

STELLA MARY'S COLLEGE OF ENGINEERING

(Accredited by NAAC, Approved by AICTE - New Delhi, Affiliated to Anna University Chennai)

Aruthenganvilai, Azhikal Post, Kanyakumari District, Tamilnadu - 629202.

ME8073 UNCONVENTIONAL MACHINING PROCESSES

(Anna University: R2017)



Prepared By

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DEPARTMENT OF MECHANICAL ENGINEERING

COURSE MATERIAL

REGULATION	2017
YEAR	IV
SEMESTER	07
COURSE NAME	UNCONVENTIONAL MACHINING PROCESSES
COURSE CODE	ME 8073
NAME OF THE COURSE INSTRUCTOR	Dr. M. SIVAPRAKASH

SYLLABUS:

UNIT I INTRODUCTION AND MECHANICAL ENERGY BASED PROCESSES 9

Unconventional machining Process – Need – classification – merits, demerits and applications. Abrasive Jet Machining – Water Jet Machining – Abrasive Water Jet Machining - Ultrasonic Machining. (AJM, WJM, AWJM and USM). Working Principles – equipment used – Process parameters – MRR- Applications.

UNIT II THERMAL AND ELECTRICAL ENERGY BASED PROCESSES 9

Electric Discharge Machining (EDM) – Wire cut EDM – Working Principle-equipments-Process Parameters-Surface Finish and MRR- electrode / Tool – Power and control Circuits-Tool Wear – Dielectric – Flushing — Applications. Laser Beam machining and drilling, (LBM), plasma, Arc machining (PAM) and Electron Beam Machining (EBM). Principles – Equipment –Types - Beam control techniques – Applications.

UNIT III CHEMICAL AND ELECTRO-CHEMICAL ENERGY BASED PROCESSES 9

Chemical machining and Electro-Chemical machining (CHM and ECM)- Etchants – Maskant - techniques of applying maskants - Process Parameters – Surface finish and MRR-Applications. Principles of ECM- equipments-Surface Roughness and MRR Electrical circuit-Process Parameters- ECG and ECH - Applications.

UNIT IV ADVANCED NANO FINISHING PROCESSES**9**

Abrasive flow machining, chemo-mechanical polishing, magnetic abrasive finishing, magneto rheological finishing, magneto rheological abrasive flow finishing their working principles, equipments, effect of process parameters, applications, advantages and limitations.

UNIT V RECENT TRENDS IN NON-TRADITIONAL MACHINING PROCESSES**9**

Recent developments in non-traditional machining processes, their working principles, equipments, effect of process parameters, applications, advantages and limitations. Comparison of non-traditional machining processes.

TEXT BOOKS :

1. Vijay.K. Jain “Advanced Machining Processes” Allied Publishers Pvt. Ltd., NewDelhi, 2007
2. Pandey P.C. and Shan H.S. “Modern Machining Processes” Tata McGraw-Hill, New Delhi, 2007.

REFERENCES:

1. Benedict. G.F. “Nontraditional Manufacturing Processes”, Marcel Dekker Inc., New York, 1987.
2. Mc Geough, “Advanced Methods of Machining”, Chapman and Hall, London, 1998.
3. Paul De Garmo, J.T.Black, and Ronald. A.Kohser, “Material and Processes in Manufacturing” Prentice Hall of India Pvt. Ltd., 8thEdition, NewDelhi , 2001.

Course Outcome Articulation Matrix

<i>Course Code / CO No</i>	<i>Program Outcome</i>												<i>PSO</i>		
	<i>1</i>	<i>2</i>	<i>3</i>	<i>4</i>	<i>5</i>	<i>6</i>	<i>7</i>	<i>8</i>	<i>9</i>	<i>10</i>	<i>11</i>	<i>12</i>	<i>1</i>	<i>2</i>	<i>3</i>
ME8073 / C419.1	3	1	1	2	3	0	0	1	2	0	1	3	3	0	3
ME8073 / C419.2	3	1	1	2	3	0	0	1	2	0	1	3	3	0	3
ME8073 / C419.3	3	1	1	2	3	0	0	1	2	0	1	3	3	0	3
ME8073 / C419.4	3	1	1	2	3	0	0	1	2	0	1	3	3	0	3
ME8073 / C419.5	3	1	1	2	3	0	0	1	2	0	1	3	3	0	3
Average	3	1	1	2	3	0	0	1	2	0	1	3	3	0	3

UNIT I INTRODUCTION

1.1 INTRODUCTION

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

Extremely hard and brittle materials are difficult to machine by traditional machining processes such as turning, drilling, shaping and milling. Nontraditional machining processes, also called advanced manufacturing processes, are employed where traditional machining processes are not feasible, satisfactory or economical due to special reasons as outlined below.

- Very hard fragile materials difficult to clamp for traditional machining
- When the work piece is too flexible or slender
- When the shape of the part is too complex

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

Manufacturing processes can be broadly divided into two groups)

a) Primary manufacturing processes: Provide basic shape and size

b) Secondary manufacturing processes: Provide final shape and size with tighter control on dimension, surface characteristics

Material Removal Processes Once Again Can Be Divided Into Two Groups

1. Conventional Machining Processes
2. Non-Traditional Manufacturing Processes or Unconventional Machining processes

Conventional Machining Processes mostly remove material in the form of chips by applying forces on the work material with a wedge shaped cutting tool that is harder than the work material under machining condition.

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

1.2. NEED FOR UNCONVENTIONAL MACHINING PROCESSES

- Extremely hard and brittle materials or Difficult to machine material are difficult to Machine by traditional machining processes.
- When the work piece is too flexible or slender to support the cutting or grinding Forces when the shape of the part is too complex.

1.3. CLASSIFICATION OF UCM PROCESSES:

1. Mechanical Processes

- Abrasive Jet Machining (AJM)
- Abrasive Water Jet Machining (AWJM)
- Water Jet Machining (WJM)
- Ultrasonic Machining (USM)

2. Electrochemical Processes

- Electrochemical Machining (ECM)
- Electro Chemical Grinding (ECG)
- Electro Jet Drilling (EJD)

3. Electro-Thermal Processes

- Electro-discharge machining (EDM)
- Laser Jet Machining (LJM)
- Electron Beam Machining (EBM)

4. Chemical Processes

- Chemical Milling (CHM)
- Photochemical Milling (PCM)

1.4. BRIEF OVERVIEW

1 ULTRA SONIC MACHINING

USM is a mechanical material removal process in which the material is removed by repetitive impact of abrasive particles carried in liquid medium on to the work surface, by a shaped tool, vibrating at ultrasonic frequency.

2 ABRASIVE JET MACHINING

It is the material removal process where the material is removed or machined by the impact erosion of the high velocity stream of air or gas and abrasive mixture, which is focused on to the work piece.

3. LASER BEAM MACHINING

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

4. ELECTRON EAM MACHINING

It is the thermo-electrical material removal process on which the material is removed by the high velocity electron beam emitted from the tungsten filament made to impinge on the work surface, where kinetic energy of the beam is transferred to the work piece material, producing intense heat, which makes the material to melt or vaporize it locally.

5. ELECTRO CHEMICAL MACHINING

It is the controlled removal of metals by the anodic dissolution in an electrolytic medium, where the work piece (anode) and the tool (cathode) are connected to the electrolytic circuit, which is kept, immersed in the electrolytic medium

6. ELECTO CHEMICAL GRINDING

ECG is the material removal process in which the material is removed by the combination of Electro- Chemical decomposition as in ECM process and abrasive due to grinding.

7. PLASMA ARC MACHINING

Plasma is defined as the gas, which has been heated to a sufficiently high temperature to Become ionized.

8. WATER JET MACHINING

Water jet cutting can reduce the costs and speed up the processes by eliminating or reducing expensive secondary machining process. Since no heat is applied on the materials, cut edges are clean with minimal burr. Problems such as cracked edge defects, crystallization, hardening, reduced wealdability and machinability are reduced in this process.

9. ELECTRICAL DISCHARGE MACHINING

EDM is the controlled erosion of electrically conductive materials by the Initiation of rapid and repetitive spark discharge between the electrode tool to the cathode and work to anode separated by a small gap kept in the path of dielectric medium. This Process also called spark erosion.

UNIT II MECHANICAL ENERGY BASED PROCESSES

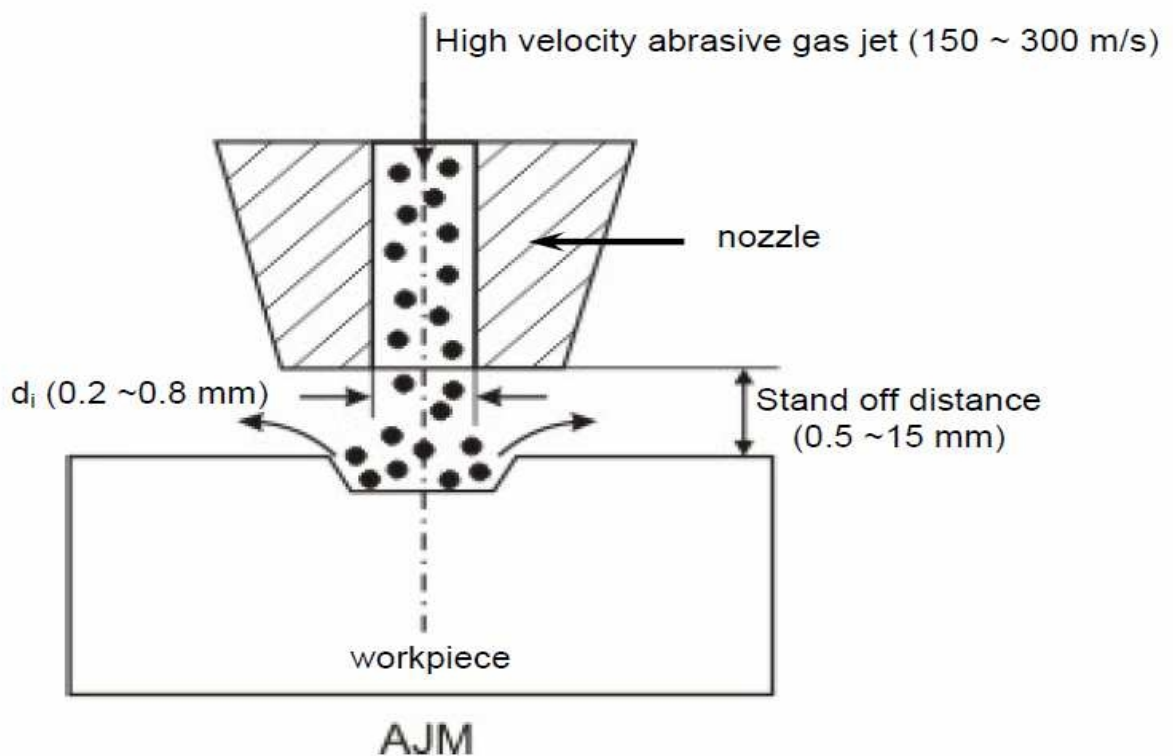
2. MECHANICAL PROCESSES

- Abrasive Jet Machining (AJM)
- Abrasive Water Jet Machining (AWJM)
- Water Jet Machining (WJM)
- Ultrasonic Machining (USM)

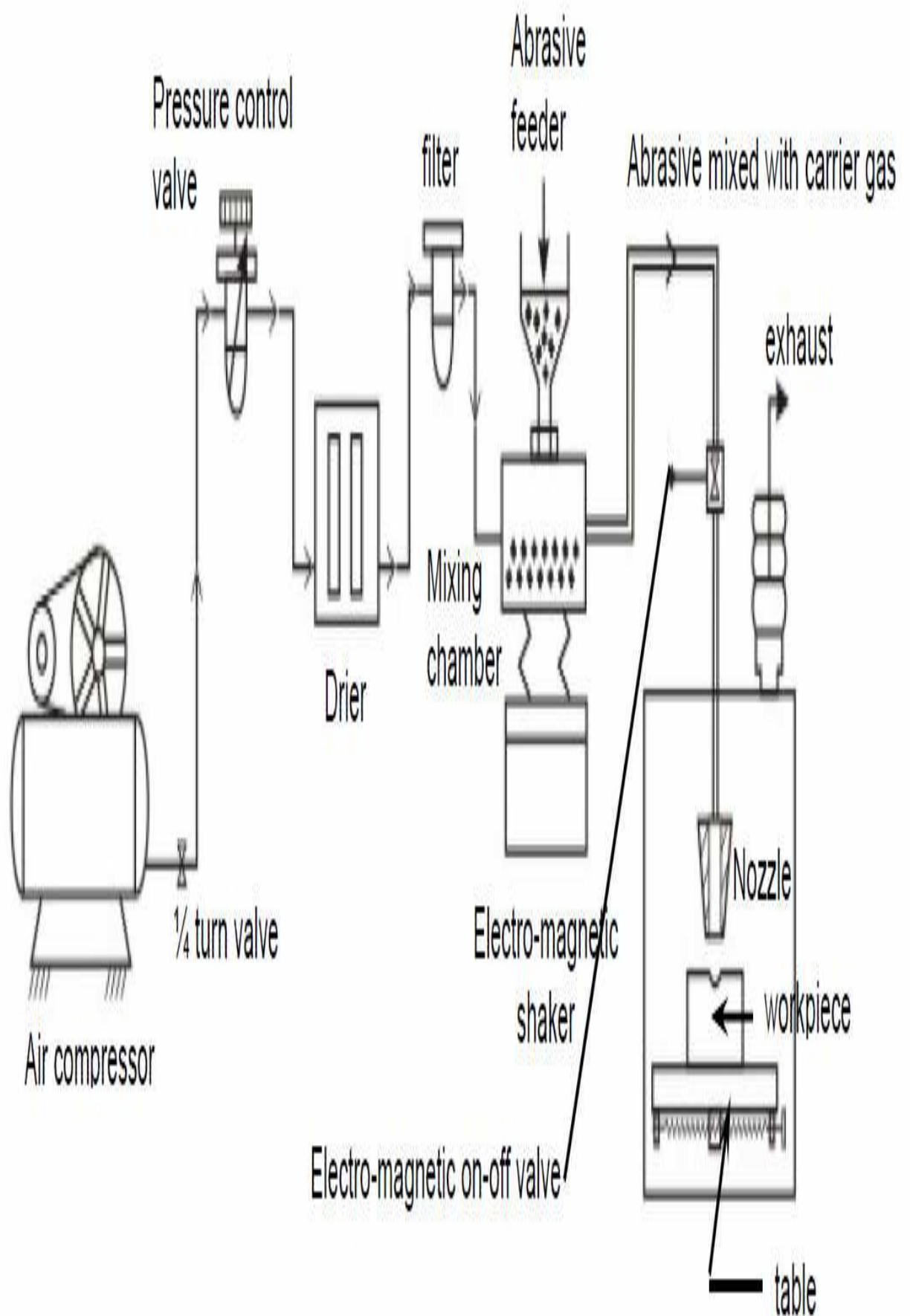
2.1 ABRASIVE JET MACHINING (AJM)

In Abrasive Jet Machining (AJM), abrasive particles are made to impinge on the work material at a high velocity. The high velocity abrasive particles remove the material by micro-cutting action as well as brittle fracture of the work material.

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 standoff distance of around 2 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.



Skematic Arrangement Of Ajm



2.1.1. Process Parameters and Machining Characteristics

Abrasive: Material – Al₂O₃ / SiC / glass beads

Shape – irregular / spherical

Size – 10 ~ 50 μ m

Mass flow rate – 2 ~ 20 gm/min

Carrier gas: Composition – Air, CO₂, N₂

Density – Air ~ 1.3 kg/m³

Velocity – 500 ~ 700 m/s Pressure – 2 ~ 10 bar

Flow rate – 5 ~ 30 lpm

Abrasive Jet : Velocity – 100 ~ 300 m/s

Mixing ratio – mass flow ratio of abrasive to gas

Stand-off distance – 0.5 ~ 5 mm

Impingement Angle – 60 ~ 90

Nozzle: Material – WC

Diameter – (Internal) 0.2 ~ 0.8 mm

Life – 10 ~ 300 hours

2.1.2. Modeling of material removal

Material removal in AJM takes place due to brittle fracture of the work material due to impact of high velocity abrasive particles.

2.1.3. Modeling has been done with the following assumptions:

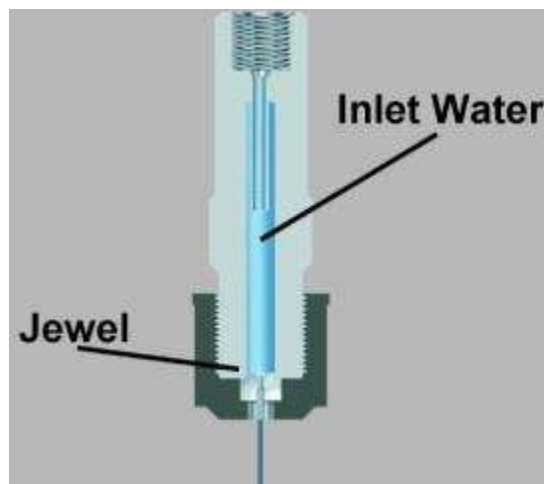
- (i) Abrasives are spherical in shape and rigid. The particles are characterized by the mean grit diameter
- (ii) The kinetic energy of the abrasives are fully utilized in removing material
- (iii) Brittle materials are considered to fail due to brittle fracture and the fracture volume is considered to be hemispherical with diameter equal to chordal length of the indentation
- (iv) For ductile material, removal volume is assumed to be equal to the indentation volume due to particulate impact

2.2. WATER JET MACHINING (WJM)

2.2.1. Introduction

Water jet cutting can reduce the costs and speed up the processes by eliminating or reducing expensive secondary machining process. Since no heat is applied on the materials, cut edges are clean with minimal burr. Problems such as cracked edge defects, crystallization, hardening, reduced weldability and machinability are reduced in this process.

Water jet technology uses the principle of pressurizing water to extremely high pressures, and allowing the water to escape through a very small opening called “orifice” or “jewel”. Water jet cutting uses the beam of water exiting the orifice to cut soft materials. This method is not suitable for cutting hard materials. The inlet water is typically pressurized between 1300 – 4000 bars. This high pressure is forced through a tiny hole in the jewel, which is typically 0.18 to 0.4 mm in diameter. Picture of water jet cutting process.



2.2.2. Applications

Water jet cutting is mostly used to cut lower strength materials such as wood, plastics and aluminium. When abrasives are added, (abrasive water jet cutting) stronger materials such as steel and tool steel.

2.2.3. Advantages Of Water Jet Cutting

- There is no heat generated in water jet cutting; which is especially useful for cutting tool steel and other metals where excessive heat may change the properties of the material.
- Unlike machining or grinding, water jet cutting does not produce any dust or particles that are harmful if inhaled.
- Other advantages are similar to abrasive water jet cutting

2.2.4. Disadvantages of water jet cutting

- One of the main disadvantages of water jet cutting is that a limited number of materials can be cut economically.
- Thick parts cannot be cut by this process economically and accurately
- Taper is also a problem with water jet cutting in very thick materials. Taper is when the jet exits the part at different angle than it enters the part, and cause dimensional inaccuracy.

2.3. ABRASIVE WATER-JET MACHINING (AWJM)

2.3.1. Introduction

Abrasive water jet cutting is an extended version of water jet cutting; in which the water jet contains abrasive particles such as silicon carbide or aluminium oxide in order to increase the material removal rate above that of water jet machining. Almost any type of material ranging from hard brittle materials such as ceramics, metals and glass to extremely soft materials such as foam and rubbers can be cut by abrasive water jet cutting. The narrow cutting stream and computer controlled movement enables this process to produce parts accurately and efficiently. This machining process is especially ideal for cutting materials that cannot be cut by laser or thermal cut. Metallic, non-metallic and advanced composite materials of various thicknesses can be cut by this process. This process is particularly suitable for heat sensitive materials that cannot be machined by processes that produce heat while machining.

The schematic of abrasive water jet cutting is shown in Figure 15 which is similar to water jet cutting apart from some more features underneath the jewel; namely abrasive, guard and mixing tube. In this process, high velocity water exiting the jewel creates a vacuum which sucks abrasive from the abrasive line, which mixes with the water in the mixing tube to form a high velocity beam of abrasives.

2.3.2.Applications

Abrasive water jet cutting is highly used in aerospace, automotive and electronics industries. In aerospace industries, parts such as titanium bodies for military aircrafts, engine components (aluminium, titanium, and heat resistant alloys), aluminium body parts and interior cabin parts are made using abrasive water jet cutting.

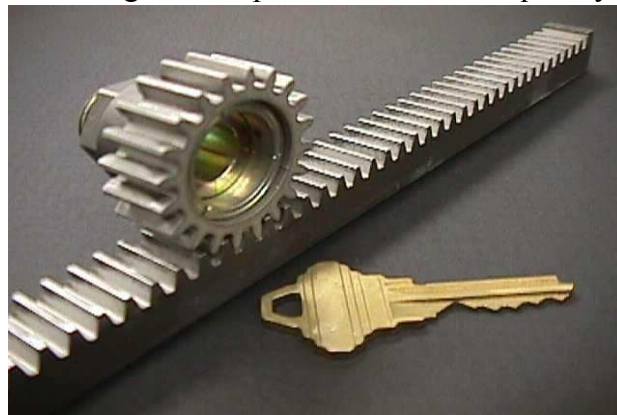
In automotive industries, parts like interior trim (head liners, trunk liners, and door panels) and fiber glass body components and bumpers are made by this process. Similarly, in electronics industries, circuit boards and cable stripping are made by abrasive water jet cutting.

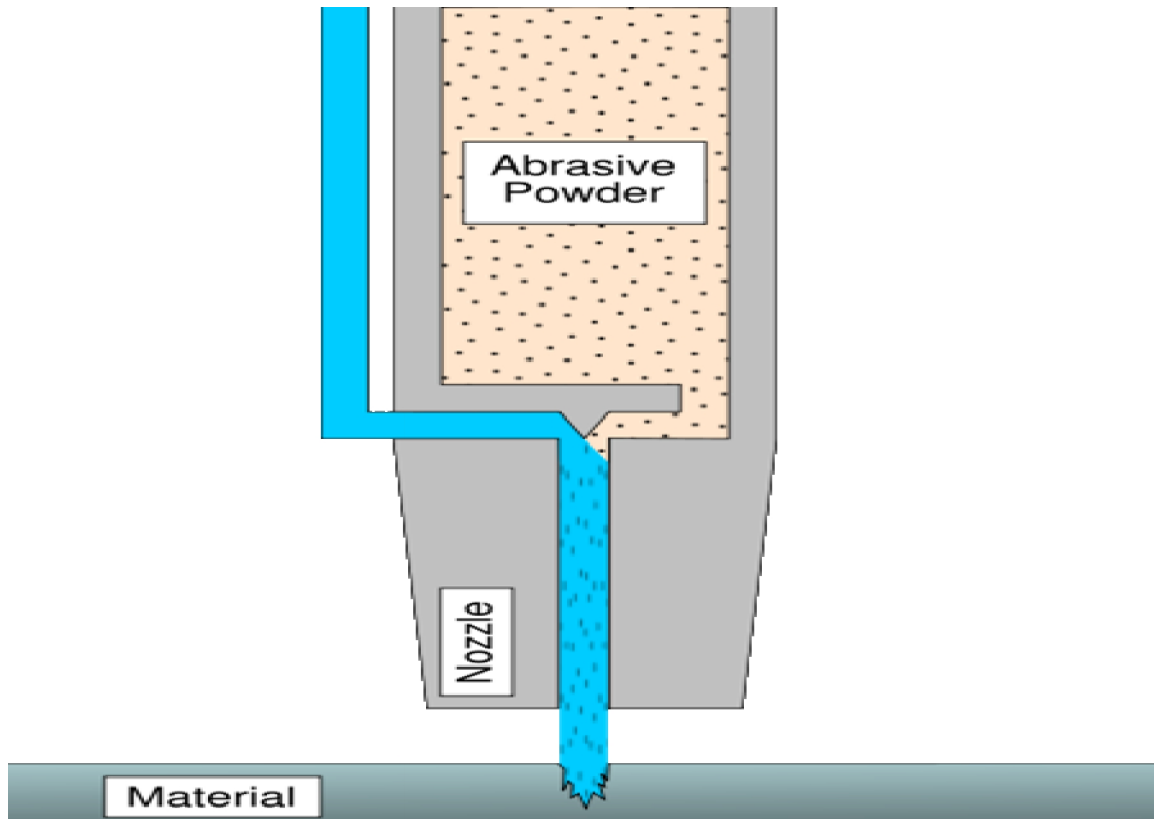
2.3.2.Advantages of abrasive water jet cutting

- In most of the cases, no secondary finishing required
- No cutter induced distortion
- Low cutting forces on work pieces
- Limited tooling requirements
- Little to no cutting burr
- Typical finish 125-250 microns
- Smaller kerf size reduces material wastages
- No heat affected zone
- Localises structural changes
- No cutter induced metal contamination
- Eliminates thermal distortion
- No slag or cutting dross
- Precise, multi plane cutting of contours, shapes, and bevels of any angle.

2.3.3.Limitations of abrasive water jet cutting

- Cannot drill flat bottom
- Cannot cut materials that degrades quickly with moisture
- Surface finish degrades at higher cut speeds which are frequently used for rough cuts





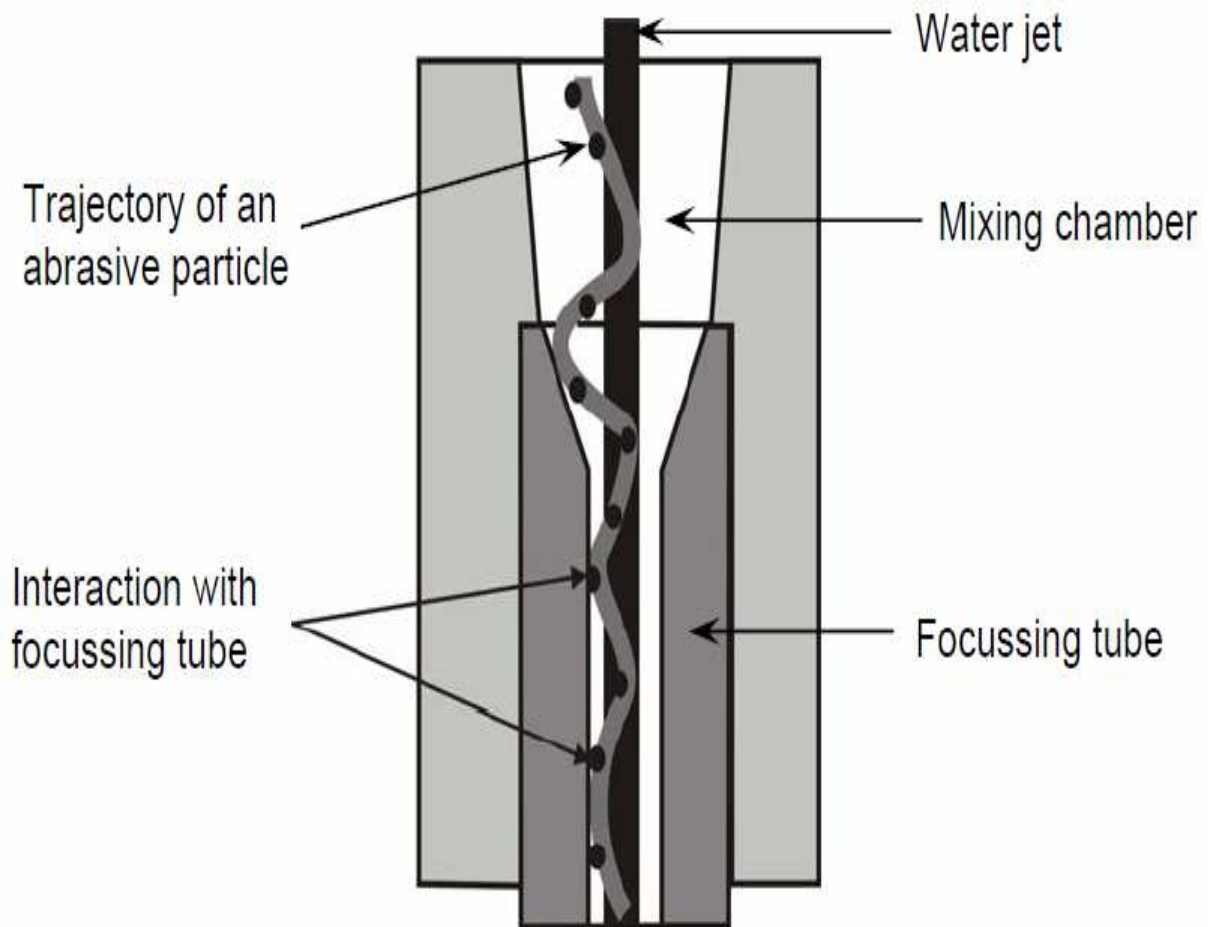
The major disadvantages of abrasive water jet cutting are high capital cost and high noise levels during operation.

A component cut by abrasive water jet cutting is shown in Figure .As it can be seen, large parts can but cut with very narrow kerfs which reduces material wastages. The complex shape part made by abrasive water jet cutting

2.3.4. Abrasive water jet cutting

- WJM - Pure
- WJM - with stabilizer
- AWJM – entrained – three phase –abrasive, water and air
- AWJM – suspended – two phase –abrasive and water o direct pumping

- i. Indirect Pumping
- ii. Bypass pumping



2.4. ULTRASONIC MACHINING (USM)

2.4.1. Introduction

USM is mechanical material removal process or an abrasive process used to erode holes or cavities on hard or brittle work piece by using shaped tools, high frequency mechanical motion and an abrasive slurry. USM offers a solution to the expanding need for machining brittle materials such as single crystals, glasses and polycrystalline ceramics, and increasing complex operations to provide intricate shapes and work piece profiles. It is therefore used extensively in machining hard and brittle materials that are difficult to machine by traditional manufacturing processes. The hard particles in slurry are accelerated toward the surface of the work piece by a tool oscillating at a frequency up to 100 KHz - through repeated abrasions, the tool machines a cavity of a cross section identical to its own.

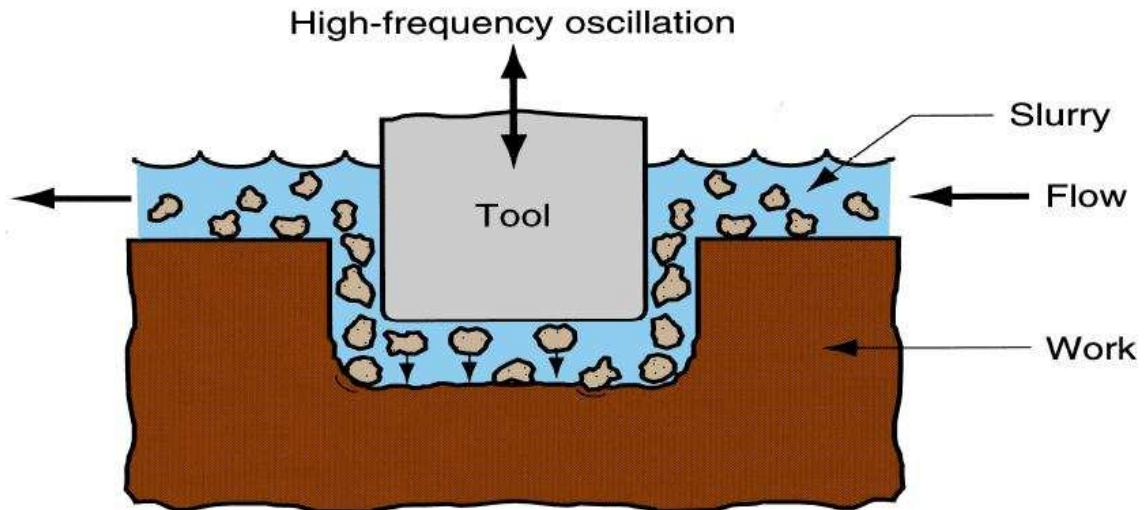


Figure : Schematic of ultrasonic machine tool

USM is primarily targeted for the machining of hard and brittle materials (dielectric or conductive) such as boron carbide, ceramics, titanium carbides, rubies, quartz etc. USM is a versatile machining process as far as properties of materials are concerned. This process is able to effectively machine all materials whether they are electrically conductive or insulator.

For an effective cutting operation, the following parameters need to be carefully considered:

- The machining tool must be selected to be highly wear resistant, such as high-carbon steels.
- The abrasives (25-60 μm in dia.) in the (water-based, up to 40% solid volume) slurry
Includes: Boron carbide, silicon carbide and aluminum oxide.

Applications

The beauty of USM is that it can make non round shapes in hard and brittle materials. Ultrasonically machined non round-hole part is shown in Figure 11.



Figure : A non-round hole made by USM

2.4.2 Advantage of USM

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

- Any materials can be machined regardless of their electrical conductivity
- Especially suitable for machining of brittle materials
- Machined parts by USM possess better surface finish and higher structural integrity.
- USM does not produce thermal, electrical and chemical abnormal surface

2.4.3. Disadvantages of USM

- USM has higher power consumption and lower material-removal rates than traditional Fabrication processes.
- Tool wears fast in USM.
- Machining area and depth is restraint in USM.

UNITIII ELECTRICAL BASED PROCESSES

3. ELECTRICAL BASED PROCESSES

- Electrical Discharge `Machining (EDM)
- Wire Cut Electrical Discharge Machining (WCEDM)

3.1. Electrical Discharge `Machining (EDM)

Electrical discharge machining (EDM) is one of the most widely used non-traditional machining processes. The main attraction of EDM over traditional machining processes such as metal cutting using different tools and grinding is that this technique utilizes thermoelectric process to erode undesired materials from the work piece by a series of discrete electrical sparks between the workpiece and the electrode. A picture of EDM machine in operation



The traditional machining processes rely on harder tool or abrasive material to remove the softer material whereas non-traditional machining processes such as EDM uses electrical spark or thermal energy to erode unwanted material in order to create desired shape. So, the hardness of the material is no longer a dominating factor for EDM process. A schematic of an EDM process is shown in Figure 2, where the tool and the workpiece are Immersed in a dielectric fluid.

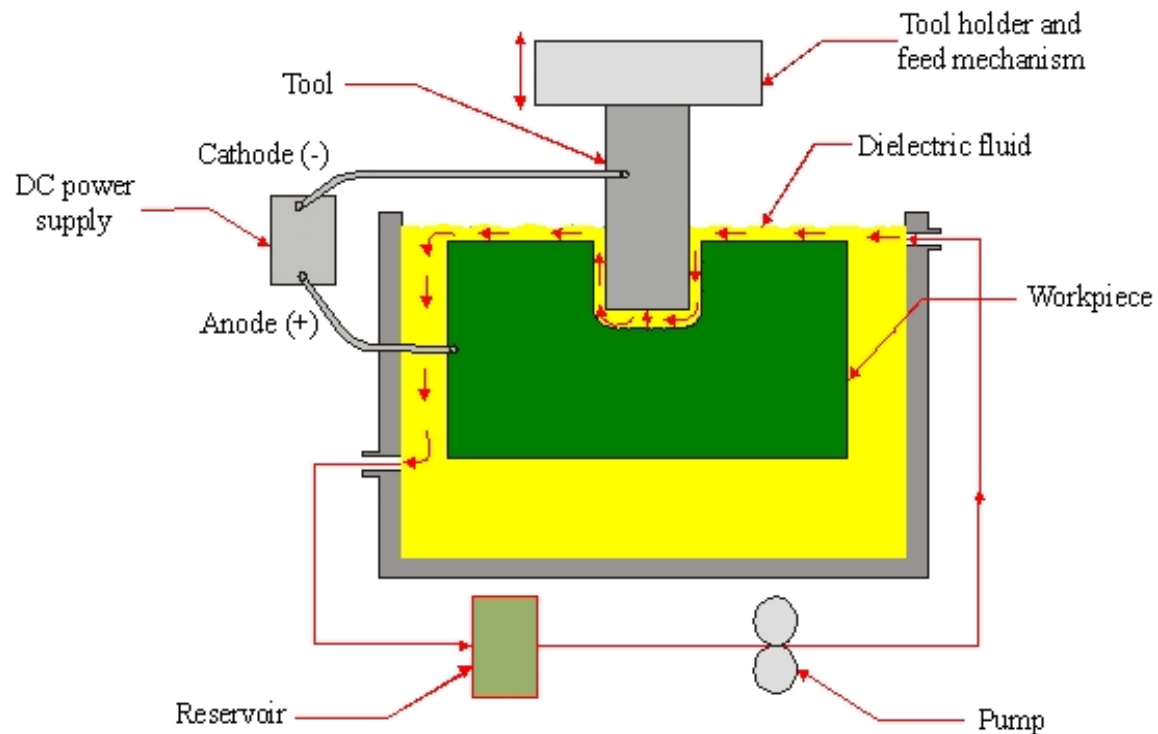


Figure: Schematic of EDM process

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

3.1.1. Application of EDM

The EDM process has the ability to machine hard, difficult-to-machine materials. Parts with complex, precise and irregular shapes for forging, press tools, extrusion dies, difficult internal shapes for aerospace and medical applications can be made by EDM process. Some of the shapes made by EDM process are shown in Figure.



Figure: Difficult internal parts made by EDM process

3.1.2. Working principle of EDM

As shown in Figure 1, at the beginning of EDM operation, a high voltage is applied across the narrow gap between the electrode and the workpiece. This high voltage induces an electric field in the insulating dielectric that is present in narrow gap between electrode and workpiece. This cause conducting particles suspended in the dielectric to concentrate at the points of strongest electrical field. When the potential difference between the electrode and the workpiece is sufficiently high, the dielectric breaks down and a transient spark discharges through the dielectric fluid, removing small amount of material from the workpiece surface. The volume of the material removed per spark discharge is typically in the range of 10^{-6} to 10^{-6} mm³.

The material removal rate, MRR, in EDM is calculated by the following formula:

$$MRR = 40 I / T_m^{1.23} \quad (\text{cm}^3/\text{min})$$

Where, I is the current amp, T_m is the melting temperature of workpiece in °C

3.1.3. Advantages of EDM

The main advantages of DM are:

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

3.1.3. Limitations of EDM

The main limitations of this process are:

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

3.1.4. Dielectric fluids

Dielectric fluids used in EDM process are hydrocarbon oils, kerosene and deionised water.

The functions of the dielectric fluid are to:

- Act as an insulator between the tool and the workpiece.
- Act as coolant.
- Act as a flushing medium for the removal of the chips.

The electrodes for EDM process usually are made of graphite, brass, copper and copper-tungsten alloys.

3.1.5. Design considerations for EDM process are as follows:

- Deep slots and narrow openings should be avoided.
- The surface smoothness value should not be specified too fine.
- Rough cut should be done by other machining process. Only finishing operation should be done in this process as MRR for this process is low.

3.2. WIRE CUT ELECTRICAL DISCHARGE MACHINING (WCEDM)

EDM, primarily, exists commercially in the form of die-sinking machines and wire-process, a slowly moving wire travels along a prescribed path and removes material from the workpiece. Wire EDM uses electro-thermal mechanisms to cut electrically conductive materials. The material is removed by a series of discrete discharges between the wire electrode and the workpiece in the presence of dielectric fluid, which creates a path for each discharge as the fluid becomes ionized in the gap. The area where discharge takes place is heated to extremely high temperature, so that the surface is melted and removed. The removed particles are flushed away by the flowing dielectric fluids.

The wire EDM process can cut intricate components for the electric and aerospace industries.

This non-traditional machining process is widely used to pattern tool steel for die manufacturing cutting machines (Wire EDM). The concept of wire EDM is shown in Figure . In this

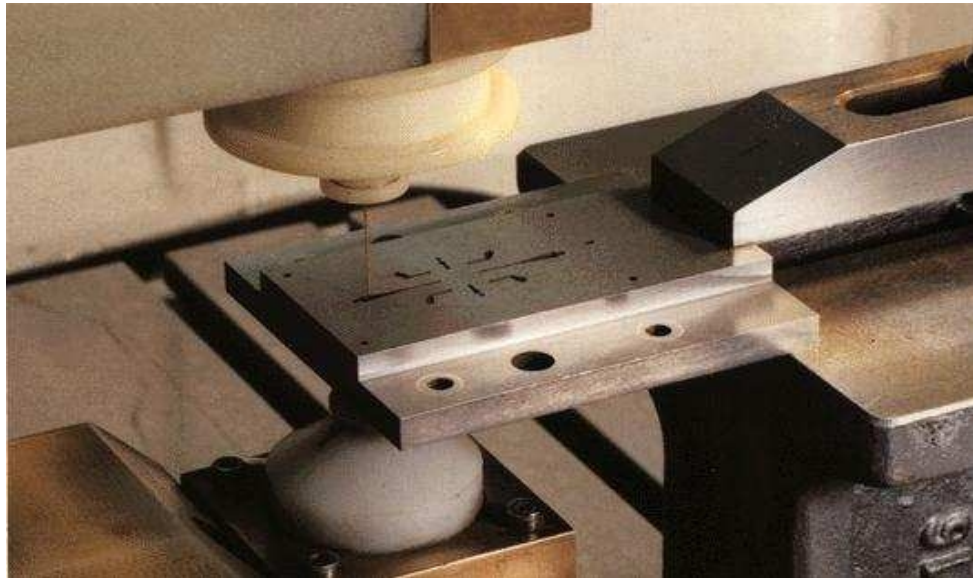


Figure: Wire erosion of an extrusion die

The wires for wire EDM is made of brass, copper, tungsten, molybdenum. Zinc or brass coated wires are also used extensively in this process. The wire used in this process should possess high tensile strength and good electrical conductivity. Wire EDM can also employ to cut cylindrical objects with high precision. The sparked eroded extrusion dies are presented in Figure.

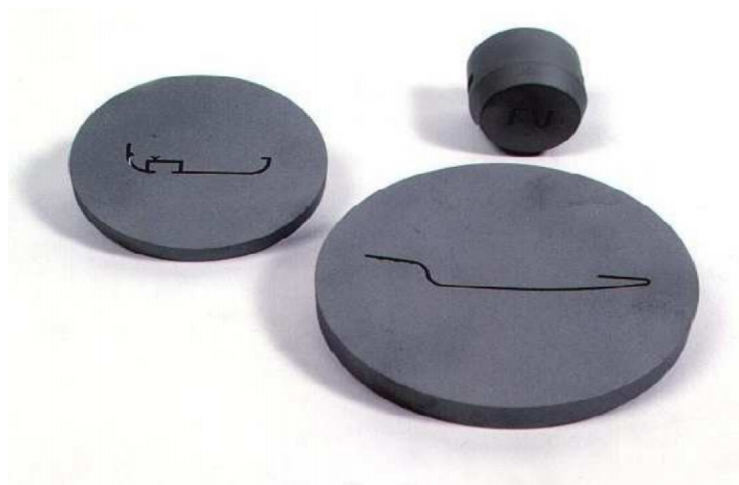


Figure : Sparked eroded extrusion dies

This process is usually used in conjunction with CNC and will only work when a part is to be cut completely through. The melting temperature of the parts to be machined is an important parameter for this process rather than strength or hardness. The surface quality and MRR of the machined surface by wire EDM will depend on different machining parameters such as applied peak current, and wire materials.

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Figure: Sparked eroded extrusion dies

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UNIT-IV CHEMICAL AND ELECTRO CHEMICAL ENERGY BASED PROCESSES

4. CHEMICAL AND ELECTRO CHEMICAL ENERGY BASED PROCESSES

- Chemical Machining
- Chemical milling
- Electrochemical Machining
- Electrochemical Honing
- Electrochemical Grinding

4.1. CHEMICAL MACHINING

Chemical machining (CM) is the controlled dissolution of work piece material (etching) by means of a strong chemical reagent (etchant). In CM material is removed from selected areas of work piece by immersing it in a chemical reagents or etchants; such as acids and alkaline solutions. Material is removed by microscopic electrochemical cell action, as occurs in corrosion or chemical dissolution of a metal. This controlled chemical dissolution will simultaneously etch all exposed surfaces even though the penetration rates of the material removal may be only 0.0025–0.1 mm/min. The basic process takes many forms: chemical milling of pockets, contours, overall metal removal, chemical blanking for etching through thin sheets; photochemical machining (pcm) for etching by using of photosensitive resists in microelectronics; chemical or electrochemical polishing where weak chemical reagents are used (sometimes with remote electric assist) for polishing or deburring and chemical jet machining where a single chemically active jet is used. A schematic of chemical machining process is shown in Figure.

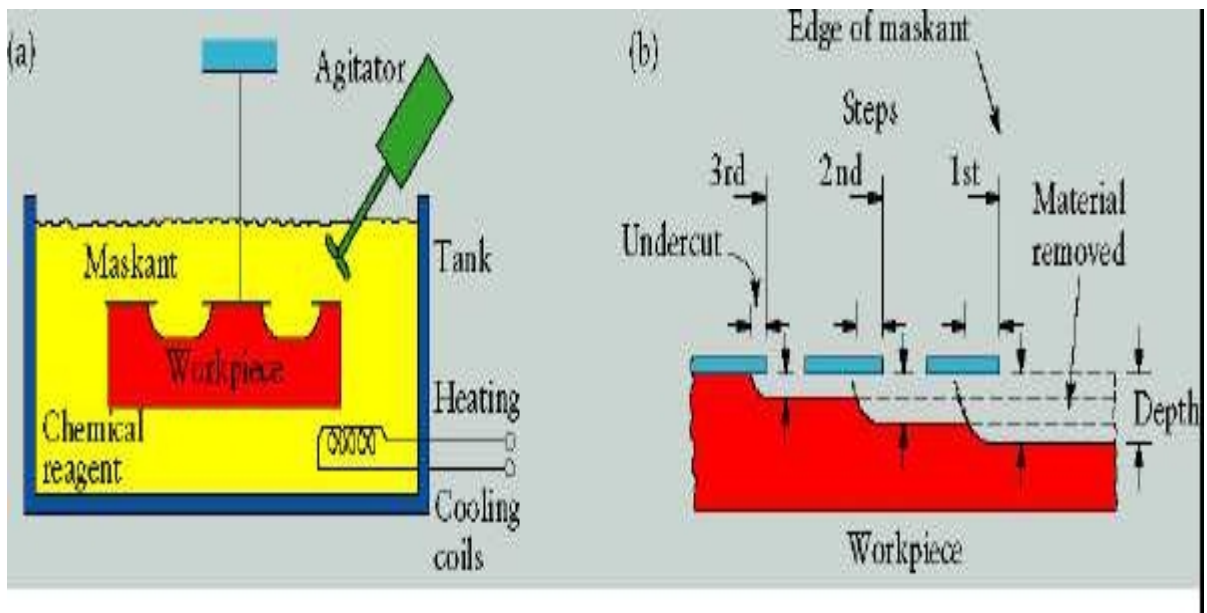


Figure. (a) Schematic of chemical machining process (b) Stages in producing a profiled cavity by chemical machining (Kalpakjain & Schmid)

4.2. Chemical milling

In chemical milling, shallow cavities are produced on plates, sheets, forgings and extrusions. The two key materials used in chemical milling process are etchant and maskant. Etchants are acid or alkaline solutions maintained within controlled ranges of chemical composition and temperature. Maskants are specially designed elastomeric products that are hand strippable and chemically resistant to the harsh etchants.

Steps in chemical milling

- Residual stress relieving: If the part to be machined has residual stresses from the previous processing, these stresses first should be relieved in order to prevent warping after chemical milling.
- Preparing: The surfaces are degreased and cleaned thoroughly to ensure both good adhesion of the masking material and the uniform material removal.
- Masking: Masking material is applied (coating or protecting areas not to be etched).
- Etching: The exposed surfaces are machined chemically with etchants.
- Demasking: After machining, the parts should be washed thoroughly to prevent further reactions with or exposure to any etchant residues. Then the rest of the masking material is removed and the part is cleaned and inspected.

Applications:

Chemical milling is used in the aerospace industry to remove shallow layers of material from large aircraft components missile skin panels (Figure 7), extruded parts for airframes.

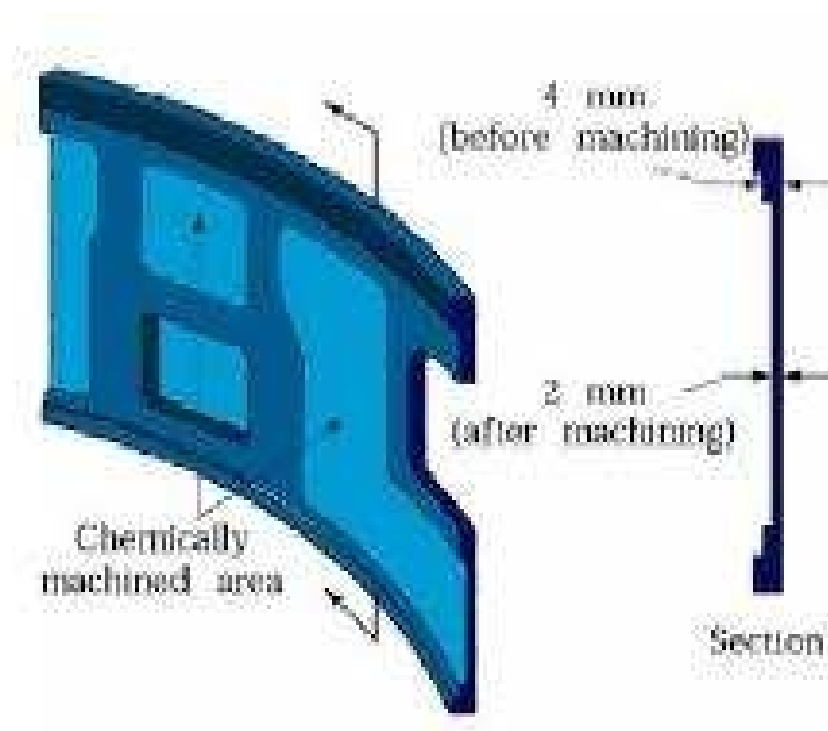


Figure: Missile skin-panel section contoured by chemical milling to improve the stiffness- to- weight ratio of the part (Kalpakjain & Schmid)

4.3. Electrochemical Machining (ECM)

Introduction

Electrochemical machining (ECM) is a metal-removal process based on the principle of reverse electroplating. In this process, particles travel from the anodic material (workpiece) toward the cathodic material (machining tool). A current of electrolyte fluid carries away the depleted material before it has a chance to reach the machining tool. The cavity produced is the female mating image of the tool shape.

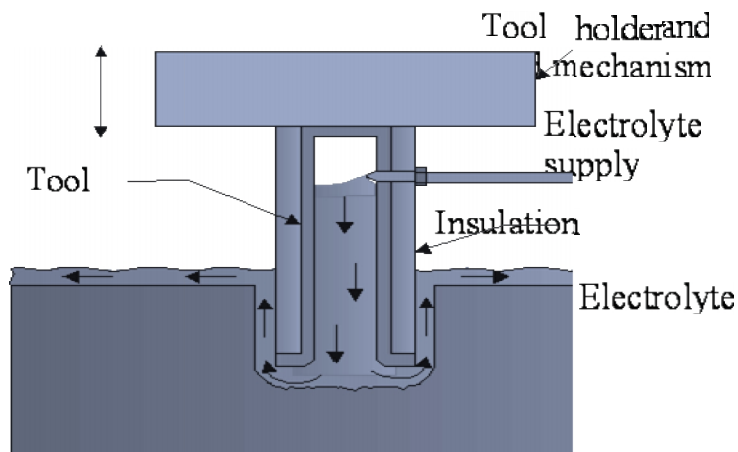


Figure :ECM process

Similar to EDM, the work piece hardness is not a factor, making ECM suitable for machining difficult-to-machine materials. Difficult shapes can be made by this process on materials regardless of their hardness. A schematic representation of ECM process is shown in Figure. The ECM tool is positioned very close to the work piece and a low voltage, high amperage DC current is passed between the work piece and electrode. Some of the shapes made by ECM process is shown in Figure.



Figure: Parts made by ECM

Advantages of ECM

- The components are not subject to either thermal or mechanical stress.
- No tool wears during ECM process.
- Fragile parts can be machined easily as there is no stress involved.
- ECM deburring can debur difficult to access areas of parts.
- High surface finish (up to 25 μm in) can be achieved by ECM process.
- Complex geometrical shapes in high-strength materials particularly in the aerospace industry for the mass production of turbine blades, jet-engine parts and nozzles can be machined repeatedly and accurately.
- Deep holes can be made by this process.

Limitations of ECM

- ECM is not suitable to produce sharp square corners or flat bottoms because of the tendency for the electrolyte to erode away sharp profiles.
- ECM can be applied to most metals but, due to the high equipment costs, is usually used primarily for highly specialized applications.

Material removal rate, MRR, in ECM

$$\text{MRR} = C \cdot I \cdot h \quad (\text{cm}^3/\text{min})$$

C: specific (material) removal rate (e.g., 0.2052 $\text{cm}^3/\text{amp-min}$ for nickel); I: current (amp);

h: current efficiency (90–100%).

The rates at which metal can electrochemically remove are in proportion to the current passed through the electrolyte and the elapsed time for that operation. Many factors other than Current influence the rate of machining. These involve electrolyte type, rate of electrolyte flow, and some other process conditions.

4.4. ELECTROCHEMICAL HONING

Electrochemical honing is one of the non-equilibrium gap processes in ECM and is a new technique, which in spite of being used in some industrial plants especially to smooth surfaces, is still not fully described due to the variety of the factors affecting the process. More information about the process is required especially the effects of the working parameters on the produced surface roughness. A special honing tool was designed by using different tool tip shapes (rectangular, circular, triangle & inclined) to study the ability for improving the surface roughness. This work presents a study for the factors affecting the electrochemical honing process especially the machining time, work piece material, initial working gap, tool rotational speed, tool tip shape and the inclined tool tip angle. The results are finally furnished with the aim to generalize a useful guideline for the user to enable proper selection of conditions for obtaining good surface quality.

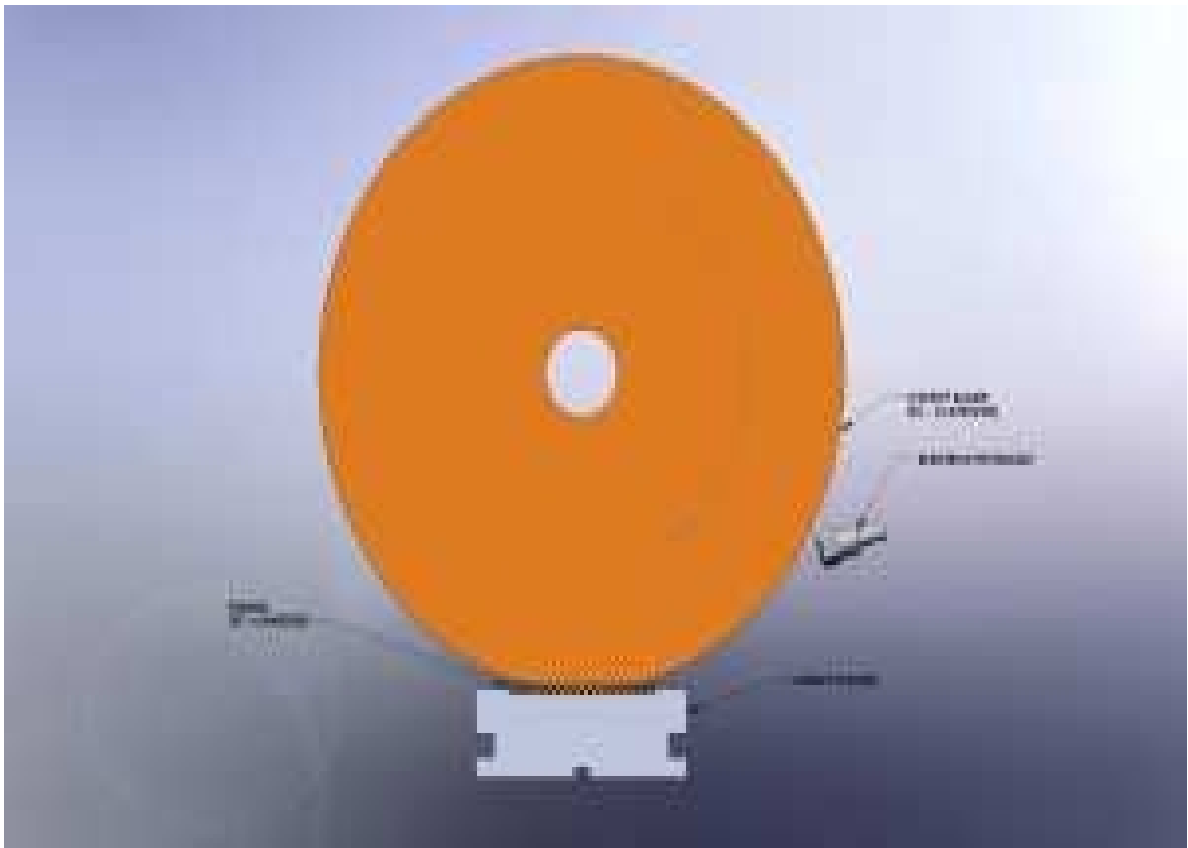
4.5. ELECTROCHEMICAL GRINDING (ECG)

Electrochemical Grinding, or ECG, is a variation of ECM (Electrochemical Machining) that combines electrolytic activity with the physical removal of material by means of charged grinding wheels. Electrochemical Grinding (ECG) can produce burr free and stress free parts without heat or other metallurgical damage caused by mechanical grinding, eliminating the need for secondary machining operations. Like ECM, Electrochemical Grinding (ECG) generates little or no heat that can distort delicate components.

Electrochemical Grinding (ECG) can process any conductive material that is electrochemically reactive. The most common reason customers choose Electrochemical Grinding (ECG) is for the burr free quality of the cut. If a part is difficult or costly to deburr, then Electrochemical GRINDING (ECG) is the best option. Materials that are difficult to machine by conventional methods, that work harden easily or are subject to heat damage are also good candidates for the stress free and no heat characteristics of Electrochemical Grinding (ECG). The stress free cutting capability of the process also makes it ideal for thin wall and delicate parts.

The real value of Electrochemical Grinding (ECG) is in metalworking applications that are too difficult or time-consuming for traditional mechanical methods (milling, turning, grinding, deburring etc.). It is also effective when compared to non-traditional machining processes such as wire and sinker EDM. Electrochemical Grinding (ECG) is almost always more cost effective than EDM.

Electrochemical Grinding (ECG) differ from conventional grinding Conventional surface grinding typically uses shallow reciprocating cuts that sweep across the work surface to create a flat plane or groove. Another conventional surface grinding process, creep feed grinding, typically uses slower feeds than conventional surface grinding and removes material in deep cuts. Because of the abrasive nature of these processes, the equipment used must be rigid and this is especially true of creep feed grinding.



Quality Electrochemical Grinding (ECG) machines must also be rigid for close tolerance results but since very little of the material removed is done so abrasively the machines do not have to be as massive as their conventional counterparts. To a user familiar with creep feed grinding Electrochemical Grinding (ECG) will appear to be very similar, that is, relatively slow feeds (as compared to conventional surface grinding) and deep cuts as opposed to shallow reciprocating cuts. Electrochemical Grinding (ECG) is a combination of electrochemical (Anodic) dissolution of a material, according to Faraday's Law, and light abrasive action. The metal is decomposed to some degree by the DC current flow between the conductive grinding wheel (Cathode) and the work piece (Anode) in the presence of an electrolyte solution.

Unlike conventional grinding techniques, Electrochemical Grinding (ECG) offers the ability to machine difficult materials independent of their hardness or strength. Electrochemical Grinding (ECG) does not rely solely on an abrasive process; the results are precise burr free and stress free cuts with no heat and mechanical distortions.



Electrochemical Grinding (ECG) compare to EDM, laser, water-jet and other non-traditional technologies EDM and laser both cut metal by vaporizing the material at very high emperatures.

This results in a re-cast layer and a heat affected zone on the material surface. Electrochemical Grinding (ECG) is a no heat process that never causes metallurgical damage. Electrochemical Grinding (ECG) is usually much faster than EDM but typically is less accurate. Laser cutting can be very fast and accurate but it is normally limited to thin materials. Water-jet cutting can be quite fast and usually leaves no metallurgical damage but the consumable costs can be very high and the cuts are limited to jigsaw type cuts much like Wire EDM. In most cases, Electrochemical Grinding (ECG) is a more accurate process than water-jet. Another difference between water jet and laser machining compared to electrochemical grinding (ecg) is laser and water jet can both process materials that are not conductive. edm and electrochemical grinding (ecg) processes can only work on materials that are conductive.

Tolerances can be achieved with electrochemical grinding (ecg) the tolerances that can be achieved using electrochemical grinding (ecg) depend greatly on the material being cut, the size and depth of cut and ecg parameters being used. on small cuts, tolerances of .0002" (.005mm) can be achieved with careful control of the grinding parameters.

4.5.1 Surface Finishes Can Be Achieved With Electrochemical Grinding (Ecg)

The Electrochemical Grinding (ECG) process does not leave the typical shiny finish of abrasive grinding. This is because there is no smearing of the metal as in conventional grinding. A 16 micro inch finish or better can be achieved but it will have a matte (dull) rather than a polished look.

4.5.2. Materials Can Be Cut With Electrochemical Grinding (ECG)

Almost any conductive metal can cut with Electrochemical Grinding (ECG). Steel, Aluminum, Copper, Stainless Steels, Inconel and Hastelloy cut very freely with Electrochemical Grinding (ECG). Nickel/Titanium, Cobalt alloys, Amorphous metals, Berilium, Berilium Copper, Iridium Neodymium Iron Boron, Titanium, Nickel/Titanium, Nitinol, Powdered Metals, Rene 41, Rhenium, Rhodium, Stellite, Vitalium, Zirconium and Tungsten can also be cut effectively.

4.5.3. Advantages of Electrochemical Grinding (ECG)

- Improved wheel life
- Burr free
- No work hardening
- Stress free
- Better finis
- No cracking
- Less frequent wheel dressing
- No metallurgical damage from heat
- Faster for tough materials
- No wheel loading or glazing
- More precise tolerances

UNIT-V THERMAL ENERGY BASED PROCESSES

5. THERMAL ENERGY BASED PROCESSES

- Laser-Beam Machining (LBM)
- Electron Beam Machining (EBM)
- Plasma Arc Machining (PAM)

5.1. Laser-Beam Machining

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

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

- CO₂ (pulsed or continuous wave): It is a gas laser that emits light in the infrared region. It can provide up to 25 kW in continuous-wave mode.
- Nd:YAG: Neodymium-doped Yttrium-Aluminum-Garnet ($\text{Y}_3\text{Al}_5\text{O}_{12}$) laser is a solid-state laser which can deliver light through a fibre-optic cable. It can provide up to 50 kW power in pulsed mode and 1 kW in continuous-wave mode.

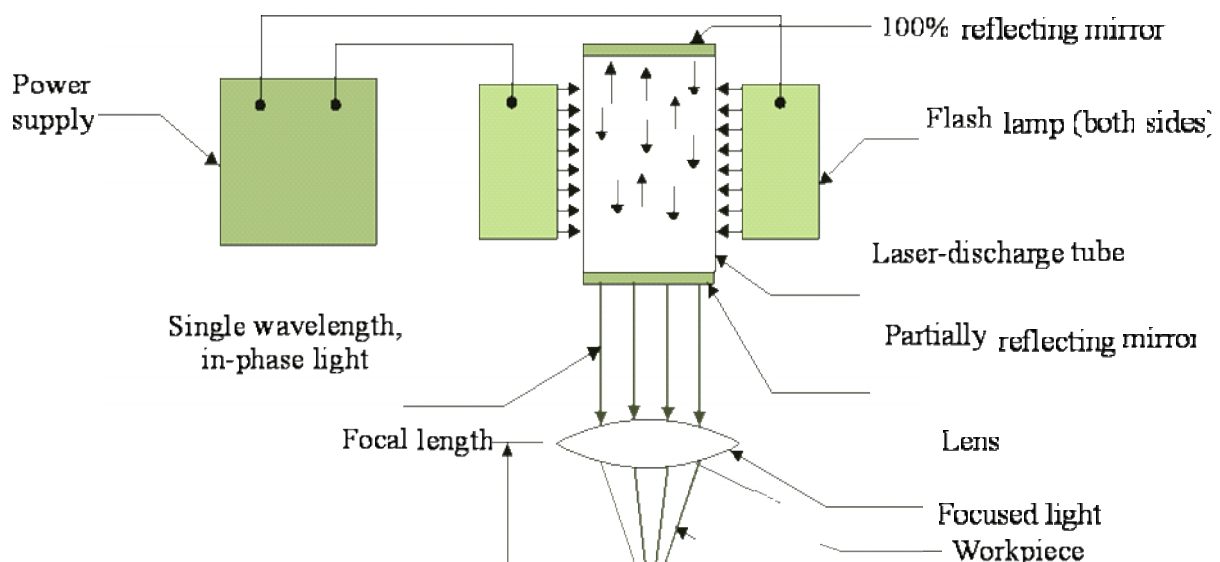


Figure: Laser beam machining schematic

5.1.1 Applications

LBM can make very accurate holes as small as 0.005 mm in refractory metals ceramics, and composite material without warping the work pieces. This process is used widely for drilling

Laser beam cutting (drilling)

- In drilling, energy transferred (e.g., via Nd YAG laser) into the workpiece melts the material at the point of contact, which subsequently changes into a plasma and leaves the region.
- A gas jet (typically, oxygen) can further facilitate this phase transformation and departure of material removed.
- Laser drilling should be targeted for hard materials and hole geometries that are difficult to achieve with other methods.

A typical SEM micrograph hole drilled by laser beam machining process employed in making a hole is shown in Figure

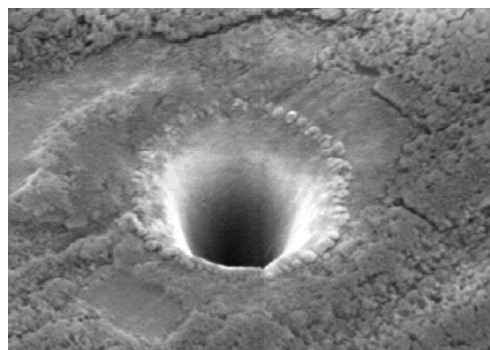


Figure: SEM micrograph hole drilled in 250 micro meter thick Silicon Nitride with 3rd harmonic Nd: YAG laser

5.2. Laser beam cutting (milling)

- A laser spot reflected onto the surface of a workpiece travels along a prescribed trajectory and cuts into the material.
- Continuous-wave mode (CO₂) gas lasers are very suitable for laser cutting providing High-average power, yielding high material-removal rates, and smooth cutting surfaces

Advantage of laser cutting

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

Limitations of laser cutting

- Uneconomic on high volumes compared to stamping
- Limitations on thickness due to taper
- High capital cost
- High maintenance cost
- Assist or cover gas required

5.3. ELECTRON BEAM MACHINING (EBM)

As has already been mentioned 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 μ s 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 μ amp 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. The energy density and power density is governed by energy per pulse duration and spot size. Spot size, on the other hand is controlled by the degree of focusing achieved by the electromagnetic lenses. A higher energy density, i.e., for a lower spot size, the material removal would be faster though the size of the hole would be smaller. The plane of focusing would be on the surface of the work piece or just below the surface of the work piece.

1. Electrons generated in a vacuum chamber
2. Similar to cathode ray tube
3. Electron gun
4. Cathode - tungsten filament at 2500 – 3000 degC
5. Emission current – between 25 and 100mA (a measure of electron beam density)

MRR:

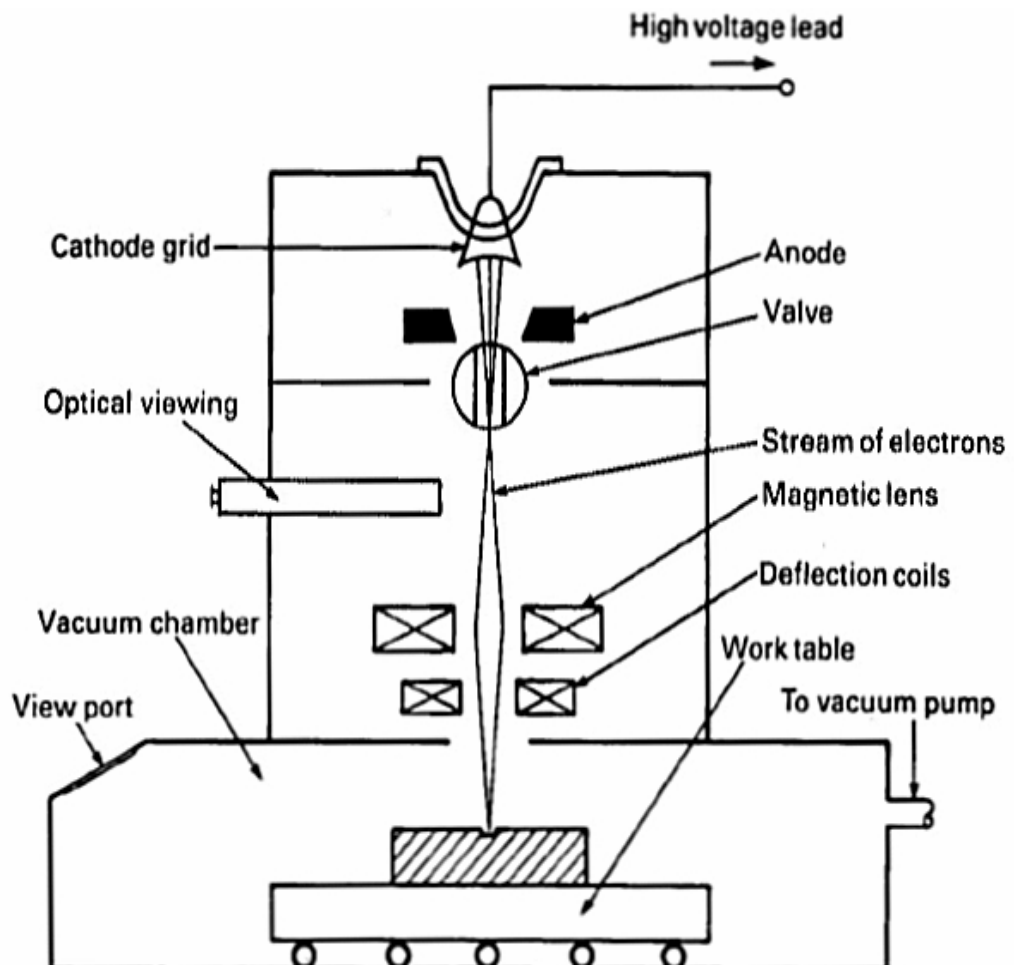
In the region where the beam of electrons meets the workpiece, their energy is converted Into heat

Workpiece surface is melted by a combination of electron pressure and surface tension

Melted liquid is rapidly ejected and vaporized to effect material removal

Temperature of the workpiece specimen outside the region being machined is reduced by pulsing the electron beam (10 kHz or less)

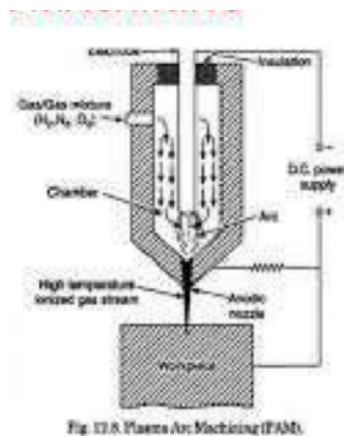
Material	Volumetric removal rate (mm s^{-3})
Tungsten	1.5
Aluminium	3.9



Advantages of Ebm:

1. Large depth-to-width ratio of material penetrated by the beam with applications of very fine hole drilling becoming feasible
2. There are a minimum number of pulses n_e associated with an optimum accelerating Voltage. In practice the number of pulses to produce a given hole depth is usually found to decrease with increase in accelerating voltage.

5.4. PLASMA ARC MACHINING (PAM)



The plasma welding process was introduced to the welding industry in 1964 as a method of bringing better control to the arc welding process in lower current ranges. Today, plasma retains the original advantages it brought to industry by providing an advanced level of control and accuracy to produce high quality welds in miniature or precision applications and to provide long electrode life for high production requirements.

The plasma process is equally suited to manual and automatic applications. It has been used in a variety of operations ranging from high volume welding of strip metal, to precision welding of surgical instruments, to automatic repair of jet engine blades, to the manual welding of kitchen equipment for the food and dairy industry.

5.5. PLASMA ARC WELDING (PAW):

Plasma arc welding (PAW) is a process of joining of metals, produced by heating with a constricted arc between an electrode and the work piece (transfer arc) or the electrode and the constricting nozzle (non transfer arc). Shielding is obtained from the hot ionized gas issuing from the orifice, which may be supplemented by an auxiliary source of shielding gas. Transferred arc process produces plasma jet of high energy density and may be used for high speed welding and cutting of Ceramics, steels, Aluminum alloys, Copper alloys, Titanium alloys, Nickel alloys.

Non-transferred arc process produces plasma of relatively low energy density. It is used for welding of various metals and for plasma spraying (coating).

Equipment:

(1) Power source. A constant current drooping characteristic power source supplying the dc Welding current is required. It should have an open circuit voltage of 80 volts and have a duty cycle of 60 percent.

(2) Welding torch. The welding torch for plasma arc welding is similar in appearance to a gas tungsten arc torch but it is more complex.

(a) All plasma torches are water cooled, even the lowest-current range torch. This is because the arc is contained inside a chamber in the torch where it generates considerable heat. During the non transferred period, the arc will be struck between the nozzle or tip with the orifice and the tungsten electrode.

(b) The torch utilizes the 2 percent thoriated tungsten electrode similar to that used for gas tungsten welding.

(3) Control console. A control console is required for plasma arc welding. The plasma arc torches are designed to connect to the control console rather than the power source. The console includes a power source for the pilot arc, delay timing systems for transferring from the pilot arc to the transferred arc, and water and gas valves and separate flow meters for the plasma gas and the shielding gas. The console is usually connected to the power source. The high-frequency generator is used to initiate the pilot arc.

Principles of Operation:

The plasma arc welding process is normally compared to the gas tungsten arc process. But in the TIG-process, the arc is burning free and unhandled, whereas in the plasma-arc system, the arc is necked by an additional water-cooled plasma-nozzle. A plasma gas – almost always 100 % argon –flows between the tungsten electrode and the plasma nozzle.

The welding process involves heating a gas called plasma to an extremely high temperature and then ionizing it such that it becomes electrically conductive. The plasma is used to transfer an electric arc called pilot arc to a work piece which burns between the tungsten electrode and the plasma nozzle. By forcing the plasma gas and arc through a constricted orifice the metal, which is to be welded is melted by the extreme heat of the arc. The weld pool is protected by the shielding gas, flowing between the outer shielding gas nozzle and the plasma nozzle. As shielding gas pure argon-rich gas-mixtures with hydrogen or helium are used.

The high temperature of the plasma or constricted arc and the high velocity plasma jet provide an increased heat transfer rate over gas tungsten arc welding when using the same current. This results in faster welding speeds and deeper weld penetration. This method of operation is used for welding extremely thin material and for welding multi pass groove and welds and fillet welds.

Uses & Applications:

Plasma arc welding machine is used for several purposes and in various fields. The common application areas of the machine are:

1. Single runs autogenous and multi-run circumferential pipe welding.
2. In tube mill applications.
3. Welding cryogenic, aerospace and high temperature corrosion resistant alloys.
4. Nuclear submarine pipe system (non-nuclear sections, sub assemblies).
5. Welding steel rocket motor cases.
6. Welding of stainless steel tubes (thickness 2.6 to 6.3 mm).
7. Welding of carbon steel, stainless steel, nickel, copper, brass, monel, inconel, aluminium, titanium, etc.
8. Welding titanium plates up to 8 mm thickness.

9. Welding nickel and high nickel alloys.
10. Melting, high melting point metals.
11. Plasma torch can be applied to spraying, welding and cutting of difficult to cut metals and alloys.

5.6. Plasma Arc Machining (PAM):

Plasma-arc machining (PAM) employs a high-velocity jet of high-temperature gas to melt and displace material in its path called PAM, this is a method of cutting metal with a plasma-arc, or tungsten inert-gas-arc, torch. The torch produces a high velocity jet of high-temperature ionized gas called plasma that cuts by melting and removing material from the work piece. Temperatures in the plasma zone range from 20,000° to 50,000° F (11,000° to 28,000° C). It is used as an alternative to oxyfuel-gas cutting, employing an electric arc at very high temperatures to melt and vaporize the metal.

Equipment:

A plasma arc cutting torch has four components:

1. The electrode carries the negative charge from the power supply.
2. The swirl ring spins the plasma gas to create a swirling flow pattern.
3. The nozzle constricts the gas flow and increases the arc energy density.
4. The shield channels the flow of shielding gas and protects the nozzle from metal spatter.

Principle of operation:

PAM is a thermal cutting process that uses a constricted jet of high-temperature plasma gas to melt and separate metal. The plasma arc is formed between a negatively charged electrode inside the torch and a positively charged work piece. Heat from the transferred arc rapidly melts the metal, and the high-velocity gas jet expels the molten material from the cut.

Applications:

The materials cut by PAM are generally those that are difficult to cut by any other means, such as stainless steels and aluminum alloys. It has an accuracy of about 0.008".

UNIT I
PART-A (QUESTIONS WITH ANSWERS)

1. What is meant by Conventional Machining Processes?

In conventional machining processes, metal is removed by using some sort of the tools which is harder than the work piece and is subjected to wear. In this process, tool and work piece being in direct contact with each other.

2. What is meant by Unconventional Machining Processes?

The Unconventional machining processes do not employ a conventional or traditional tool for metal removal; instead, they directly utilize some form of energy for metal machining. In this process, there is no direct physical contact between the tool and the work piece.

3. What is a thermal energy method of unconventional machining machining?

In these methods, heat energy is concentrated on a small area of the work piece to melt and vaporize the tiny bits of work material. The required shape is obtained by the continued repetition of this process.

Examples: LBM, PAM, EBM, IBM

4. What is an electro chemical energy method of unconventional machining machining?

In these methods, material is removed by ion displacement of the work piece material in contact with a chemical solution.

Examples: ECM, ECG, ECH, ECD

5. What is a chemical energy method of unconventional machining?

The chemical energy methods involve controlled etching of the work piece material in contact with a chemical solution.

Example: CHM

6. What is a mechanical energy method of unconventional machining?

In mechanical energy methods, the material is removed by mechanical erosion of the work piece material.

Examples: USM, AJM, WJM

7. List the unconventional machining process which uses mechanical energy?

1. Ultra Sonic Machining (USM)
2. Abrasive Jet Machining (AJM)
3. Water Jet Machining (WJM)

8. List the unconventional machining process, which uses thermal or heat energy?

1. Laser Beam Machining (LBM)
2. Plasma Arc Machining (PAM)
3. Electron Beam Machining (EBM)
4. Ion Beam Machining (IBM)

9. List the Unconventional machining process, which uses Electro chemical energy?
1. Electro Chemical Machining (ECM)
 2. Electro Chemical Grinding (ECG)
 3. Electro Chemical Honing (ECH)
 4. Electro Chemical Deburring (ECD)
10. What are the characteristics of unconventional machining process?
1. The Unconventional machining processes do not empty a conventional or traditional tool for metal removal; instead, they directly utilize some form of energy for metal machinery.
 2. The tool material need not be harder than the work piece material.
 3. A harder and difficult to machine materials such as carbides, stainless steel, nitralloy hastalloy and many other high strength temperature resistant alloys can be machined by unconventional machining processes.
11. Name the unconventional machining processes which are used to remove maximum material?
1. Electro Chemical Machining (ECM)
 2. Plasma Arc Machining (PAM)
12. Name the unconventional machining process which is used to remove minimum material?
- Electron Beam Machining
13. Name the unconventional machining process which consumes maximum power?
- Laser Beam Machining
14. Name the unconventional machining process which consumes minimum power?
- Plasma Arc Machining
15. Name the unconventional machining processes for machining following material?
1. Non metal like ceramic , Plastics and glass
 2. Refractories
 3. Titanium
 4. Super alloys
 5. Steel

PART-B (QUESTIONS)

16. Compare the mechanical and electrical energy processes in terms of physical parameters. Shape capabilities, Process capability, and Process economy. (16)
17. Explain the reasons for the development of Unconventional Machining Process. Discuss about the criteria recommended in selection of these processes. (16)
18. Make a comparison between traditional and unconventional machining processes in terms of cost,
19. Application, scope, Machining time, advantages and limitations. (16)
20. For different non-conventional processes, present in the form of a table, various process parameters recommended (16)

UNIT II
PART-A (QUESTIONS WITH ANSWERS)

1. State the working principle of Abrasive Jet Machining?

In abrasive jet machining process, a high speed stream of abrasive particles mixed with high pressure air or gas are injected through a nozzle on the work piece to be machined.

2. List any four advantages of AJM process?

- a. This process is suitable for cutting all materials. Even diamond can be cut by using diamond as abrasive.
- b. Initial investment is low.
- c. It can be used to cut intricate hole shapes in hard and brittle materials.
- d. There is no heat generation during this process. So, thermal damage to the workpiece is avoided.

3. What are the applications of AJM process?

This process is widely used for

- a. Machining of hard and brittle materials like quartz, ceramics, glass, sapphire, etc.,
- b. Fine drilling and micro welding.
- c. Cleaning and polishing of plastics, nylon and Teflon components.
- d. Machining of semiconductors.

4. What are the factors that affect the material removal rate in AJM process?

The following factors will affect the material removal rate in AJM process.

- a. Mass flow rate
- b. Abrasive grain size
- c. Gas pressure
- d. Velocity of abrasive particles
- e. Mixing ratio
- f. Nozzle tip clearance.

5. What is water jet machining process?

In water jet machining process, high pressure and high velocity stream of water is used to cut the relatively softer and non-metallic materials like paper board, wood, plastics, rubber, fibre glass, leather etc.,

6. State the working principles of HJM process?

In hydrodynamic jet machining process, abrasive particles are added to the high velocity stream of water jet and the material is removed from the workpiece due to the combined effect of abrasion and water impact.

7. List the unique benefits offered by WJM process?

- a. In WJM process, water is used as energy transfer medium. It is cheap, non-toxic and easy to dispose.
- b. Low operating cost.
- c. The work area remains clean and dust free.
- d. Low maintenance cost.

8. Differentiate abrasive jet machining process and sand blasting process?

Abrasive Jet Machining (AJM) is basically meant for metal removal with the use of small abrasive particles, whereas the sand blasting process is a surface cleaning process which does not involve any metal cutting.

9. State the working principle of ultrasonic machining process?

In ultrasonic machining process, a slurry of small abrasive particles are forced against the workpiece by means of a vibrating tool and it causes the removal of metal from the workpiece in the form of extremely small chips.

10. What are the types of transducers used in ultrasonic machining processes?

There are two types of transducers used in ultrasonic machining processes for the production of ultrasonic wave. They are

- a. Magnetostriction transducer
- b. Piezoelectric transducer.

11. What is magnetostriction effect?

When a rod of ferromagnetic material such as iron or nickel is kept in a magnetic field to its length, the rod suffers a change in its length. This phenomenon is known as magnetostriction effect.

12. What is piezoelectric effect?

When mechanical force is applied to one pair of opposite faces of certain crystals like quartz, tourmaline, etc., equal and opposite electrical charges appear across its other faces.

13. What is feed mechanism and state its types?

Feed system is used to apply the static load between the tool and workpiece during ultrasonic machining operation. There are three types of feed mechanism. They are:

- a. Gravity feed mechanism
- b. Spring loaded feed mechanism
- c. Pneumatic or hydraulic feed mechanism.

14. State tool wear ratio?

Wear ratio is defined as the ratio of volume of material removed from the work to volume of material eroded from tool.

Wear ratio = Volume of material removed from work/ Volume of material eroded from tool.

15. Write the typical applications of ultrasonic machining?

- a. Holes as small as 0.1 mm can be drilled.
- b. Precise and intricate shaped articles can be machined.
- c. It is used for making tungsten carbide and diamond wire drawing dies for forging and extrusion processes.
- d. It has been efficiently applied to machine glass, ceramics, tungsten, precision mineral stones, etc.,

PART-B (QUESTIONS)

16. (i) Explain the principle of AJM. Mention some of the specific applications. (6)

(ii) Discuss in detail about the AJM process variables that influence the rate of material removal and accuracy in the machining. (10)

17. (i) Explain the method of AJM with help of schematic diagram. (10) (ii) Mention the advantages and limitations of AJM. (6)

18. Explain the process parameters in WJM processes. (16)

19. With neat sketch explain the process of AJM .List its application and limitations. (16)

20. . (i) Explain the process parameters that influence WJM. List the app and limitations of WJM (10)

(ii) Briefly discuss the application and limitation of WJM. (6)

21. Explain the USM machine setup an discuss various feed mechanisms. (16)

22. (i) Discuss the influence process parameters and applications of USM (10)

(ii) Give a note o the various types of transducers. (6)

UNIT III
PART-A (QUESTIONS WITH ANSWERS)

1. What is the working principle of Electrical Discharge machining process?
In electrical discharge machining process, metal is removed by producing powerful electric spark discharge between the tool (cathode) and the work material (anode).
2. What are the factors affecting metal removal rate?
 - a. Metal removal rate increases with forced circulation of dielectric fluid.
 - b. It increases up to optimum value of work-tool gap, after that it drops suddenly.
 - c. Metal removal rate is maximum when the pressure is below atmospheric.
3. What are the basic requirements of tool material of EDM?
 - a. It should have low erosion rate.
 - b. It should be electrically conductive
 - c. It should have good machinability.
 - d. Melting point of the tool should be high.
4. How the tool materials are classified?
Tool or electrode can be classified into four groups
 1. Metallic electrodes :
 - Brass
 - Copper tungsten
 - Chromium copper
 - Aluminium tungsten
 - Silver tungsten
 2. Non metallic : Graphited
 3. Combined metallic and non-metallic : Copper graphite
 4. Metallic coating as Insulators : Copper on moulded Plastic and copper on ceramic.
5. Indicate the range of pulse duration and current in EDM?
The current density in the discharge of channel is of the order of $10,000 \text{ A/cm}^2$. Spark discharge frequencies range from 200-500 KHz pulses per second at voltage level of 30 – 250 V.
6. Give the wear ratio for brass, copper and copper tungsten?

	Wear ratio
Brass	1:1
Copper	2:1
Copper tungsten	8:1

7. Name the most commonly used spark generating circuits?
 - a. Resistance – capacitance circuit (R-C) (or) Relaxation circuit
 - b. R-C-L circuit
 - c. Rotary pulse generator circuit
 - d. Controlled pulse generator circuit
8. What are the draw backs of using relaxation circuit?
 - a. Though the discharge current in a relaxation circuit reaches a high value, it is of very short duration.
 - b. The use of high frequencies is limited, since the time for charging the capacitor is high.
9. What are the advantages of EDM processes?
 - a. Machining of very thin section is possible.
 - b. It does not leave any chips or burrs on the workpiece.
 - c. It is well suited for complicated components.
 - d. Since there is no cutting forces act on the job, error due to elastic deformation is eliminated.
 - e. Fine holes can be easily drilled.
10. List the applications of EDM?

This is most widely used machining process among the non – traditional machining methods. Its applications are as follows.

 - a. Production of complicated and irregular shaped profiles.
 - b. Thread cutting in jobs.
 - c. Drilling of micro holes.
 - d. Helical profile drilling.
 - e. Curved hold drilling.
11. List the advantages of wire cut EDM process?
 - a. It gives high surface finish.
 - b. Complicated shapes can be efficiently machined.
 - c. Tool manufacturing and storage is avoided.
 - d. It is economical for small batch production.
12. List the advantages of wire – cut EDM process?
 - a. Capital cost is high.
 - b. Cutting rate is slow.
 - c. It is not suitable for large workpiece.
13. What is the shape of electrode in traveling wire EDM process?

A very thin wire made of brass or molybdenum having circular cross section is used as electrode in traveling wire EDM process.

14. What is the function of servo mechanism in EDM?

The function of servo mechanism is to maintain very small gap, known as 'sparkplug' ranges of 0.005 to 0.05 mm between the workpiece and the tool.

15. What is overcutting in EDM process and how is it affected by amphere and frequency?

Overcutting is cutting of larger cavity than the size of electrode in EDM process. It increases with increase in current and decreases at high frequencies.

PART-B (QUESTIONS)

16. Explain the process of electrical discharge machining, its process parameters and applications.(16)

17. Describe the wire cut EDM equipment, its working, applications and advantages (16)

18. (i) With the help of neat sketch, Describe the EDM process. (12) (ii) Explain briefly advantages of wire EDM process. (4)

19. (i) Explain the classification and characteristics of various spark erosion generators. (8)
(ii) With help of neat sketch describe the mechanism of material removal in EDM. (8)

20. (i) Explain the working principle, elements and characteristics of wire EDM. (10)
(ii) Explain how the stratified wire works. Also discuss about the recent developments in wire EDM. (6)

UNIT IV
PART-A (QUESTIONS WITH ANSWERS)

1. State the principle of chemical machining process?
In chemical machining process, material is removed from the workpiece through a controlled etching or chemical attack of the workpiece material.
2. Name the etchants used in chemical machining process?
 - a. Caustic Soda
 - b. Hydrochloric acid
 - c. Nitric acid
 - d. Iron carbide.
3. Name some of the maskants used in CHM?
 - a. Butyl rubber
 - b. Neoprene rubber
 - c. Polymers
 - d. Polyethylene, etc.,
4. Write the principle of ECM process?
ECM is based on the principle of Faraday's laws of Electrolysis and reverse electroplating. In this process, the work piece is connected to positive terminal (anode) and the tool is connected to negative terminal (cathode). When the current is passed, the workpiece loses metal and the dissolved metal is carried out by circulating an electrolyte between the work and tool.
5. What are the requirements of tool materials in ECM process?
 - a. It should be conductor of electricity.
 - b. It should be chemically inert to the electrolyte.
 - c. It should be easily machinable.
6. What are the factors to be considered while designing the tool?
 - a. Determine the tool shape, so that the desired shape of the job is obtained under existing machining conditions.
 - b. Design the tool by considering the electrolyte flow, insulation strength and fixing arrangements.
7. State the function of electrolyte used in ECM process?
 - a. It carries the current between the tool and the work piece.
 - b. It cools the cutting zone which becomes hot due to the flow of high current.
 - c. It removes products of machining from the cutting zone.

8. What are essential characteristics of an electrolyte used in ECM process?
- It should be good conductor of electricity.
 - It should have non- corrosive property
 - It should have low viscosity and high specific heat.
 - It should be non-toxicity and chemical stability.
9. What are materials used for tools in Electro chemical Machining?
- Most commonly used tool materials are copper, brass, titanium, copper- tungsten and stainless steel when the electrolyte is made of sodium or potassium.
- The other materials which can be used as tool materials are aluminum. Graphite, bronze, platinum, tungsten carbide.
10. What are the advantages of ECM?
- Metal removal rate is high compared to conventional machining process.
 - Wear and tear of the tool is negligible.
 - The machined work surface is free of stresses.
 - No cutting forces are involved in the process.
 - High surface finish of the order 0.2 to 0.8 microns can be obtained.
11. What are the disadvantages of Electro Chemical Machining process?
- Non- conducting materials cannot be machined.
 - Initial investment is quite high.
 - More space is required.
 - Consumption of power is high.
12. List the applications of ECM process?
- It is used for
- Machining complicated profiles
 - Drilling small deep holes.
 - Machining of hard materials and heat resistant materials.
 - Machining of cavities and holes of irregular shapes.
13. What are the limitations of ECM process?
- Sharp internal corners cannot be obtained. Tool design is very complicated and it requires cut and try method to achieve the final shape.
 - Post machining cleaning is needed to reduce the corrosion of the work piece.
14. List the advantages of Electro Chemical Grinding (ECG) process/
- Tool wear is negligible. So, the life of the grinding wheel is increased.
 - Good surface finish is obtained.
 - Burr free and stress free components are produced.
 - As compared to conventional grinding, a very little cutting force is applied to the work piece.

15. List the disadvantages of ECG process?

- a. Initial cost is high.
- b. Power consumption is high.
- c. Metal removal rate is lower than conventional grinding.
- d. Non- conducting materials cannot be machined.

16. What is the difference between ECG and conventional grinding?

In conventional grinding process, metal is removed from the workpiece by using grinding wheel.

In electrochemical grinding process, the work is machined by the combined action of electrochemical effect and conventional grinding operation.

PART-B (QUESTIONS)

1. (i) Describe the chemistry involved in ECM process. (8)
(ii) Briefly discuss about the effect of high temp and pressure of electrolyte on the ECM process. (4) (iii) Discuss about the economics of ECM. (4)
2. (i) Describe the working principle and elements of chemical machining. What are the factors on which the selection of a resist for use in chemical machining? (10)
(ii) What are the specific advantages of using chemical machining over electrochemical machining? Give some of the practical applications of chemical machining process. (6)
3. (i) Explain the principle of ECG with sketch. (8)
(ii) List out the advantage of EGC over conventional grinding. (4) (iii) Mention the product application of ECG. (4)
4. Explain in detail the ECM process with neat sketch and also mention the advantages and apps. (16)
5. (i) Describe the process of electrochemical machining. (8)
(ii) Discuss about the electrochemical honing and electrochemical grinding (8)

UNIT V
PART-A (QUESTIONS WITH ANSWERS)

1. State the working principle of EBM?
When the high velocity beam of electrons strike the workpiece, its kinetic energy is converted into heat. This concentrated heat raises the temperature of work material and vaporizes a small amount of it, resulting in removal of metal from the work piece.
2. List any two advantages of EBM?
 - a. Very small holes can be machined in any type of material to high accuracy.
 - b. It is a quicker process. Harder materials can also be machined at a faster rate than conventional machining.
3. What are the limitations of EBM?
 - a. The metal removal rate is very slow.
 - b. It is not suitable for large work pieces.
 - c. Cost of equipment is very high
 - d. A little taper produced on hole.
 - e. It is applicable only for thin materials.
4. State the principle of LBM?
In laser beam machining process, laser beam is focused on the workpiece by means of lens to give extremely high energy density to melt and vapourise the work material.
5. Give the examples of solid state laser?
 - a. Ruby laser.
 - b. Neodymium doped Yttrium – aluminium – Garnet (YAG) laser.
 - c. Neodymium – doped glass laser (Nd-glass).
6. What are basic requirements of laser welding?
 - a. The focus of the beam should be adjusted to the thickness or the material.
 - b. The wave length of the laser beam must be compatible with the materials being welded.
7. List any two advantages of LBM?
 - a. Machining of any materials including non-metal is possible.
 - b. Micro – sized holes can be machined.
 - c. Heat affected zone is small around the machined surface.
8. List the limitations of LBM?
 - a. High skilled operators are needed.
 - b. Rate of production is high.
 - c. Initial investment is high.
 - d. Life of flash lamp is short.

9. What are the applications of LBM?

- a. It is used for making very small holes, difficult welding of non- conductive and refractory materials, cutting complex profiles in thin and hard materials.
- b. It can be used for mass micro – machining production.
- c. It can also be used for selective heat treating of materials.

10. State the working principle of PAM?

In plasma arc machining process, material is removed by directing a high velocity jet of high temperature (11,000°C to 28,000°C) ionized gas on the workpiece. The high temperature plasma jet melts the material of the workpiece.

11. What are the gases used in PAM?

The commonly used gases are nitrogen, hydrogen, air, mixture of nitrogen – hydrogen and argon – hydrogen etc.,

12. What are the types of plasma arc torches?

There are two types of plasma arc torches. They are :

- a. Direct arc plasma torches (or) Transferred arc type.
- b. Indirect arc plasma torches (or) Non- transferred arc type.

13. What is transferred arc type plasma?

In transferred arc type process, electrode is connected to the negative terminal of the D.C power supply and workpiece is connected to the positive terminal of a D.C power supply, so, more electrical energy is transferred to the work, thus giving more heat to the work.

14. What is non – transferred arc type plasma?

In non- transferred arc type, electrode is connected to the negative terminal of a D.C. power supply and nozzle is connected to the positive terminal of a D.C. power supply. When the working gas passing through the nozzle, a part of the working gas becomes heated, ionized and emerges from the torch as the plasma jet. This plasma feeds the heat to the workpiece. This type of torches is used for non- conducting materials.

15. Write any two applications of PAM?

- a. It is used for cutting alloy steels, stainless steel, cast iron, copper, nickel , titanium. Aluminium and alloy of copper and nickel, etc.,
- b. It is used for profile cutting.

PART-B (QUESTIONS)

16. (i) Describe the chemistry involved in ECM process. (8)
(ii) Briefly discuss about the effect of high temp and pressure of electrolyte on the ECM process. (4) (iii) Discuss about the economics of ECM. (4)
17. (i) Describe the working principle and elements of chemical machining. What are the factors on which the selection of a resist for use in chemical machining? (10)
18. What are the specific advantages of using chemical machining over electro chemical machining? Give some of the practical applications of chemical machining process. (6)
19. (i) Explain the principle of ECG with sketch. (8)
(ii) List out the advantage of EGC over conventional grinding. (4)
(iii) Mention the product application of ECG. (4)
20. Explain in detail the ECM process with neat sketch and also mention the advantages and apps. (16)
21. (i) Describe the process of electrochemical machining. (8)
(ii) Discuss about the electrochemical honing and electrochemical grinding (8)