

Advantages

Several parts can be produced simultaneously

2. No effect of workpiece materials properties such as hardness, inducement of stress on material

3. Simultaneous material removal operation

4. No burr formation

5. Weight reduction of forgings and castings

6. Low capital cost of equipment

7. Easy and quick design changes

8. Requirement of less skilled worker

10. The good surface quality

11. Using decorative part production

12. Low scrap rates (3%).

Limitations

1. Very low MRR (0.0025–0.1 mm/min.)

2. Difficult to get sharp corner

3. Difficult to chemically machine thick material (limit is depended on workpiece material, but the thickness should be around maximum 10 mm)

4. Scribing accuracy is very limited, causes less dimensional accuracy

5. Etchants are very dangerous for workers

6. Etchant disposals are very expensive

UNIT 6

Electro Discharge machining (EDM)

INTRODUCTION

- Electro Discharge Machining (EDM) is an electro-thermal non-traditional machining process, where electrical energy is used to generate electrical spark and material removal mainly occurs due to thermal energy of the spark.
- Metal removal by a series of discrete electrical discharges (sparks) causing localized temperatures high enough to melt or vaporize the metal

Basic principle

- When potential difference between tool and work piece is high, a transient spark discharges through the fluid, removing a small amount of metal from the work piece surface.
- Produced by a spark generator, the sparks at regular intervals create a succession of craters in the work piece.
- The spark discharges are pulsed on and off at a high frequency cycle and can repeat 250,000 times per second.
- Each spark produces a temperature between 8,000 and 12,000° C.
- The size of the crater depends on the energy turned out by the spark generator.
- The range of the sparks varies from a few microns to 1 mm.

Mechanism of metal removal

1 The electrode approaches the workpiece. The two units are energized

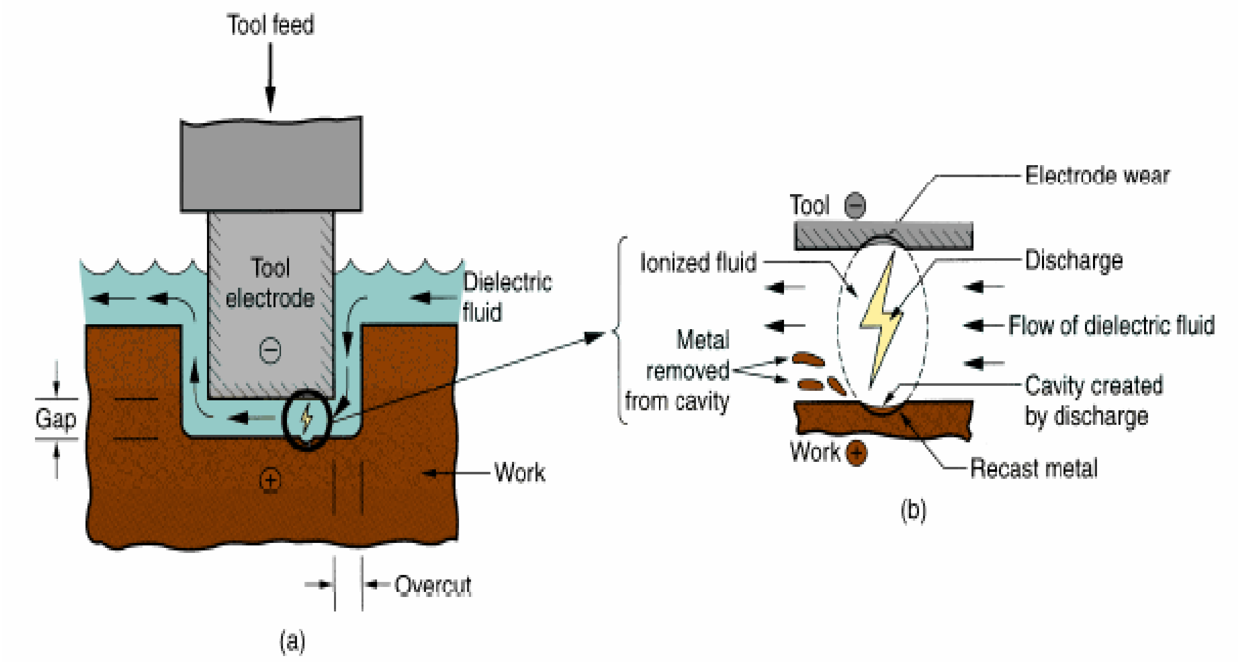
2 Concentration of the electrical field towards the point where the space between the electrode and work

3 Creation of an ionized channel between the electrode and workpiece

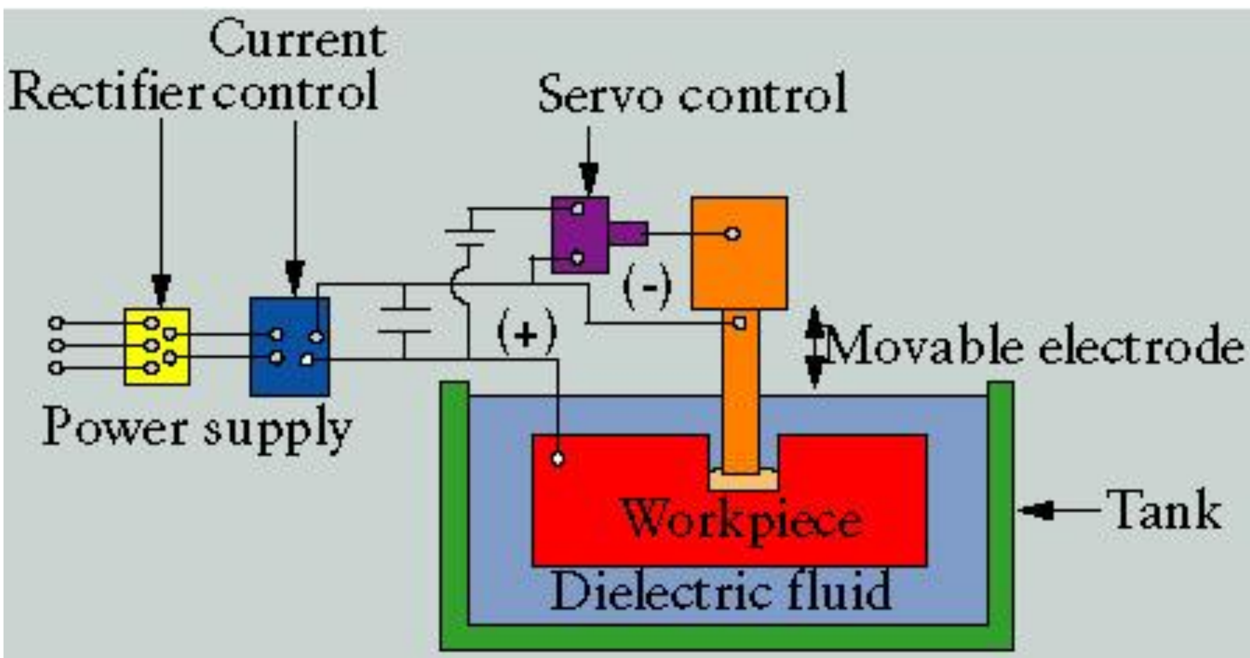
4 Breakdown of the spark. The work piece material melts locally and disintegrates. The electrode only wears out slightly.

5 The current is cut off, causing implosion of the spark

6 Evacuation of the metallic particles by flushing with dielectric



Equipment



Base and Container

- A container of non-conducting, transparent material is used for carrying out EDM. The container is filled with dielectric solution. A base to keep workpiece is installed at the bottom of container. The base is made of conducting material and given positive polarity.

Tool

- Tool is given negative polarity. It is made of electrically conducting material line brass, or copper. Tool is made slightly under size for inside machining and over sized for cut side machining. The shape of the tool is similar to that of the geometry to be machined

Dielectric Solution

- Dielectric solution is a liquid which should be electrically conductive. This solution provides two main functions, firstly it drives away the chips and prevents their sticking to workpiece and tool then it enhances the intensity of discharge after getting ionized and so accelerates metal removal rate.

Power Supply

- A DC power supply is used, 50 V to 450 V is applied. Due to ionization of dielectric solution an electrical breakdown occurs. The electric discharge so caused directly impinges on the surface of workpiece. It takes only a few micro seconds to complete the cycle and remove the material.

Tool Feed Mechanism

- In case of EDM, feeding the tool means controlling gap between workpiece and the tool. This gap is maintained and controlled with the help of servo mechanism. The movement speed is maintained by the help of gear and rack and pinion arrangement. The servo system senses the change in gap due to metal removal and immediately corrects it by moving the tool accordingly. The spark gap normally varies from 0.005 mm to 0.50 mm.

Workpiece and Machined Geometry

- Any material which is electrical conductor can be machined through this process, whatever be the hardness of the same. The geometry which is to be machined into the workpiece decides the shape and size of the tool.

Dielectric fluid

- The essential properties of a dielectric (water or mineral oil) are:

1. Remain electrically non conductive till a required breakdown voltage is reached – dielectric strength
2. Breakdown electrically in the shortest possible time
3. Quench the spark immediately after the discharge has occurred

4. Provide an effective cooling medium
5. Remove the residual metallic particles
6. Dielectric fluid should provide an oxygen free machining environment.
7. Have a good degree of fluidity
8. to lower the temperature in the machining area
9. Be cheap and easily available
10. The choice of any dielectric fluid depends on the workpiece size, complexity of shape, tolerance, surface finish and MRR.
11. Generally kerosene and de-ionized water is used as dielectric fluid in EDM.
12. Tap water cannot be used as it ionizes too early and thus breakdown due to presence of salts as impurities occur.
13. Dielectric medium is generally flushed around the spark zone. It is also applied through the tool to achieve efficient removal of molten material

Spark generators

- In EDM as the material is removed through sparks, specially designed spark generators have to be used.
- Spark generation could be in controlled natural form like ignition and relaxation or using a switch element like thyristor, transistor or changing the polarity
- Based on the above variations, EDM generators can be classified as

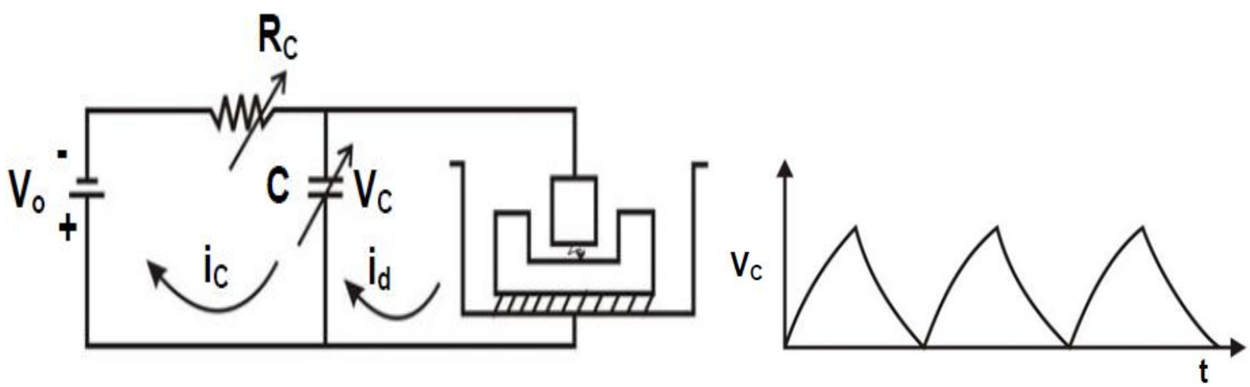
1. Relaxation generators
2. Rotary pulse generator

   Static pulse generator

Relaxation generator

- Also known as Resistance-capacitance type (RC type) generators
- In RC type generator, the capacitor is charged from a DC source.
- As long as the voltage in the capacitor is not reaching the breakdown voltage of the dielectric medium under the prevailing machining condition, capacitor would continue to charge.
- Once the breakdown voltage is reached the capacitor would start discharging and a spark would be established between the tool and workpiece leading to machining.

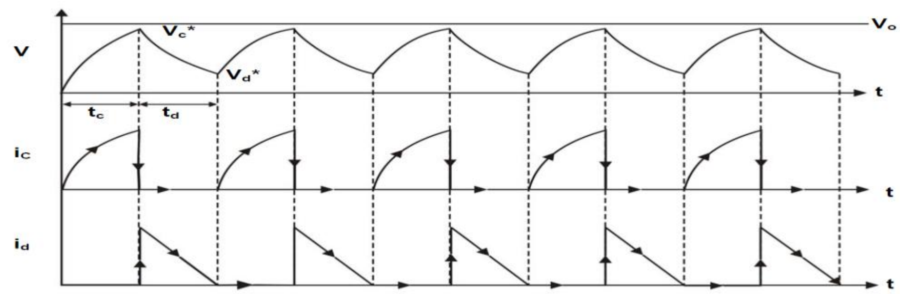
Such discharging would continue as long as the spark can be sustained. Once the voltage becomes too low to sustain the spark, the charging of the capacitor would continue



$$V_c = V_o\left\{1 - e^{-\frac{t}{R_C C}}\right\}$$

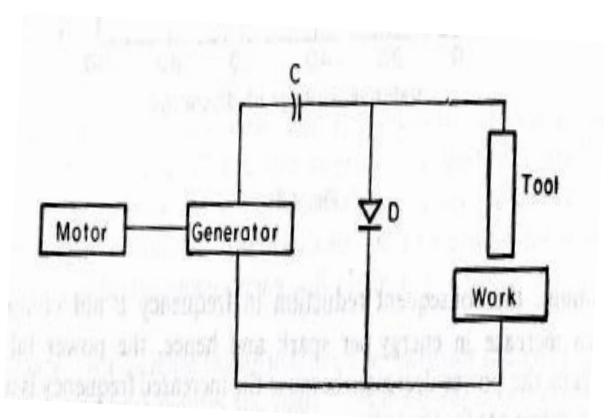
I_c = charging current
V_o= open circuit voltage
R_c= charging resistance
C = capacitance
V_c= instantaneous capacitor voltage during charging

- For maximum power dissipation in RC type EDM generator $V_c = 0.716\ V_o$.
- For high MRR, forced circulation of dielectric is required.
- RC generators are cheaper, simple in design, robust
- They are best suited for low energy and high frequency required for finishing operations
- But they are liable for high tool wear and low MRR



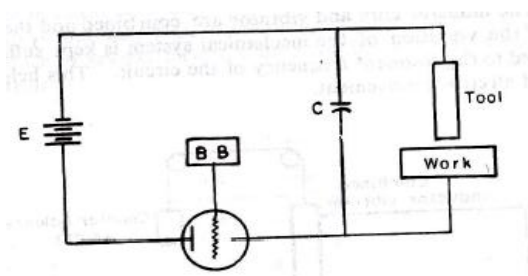
Rotary pulse generator

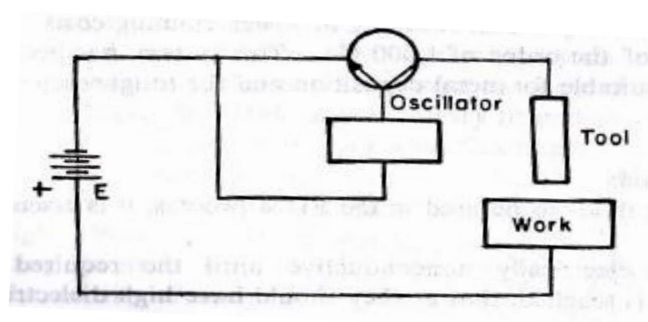
- These generators are observed to impart higher MRR in the process
- The circuit consists of a capacitor through diode.
- In the first half, the current passes through the diode through the capacitor, while in the reverse, the sum of the voltage from the generator and charged capacitor is applied to the gap.
- As the current is continuous, the MRR is high, but poor surface finish.



Static pulse generators

- The earlier circuits had the drawback of ignoring the effect of short circuit
- The current has to be cut off in case of a short circuit that could produce excessive damage to the work surface.
- This care is taken by controlled pulse circuits also known as static pulse generators.
- These contain electronic tubes and transistors.
- They offer higher MRR and lower tool wear rate with high accuracy.
- A vacuum tube circuit has series of vacuum tubes connected in parallel.
- The electronic circuit switches on the tubes.
- In case of short circuit, the tube fails thereby avoiding the damage.
- These vacuum tube generators need high voltage and low current.
- Hence it has been replaced by low voltage device oscillator, which is the switching circuit.
- Here the oscillator switches on at a particular frequency and does not need capacitors.
- In case of short circuit, the oscillator's frequency varies and the current is cut off





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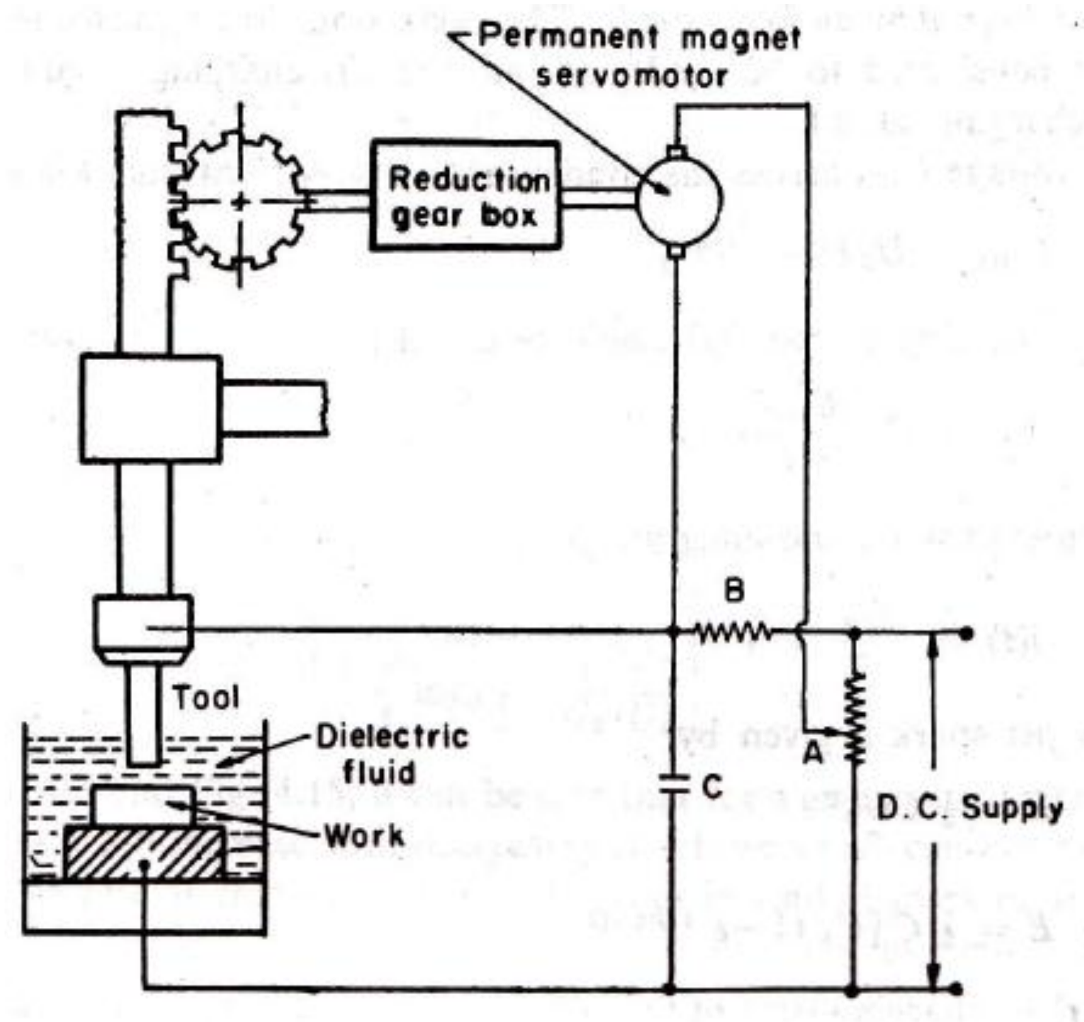
Electrode feed control

- The tool should be fed at such a rate that the sparking voltage remains unaltered
- If the gap is more the spark is quenched, if the gap reduces then short circuit occurs.
- This is controlled by a servo mechanism derived from error indication signal obtained from an electrical sensing device
- Servo mechanism affecting the movement of the electrode may be electrical driven or solenoid operated or hydraulically operated or a combination thereof.
- The electric motor driven type is as shown



When the electrode is widely spaced, the current supply is switched on and charges the condenser and voltage will rise to supply voltage level across one arm of the bridge.

The other arm of the bridge, is connected through potentiometer.

If the setting is midway then the voltage across the bridge will be half the supply voltage and tends to rotate the motor making the electrode to approach workpiece and hence the spark is struck.

This movement ceases when this average voltage equals that prevailing across the other arm of the bridge

Under these conditions the bridge is balanced.

If the electrode overshoots, then the bridge is unbalanced, with a reverse polarity and hence the motor rotates in reverse direction to increase the gap.

In case of short circuit, the supply voltage appears across ballast resistance and the electrode is lifted up

EDM tools – electrodes

- The electrode must send electric pulses to allow workpiece erosion to take place
- Hence any electrically conducting material can be used as electrode
- However depending on material to be machined, generator used, electrode materials are classified as follows

1. Metallic materials – electrolytic copper, chromium copper, copper tungsten, brass, tungsten, steel, zinc, aluminium, tungsten carbide
2. Non metallic materials – graphite
3. Combination – copper graphite

(For further details refer table 14.8 pg.no. 463 – Production technology by HMT)

Electrode manufacture

- Electrodes are manufactured through conventional machining methods - copper, graphite, copper tungsten and castings – aluminium alloys
- Metal spraying, press forming and electroplating are also used – metallic electrodes
- High dimensional accuracy is essential for finishing electrodes

Electrode wear

- Electrode wear has to be estimated for proper dimensioning of the electrode.

- It is function of factors such as polarity, thermal conductivity, melting point of the electrode, duration and intensity of the spark, type of power supplies, and the type of the work material.
- Type of wear is also to be considered
- Corner wear ratio is to be considered for finish machining, volume wear ratio for cavity sinking
- With the use of graphite electrode and pulse generators we can have 'no wear EDM'.
- Here the electrode is positive with high current density and low pulse frequency are employed
- Relation to on time to off time is 95:5.
- This reduces the MRR by 20% but reduces wear ratio.
- The dielectric flow also decides the wear ration.
- The turbulent flow increases the wear ratio. Hence pulsed injection can reduce the wear.

EDM tool design

- Tool design can be categorized in to two types – cylindrical hole machining (includes all through holes and cavities with uniform cross section) and 3D cavity machining (needs one or more electrodes with varying cross section)

The procedure used for both is same

1. Choice of machining operations -
2. Electrode material selection
3. Machine settings
4. Under sizing and length of electrode
5. Machining time
6. Choice of machining operations – better to use more than one machining operations, which saves total time. As a general rule 3 operations are used if the required surface finish is 1.2 µm and less however the surface finish between two operations should not exceed 0.8 µm
7. Electrode material selection – graphite not suitable for machining carbides also on machines with RC generators
8. Machine settings – in case of RC generators the capacitor value decides the surface finish, in case of pulse generators, current intensity, discharge time, pause time will affect the machining

9. Under sizing and length of electrode – roughing electrodes must be undersized by the amount of maximum spark gap which is 0.1 to 0.3 mm. the manufacturer will give a table to consider the length of the electrode. Usually the roughing electrodes will be longer than the finishing electrode
10. Machining time – varies by +/-5% for holes and +/- 14% for cavities

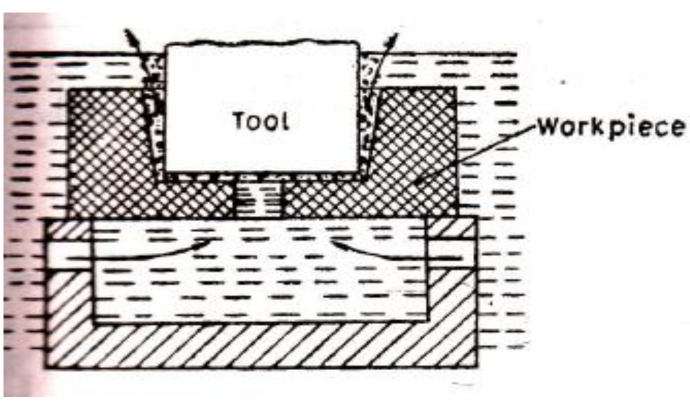
Flushing

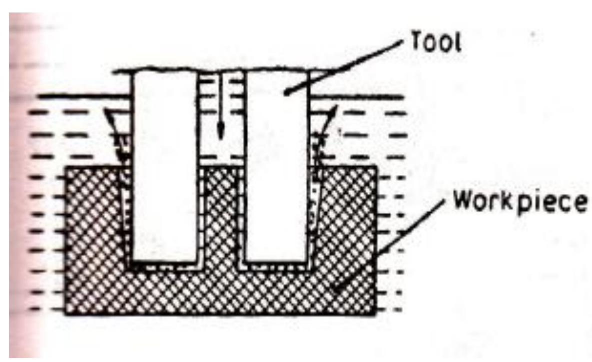
- Dielectric fluid is flushed through the spark gap in the form of jet or through tool
- It is the circulation of the dielectric fluid between the workpiece and the electrode.
- If the machined particles are not flushed, they become obstacles in the process.
- Various methods of flushing are:

1. Pressure flushing,
2. Suction flushing
3. Side flushing
4. Pulsed flushing synchronized with electrode movement

Pressure flushing

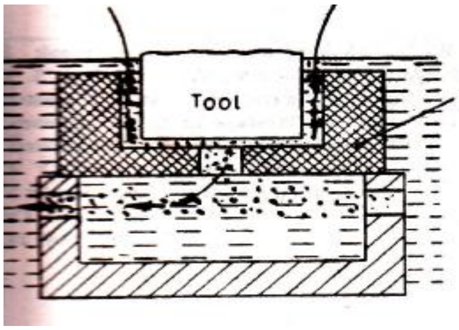
- Here the fluid is injected through the workpiece or through the tool.
- Pressure is in the range of 1.5 to 2 kg/cm^2
- Components machined with pressure flushing are slightly tapered due to particles being forced up the sides of the electrode producing lateral discharge

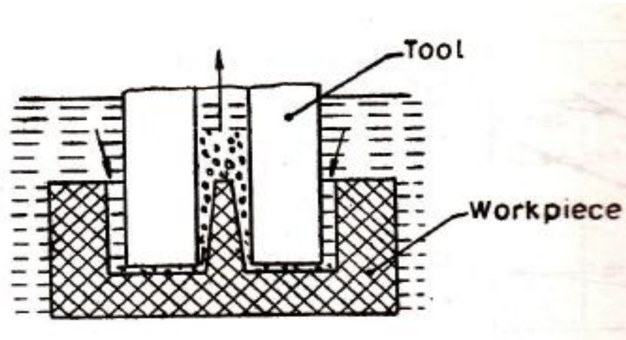




Suction flushing

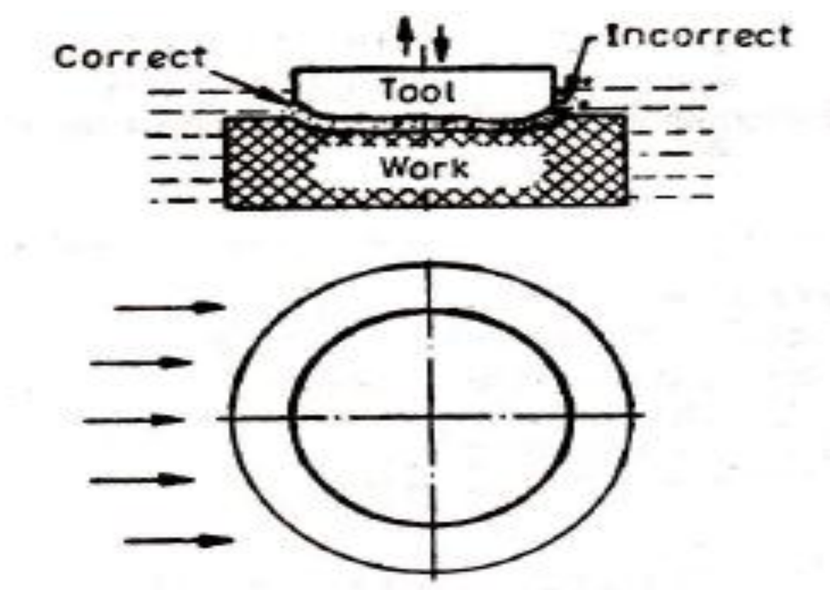
- Here the fluid is sucked through the workpiece or through the electrode.
- Taper effect is absent in this method
- The vacuum pressure is of the order 0.8 to 0.9 kg/cm^2





Side flushing

- This is used when it is impossible to drill a hole either in the electrode or in the workpiece
- This is used for deep narrow slots or coining
- It is very important here to provide even flushing. Hence nozzles are provided at right place.



Pulsed flushing synchronized with electrode movement

- In the pressure and suction flushing the electrode wear is high due to flushing pressure
- To avoid this flushing is done in pulses only when machining takes place
- This reduces the electrode wear

Process characteristics

1. **Metal Removal Rate**

The MRR is proportional to the working current

It is defined as volume of metal removed per unit time per ampere.

The MRR of steel with graphite electrode and 50A generator, is 400mm^3/min and with 400A generator 4800mm^3/min

Pulse frequency, kc	**Current, A**	**Surface roughness, µm**	**Crater depth, mm**		**MRR, mm^3/min**
			Work piece	Electrode	
5	1-20	6-12	.05-.1	.03	460
10	5-17	4-6	.04-.05	.014	130
450	3-10	1.2-2	.01-.015	.004	27
1000	.5-3	.2-.8	.0025	.0008	.15-1.5

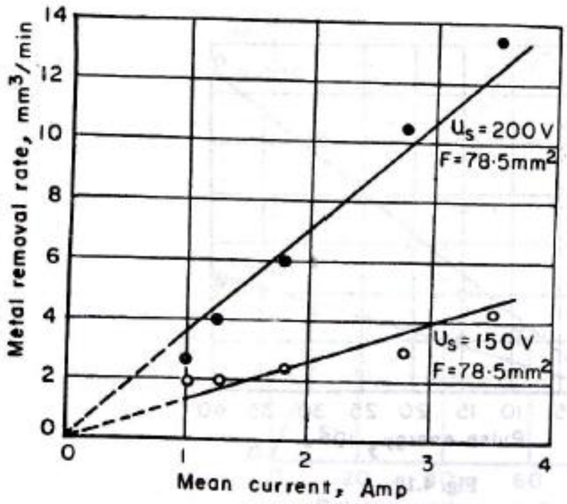


Fig. 4.16 Effect of voltage and current on the rate of metal removal. Dielectric: Kerosene; Tool: Brass; Work material: Low C steel; F: Tool electrode area.

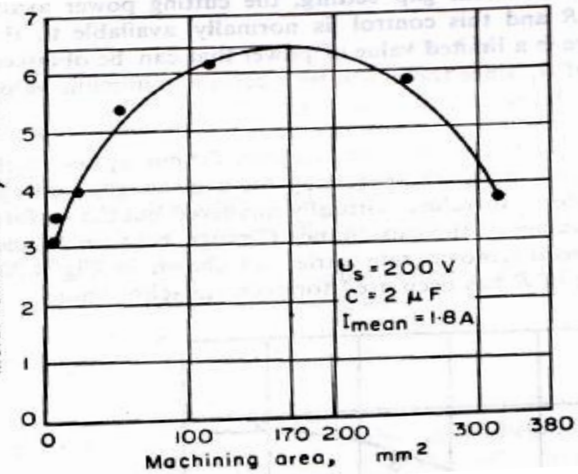
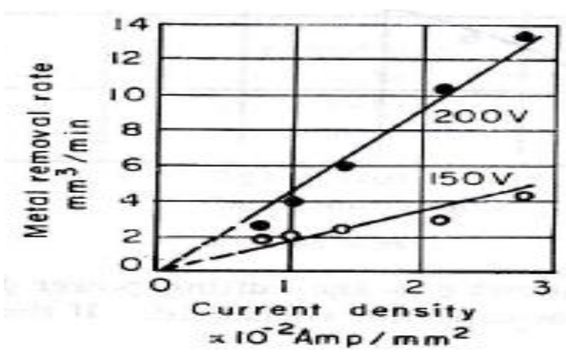
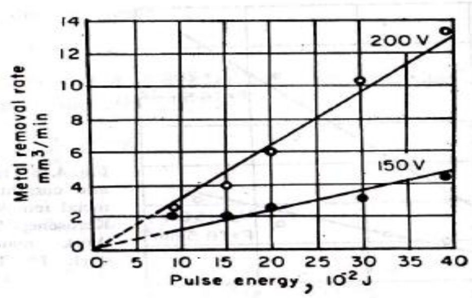
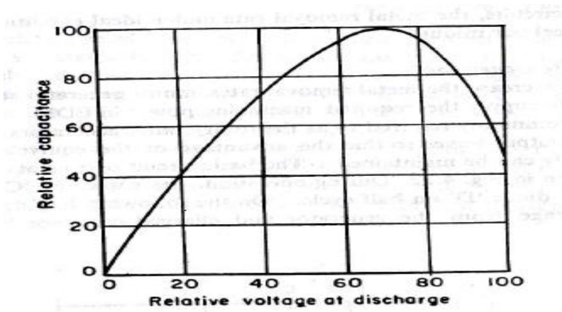


Fig. 4.17 Effect of machining area on the rate of metal removal. Work material: Low C steel; Tool: Brass; Dielectric: Kerosene.







2. Accuracy

Tolerance of +/-0.05mm could be easily achieved, with close control, +/-0.0003mm is also possible

The taper value is around 0.005 to 0.05 mm per 10mm depth

An overcut of 5 to 100µm is produced due to flushing or roughing

Corner radii is inevitable in EDM which is equal to the spark gap.

3. Surface finish

The surface finish depends on the dimensions of the sparks. If they are energetic, the surface finish will be rough, but on the other hand the speed of machining will be high

If the sparks are of low energy, the surface finish will be fine, but machining speed will be low

The finest surface finish is in the order of 0.4 µm

4. Heat Affected Zone

The removed metal is not completely removed during the process

It re-solidifies to an extent of 2 -10µm thick having a hardness of 60HRC.

Thermal cracks may appear in this layer

This can be removed by polishing

Machine tool selection

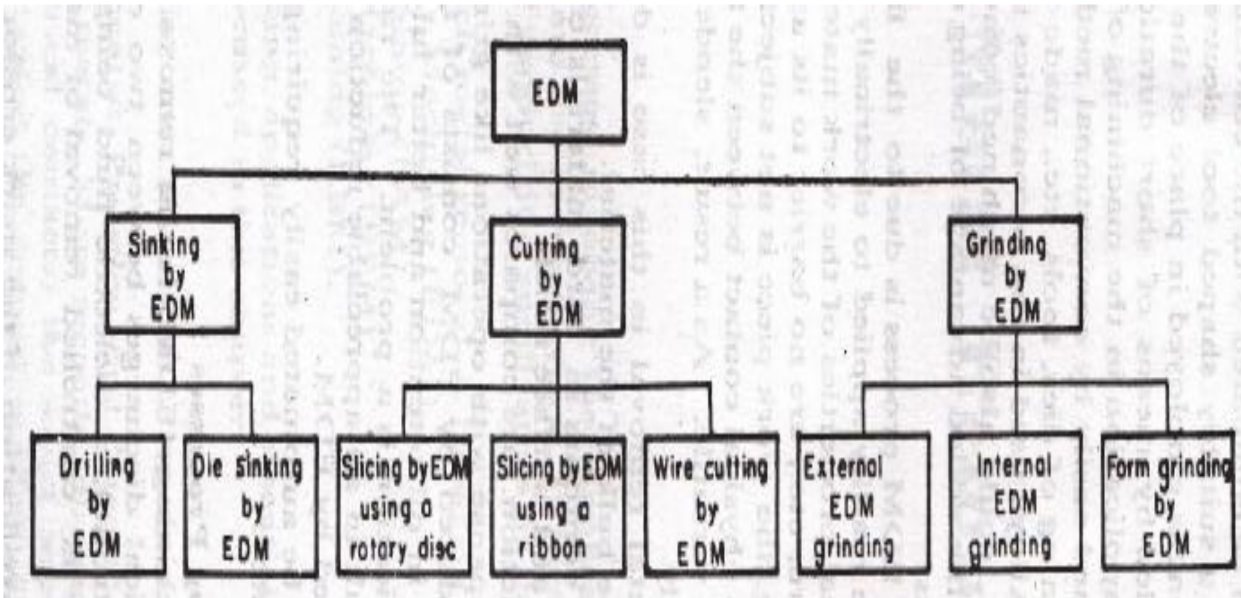
- Variety of EDM machines are available
- The following factors have to be considered for selection

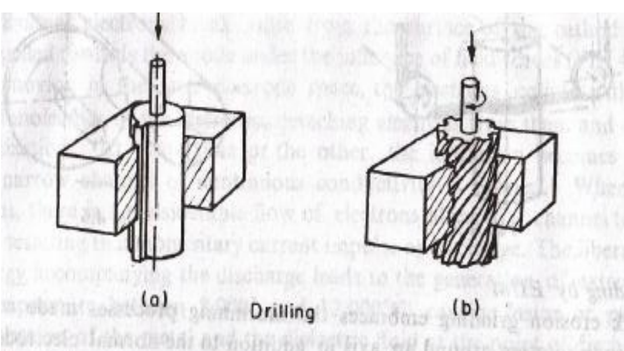
1. Number of parts to be machined
2. Accuracy required

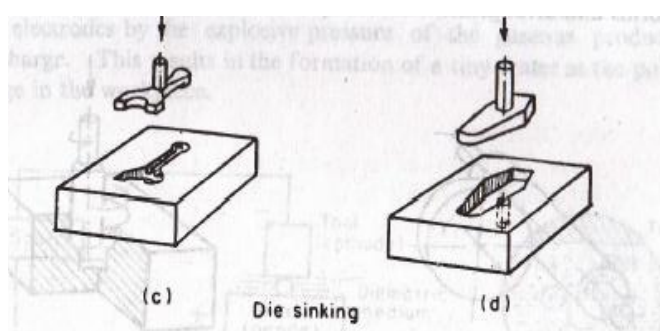
3. Size of the workpiece
4. Depth of the cavity
5. Orientation of the cavity

They should be versatile, rigid and accurate.

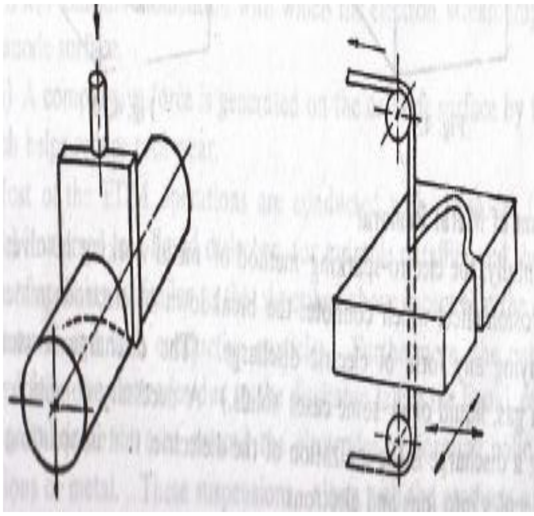
Applications

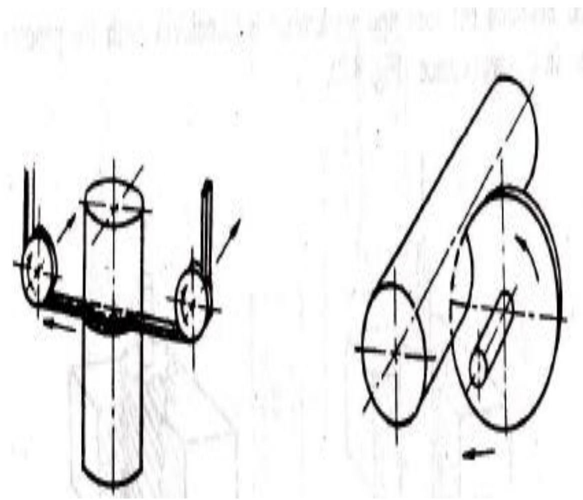






Cutting by EDM





Wire cut EDM

- Special form of EDM that uses small diameter wire as electrode to cut a narrow kerf in work
- Work is fed slowly past wire along desired cutting path, like a bandsaw operation.
- CNC used for motion control
- While cutting, wire is continuously advanced between supply spool and take-up spool to maintain a constant diameter
- Dielectric required, using nozzles directed at tool-work interface or submerging work part
- Depending on the accuracy and surface finish needed a part will either be one cut or it will be roughed and skimmed.
- On a one cut the wire ideally passes through a solid part and drops a slug or scrap piece when it is done.
- This will give adequate accuracy for some jobs but most of the time skimming is necessary.
- A skim cut is where the wire is passed back over the roughed surface again with a lower power setting and low pressure flush.
- There can be from one to nine skim passes depending on the accuracy and surface finish required.

Advantages of EDM

This process is very much economical for machining very hard material.

(b) Maintains high degree of dimensional accuracy so it is recommended for tool and die making.

(c) Complicated geometries can be produced which are very difficult otherwise.

(d) Highly delicate sections and weak materials can also be processed without nay risk of their distortion, because in this process tool never applies direct pressure on the workpiece.

(e) Fine holes can be drilled easily and accurately.

(f) Appreciably high value of MRRR can be achieved as compared to other non-conventional machining processes.

Disadvantages of EDM Process

There are some limitations of EDM process as listed below :

(a) This process cannot be applied on very large sized work pieces as size of workpiece is constrained by the size of set up.

(b) Electrically non-conducting materials cannot be processed by EDM.

(c) Due to the application of very high temperature at the machining zone, there are chances of distortion of workpiece in case of this sections.

(d) EDM process is not capable to produce sharp corners.

(e) MRR achieved in EDM process is considerably lower than the MRR in case of conventional machining process so it cannot be taken as an alternative to conventional machining processes at all.

UNIT 7

PLASMA ARC MACHINING (PAM)

INTRODUCTION

- Plasma can be defined as a "superheated, electrically ionized gas."
- The term plasma arc is defined as gas that has been heated to at least a partially ionized condition, enabling it to conduct an electric current.
- PAM is a thermal material removal process that is primarily used for cutting thick sections of electrically conductive materials.
- This process is used as an alternative to oxy-gas cutting, employing an electric arc at temperatures as high as 27,800°C to melt and vaporize the metal.
- ➢ PAM uses a high velocity jet of plasma to cut through the metal by melting it.
- The high gas flow rate facilitate the removal of molten metal through the 'kerf' (The kerf is the space left in the work piece as the metal is removed during a cut.)
- ➢ Stream pressures can reach up to 1.4 MPa.

Basic principle of PAM

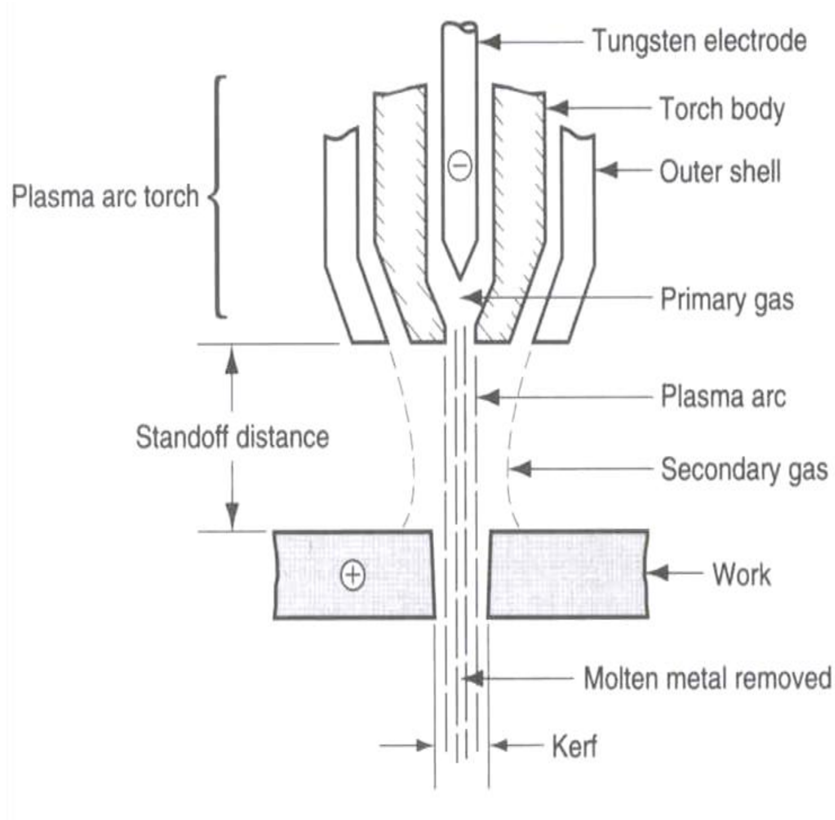
Non thermal generation of plasma

- The heating of the gases can be done by applying an electric field across the gas or by exposing the gas to ionizing radiation.
- Mostly the first method is used.
- The changes that take place when gas heated to elevated temperature are:

  1. Number of collisions between the atoms increase.

  2. The gas ionizes that strips the atoms off their outer electrons creating electrons and ions

  3. The electrons thus produced collide with atoms thereby increasing the thermal kinetic energy due to increased heat, excite them so that de-excitation light is emitted from the atoms and ionize them so that more electrons and ions are produced.



When gases are heated by an electric field, an igniter supplies the initial electrons, which accelerate before colliding with atoms.

The free electrons in turn get accelerated and further ionize and heat the gas.

This process is continued till the loss of electrons due to collision to the wall is balanced by production of free charges.

The actual heating of the gas takes place due to energy liberated when free ions and electrons recombine into atoms or when atoms recombine into molecules.

Thus the kinetic energy of the atom is due to recombination.

The energy releases depends on the enthalpy of the gas, thermal conductivity and loss of energy in the form of radiation.

The electrical conductivity of the gas also plays an important role in this process.

Mechanism of metal removal

- Due to heat produced via electron bombardment resulting in plasma.
- This melts the workpiece and a high velocity gas blows the molten metal away

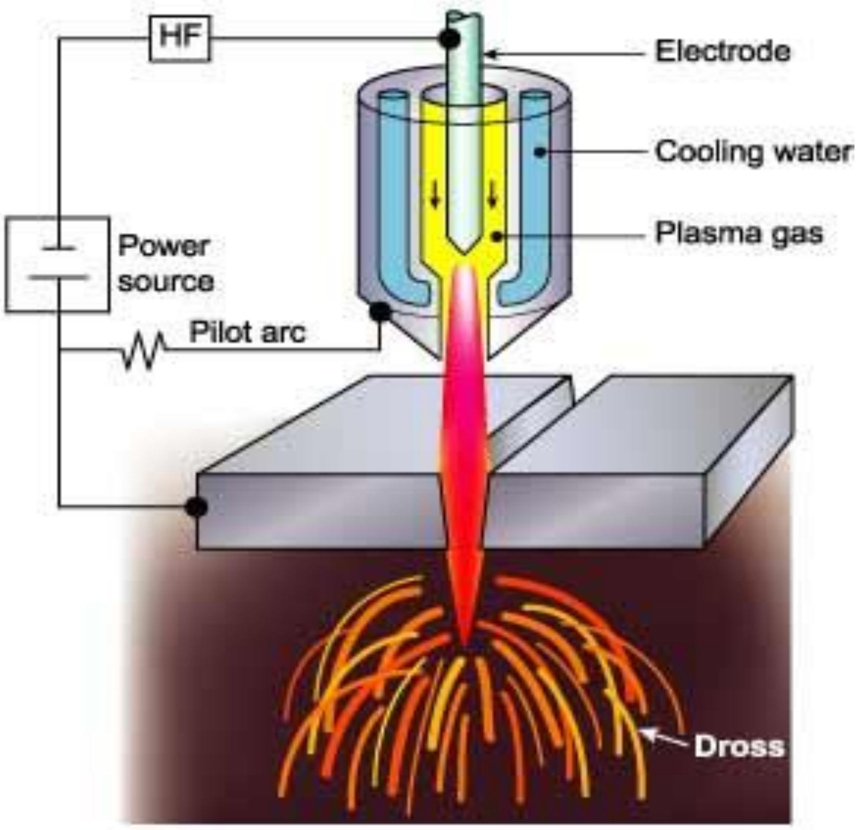
Equipment

Details of PAM are described below.

- ***Plasma Gun***

Gases used to create plasma like are, nitrogen, argon, hydrogen or mixture of these gases.

The plasma gun consists of a tungsten electrode fitted in the chamber. The electrode is given negative polarity and nozzle of the gun is given positive polarity.



- Supply of gases is maintained into the gun.
- A high frequency spark is used to initiate a pilot arc between tungsten electrode (cathode) and copper nozzle (anode), further continued by an external arc.
- 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.

Power Supply and Terminals

- Power supply (DC) is used to develop two terminals in the plasma gun. A tungsten electrode is inserted to the gun and made cathode and nozzle of the gun is made anode. Heavy potential difference is applied across the electrodes to develop plasma state of gases.

Cooling Mechanism

- As we know that hot gases continuously comes out of nozzle so there are chances of its over heating. A water jacket is used to surround the nozzle to avoid its overheating.

Tooling

- There is no direct visible tool used in PAM. Focused spray of hot, plasma state gases works as a cutting tool.

Workpiece

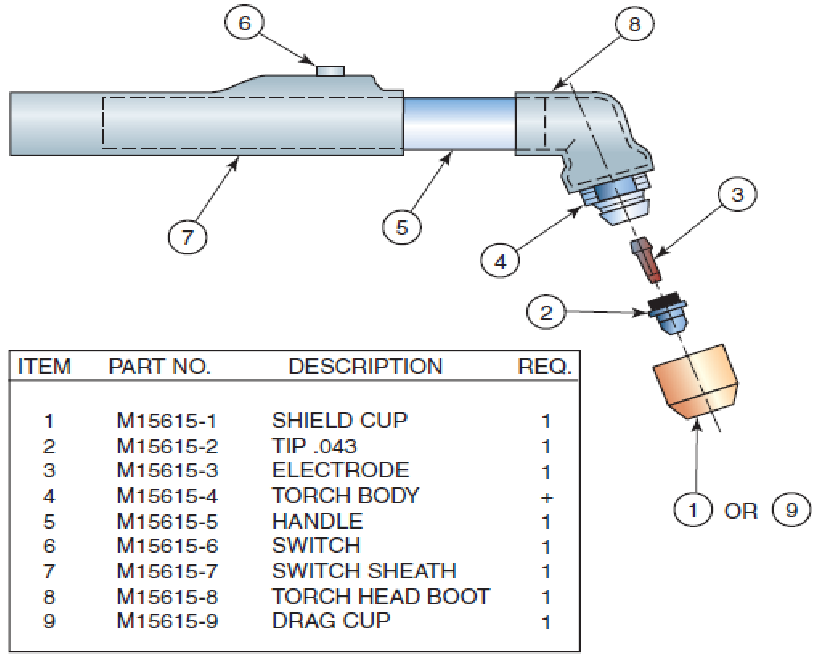
- Workpiece of different materials can be processed by PAM process. These materials are aluminium, magnesium, stainless steels and carbon and alloy steels. All those material which can be processed by LBM can also be processed by PAM process.

PAM parameters

1. Torch
2. Physical configurations
3. Work environment

The Torch

- The plasma torch is a device, depending on its design, which allows the creation and control of the plasma for welding or cutting processes.
- The torch consists of nonconsumable electrode of 2 % tungsten and a converging anode nozzle.
- The electrodes are separated by an insulator
- For vortex stabilization, gas is fed tangentially through an inlet in the insulator.
- For sheath stabilization, the gas is fed through small ports around cathode



ITEM	PART NO.	DESCRIPTION	REQ.
1	M15615-1	SHIELD CUP	1
2	M15615-2	TIP .043	1
3	M15615-3	ELECTRODE	1
4	M15615-4	TORCH BODY	+
5	M15615-5	HANDLE	1
6	M15615-6	SWITCH	1
7	M15615-7	SWITCH SHEATH	1
8	M15615-8	TORCH HEAD BOOT	1
9	M15615-9	DRAG CUP	1

Factors to be considered

The torch is designed to have maximum thermal output

This not only increases the efficiency, but also increases the life of the electrode as this ensures minimum corrosion of the electrode.

The parameters that affect the performance of torch are cathode size, its taper near gap, convergence of the nozzle, nozzle orifice diameter, orifice length, electrode gap and cooling of electr The following factors must be considered while designing the torch

1. Large current requires large orifice diameter cathode, orifice length and electrode gap
2. At larger voltage, the taper angle at cathode tip must be higher
3. To avoid turbulence the cathode tip is rounded off
4. Non transferred arc use long throat lengths, while transferred arc modes use minimum orifice length
5. Alignment between cathode and anode is very critical for better accuracy
6. The cathode tip should be the nearest point to the anode
7. The insulator should be kept away from the arc zone and it should be properly provided
8. Cooling should be optimum, as too much cooling may lead to cracks
9. Oxygen is detrimental to the cathode.

Selection of gas

- Almost any gas or gas mixture can be used today for the PAM process.
- Changing the gas or gas mixture is one method of controlling the plasma cut.
- Although the type of gas or gases used will have a major effect on the cutting performance, it is only one of a number of changes that a technician can make to help produce a quality cut.
- The following are some of the effects on the cut that changing gas(es) will have:

  ■ Force—The amount of mechanical impact on the material being cut; the density of the gas and its ability to disperse the molten metal

  ■ Central concentration—Some gases will have a more compact plasma stream. This factor will greatly affect the kerf width and cutting speed.

- Heat content—As the electrical resistance of a gas or gas mixture changes, it will affect the heat content of the plasma it produces. The higher the resistance, the higher the heat produced by the plasma.
- Kerf width—The ability of the plasma to remain in a tightly compact stream will produce a deeper cut with less of a bevel on the sides.
- Dross formation—The dross that may be attached along the bottom edge of the cut can be controlled or eliminated.
- Top edge rounding—The rounding of the top edge of the plate can often be eliminated by correctly selecting the gas(es) that are to be used.
- Metal type—Because of the formation of undesirable compounds on the cut surface as the metal reacts to elements in the plasma, some metals may not be cut with specific gas(es).

Safety precautions

- Machine the heat affected zone (0.75-5 mm).
- Regulate gas pressure (approx. 1-1.4 MPa).
- Maintain constant distance between torch and work piece.
- High labor safety (i.e. goggles, gloves, etc…).
- Proper training for operators.
- Protection against glare, spatter and noise from the plasma.

Applications of PAM

- Plasma arc welding

- Plasma arc surfacing
- Plasma arc spraying

Plasma arc welding

- **Plasma arc welding** (**PAW**) is an arc welding process similar to gas tungsten arc welding (GTAW).
- The electric arc is formed between an electrode and the workpiece.
- The key difference from GTAW is that in PAW, by positioning the electrode within the body of the torch, the plasma arc can be separated from the shielding gas envelope.
- The plasma is then forced through a fine-bore copper nozzle which constricts the arc and the plasma exits the orifice at high velocities and a temperature approaching 20,000 °C.
- Plasma arc welding is an advancement over the GTAW process. This process uses a non-consumable tungsten electrode and an arc constricted through a fine-bore copper nozzle.
- PAW can be used to join all metals that are weldable with GTAW (i.e., most commercial metals and alloys).

Plasma arc surfacing

- Surfacing is defined as the deposition of filler metal on metal surface to obtain desired properties or dimensions First, the pilot power supply arcs in argon gas flow between tungsten electrode and water cooled nozzle to make argon gas into plasma.
- The produced hot plasma gas is converged by the thermal pinch effect of the water cooled nozzle to reach the base metal as the plasma arc with high energy density.
- When the arc reaches the base metal, the main power begins to be supplied to keep the condition, and the arc current begins to flow in the base metal to form the molten pool on the surface of the base metal.
- On the other hand, the powdered material is force-fed into the plasma arc by the carrier gas such as helium or argon and after melted it is thrown into the molten pool on the base metal surface to form the overlay layer.

Plasma arc spraying

- Plasma spraying is part of thermal spraying, a group of processes in which finely divided metallic and non-metallic materials are deposited in a molten or semi-molten state on a prepared substrate.

- Powered materials are injected within the plasma jet (dc arcs) where particles are accelerated and melted, or partially melted, before they flatten and solidify onto the substrate

Advantages of PAM

- Both non ferrous and ferrous metals can be cut
- 5 to 10 times faster than oxy-fuel.
- Cutting ability of thick parts.
- Easy to automate
- Cutting with no preheating
- Little or no distortion of the metal

Limitations of PAM

- Large heat affected zone.
- Rough Surfaces
- Difficult to produce sharp corners.
- Burr often results.
- More expensive even though it is faster
- Potential health hazard created because of noise excessive
- The side of the kerfs' may be slightly beveled

UNIT 8

LASER BEAM MACHINING (LBM)

INTRODUCTION

- A laser is an optical transducer that converts electrical energy into a highly coherent light beam.
- Laser stands for “light amplification of stimulated emission of radiation”.
- In the model of atom, negatively charged electrons rotate around the positively charged nucleus in some specified orbital paths.
- The geometry and radii of such orbital paths depend on a variety of parameters like number of electrons, presence of neighboring atoms and their electron structure, presence of electromagnetic field etc.
- Each of the orbital electrons is associated with unique energy levels. At absolute zero temperature an atom is considered to be at ground level, when all the electrons occupy their respective lowest potential energy
- The electrons at ground state can be excited to higher state of energy by absorbing energy form external sources like increase in electronic vibration at elevated temperature, through chemical reaction as well as via absorbing energy of the photon.
- On reaching the higher energy level, the electron reaches an unstable energy band. And it comes back to its ground state within a very small time by releasing a photon. This is called spontaneous emission. The spontaneously emitted photon would have the same frequency as that of the “exciting” photon.
- Sometimes such change of energy state puts the electrons in a meta-stable energy band.
- Instead of coming back to its ground state immediately (within tens of ns) it stays at the elevated energy state for micro to milliseconds.
- In a material, if more number of electrons can be somehow pumped to the higher meta-stable energy state as compared to number of atoms at ground state, then it is called “population inversion”.
- Such electrons, at higher energy meta-stable state, can return to the ground state in the form of an avalanche provided stimulated by a photon of suitable frequency or energy. This is called stimulated emission

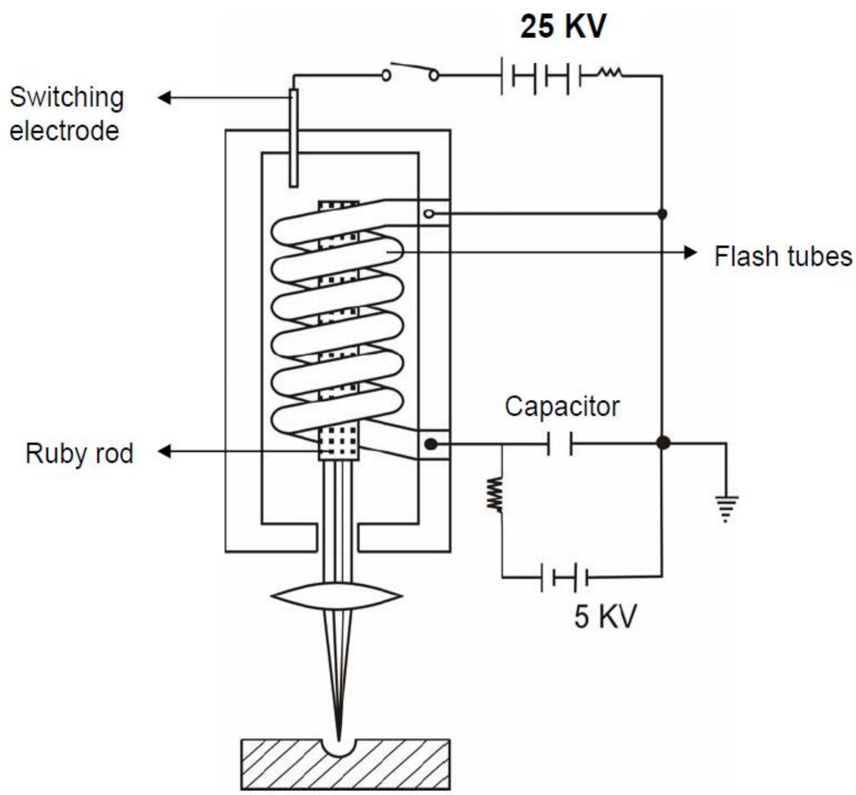
Laser Tube and Lamp Assembly

- This is the main part of LBM setup. It consists of a laser tube, a pair of reflectors, one at each end of the tube, a flash tube filled with xenon or lamp, an amplification source, a power supply unit and a cooling system.
- This whole setup is fitted inside a enclosure, which carries good quality reflecting surfaces inside.

In this setup the flash lamp goes to laser tube, that excites the atoms of the inside media, which absorb the radiation of incoming light energy.

- This enables the light to travel to and fro between two reflecting mirrors. The partial reflecting mirror does not reflect the total light back and apart of it goes out in the form of a coherent stream of monochromatic light. This highly amplified stream of light is focused on the workpiece with the help of converging lens. The converging lens is also the part of this assembly.

Equipment



Workpiece

- The range of workpiece material that can be machined by LBM includes high hardness and strength materials like ceramics, glass to softer materials like plastics, rubber wood, etc.
- A good workpiece material high light energy absorption power, poor reflectivity, poor thermal conductivity, low specific heat, low melting point and low latent heat.

Cooling Mechanism

- A cooling mechanism circulates coolant in the laser tube assembly to avoid its over heating in long continuous operation.

Material removal

- Material removal involves a combination of melting and evaporation processes.
- The radiant energy delivered to a surface by a focused laser beam is consumed in the following ways

1. A part is reflected and lost
2. Energy which is not reflected is used for melting
3. Relatively small part is used for evaporating the liquid metal
4. A very small part is conducted into the base metal
5. It's seen that all energy (10kW/cm^2) does not reach the metal as some energy is lost as spatters while travelling

Process characteristics

- The laser beam having an output energy of 20 joules with a pulse duration of 3-10 sec can produce a peak power of 20kW.
- With a beam divergence of 0.002 radians and a spot diameter of 0.05mm, can result in a power density of 1.2 W/cm^2
- The power density is given by

$$D = 4P/\pi f^2 \theta T$$

Where D = power density in W/cm^2

P = laser energy output, W

T = laser pulse duration, sec

θ = beam divergence, radian

f = focal length of lens

- To have a perfect machining, the following requirements have to be fulfilled

1. The radiation must penetrate and be absorbed in to the material
2. The power supplied must be greater than that which is conducted away in the form of convection, thermal conduction, and radiation.

Applications

APPLICATION	LASER TYPE
Cutting	
Metals	PCO_2; $CWCO_2$; Nd:YAG; ruby
Plastics	$CWCO_2$
Ceramics	PCO_2
Drilling	
Metals	PCO_2; Nd:YAG; Nd:glass; ruby
Plastics	Excimer
Marking	
Metals	PCO_2; Nd:YAG
Plastics	Excimer
Ceramics	Excimer
Surface treatment (metals)	$CWCO_2$
Welding (metals)	PCO_2; $CWCO_2$; Nd:YAG; Nd:glass; ruby

Note: P = pulsed, CW = continuous wave.

- LBM is used to perform different machining operations like drilling, slitting, slotting, scribing operations. It is used for drilling holes of small diameter of the order of 0.025 mm. It is used for very thin stocks. Other applications are listed below :

(a) Making complex profiles in thin and hard materials like integrated circuits and printed circuit boards (PCBS).

(b) Machining of mechanical components of watches.

(c) Smaller machining of very hard material parts.

Advantages

– Excellent control of the laser beam with a stable motion system achieves an extreme edge quality. Laser-cut parts have a condition of nearly zero edge deformation, or roll-off

- It is also faster than conventional tool-making techniques.
- Laser cutting has higher accuracy rates over other methods using heat generation, as well as water jet cutting.
- There is quicker turnaround for parts regardless of the complexity, because changes of the design of parts can be easily accommodated. Laser cutting also reduces wastage.
- In laser machining there is no physical tool. Thus no machining force or wear of the tool takes place.
- Large aspect ratio in laser drilling can be achieved along with acceptable accuracy or dimension, form or location
- Micro-holes can be drilled in difficult – to – machine materials.
- Though laser processing is a thermal processing but heat affected zone specially in pulse laser processing is not very significant due to shorter pulse duration.

Limitations

- High initial capital cost
- High maintenance cost
- Not very efficient process
- Presence of Heat Affected Zone – specially in gas assist CO_2 laser cutting
- Thermal process – not suitable for heat sensitive materials like aluminium glass fiber laminate and copper alloys due to their ability to reflect light as well as absorb and conduct heat.
- The material being cut gets very hot, so in narrow areas, thermal expansion may be a problem.
- Distortion can be caused this is typically a problem in dense patterns of holes.

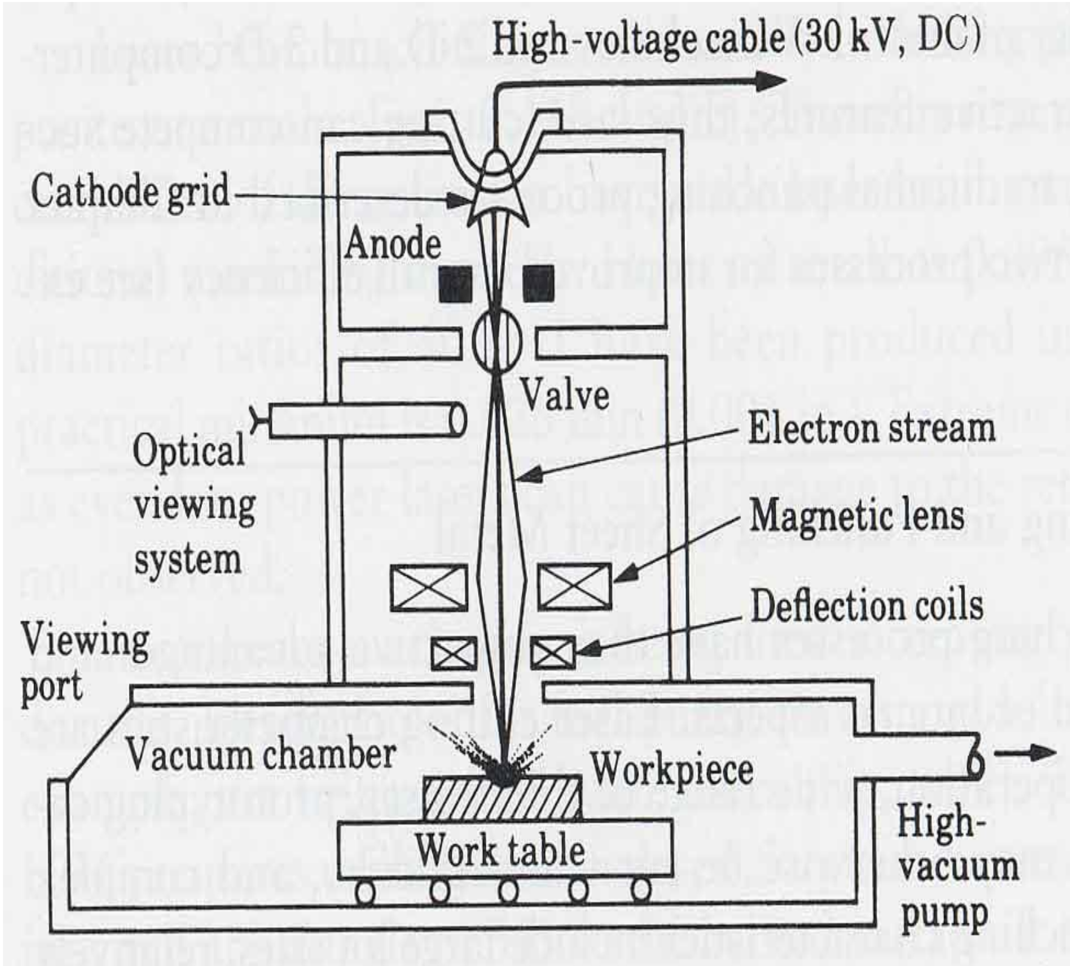
Electron beam machining (EBM)

- Instead of electrical sparks, this method uses a stream of focused, high-velocity electrons from an electron gun to melt and vaporize the work-piece material.
- In EBM, electrons are accelerated to a velocity of 200,000 km/s or nearly three-fourths that of light
- Electron Beam Machining is required to be carried out in vacuum.
- Otherwise the electrons would interact with the air molecules, thus they would loose their energy and cutting ability.
- Unlike in LASER Beam Welding, the gun in EBM is used in pulsed mode.
- Holes can be drilled in thin sheets using a single pulse. For thicker plates, multiple pulses would be required

Principle of working

- The electron gun consists of a tungsten filament, which acts as cathode.
- Such cathode filaments are heated to a temperature of around 2500^0C. Such heating leads to thermo-ionic emission of electrons, which is further enhanced by maintaining very low vacuum within the chamber of the electron beam gun.
- Just after the cathode, there is an annular bias grid.
- A high negative bias is applied to this grid so that the electrons generated by this cathode do not diverge and approach the next element, the annular anode, in the form of a beam.
- The annular anode now attracts the electron beam and gradually gets accelerated. As they leave the anode section, the electrons may achieve a velocity as high as 75% of the velocity of light.
- Beam is focused through electromagnetic lens, reducing diameter to as small as 0.025 mm (0.001 in)On impinging work surface, kinetic energy of electrons is converted to thermal energy of extremely high density (1.5billion W/mm^2)which melts or vaporizes material in a very localized area

Equipment



- in EBM the gun is operated in pulse mode. This is achieved by appropriately biasing the biased grid located just after the cathode.
- Switching pulses are given to the bias grid so as to achieve pulse duration of as low as 50 μs to as long as 15 ms.
- Beam current is directly related to the number of electrons emitted by the cathode or available in the beam. Beam current once again can be as low as 200 μamp to 1 amp.
- Increasing the beam current directly increases the energy per pulse. Similarly increase in pulse duration also enhances energy per pulse. High-energy pulses (in excess of 100 J/pulse) can machine larger holes on thicker plates.

Application

- Ideal for micromachining

- Drilling small diameter holes - down to 0.05 mm like for orifices in nuclear reactors, rotors and aircraft engines
- Cutting slots only about 0.025 mm wide
- To produce wire drawing dies, light ray orifices
- To produce metering holes of valves
- To scribe thin films
- Drilling holes with very high depth-to-diameter ratios greater than 100:1

Limitations

- However, EBM has its own share of limitations. 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