SREENIVASA INSTITUTE OF TECHNOLOGY AND MANAGEMENT STUDIES.
(AUTONOMOUS)
DEPARTMENT OF MECHANICAL ENGINEERING

16MEC424A MODERN MACHINING PROCESSES

Course Educational Objectives:

CEO1: To understand the working principles of mechanical energy based machining process.
CEO2: To learn electric discharge machining and wire cut EDM process for machining
CEO3: To understand the working principles of thermal energy based machining process.
CEO4: To know the chemical based and electro chemical based machining process.
CEO5: To learn advanced surface finishing processes and recent developments in the non-traditional machining processes.

UNIT – 1: MECHANICAL ADVANCED MACHINING PROCESS

Introduction: Need for non-traditional machining methods – Classification of modern machining processes – Considerations in process selection materials and applications. **Abrasive Jet, Water Jet and Abrasive Water Jet Machining:** Basic principles, equipments, process variables and mechanics of metal removal, MRR, application and limitations. **Ultrasonic machining:** Elements, mechanics of metal removal, process parameters, economic considerations, applications, limitations and recent development.

UNIT – 2: THERMO ELECTRIC ADVANCED MACHINING PROCESS

Electric Discharge Machining: Principle of working – Power supply, dielectric system, electrodes and servo system – Circuit analysis – Material removal rate – Process variables and characteristics – Applications. **Wire-Electric Discharge Machining:** Principle of working, process variables and characteristics and applications – Principle and working of Electric Discharge grinding, electric discharge diamond grinding and micro electric discharge machining.

UNIT – 3: ELECTRON BEAM AND LASER BEAM MACHINING PROCESS

Electron Beam Machining: Generation and control of electron beam for machining, theory of electron beam machining, comparison of thermal and non-thermal processes. **Plasma Arc Machining:** Principle and working – Metal removal mechanism, process parameters, accuracy and surface finish and Applications. **Laser Beam Machining:** General principle and application of laser beam machining – Thermal features, cutting speed and accuracy of cut.

UNIT – 4: ELECTRO CHEMICAL AND CHEMICAL ADVANCED MACHINING PROCESS

Electro Chemical Machining: Principle, ECM system, advantages, limitations and applications. **Electro Chemical Grinding:** Principle and working, process characteristics and applications. **Chemical Machining:** Fundamentals of chemical machining – Principle – Maskants – Etchants – Advantages and applications.

UNIT – 5: OTHER ADVANCED MACHINING PROCESS

Electro Stream Drilling: Principle and working – Process performance. **Magnetic Abrasive Finishing:** Principle and working, material removal and surface finish and applications. **Shaped Tube Electrolytic Machining:** Principle and working, applications. **Rapid Prototyping:** Classification – Stereo lithography - Selective laser sintering and applications.

Course Outcomes:

On successful completion of the course, Students will be able to		POs related to COs
CO1	Understand the working principles of mechanical energy based machining process	PO1,PO2,PO3,PO7
CO2	Explain electric discharge machining and wire cut EDM process for machining	PO1,PO2,PO7
CO3	Understand the working principles of thermal energy based machining process	PO1,PO2,PO3,PO7
CO4	Explain the chemical based and electro chemical based machining process.	PO1,PO2,PO3,PO7
CO5	Summarize the advanced surface finishing processes and recent developments in the non-traditional machining processes.	PO1

Text Books:

1. Advanced Machining Processes, V. K. Jain, 2002, Allied Publishers Pvt. Ltd., New Delhi.
2. Modern Machining Processes, Pandey P.C. and Shan H.S., 1980,Tata McGraw Hill, New Delhi.

Reference Books:

1. Unconventional Machining Process, M Adithan, 2014, Atlantic Publications, New Delhi
2. Non-Traditional Manufacturing Processes, G.F., Marcel Dekker Inc., New York 1987.
3. Manufacturing Engineering and Technology, Serope Kalpakjian and Steven R. Schmid, 2013, Prentice Hall.
4. Introduction to Micromachining, V. K. Jain, 2014, Narosa publishing House, New Delhi.
5. Advanced Machining, Brahem T. Smith, 1989, I.F.S., U.K.

CO\PO	PO1	PO2	PO3	PO4	PO5	PO6	PO7	PO8	PO9	PO10	PO11	PO12
CO.1	3	2	2	-	-	-	2	-	-	-	-	-
CO.2	3	2	-	-	-	-	2	-	-	-	-	-
CO.3	3	2	2	-	-	-	2	-	-	-	-	-
CO.4	3	2	2	-	-	-	2	-	-	-	-	-
CO.5	3	-	-	-	-	-	-	-	-	-	-	-
CO*	**3**	**2**	**2**	-	-	-	2	-	-	-	-	-

Modern Machining Processes

16MEC 424A

Introduction :

* Modern Machining Process is also known as Un Conventional machining Process

* In Conventional machining Processes, metal is removed by using some sort of tool which is harder than the work piece and it is subjected to wear.

* In other words, the conventional machining Processes involve removal of metal by Compression shear chip formation.

Demerits of Conventional machining :

* Very large cutting forces are involved in this Process. So, Proper holding of the work Piece is most important.

* Due to the large cutting forces and large amount of heat generated between the tool and the work piece interface, undesirable deformation and residual stresses are developed in the work piece

* It is not Possible ~~to~~ for machining delecate components like semi conduct

Unconventional ~~Machining~~ Manufacturing Processes :

* unconventional manufacturing Processes can be divided into the following two categories.

  * 1. Unconventional machining Processes/ Non-Traditional machining Processes
  2. Unconventional forming Processes.

Unconventional Machining Processes :

* In this Process, there is no direct physical contact between the tool and the work piece. Therefore the tool material need not be harder than the work piece material as in conventional machining.

Unconventional forming Processes :

* The metals are formed through the ~~release~~ release and application of large amount of energy in a very short time interval.

Need of Unconventional Machining Processes :

* A harder and difficult to machine materials such as carbides, stainless steel, nitralloy etc., and many other high ~~temp~~ strength-temperature resistant alloys find wide applications in aerospace and nuclear engineering industries, owing to their high strength to weight ratio, hardness and heat resisting qualities.

* For such materials the conventional machining is highly difficult and the degree of accuracy and surface finish attainable are poor.

* The unconventional machining processes have been developed to over come all these difficulties.

Classification of unconventional Machining Processes :

* Unconventional Machining Processes are classified as follows

1. ~~Typ~~ Based on the type of energy required to shape the material
2. " " Mechanism involved
3. Source of energy required for material removal
4. Medium of transfer of energies

UMP

- Type of Energy required.
  - Thermal energy methods
    - * Laser Beam Maching
    - * Plasma Arc Machining
    - * Electron Beam Machining
    - * Ion Beam Machining
  - Electrical energy methods
    - * Electro discharge Machining
    - * Wire cut EDM
  - Electrochemical energy methods
    - * Electrochemical Machining
    - * Electro chemical Grinding
    - * Electro chemical Honing
    - * Electro chemical Deburring
  - chemical energy methods
    - * Chemical Machining
  - Mechanical energy methods
    - * Ultrasonic Machining
    - * Abrasive Jet Machining
    - * water Jet machining
- Mechanism
  - * Erosion
  - * Ionic dissolution
  - * Vaporisation
- Source of energy required
  - * Hydrostatic Pressure
  - * High Current density
  - * High Voltage
  - * Ionised material
- Medium of trans of energies
  - * High voltage Partic
  - * Electrolyte
  - * Electron
  - * Hot gases.

* Depending on the material to be machined, following methods can be used as shown in the table.

S.No	Material	Method of Machining
1.	Non metals like ceramics, Plastics and glass	USM, AJM, EBM, LBM
2.	Refractories	USM, AJM, EDM, EBM
3.	Titanium	EDM
4.	Super alloys	AJM, ECM, EDM, PAM
5.	Steel	ECM, CHM, EDM, PAM

Process selection :

* The following Points must be considered for the correct selection of the Unconventional machining Process.

1. Physical Parameters
2. Shapes to be machined
3. Process capability (or) machining characteristics
4. Economic Consideration.

1. Physical Parameters :

Parameters	ECM	EDM	EBM	LBM	PAM	USM	AJM
Potential, V	5-30	50-500	200×10^3	4.5×10^3	250	220	220
Current, A	40,000	15-500	0.001	2	600	12	1.0
Power, K.W	100	2.7	0.15	20	220	2.4	0.22
Gap, mm	0.5	0.05	100	150	7.5	0.25	0.75
Medium	Electrolyte	Dielectric Fluid	Vacuum	Air	Argon (or) Hydrogen (or) Nitrogen	Abrasive grains and water	N_2 (or) Co_2 (or) Air
Work Material	Difficult to machine Materials	Tungsten Carbide and electrically conductive material	All materials	All materials	All materials which Conduct electricity	Tungsten Carbide, glass, quartz etc.	Hard and brittle materials

(2) Shapes to be machined

* The application of the unconventional machining Processes is also influenced by the shape and size of the work piece to be produced.

* For Producing micro holes — LBM is best suited

* For Producing small holes — EBM is well suited.

* For deep holes (L/D > 20) and contour Machining — ECM is best suited.

* For shallow holes — USM and EDM are well suited

* For Precision through cavities in work pieces — USM and EDM are best suited.

* For honing — ECM is well suited

* For Grinding — AJM and EDM are best suited

* For deburring — USM and AJM are well suited

* For threading — EDM is best suited

* For clean, rapid cuts and Profiles — PAM is well suited.

* For shallow Pocketing — AJM is well suited.

(3) Process capability (or) Machining characteristics

* The machining characteristics can be analyzed with respect to

1. Metal removal rate obtained
2. Tolerance maintained
3. Surface finish obtained
4. Depth of surface damage
5. Power required for machining.

Process	Process Capability			
	MRR (mm^3/s)	Surface finish (μm, CLA)	Accuracy (μm)	Specific Power ($kw/cm^3/min$)
LBM	0.1	0.4 - 6.0	25	2700
EBM	0.15 to 40	0.4 - 6.0	25	450
EDM	15 to 80	0.25	10	1.8
ECM	27	0.2 - 0.8	50	7.5
PAM	2500	Rough	250	0.9
USM	14	0.2 - 0.7	7.5	9.0
AJM	0.014	0.5 - 1.2	50	312.5

(4) Process Economy : The economics of the various Processes are analyzed by considering the following Points.

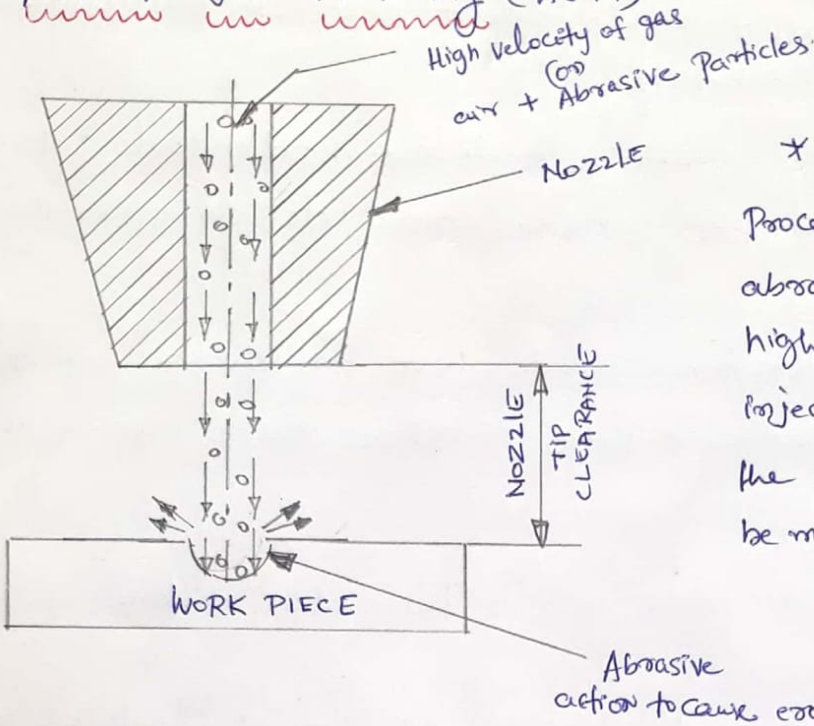
* Capital cost, * Tooling cost * Power requirement * MRR efficiency

* Tool Consumption.

* The following table gives the Process economy of UCMP.

Process	Capital Cost	Tooling and fixtures	Power requirement	Efficiency	Total consumption
EDM	Medium	High	Low	High	High
CHM	Medium	Low	High	Medium	V. Low
ECM	V. High	Medium	Medium	Low	V. Low
AJM	V. Low	Low	Low	High	Low
USM	High	High	Low	High	Medium
EBM	High	Low	Low	V. High	V. Low
LBM	Medium	Low	V. Low	V. High	V. Low
PAM	V. Low	Low	V. Low	V. Low	V. Low

Abrasive Jet Machining (AJM)



Principle of AJM:

* 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~~ work piece to be machined as shown in the fig.

Construction and working of AJM

* The schematic arrangement of abrasive Jet Machining as shown in the figure.
* It consists of mixing chamber, Nozzle, Pressure gauge, hopper, filter, Compressor, Vibrating device, regulator, etc.,
* The gases generally used in this Process are nitrogen, Carbon dioxide (or) Compressed air.

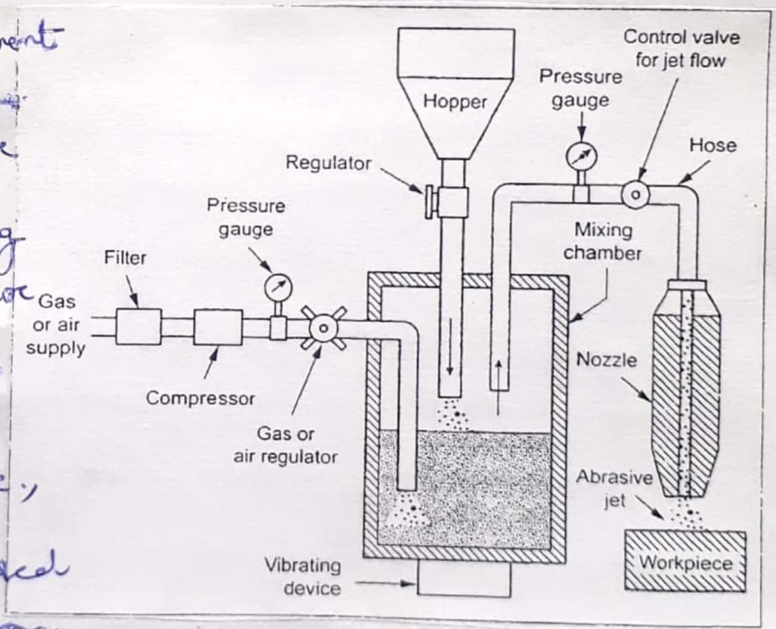


Fig: Arrangement of AJM

* The various abrasive Particles used in this Process are aluminium oxide, silicon Carbide, glass powder, dolomite and specially prepared sodium bicarbonate.
* Aluminium oxide (Al_2O_3) is a general Purpose abrasive and it is used in sizes of 10, 25 and 50 micron. Silicon Carbide (SiC) is used for faster cutting on extremely hard materials. It is used in sizes of 25 and 50 microns.

* Dolomite of 200 grite size is suitable for light cleaning and etching. Glass Powder of diameter 0.30 to 0.60 m.m are used for light Polishing and deburring.

* ~~As the nozzle is subs~~ Nozzle is made up of hard materials such as tungsten carbide, synthetic sapphire (ceramic) etc., to reduce the wear rate.

* Nozzles made of tungsten carbide have an average life of 12 to 20 hours, whereas synthetic sapphire nozzle have an average life of 300 hours.

* Nozzle tip clearance from work is kept at a distance of 0.25 to 0.75 m.m.

* The abrasive Powder feed rate is controlled by the amplitude of the vibration of mixing chamber.

* A Pressure regulator controls the gas (or) air flow and Pressure. To control the size and shape of the cut, either the workpiece (or) the nozzle is moved by a well designed mechanism such as cam mechanism, Pantograph mechanism etc.

Working :

* Dry air (or) gas (N_2 (or) CO_2) is entered into the compressor through a filter where the pressure of air (or) gas is increased. The Pressure of the air varies from 2 kg/cm^2 to 8 kg/cm^2.

* Compressed air (or) high Pressure gas is supplied to the mixing chamber through a pipe line. This pipe line carries a pressure gauge and a regulator to control the air (or) gas flow and its pressure.

* The fine abrasive Particles are collected in the hopper and fed into the mixing chamber. A regulator is incorporated in the line to control the flow of abrasive particles.

* The mixture of Pressurised air and abrasive Particles from the mixing Chamber flows into the nozzle at a considerable speed.

* Nozzle is used to increase the speed of the abrasive particles and it is increased upto 300 m/s.

* This high speed stream of abrasive particles from the nozzle, impact the workpiece to be machined. Due to repeated impacts small chips of material get loosened and a fresh surface is exposed.

* A vibrator is fixed at the bottom of the mixing chamber. When it vibrates, the amplitude of the vibrations controls the flow of abrasive particles.

* This process is widely used for machining hard and brittle materials, non-metallic materials (Germanium, glass, ceramics and mica) of thin sections.

* This process is capable of performing drilling, cutting, deburring, etching and cleaning the surfaces.

Metal Removal rate Process Parameters:

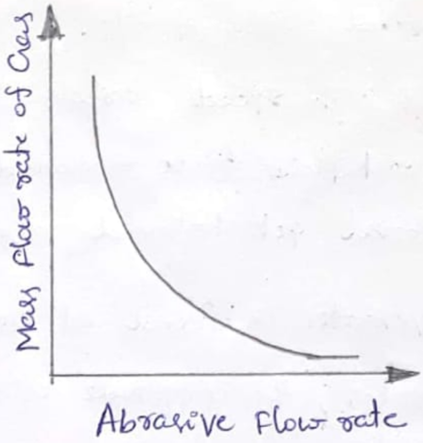
* The metal removal rate depends upon the following parameters.

1. Mass flow rate
2. Abrasive grain size
3. Gas Pressure
4. Velocity of abrasive particles
5. Mixing ratio
6. Nozzle tip clearance.

Mass flow rate:

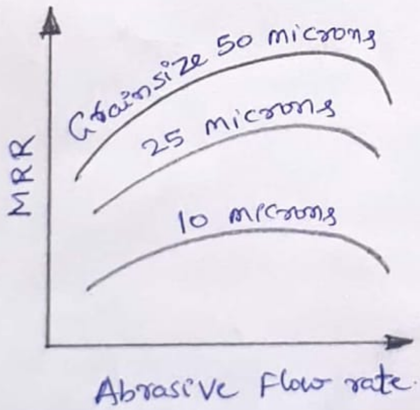
* At particular pressure, the material removal rate increases with the increase of abrasive flow rate. But, after reaching an optimum values the material removal rate decreases with further increase in abrasive flow rate.

* This is due to the mass flow rate of gas (or) air decreases with the increase of abrasive flow rate.



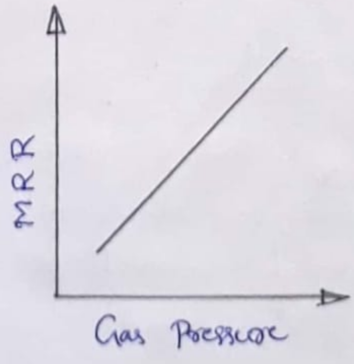
2. Abrasive Grain size

* The various abrasive particles used in AJM Process are aluminium oxide (Al_2O_3), silicon carbide (SiC), glass Powder, dolomite and specially Prepared sodium bicarbonate.
* In general larger sizes are used for rapid removal rate while smaller sizes are used for good surface finish and Precision

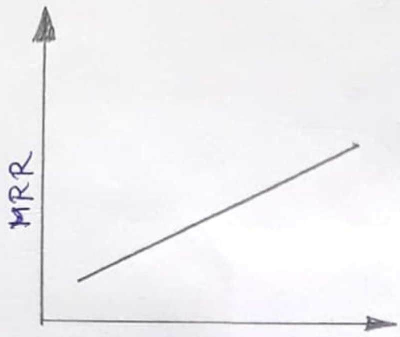


Gas Pressure

* The metal removal rate increases with increase in gas or air Pressure as shown in the figure.



Velocity of Abrasive Particles :



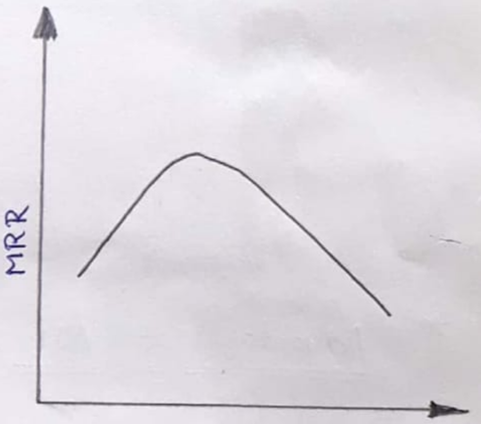
* The metal removal rate increases with the increase of velocity of abrasive particles as shown in the figure.

Mixing Ratio :

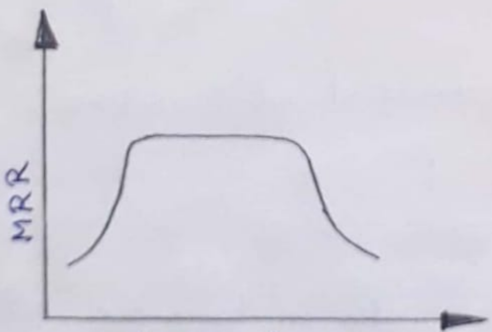
* Mixing ratio is defined as the ratio of mass flow rate of abrasive to the mass flow rate of gas

$$\text{Mixing ratio} = \frac{\text{Mass flow rate of abrasive}}{\text{Mass flow rate of gas}}$$

* Metal removal rate first increases with the increase of mixing ratio upto certain limit after that it decreases gradually as shown in figure.



Nozzle Tip clearance (or) Stand-off Distance :



* The distance between the nozzle tip and the workpiece has great influence on the diameter of cut, its shape, size and also on the rate of material removal.
* The material removal rate first increases with the increase of tip clearance from workpiece upto a certain limit after that it remains unchanged for a certain tip clearance and then decreases gradually as shown in figure. It would be noted that the metal removal rate keeps on increasing upto a nozzle tip clearance of 10mm after that it decreases due to drag of atmosphere.

* The various tip clearance influence on the diameter of cut, shape of cut and metal removal rate is shown in the following table.

Consider

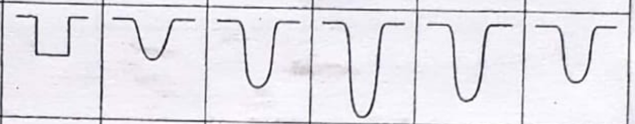
Nozzle orifice dia – 0.45 mm

Abrasive – Aluminium oxide

Flow rate of abrasive – 10g/min

Flow rate of air – 5 kg/cm²

Work material – Glass

Tip Clearance (mm)	0.75	3	5	10	15	20
Diameter of cut (mm)	0.45	0.6	0.64	1.4	2	2.5
Shape of cut						
Metal removal rate (mg/min)	10	25	52	62	56	50

* Advantages of AJM :

* This process is suitable for cutting all materials. Even diamond can be machined by using diamond as abrasive
* There is no heat generation during this process. So, thermal damage to the workpiece is avoided
* Very thin and brittle materials can be cut without any risk of breaking
* There is no direct contact between the tool and workpiece.
* Low initial investment.
* Good surface finish
* It can be used to cut intricate hole shapes in hard and brittle materials.

Dis-Advantages of AJM :

* Material removal rate is slow
* soft material cannot be machined
* Machining accuracy is poor

Dis-Advantages of AJM Continuation:

* Nozzle wear rate is high.
* Abrasive Powder used in this Process cannot be reused
* There is always a danger of abrasive Particles getting embedded in the workpiece. So, cleaning is essential after the operation.
* It requires some kind of dust collection system.

Applications of AJM:

* This Process is widely used for
* Machining of hard and brittle materials like quartz, ceramics, glass, sapphire etc.,
* Fine drilling and microwelding
* Machining of semi-Conductors.
* Machining of intricate Profiles on hard and brittle materials.
* Cleaning and Polishing of plastics, nylon and teflon Components.
* Frosting of the interior surface of the glass tubes
* Surface etching and surface Preparation

Synopsis (or) characteristics of AJM:

Work material	:	Hard and brittle materials like glass, quartz, ceramics, mica etc.,
Abrasive	:	Aluminium oxide (Al_2O_3), Glass Powder, dolomite, Silicon Carbide (SiC) etc.
Size of Abrasive	:	Around 25 µm
Flow rate	:	2-20 g/min
Medium	:	N_2 (or) CO_2 (or) Air
Velocity	:	125-300 m/s
Pressure	:	2 to 8 kg/cm^2

Nozzle material : Tungsten Carbide (WC) (or) Synthetic Sapphire

Life of nozzle : Tungsten Carbide - 12 to 20 hours
Sapphire - 300 hours.

Nozzle tip clearance : 0.25 to 15 mm

Tolerance : ± 0.05 m.m

Machining operation : Drilling, cutting, deburring, cleaning etc.

WaterJet Machining (WJM):

* WaterJet Machining (WJM) Process is an extension of abrasive Jet machining Process.
* In this Process, high Pressure and high velocity steam of water is used to cut the relatively soft and non-metallic materials like Paper boards, wood, Plastics, Rubber, fibre glass, Leather etc.,

Principle:

* When the high velocity of water Jet comes out of the nozzle and strikes the material, its kinetic energy is converted into Pressure energy including high stresses in the work material.
* When this induced stress exceeds the ultimate shear stress of the material, small chips of the material get loosened and fresh surface is exposed.

Construction and working:

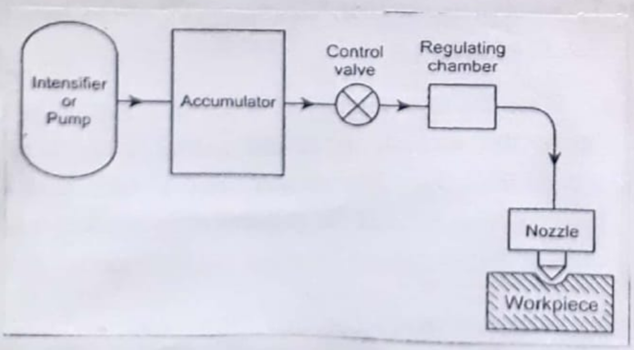


Fig: Schematic diagram of WJM

Construction:

* It consists of Pump, accumulator, control valve, regulating chamber, nozzle etc.,
* A Pump (or) Intensifier is used to raise the Pressure of water. Pressure normally used in the system are in the range of 1500 to 4000 N/mm^2.
* Since the cutting action may not be continuous, the accumulator is used to store the water and also it helps in

eliminating plusation.

* Nozzle is used to increase the velocity of the water Jet. The nozzle is made up of sintered diamond, tungsten carbide (or) synthetic Sapphire.

* The exit diameter of the nozzle is in the range of 0.05 to 0.35 mm and the exit velocity of the water Jet from the nozzle varies upto 920 m/s.

* A regulating chamber is incorporated in the line to control the flow of water Jet to the nozzle

Working :

* The working Principle of water jet machining is very similar to that of abrasive jet machining.

* A Pump (or) intensifier is used to increase the Pressure of the water and the water passes on to accumulator from the Pump.

* Water under Pressure from a hydraulic accumulator is Passed through the orifice of a nozzle to increase its velocity.

* When the high velocity of water jet comes out of the nozzle and strikes the work material, its kinetic energy is converted into Pressure energy including high stresses in the work material.

* When this induced stress exceeds the ultimate shear stress of the material, small chips of the material get loosened and fresh surface is exposed.

Process Parameters :

* The following Process Parameters are needed to utilise the WJM Process successfully.

→ Material Removal Rate (MRR)

→ Geometry and Surface finish of work material

→ Wear rate of the nozzle.

Material Removal Rate (MRR)

In WJM, material removal rate is directly Proportional to the reactive force (F) of the Jet.

$$MRR \propto F$$

$$MRR \propto m \times V \quad [\because F = m \times V]$$

Where m = mass flow rate

V = Jet velocity.

* mass flow rate depends on nozzle diameter (d) and fluid Pressure (P)
* Jet velocity depends on fluid Pressure.

$$\therefore MRR \propto d \propto P$$

* Stand off distance (SOD) is the distance between the nozzle tip and the surface of the material being machined.
* When MRR increases, the SOD also increases upto a certain limit, after that it remains unchanged for a certain tip distances and then falls gradually.

Geometry and Surface finish of work material:

Geometry and surface finish of work material mainly depends upon the following Parameters.

1. Nozzle design
2. Jet velocity
3. Cutting speed
4. Depth of cut
5. Properties of the material to be ~~machined~~ machined.

Wear Rate of the Nozzle:

Nozzle wear rate depends upon the following factors

1. Hardness of the nozzle material
2. Pressure of the Jet
3. Velocity of the Jet
4. Nozzle design.

Advantages :

* In WJM Process, water is used as energy transfer medium. It is cheap, non-toxic and easy to dispose.
* Low operating cost.
* Low maintenance cost.
* The work area remains clean and dust free.
* Very less amount of heat is generated during cutting operation. So there is no thermal damage to the work.
* Easily automated.

Dis-advantages :

* Initial cost of this process is high
* It is difficult to machine hard material.
* Noise operation.

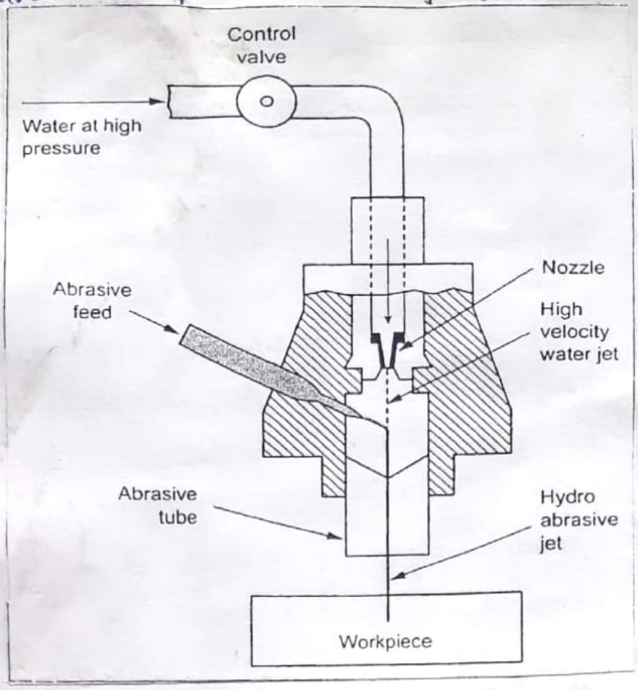
Applications :

* This Process is very convenient for cutting relatively soft and non-metallic materials like Paper boards, plastic, wood, rubber, leather, fibre glass etc.,
* It can be used to cut intricate contours.

Recent development in WJM :

* A Recent development of water jet machining Process is Hydrodynamic Jet machining.
* It has been successfully used to machine almost all types of ferrous and non-ferrous metals and alloys.
* In WJM Process, high velocity stream of water Jet is used to cut the material. But in HJM Process, abrasive Particles are also added to the high velocity stream of water Jet.
* The mixture of water and abrasives that comes out of the nozzle with very high velocity are directed to the workpiece. The material is removed from the workpiece due to combined effect of abrasion and water impact.

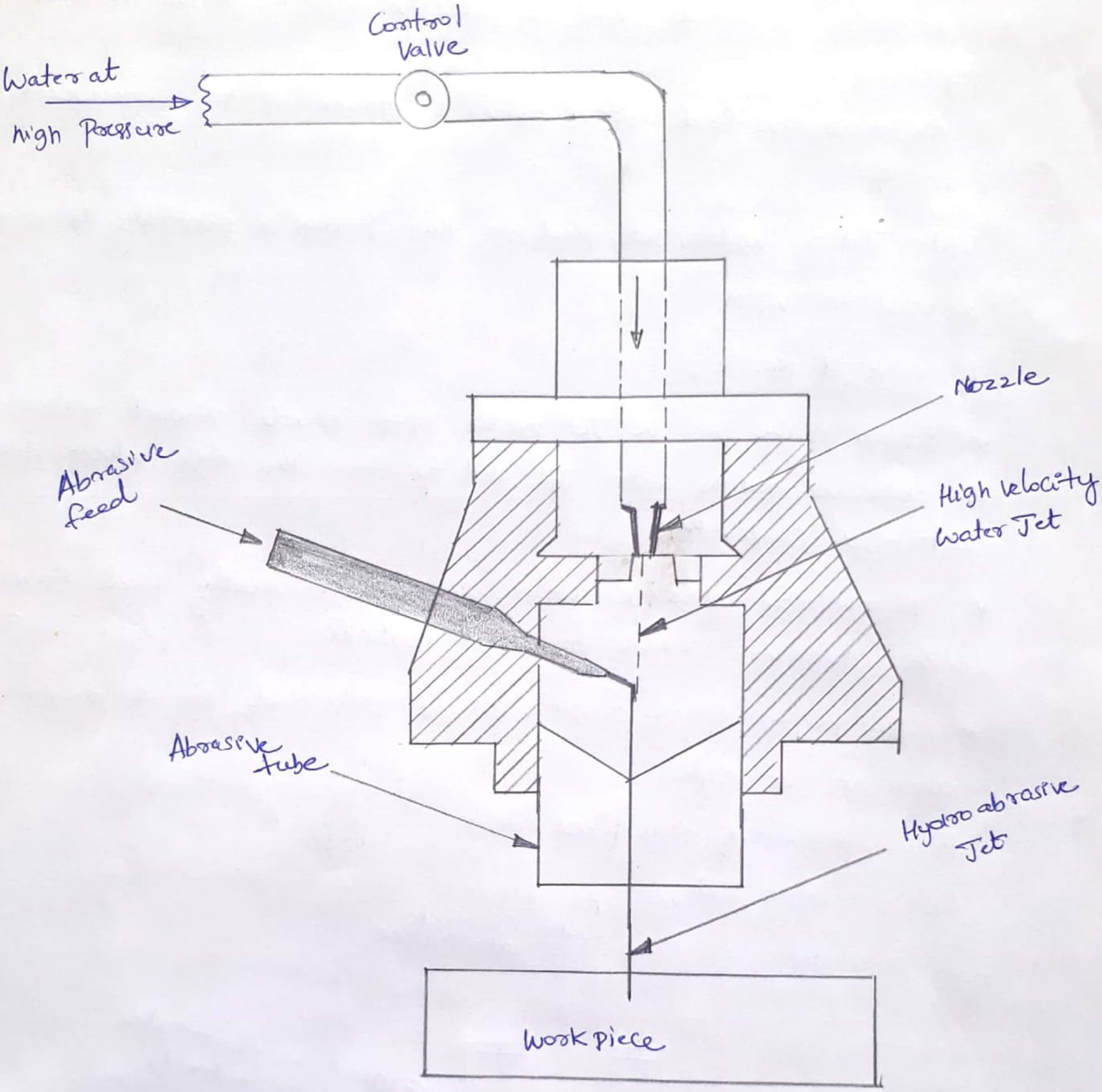
* Any material can be cut through this Process by using proper abrasive and adequate water pressure.



* Characteristics of WJM :

Work material	: soft and non-metallic materials like Paper boards, wood, Plastics, rubber etc.
Tool	: water (or) water with additives.
Additives	: Glycerin, Polyethylene oxide
Pressure of water	: 100 to 1000 MPa
Mass flow rate	: 8 lit/min
Power	: 45 KW
metal removal rate	: $0.6\ mm^3/s$
Feed rate	: 1-4 mm/s
Nozzle material	: Tungsten Carbide, synthetic sapphire
stand off distance	: 2 to 50 mm

Abrasive Water Jet Machining



Process Principle :

* An abrasive Jet starts out the Same as a Pure water Jet.
* As the thin stream of water leaves the nozzle, abrasive is added to the stream and mixed.
* The beam of water accelerates abrasive Particles to speeds fast enough to cut through much harder materials.
* The coherent, abrasive water Jet that exits the AWJM nozzle has the ability to cut various materials, such as metals, glass, Ceramics and composites.

Abrasive feed Systems:

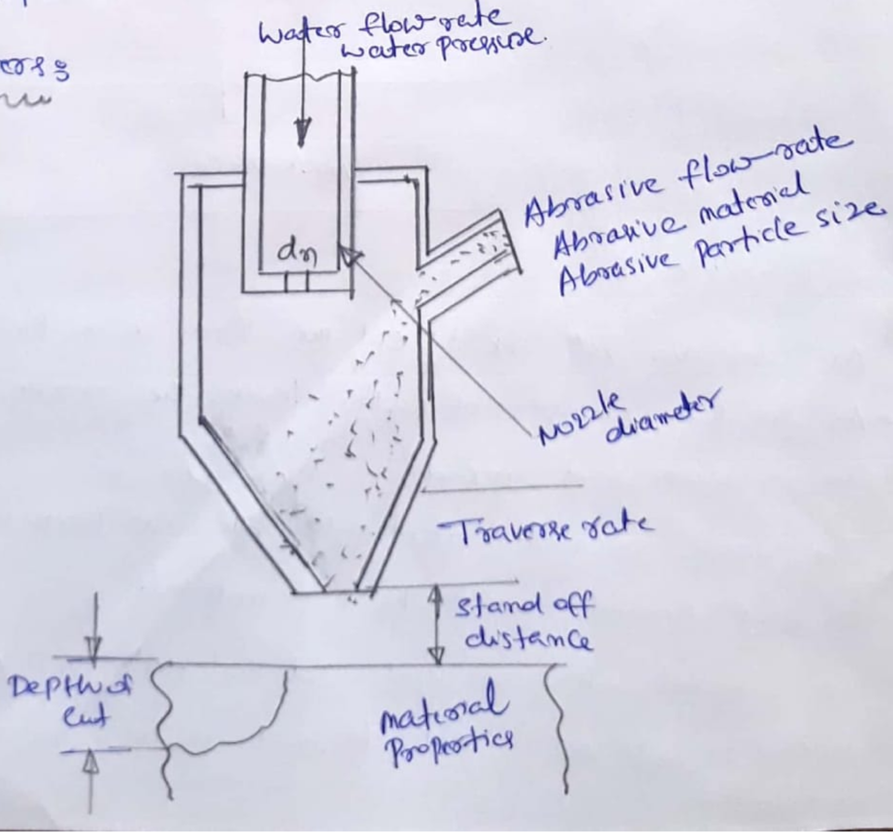
* Purpose: Controlled flow of abrasive particles to the abrasive Jet nozzle.
* AWJM abrasive feed systems deliver a stream of dry abrasives to the nozzle.

Water Jet: water Jet used for this Process is essentially the same as used for WJM.

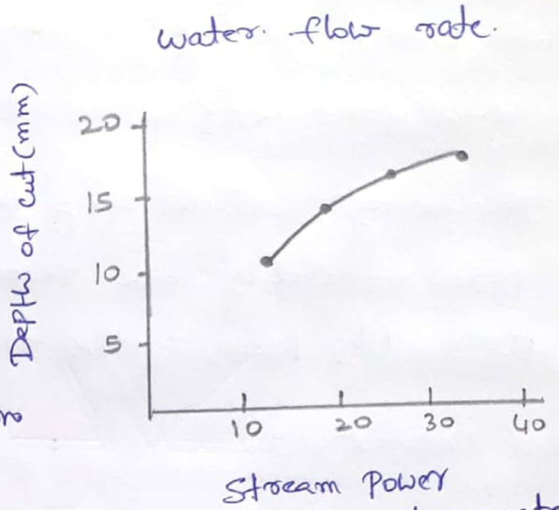
Abrasive Jet Nozzle:

* Purpose of the abrasive Jet nozzle is to Provide efficient mixing of the abrasives and the water Jet and to form the high-velocity abrasive water-Jet Combination.
* To minimize abrasive wear, the nozzle is usually made from either tungsten Carbide (or) boron Carbide
* Two major design concepts are currently used for the design of abrasive jet nozzles.
  (a) single-Jet side feed nozzle
  (b) multiple Jet.

Process Parameters:



* Fig. shows the depth of cut is affected by varying the water flow rate (Increasing the nozzle diameter) while maintaining the constant pressure



* As the flow rate increases, the slope of the curve decreases because the ~~Saturatoration~~ ~~is~~ saturation point is reached.

* As the nozzle diameter increases and the water flow rate increases, the rate of increase in the particle velocity is reduced, thus reducing the depth of cut.

Abrasive flow rate:

* Abrasive flow rate versus depth of cut is a linear relationship up to a point.

* Above a critical flow rate, the cutting efficiency decreases.

* This is due to, ~~the~~ as the abrasive flow rate increases (with a fixed water flow rate), particle velocity begins to decrease faster than the rate at which the number of abrasive particle impacts increase.

Abrasive particle size:

* The most common abrasive particle sizes used for AWJM range from 100 to 150 grit.

Abrasive type:

* Garnet, silica, and silicon carbide are the most commonly used abrasives

* Selection of abrasive type is usually determined by the hardness of the material that is being cut.

Traverse rate :

* When traverse rates are increased the depth of cut decreases.

Stand-off-distance :

* Increasing SOD decreasing the depth of cut.
* Data generated by some researchers indicate that depth of cut is approximately linear relative to SOD.

Process Capabilities :

* AWJM can be thought of as a Combination of WJM and AJM Principles
* But in terms of Capability, AWJM Combines the best of both processes, resulting in a new process that can cut materials whether they are hard (or) soft at high rates and in very thick sections.

Ultrasonic Machining :

* Ultrasonic machining is one kind of grinding method. It is also known as Ultrasonic grinding (or) Impact grinding.
* The term Ultrasonic refers to waves of high frequency.
* Human ear can hear the sound waves between 20 HZ to 20 KHZ. This range is known as audible range.
* The sound waves which have frequencies less than the audible range are called infrasonic waves.
* The sound waves having frequencies above the audible range are known as Ultrasonic waves.
* The ultrasonic machining Process is suitable only for hard and brittle materials like carbides, glass, ceramics, silicon, Precious stones, germanium, titanium, tungsten, tool steels, die steels etc.

Principle of USM:

* In this machining method, 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.

Construction and working:

* The general arrangement of ultrasonic machining is shown in the following diagram

* It consists of abrasive slurry, workpiece, fixture, table, cutting tool, circulating pump, reservoir, ultrasonic oscillator, Leads, excitation coil, feed mechanism, ultrasonic transducer, transducer cone, connecting body and tool holder.

* The ultrasonic oscillator and amplifier also known as generator is used to convert the applied electrical energy at low frequency to high frequency.

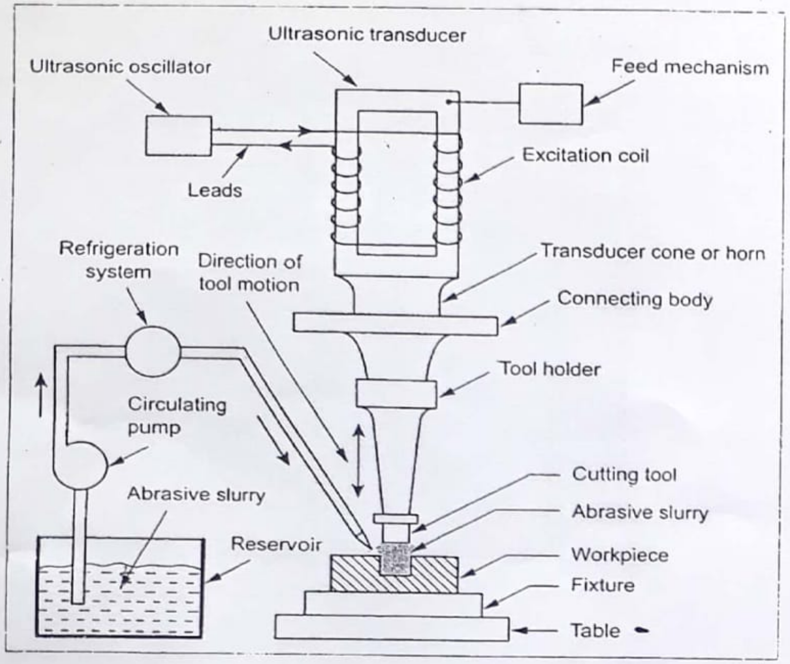


Fig. 2.12. Arrangement of ultrasonic machining process

- The transducer is made up of magnetostrictive material and it consists of a stack of nickel laminations that are wound with a coil.
- The function of the transducer is to convert the electrical energy into mechanical energy.
- Generally tough and ductile tool material is used in this process. Low carbon steels and stainless steels are commonly used as tool materials.
- The tool is brazed, soldered or fastened mechanically to the transducer through a tool holder. Generally tool holder is of cylindrical or conical in shape.

- The materials used for tool holders are titanium alloys, monel, aluminium, stainless steel, *etc.*
- An abrasive slurry, usually a mixture of abrasive grains and water of definite proportion (20 – 30 percent), is made to flow under pressure through the gap between tool and workpiece. The gap between the tool and workpiece is of the order 0.02 to 0.1 mm.
- The most commonly used abrasives are boron carbide (B_4C), silicon carbide (SiC), aluminium oxide (Al_2O_3), and diamond. Boron carbide is most commonly used abrasive slurry, since it has the fastest cutting abrasive property.

Working :

- Electric power is given to ultrasonic oscillator and this oscillator converts the electrical energy at low frequency to high frequency (20 kHz).
- High frequency power (20 kHz) from oscillator is supplied to the transducer.
- The function of the transducer is to convert the electrical energy into mechanical vibrations. The transducer is made up of magnetostrictive material, which is excited by flowing high frequency electric current and this results in the generation of mechanical vibrations. The vibrations are generated in the transducer of the order of 20 kHz to 30 kHz and hence ultrasonic waves are produced.
- These vibrations are then transmitted to the cutting tool through transducer cone, connecting body and tool holder. This makes the tool to vibrate in a longitudinal direction as shown in Fig.2.12.

- Abrasive slurry is pumped from the reservoir and it is made to flow under pressure through the gap between tool and workpiece.
- In an abrasive slurry, when the cutting tool vibrates at high frequency, it leads in the removal of metal from the workpiece.
- The impact force arises out from the vibration of tool end and the flow of slurry through the workpiece – tool gap causes thousands of microscopic grains to remove the workpiece material by abrasion.
- A refrigerated cooling system is used to cool the abrasive slurry to a temperature of 5 to 6°C.
- The ultrasonic machining process is a copying process in which the shape of the cutting tool is same as that of the cavity produced.

2.3.3. COMPARISON OF ULTRASONIC MACHINING WITH TRADITIONAL ABRASIVE MACHINING

S.No.	Traditional Abrasive Machining	Ultrasonic Machining
1.	Motion of the grinding grit is tangential to the work surface.	Motion of the grinding grit is normal to the work surface.
2.	Abrasive particle is used to remove the metal from the workpiece.	Abrasive slurry is used to remove the metal from the workpiece.
3.	Abrasive wheel is rotated by electric power.	Tool is vibrated by magnetostriction effect which produces ultrasonic waves.

2.3.15. METAL REMOVAL RATE

- The material removal rate per unit time is inversely proportional to the cutting area of the tool. Boron carbide is the hardest material and has the highest metal removal rate.
- Wear ratio is defined as the ratio of volume of material removed from the work to volume of material eroded from tool.

$$\text{Wear ratio} = \frac{\text{Volume of material removed from the work}}{\text{Volume of material eroded from the tool}}$$

- Material removal in USM is a very complex process and it depends on certain factors. They are :
  1. Grain size of abrasive.
  2. Abrasive materials.
  3. Concentration of slurry.
  4. Amplitude of vibration.
  5. Frequency of ultrasonic waves.

1. Grain Size of Abrasive

Material removal rate and surface finish are greatly influenced by grit or grain size of the abrasive. Maximum rate in machining is attained when the grain size of the abrasive is comparable to the tool amplitude.

For rough work operation, grit size of 200 – 400 are used and for finishing operation, grit size of 800 – 1000 are used. Fig.2.22 shows the effect of grain size for the material removal rate (MRR) in ultrasonic machining process.

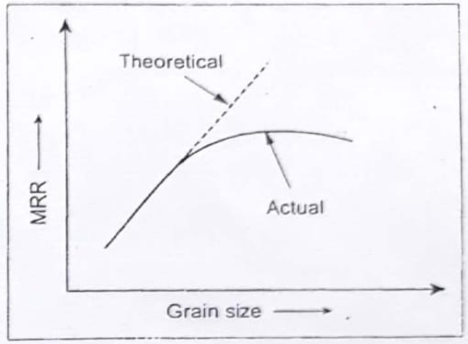


Fig. 2.22.

2. Abrasive Materials

For effective machining, the abrasive materials should be replaced periodically since the dull abrasives stop the cutting action.

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

3. Concentration of Slurry

An abrasive slurry, usually a mixture of abrasive grains and water of definite proportion (20 – 30 percent), is made to flow under pressure through the gap between tool and workpiece. Fig.2.23 shows how the material removal rate in ultrasonic machining process varies with slurry concentration.

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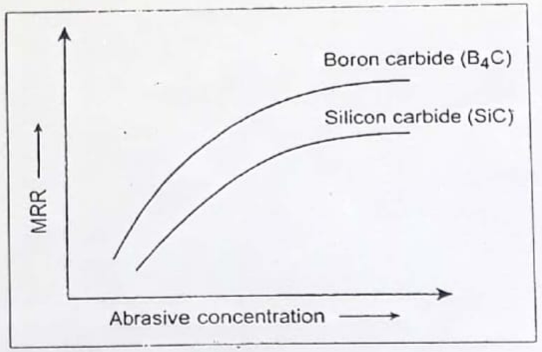

Fig. 2.23.

4. Amplitude of Vibration

Metal removal rate in ultrasonic machining process increases with increasing amplitude of vibration which is shown in Fig.2.24.

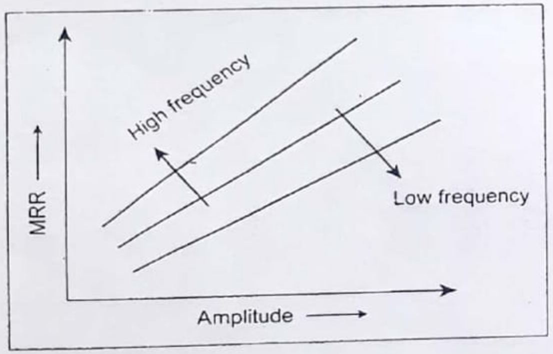

Fig. 2.24.

5. Frequency

Ultrasonic wave frequency is directly proportional to the metal removal rate which is shown in Fig.2.25.

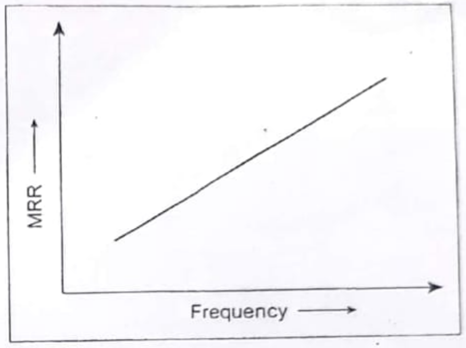

Fig. 2.25.

2.3.16. PROCESS PARAMETERS

The various process parameters involved in USM methods are as follows :

(*i*) Metal removal rate.

(*ii*) Tool material.

(*iii*) Tool wear rate.

(*iv*) Abrasive materials and abrasive slurry.

(*v*) Surface finish.

(*vi*) Work material.

(i) Metal Removal Rate : Explained in Section 2.3.15.

(ii) Tool material : Generally, tough and ductile tool material is used in USM process. Low carbon steels and stainless steels are commonly used as tool materials. Since very long tools cause overstress, the tool should be short and rigid.

Hollow tool can be made with wall thickness greater than 0.5 to 0.8 mm. Side clearance to the tool is of the order of 0.06 mm to 0.36

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mm depending on grain size of abrasive. The USM process is a copying process in which the shape of the cutting tool is same as that of the cavity produced.

(iii) Tool wear rate : Tool wear ratio is defined as "the ratio of volume of material removed from the work to the volume of material eroded from the tool".

$$\text{Wear ratio} = \frac{\text{Volume of material removed from work}}{\text{Volume of material eroded from tool}}$$

The wear ratio is approximated to 1.5 : 1 for tungsten carbide (WC) workpiece, 100 : 1 for glass, 50 : 1 for quartz, 75 : 1 for ceramics and 1 : 1 for hardened tool steel.

(iv) Abrasive materials and Abrasive slurry : The most commonly used abrasives are boron carbide, silicon carbide, aluminium oxide and diamond. Boron is the most expensive abrasive material and is best suited for the cutting of tungsten carbide, tool steels, *etc.* Aluminium oxide is the softest abrasive and it is used for machining glass and ceramics.

Material removal rate and surface finish are greatly influenced by grit or grain size of the abrasive. For roughing work operation, grit size of 200 – 400 are used and for finishing operation, grit size of 800 – 1000 are used.

An abrasive slurry is a mixture of abrasive grains and water of definite proportion (20 – 30 percent). Abrasive in a slurry form is more effective compared to abrasives in loose form, since the liquid (water) would help removal of material due to cavitation effect during return stock of the tool. Moreover, the liquid is used to distribute the abrasive particles evenly into the working gap.

The cutting power of different abrasives are shown in the Table.

Table 2.1.

Sl. No.	Abrasive	Hardness	Relative Cutting Power
1.	Boron carbide (B_4C)	2800	0.50 – 0.60
2.	Silicon carbide (SiC)	2450 – 2500	0.25 – 0.45
3.	Aluminium oxide (Al_2O_3)	2000 – 2100	0.14 – 0.16
4.	Diamond	6500 – 7000	1

(v) Surface Finish : The maximum speed of penetration in soft and brittle materials such as soft ceramics are of the order of 200 mm / min. Penetration rate is lower for hard and tough materials. Accuracy of this process is ± 0.006 mm and surface finish upto 0.02 to 0.8 micron value can be achieved.

(vi) Work materials : Hard and brittle metals, non-metals like glass, ceramics, *etc.*, and semiconductors are used as work material in USM process. Wear ratio, average penetration rate and maximum machining area of the different workpiece materials are shown in the following table.

Table 2.2.

Sl. No.	Material	Ratio of metal removal rate to tool wear rate	Maximum Machining Area (cm^2)	Average Penetration Rate (mm / min)
1.	Boron carbide	2 : 1	5.6	0.20
2.	Tungsten carbide	1.5 : 1	7.6	0.25

Sl. No.	Material	Ratio of metal removal rate to tool wear rate	Maximum Machining Area (cm^2)	Average Penetration Rate (mm / min)
3.	Tool steel	1 : 1	5.5	0.13
4.	Glass	100 : 1	25.2	3.8
5.	Ceramics	75 : 1	19.2	1.5
6.	Germanium	100 : 1	22.5	2.15

2.3.17. ADVANTAGES OF USM

1. Extremely hard and brittle materials can be easily machined.
2. Cost of metal removal is low.
3. Noiseless operation.
4. High accuracy and good surface finish can be easily obtained.
5. There is no heat generation in this process. So, the physical properties of the work material remain unchanged.
6. Equipment is safe to operate.
7. Non-conducting materials of electricity such as glass, ceramics and semi-precious stones can be easily machined.
8. The machined workpieces are free of stresses.

2.3.18. DISADVANTAGES OF USM

1. Metal removal rate is slow.
2. Softer materials are difficult to machine.
3. Wear rate of the tool is high.
4. The initial equipment cost is high.

5. For effective machining, the abrasive materials should be replaced periodically since the dull abrasives stop cutting action.
6. High power consumption.
7. Tool cost is high.
8. The size of the cavity that can be machined is limited.

2.3.19. LIMITATIONS

Under ideal conditions,

Penetration rate – 5 mm^3 / min
Power – 500 – 1000 watts
Metal removal rate on brittle materials – 0.018 mm^3 / joule
Hole tolerance – 25 μm
Surface finish – 0.2 to 0.7 μm

2.3.20. APPLICATIONS OF USM

1. Holes as small as 0.1 mm can be drilled.
2. Precise and intricate shaped articles can be machined.
3. It has been efficiently applied to machine glass, ceramics, tungsten, precision mineral stones, *etc.*
4. It is used for making tungsten carbide and diamond wire drawing dies and dies for forging and extrusion processes.
5. Several machining operations like drilling, grinding, turning, threading, profiling, *etc.*, on all materials both conducting and non-conducting.

UNIT - 2

* Introduction :

In electrical energy based Processes, electrical energy is directly Used to cut the material to get the final shape and size

Examples :

1. Electrical discharge machining (EDM)
2. Wire cut Electrical discharge Machining (WC EDM)

Working Principle of EDM :

* In Electrical discharge machining (also known as Spark erosion machining (or electro - erosion maching), metal is removed by Producing Powerful electrical spark discharge between the tool (cathode) and the work piece material (anode).

Construction and working of EDM :

* The main components are the electric Power supply, dielectric medium, work piece, tool and a Servo Control mechanism.
* The work piece and the tool are electrically connected to a D.C. Power supply.
* The following diagram shows the schematic layout of the electric discharge machining Process.

- The work piece is connected to the positive terminal of the electric source, so that it becomes the anode. The tool is connected to the negative terminal of the electric source, so that it becomes the cathode.
- The tool and workpiece are submerged in a dielectric fluid medium such as paraffin, white spirit or transformer oil having poor electrical conductivity.
- The function of the servo mechanism is to maintain a very small gap, known as 'spark gap' ranges of 0.005 to 0.05 mm between the work piece and the tool.

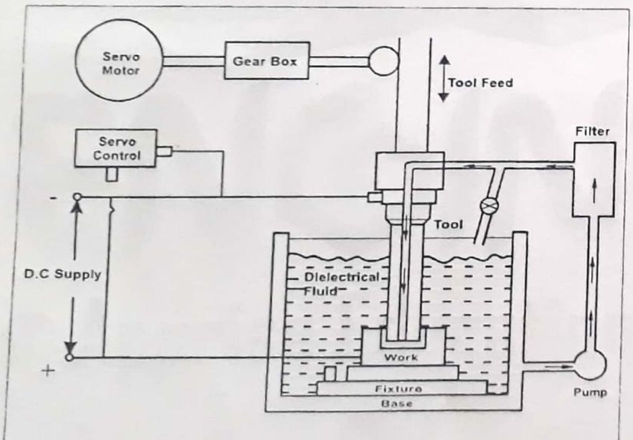


Fig 3.1. Schematic layout of EDM

Working :

- When the D.C supply is given to the circuit, spark is produced across the gap between the tool and the workpiece.
- When the voltage across the gap becomes sufficiently larger (more than 250 V), the high power spark is produced. So, the dielectric breaks down and electrons are emitted from the cathode (tool) and the gap is ionized.
- This spark occurs in an interval of 10 to 30 microseconds and with a current density of 15-500A per mm^2 approximately. So, thousands of spark-discharge occur per second across the gap between the tool and the work, which results in increasing temperature of about 10,000°C.
- At this high pressure and temperature, workpiece metal is melted, eroded and some of it is vaporised. In this way the metal is removed from the workpiece.
- The removed fine material particles are carried away by dielectric fluid circulated around it.
- The metal removal rate depends on the spark gap maintained. If anode and cathode are made of same material, it has been found that the greatest erosion takes place at anode. Therefore, in order to remove maximum metal and have minimum wear on the tool, the tool is made as cathode the workpiece as anode.
- When the voltage drops to about 12 volts, the spark discharge extinguishes and the dielectric fluid once again

becomes deionized. The condensers start to recharge and the process repeats itself.

3.4 DIELECTRIC FLUID

- A dielectric fluid is a medium that does not conduct electricity. In electrical discharge machining process, the tool and work piece are submerged in a dielectric fluid medium. The dielectric fluids generally used are petroleum based hydrocarbon fluids, paraffin, white spirit, transformer oil, kerosene, mineral oil or mixture of these.
- Dielectric fluids must not be hazardous to operators or corrosive to equipment.
- The choice of any dielectric fluid depends on the workpiece size, type of shape, tolerance, metal removal rate and surface finish. White spirit is best suited for machining tungsten carbide.
- The dielectric fluid should not be changed frequently on a machine, and it is chosen according to the most frequent application to be carried out in the machine.
- The dielectric fluid must circulate freely between the tool and work piece.
- The eroded particles should be flushed out at the earliest since it reduces the further metal removal rate.
- The various methods of flushing are pressure flushing, suction flushing and side flushing which are shown in Fig 3.2.

3

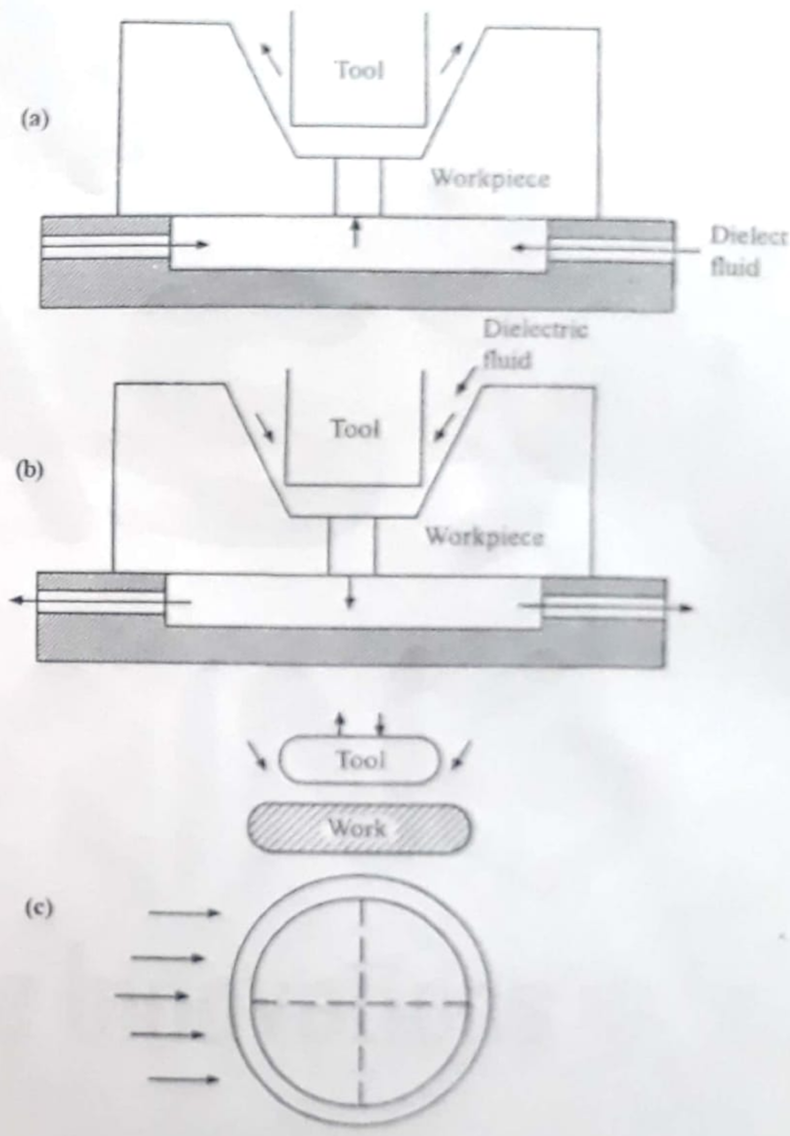


Fig 3.2. Flushing system in EDM

(a) pressure flushing (b) Suction flushing, (c) Side flushing

- The dielectric fluid should be filtered before reuse so that chip contamination of the fluid will not affect machining accuracy.
- The dielectric fluid should be easily available at reasonable price

3.5 FUNCTION OF DIELECTRIC FLUIDS

The dielectric fluid has the following functions

1. It acts as an insulating medium.
2. It cools the spark region and helps in keeping the tool and workpiece cool.
3. It carries away the eroded metal particles along with it.
4. It maintains a constant resistance across the gap.
5. It remains electrically non conducting until the required breakdown voltage has been reached.
6. It breakdown electrically in the shortest possible time once the breakdown voltage has been reached.

3.6. TOOL (ELECTRODE) MATERIALS AND TOOL WEAR

- The tool materials generally used can be classified as metallic materials(copper, brass, copper-tungsten etc), non-metallic materials (graphite) and combination of metallic and non-metallic materials (copper – graphite).
- Copper, yellow brass, alloys of zinc, copper tungsten, silver tungsten, tungsten carbide and graphite are used for tool materials.

4

- For commercial applications, copper is best suited for fine machining, aluminum is used for die-sinking and cast iron for rough machining.

The three most commonly used materials are given below.

i. Graphite

Graphite is a non-metallic which is generally used as a tool material in Electrical Discharge Machining processes. A wide range of grades are available in graphite and these are used for variety of applications.

A big advantage of graphite is though it is abrasive, it can be produced by several methods like machining, moulding, milling, grinding etc. Graphite can generally achieve better metal removal rates and fine surface finishes than metallic tool materials. One disadvantage of graphite is; it is costlier than copper.

ii. Copper

Copper is a second choice for using as tool material in Electrical Discharge Machining processes. It can be produced by casting or machining. Copper tools with very complex features are formed by chemical etching or electro forming.

iii. Copper – tungsten

Copper – tungsten tool material is difficult to machine and it has low metal removal rate. It is costlier than graphite and copper.

- The selection of proper tool material is influenced by
  - i. Size of electrode and volume of material to be removed.
  - ii. Surface finish required.
  - iii. Tolerance required.

iv. Nature of coolant application etc.

- The basic requirements of any tool material are
  i. It should have low erosion rate.
  ii. It should be electrically conductive.
  iii. It should have good machinability.
  iv. Melting point of the tool should be high.
  v. It should have high electron emission.

Tool wear

- As the tool does not come into contact with the work, life of tool is long and less wear and tear takes place.
- The tool wear ratio is defined as the ratio of volume of work material removed to the volume of electrode (tool) consumed.

$$\text{Wear ratio} = \frac{\text{Volume of work material removed}}{\text{Volume of electrode consumed}}$$

- The wear ratio for brass electrode is 1:1, for copper is 2:1 and for copper tungsten is 8:1 for non metallic (graphite) wear ratio may vary from 5:1 to 50:1.

3.7 METAL REMOVAL RATE (MRR) AND SURFACE FINISH

The metal removal rate is generally described as the volume of metal removed per unit time.

- Metal removal rate depends upon current density and it increases with current. But high removal rates produce poor finish. Therefore, the usual practice in EDM is, a roughing cut with a heavy current followed by a finishing cut with less current.

- Metal removal rates upto 80mm³/s can be achieved and surface finishes of 0.25 μm can be obtained at very low cutting rates.
- The material being cut will affect the metal removal rate. The experiments indicate that the metal removal rate (MRR) varies inversely with melting point of the metal. The approximate value is

$$MRR = \frac{2.44}{(\text{Melting point } ^{\circ}C)^{1.25}}$$

- Tolerances of the order of ± 0.05 to 0.13 mm are commonly achieved by EDM in normal production and with extra care, tolerances of ± 0.003 to 0.013 mm are possible.

3.8 FACTORS AFFECTING THE METAL REMOVAL RATE (MRR)

1. Metal removal rate increases with forced circulation of dielectric fluid.
2. It increases with capacitance.
3. It increases upto optimum value of work-tool gap, after that it drops suddenly.
4. It increases upto optimum value of spark discharge time, after that it decreases.
5. Metal removal rate is maximum when the pressure is below the atmospheric pressure.

3.9 BREAKDOWN MECHANISM

- The cathode electrode is assumed to be source of producing electrons which are emitted either by field effect or by schottky effect.

- The electrons liberated from the cathode are accelerated until they gain sufficient energy to ionize the liquid molecules and initiate an electron avalanche.
- The applied field E, at which an electron avalanche can be initiated is given as

$$eE\lambda = ch\nu$$

Where

e – charge

E – Applied field

λ – Mean free path of electron

c – velocity of light

$h\nu$ – Ionization quantum for the liquid molecule

This theory is used to magnify the breakdown strength of hydrocarbons. But it does not take into account the ignition delay observed between the applied voltage and breakdown voltage.

- Breakdown in gas is introduced by collisional ionization of the molecules. But in liquid, collisional ionization of the molecules by electrons is not possible due to insufficient kinetic energy of the electrons. In order to avoid this, a pre-breakdown electron current flows from the cathode to anode. This low current heats the liquid to form a vapour bubble of sufficient pressure in between the electrodes. Then a spark is produced in the vapour bubble according to the high pressure gas-discharge mechanism.

3.10. POWER GENERATING CIRCUITS OR SPARK GENERATING CIRCUITS

- Power generator is one of the most important part of an electrical discharge machining processes.
- Its primary function is to convert an alternating current (AC) into a pulsed direct current (DC) which is required to produce the unidirectional spark discharges between the gap of the tool and workpiece. A rectifier is used to convert the AC into DC.
- The most commonly used spark generating circuits are given below

1. Resistance - Capacitance circuit (RC circuit) or Relaxation circuit.
2. R-C-L circuit.
3. Rotary pulse generator circuit.
4. Controlled pulse generator circuit.

i. Relaxation circuit

Fig 3.3 shows the operation of Resistance – Capacitance (R-C) generator circuit. This type of generators are quite common because of its simplicity and lower cost. In this system, Direct Current (D.C) is flowing through a resistor (R) and it charges the capacitor (C). The charged capacitor is connected to the machine. When the voltage across the capacitor is sufficiently high (50 to 200V), dielectric medium breakdown occurs. So, the dielectric medium between the tool and workpiece is ionized and spark takes place. Millions of electrons are developed in each spark. During sparking period, the voltage falls and it again starts rising (since the capacitor is charged again) as shown in fig. 3.3.

6

Energy released per spark $= E = \frac{1}{2} C.V_d^2$

Where

C = Capacitor value

V_d = Discharge voltage

= Vo [1 – exp [-t/R_c]]

V_o = D.C. Source voltage

For maximum power delivery, the discharge voltage (V_d) should be 75% of the supply voltage (V_o)

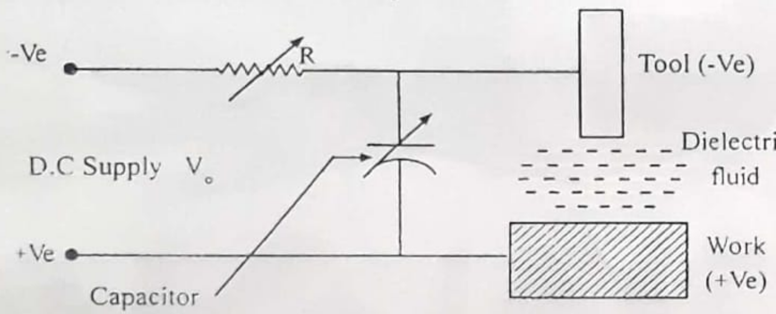


Fig. 3.3 Basic R-C Relaxation circuit

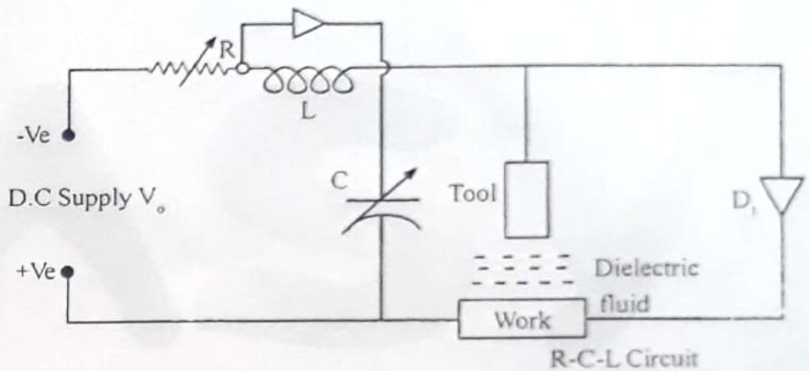
Drawbacks of Relaxation circuit

1. Though the discharge current in a relaxation circuit reaches a high value, it is of very short duration.
2. Since the time for charging the capacitor is high, the use of high frequencies is limited.

II. R-C-L circuit

In the relaxation circuit, metal removal rate increases as R is decreased. But R cannot be decreased below a critical value.

If R decreases below a critical value, arcing will take place instead of sparking. Further, the capacitor charging time in R-C circuit is much higher than discharging time. Therefore an inductance (L) is included in the charging circuit. This R-C-L circuit is shown in Fig.3.4.



R- Resistance C- Capacitance L - Inductance

Fig. 3.4 Basic Principle R-C-L Circuit

iii. Rotary pulse generator

The introduction of pulse generator has overcome the drawbacks of R-C and R-C-L circuits

R-C and R-L-C circuits yield low metal removal rate. Therefore, rotary pulse generator is used for spark generation. It yields high metal removal rate, low tool wear and more precise control of parameters. Fig. 3.5 shows the schematic diagram of rotary impulse generator circuit. In this circuit, the capacitor (C) is discharged through the diode during the first half cycle. During the next half cycle, the sum of voltages generated by the generator and the charged capacitor is applied to the work- tool gap. This arrangement gives more metal removal rate, but surface finishing is poor.

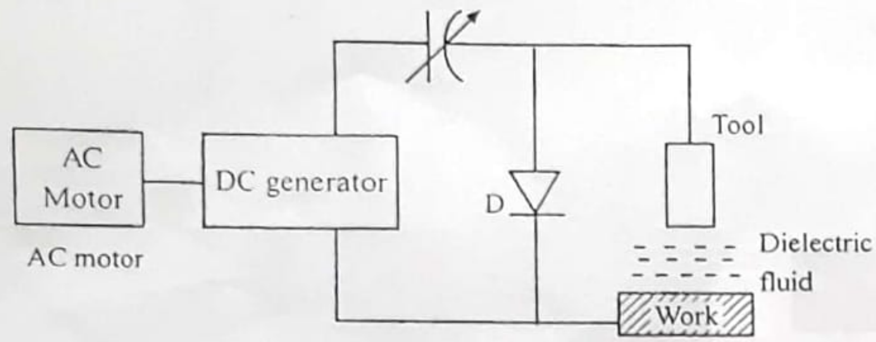


Fig 3.5 Rotary Pulse generator

iv. Controlled pulse generator circuit

Fig 3.6 shows the arrangement of controlled pulse circuit. R-C, R-C-L and rotary pulse generator circuits are not having automatic prevention of the current flow incase a short circuit is developed. To obtain such an automatic control, a vacuum tube or a transistor is used as switching device as shown in Fig. 3.6.

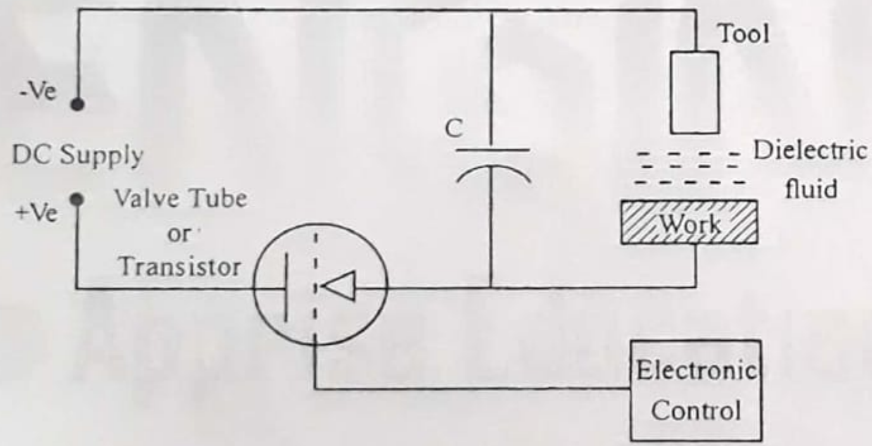


Fig 3.6 Controlled Pulse Circuits

ADVANTAGES OF EDM PROCESS

1. It can be used for machining various material such as tungsten carbide, electrically conductive materials and other hard materials.
2. It gives good surface finish.
3. Machining of very thin section is possible.
4. It does not leave any chips or burrs on the workpiece.
5. It is well suited for complicated components.
6. Since there is no cutting forces act on the job, error due to elastic deformation is eliminated.
7. High accuracy is obtained.
8. Fine holes can be easily drilled.
9. It is a quicker process. so, harder materials can also be machined at much faster rate than conventional machining.
10. The process once setup does not need constant operators attention.

3.13. DISADVANTAGES (LIMITATIONS)

1. It is only used for machining electrically conductive materials. So non-metallics such as plastics, ceramics or glass can not be machined by EDM.
2. It is suitable only for machining small work pieces.
3. Electrode wear and over cut are serious problems.
4. Perfectly square corners cannot be made by EDM process.
5. Metal removal rate is slow.
6. Power requirement is very high.
7. In many cases, the surface machined has been found to have micro cracks.

3.14. APPLICATIONS

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

1. Production of complicated and irregular shaped profiles.
2. Thread cutting in jobs.
3. Drilling of micro holes.
4. Helical profile drilling.
5. Curved hole drilling.
6. Resharpening of cutting tools and broaches.
7. Remachining of die cavities without annealing.

3.15. Wire Cut Electro–Discharge Machining (WCEDM)

or

Travelling Wire Electro–Discharge Machining (TWEDM)

Construction

- Fig 3.9 shows the schematic diagram of WCEDM process.
- A very thin wire (.02 to 0.3mm) made of brass or molybdenum having circular cross section is used as a electrode (tool).
- The wire is stretched and moved between two rollers. The part of wire is eroded by the spark.
- The prominent feature of a moving wire is that a complicated cutout can easily machined without using an electrode.

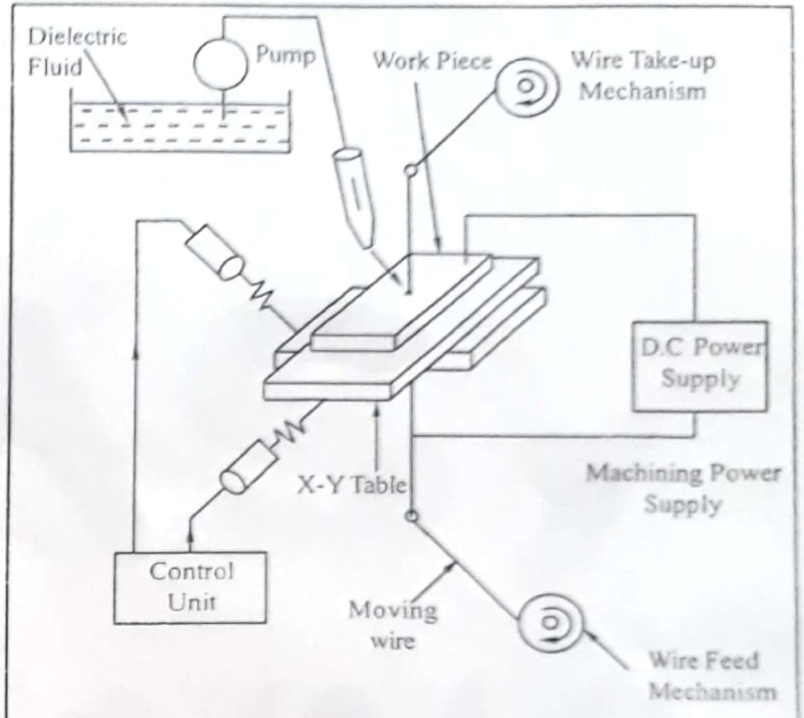


Fig. 3.9 Wire Cut EDM Process

- It consist of
  - i. Workpiece movement control unit.
  - ii. Workpiece mounting table.
  - iii. Wire drive section for accurately moving the wire at constant tension.
  - iv. Dielectric fluid supplying unit
  - v. Power supplying unit.

Working :

- Workpiece to be machined is mounted on the table which is operated by control unit.

- A very small hole is predrilled in the workpiece, through which a very thin wire made of brass or molybdenum is passed as shown in fig. 3.9 and this wire is operated by wire feed mechanism.
- Dielectric fluid (distilled water) is passed over the workpiece and the wire (tool) by using pump.
- When the D.C supply is given to the circuit, spark is produced across the gap between the wire and the workpiece.
- When the voltage across the gap becomes sufficiently large, the high power spark is produced.
- This spark occurs in an interval of 10 to 30 microseconds and with a current density of 15-500 A per mm^2 approximately. So, thousands of spark discharge occur per second across the very small gap between the wire and the workpiece, which results in increasing temperature of about 10,000°C.
- At this high pressure and temperature, workpiece metal is melted, eroded and some of it is vaporised. The metal is thus removed in this way from the workpiece.
- The removed fine material particles are carried away by dielectric fluid circulated around it.

3.16. FEATURES OF WIRE CUT EDM PROCESS (OR) ADVANTAGES OF WIRE CUT EDM PROCESS

i. Manufacturing Electrode

In this process a very thin wire made of brass or

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molybdenum is used as the electrode (tool) to machine the workpiece material. So, there is no need for manufacturing electrodes (as in EDM) which are traditionally made by cutting and grinding by using an expensive alloy of silver and tungsten. This feature is used to reduce the man – hour requirements and ensures greater economy.

ii. Electrode wear

During machining process, the wire electrode (tool) is constantly fed into the workpiece. So the wear of tool is practically ignored.

iii. Surface finishing

A very thin wire electrode is constantly fed into the workpiece at speed of about 10 to 30 mm/s by wire feed mechanism as shown in fig. 3.9. So machining is continued without any accumulation of chips and gases. It gives high surface finish and reduces the manual finishing operating time.

iv. Complicated shapes

By using programme, complicated and very minute shapes can be efficiently machined. So there is no need of skilled operators.

v. Time Utilization

Since all the machine motions of wire cut EDM processes are controlled by NC, it can be operated throughout the day without any fire hazards.

vi. Straight holes

The electrode wire is maintained at optimum tension by a

(12)

unique wire tension control mechanism. So, it prevents taper holes, barrel-shaped holes, wire breakage and wire vibration.

vii. Rejection

Rejection of material is minimized due to initial planning and checking the programme.

viii. Economical

Since most of the programming can be easily done, it is economical for small batch production, including prototypes.

xi. Cycle time

Cycle time for die manufacture is shorter, as the whole work is done on one machine.

ix. Inspection time

Inspection time for wire cut EDM process is reduced due to single piece construction of dies with high positioning accuracy.

3.17. DISADVANTAGES

1. Capital cost is high.
2. Cutting rate is slow.
3. It is not suitable for large workpieces.

3.18. APPLICATIONS

The wirecut EDM process is best suited for the production of gears, tools, dies, rotors,turbine blades and cams for small to medium size batch production.

3.19. DIFFERENCE BETWEEN EDM AND WIRE CUT EDM PROCESS

S.No	Wire cut EDM	EDM
1.	Very thin wire made of brass or molybdenum is used as the electrode (tool).	Expensive alloy of silver and tungsten are used as the electrode (tool) which are traditionally made by cutting and grinding.
2.	The whole workpiece is not submerged in dielectric medium instead, the working zone alone is supplied with a co-axial jet of dielectric medium.	The whole workpiece is submerged in dielectric medium.
3.	It is easy to machine complex two dimensional profiles.	It is difficult to cut complex two dimensional profiles.

3.20. RECENT DEVELOPMENTS IN EDM PROCESS

- Electrical discharge machines change from using relaxation circuits to faster and more efficient impulse circuits.
- Instead of using copper as electrode, harder tungsten-copper is preferred.

3.21 CHARACTERISTICS OF EDM

Metal removal technique	:	By using powerful electric spark.
Work material	:	Electrically conductive materials and alloys.

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Tool material	: Copper, Yellow brass, Alloy of Zinc, Copper tungsten etc.,
Metal removal rate	: 15 to 80 mm^3 / s
Spark gap	: .005 to .05 mm
Spark frequency	: 200 - 500 KHz
Volts	: 30 - 250V
Current	: 5 - 60 A
Temperature	: 10,000°C
Dielectric fluid	: Petroleum based hydrocarbon fluids, paraffin, white spirit etc.,

UNIT-3

Thermal Energy Based Processes :

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

Examples :

1. Electron Beam machining (EBM)
2. Laser Beam Machining (LBM)
3. Plasma Arc Machining (PAM).

1. Electron Beam Machining (EBM) :

In Electron Beam Machining Process, high velocity focused beam of electrons are used to remove the metal from the workpiece. These electrons are travelling at half the velocity of light i.e 1.6×10^8 m/s.

This Process is best suited for micro-cutting of materials.

Principle :

* When the high velocity beam of electrons strike the workpiece, its kinetic energy is converted into heat.
* This concentrated heat raises the temperature of workpiece material and vaporises a small amount of it, resulting in removal of material from the work piece.

5.1.3. TYPES OF EBM PROCESS

The following two methods are used in EBM process.

1. Machining inside the vacuum chamber.
2. Machining outside the vacuum chamber.

5.1.4. CONSTRUCTION AND WORKING OF EBM (Machining Inside the Vacuum Chamber)

Construction

- The schematic arrangement of Electron Beam Machining (EBM) is shown in Fig.5.1.
- It consists of electron gun, diaphragm, focusing lens, deflector coil, work table, *etc.*
- In order to avoid collision of accelerated electrons with air molecules, vacuum is required. So, the entire EBM setup is enclosed in a vacuum chamber, which carries vacuum of the order 10^{-5} to 10^{-6} mm of mercury. This chamber carries a door, through which the workpiece is placed over the table. The door is then closed and sealed.
- The electron gun is responsible for the emission of electrons, which consists of the following three main parts.
  1. ***Tungsten Filament*** – which is connected to the negative terminal of the DC power supply and acts as cathode.
  2. ***Grid cup*** – which is negatively based with respect to the filament.
  3. ***Anode*** – which is connected to positive terminal of the DC power supply.
- The focusing lens is used to focus the electrons at a point and reduces the electron beam upto the cross sectional area of 0.01 to 0.02 mm diameter.

- The electromagnetic deflector coil is used to deflect the electron beam to different spot on the workpiece. It can also be used to control the path of the cut.

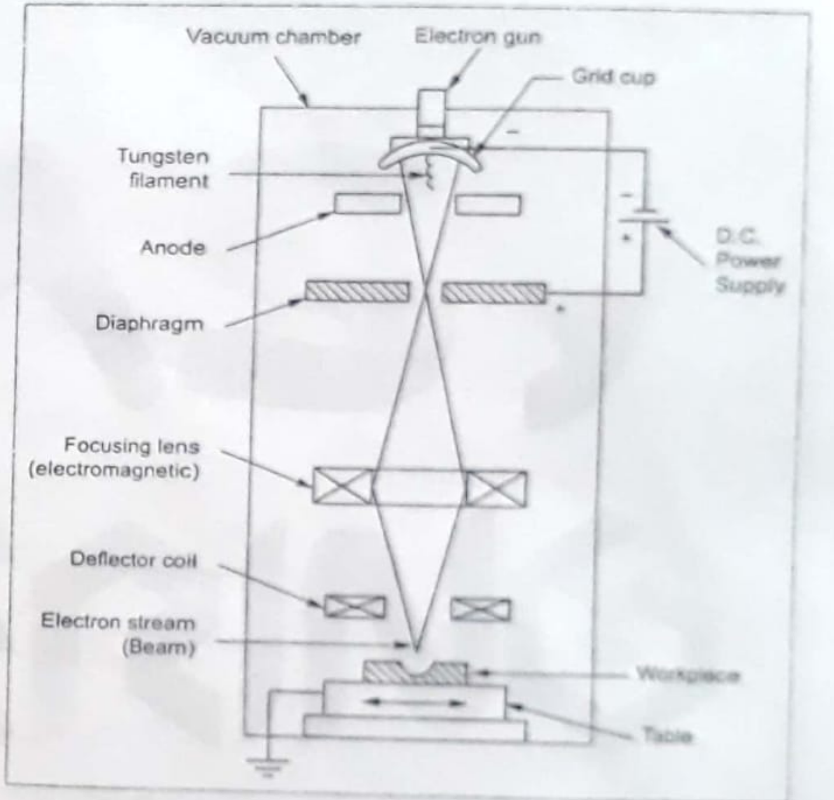

Fig. 5.1. Arrangement of Electron Beam Machining

Working

- When the high voltage DC source is given to the electron gun, tungsten filament wire gets heated and the temperature raises upto 2500°C.

- Due to this high temperature, electrons are emitted from tungsten filament. These electrons are directed by grid cup to travel towards downwards and they are attracted by anode.
- The electrons passing through the anode are accelerated to achieve high velocity as half the velocity of light (*i.e.*, 1.6×10^8 m / s) by applying 50 to 200 kV at the anode.
- The high velocity of these electrons are maintained till they strike the workpiece. It becomes possible because the electrons travel through the vacuum.
- This high velocity electron beam, after leaving the anode, passes through the tungsten diaphragm and then through the electromagnetic focusing lens.
- Focusing lens are used to focus the electron beam on the desired spot of the workpiece.
- When the electron beam impacts on the workpiece surface, the kinetic energy of high velocity electrons is immediately converted into the heat energy. This high intensity heat melts and vaporises the work material at the spot of beam impact.
- Since the power density is very high (about 6500 billion W/mm^2), it takes a few micro seconds to melt and vaporise the material on impact.
- This process is carried out in repeated pulses of short duration. The pulse frequency may range from 1 to 16,000 Hz and duration may range from 4 to 65,000 microseconds.
- By alternately focusing and turning off the electron beam, the cutting process can be continued as long as it is needed.

(3)

- A suitable viewing device is always incorporated with the machine. So, it becomes easy for the operator to observe the progress of machining operation.

5.1.5. MACHINING OUTSIDE THE VACUUM CHAMBER

Since the fully vacuum system is more costly, the recent development have made it possible to machine outside the vacuum chamber. In this arrangement, the necessary vacuum is maintained within the electron gun and the gases are removed as soon as they enter into the system.

5.1.6. MECHANICS OF EBM

Electrons are the smallest stable elementary particles with a mass of 9.109×10^{-31} kg with a negative charge of 1.602×10^{-19} coulomb. If it is assumed that the initial velocity of emitting electrons to be negligible then the electron velocity at the striking is given as,

$$V_s = 600\sqrt{E_s} \text{ km/s} \quad \text{... (1)}$$

where, E_s – Voltage of the electric field, volt

The power of the electron beam is given by,

$$P_b = E_s I_b, \text{ watts} \quad \text{... (2)}$$

where, I_b – Beam current, amp

The electron beam pressure is given by,

$$F_b = 0.34 \times I_d \sqrt{E_s} \text{ , dyne/cm}^2 \quad \text{... (3)}$$

where, I_d – Current density, A/cm^2

The thermal velocity acquired by an electron is given by,

$$V_a = \sqrt{\frac{2K\theta}{M_a}} \ m/s \quad \ldots (4)$$

where, K – Boltzmann's constant = 1.38×10^{-23} J/K/atom

θ – Temperature raised, K

M_a – Mass of one atom of the workpiece, kg

5.1.7. PROCESS PARAMETERS

The parameters which have significant influence on the beam intensity and metal removal rate are given below :

1. Control of current.
2. Control of spot diameter.
3. Control of focal distance of magnetic lens.

1. Control of Current

The heated tungsten filament cathode emits electrons depending upon the thermionic emission capability of the filament. It is given by Richardson-Dushman equation.

$$J = AT^2 \, e^{-\left(\frac{EW}{KT}\right)}$$

where, J – Current density of the emitted current $\left(\frac{amp}{cm^2}\right)$,

W – Work function of the material of the filament (volts),

T – Absolute temperature of the filament (K),

E – Electronic charge (coulomb),

K – Boltzmann constant (1.3×10^{-23} J/K), and

A – Constant [120 amp / cm² (degree)²].

The above mentioned equation is valid only when the tungsten filament (cathode) is in free space. But in the presence of electric field around the filament, alters this current density very much.

The grid bias voltage is used to control the beam current. The more negative grid with respect to the cathode, the restriction of electron emission will be more.

2. Control of Spot Diameter

The diameter of the spot depends upon beam current, accelerating voltage, magnetic lens, distance between gun and workpiece, etc. The most important three factors which contribute to change in spot diameter are given below.

(i) Effect of thermal velocities : We know that, different electrons converging at different points along the longitudinal axis of the beam. So, the spot size will get spread out and the minimum spot diameter is given by,

$$\delta D_t = \frac{2 r_c}{r_l} \, x \, \sqrt{\frac{KT}{EV}}$$

where, δD_t – Minimum spot diameter,

r_c – Cathode (tungsten filament) spot radius,

r_l – Radius of beam at magnetic lens,

x – Distance between gun and workpiece,

E – Electronic charge,

V – Anode voltage,

K – Boltzmann constant (1.3×10^{-23} J/K), and

T – Absolute temperature of cathode.

(ii) Spherical deviation of the focusing lens : The spherical deviation results in the marginal rays causing the axis at a different position from the rays. So, it leads an ideal point image to be confused in a disc whose diameter is given by,

$$\delta D_s = 2.5\, r_i^3 \left[\frac{x}{f\,(S + D)^2} \right]$$

where, S – Lens pole piece separation of the magnetic lens,

D – Bore diameter of the magnetic lens, and

f – Focal length of the magnetic lens.

(iii) Space charge spreading of target : The minimum spot size is limited when the electrons converging in a conical beam to a point as the target is subjected to mutual repulsion and the equation is given as,

$$\delta D_c = 11.8 \times 10^4 \times x^{5/2}\ I^{5/4}\ V^{-15/8}\ r_i^{-3/2}$$

The combined effect of these three gives the reduced formula for minimum spot diameter.

$$\delta D = \sqrt{\delta D_t^2 + \delta D_s^2 + \delta D_c^2}$$

3. Control at Focal Distance of Magnetic Lens

The focal distance at magnetic lens is given by,

$$\frac{f}{S + D} = \frac{25\ V}{(NT)^2}$$

where, V – Electron accelerating voltage, and

NT – Amphere turns in the lens winding,

(5)

5.1.8. CHARACTERISTIC OF EBM PROCESS

Accelerating voltage	:	50 to 200 kV
Beam current	:	100 to 1000 μA
Electron velocity	:	1.6×10^8 m / s
Power density	:	6500 billion W/mm^2
Medium	:	Vacuum (10^{-5} to 10^{-6} mm of Hg)
Workpiece material	:	All materials
Depth of cut	:	Upto 6.5 mm
Material removal rate	:	Upto 40 mm^3 / s
Specific power consumption	:	0.5 to 50 kW

5.1.9. ADVANTAGES OF EBM PROCESS

Electron beam machining has the following advantages :

1. It is an excellent process for microfinishing (milligram / s).
2. Very small holes can be machined in any type of material to high accuracy.
3. Holes of different sizes and shapes can be machined.
4. There is no mechanical contact between the tool and workpiece.
5. It is a quicker process. Harder materials can also be machined at a faster rate than conventional machining.
6. Electrical conductor materials can be machined.

7. The physical and metallurgical damage to the workpiece are very less.
8. This process can be easily automated.
9. Extremely close tolerances are obtained.
10. Brittle and fragile materials can be machined.

5.1.10. DISADVANTAGES (LIMITATIONS)

1. The metal removal rate is very slow.
2. Cost of equipment is very high.
3. It is not suitable for large workpieces.
4. High skilled operators are required to operate this machine.
5. High specific energy consumption.
6. A little taper produced on holes.
7. Vacuum requirements limits the size of workpiece.
8. It is applicable only for thin materials.
9. At the spot where the electron beam strikes the material, a small amount of recasting and metal splash can occur on the surface. It has to be removed afterwards by abrasive cleaning.
10. It is not suitable for producing perfectly cylindrical deep holes.

5.1.11. APPLICATIONS

1. EBM is mainly used for micro-machining operations on thin materials. These operations include drilling, perforating, slotting, and scribing, *etc.*
2. Drilling of holes in pressure differential devices used in nuclear reactors, air craft engines, *etc.*
3. It is used for removing small broken taps from holes.
4. Micro-drilling operations (upto 0.002 mm) for thin orifices, dies for wire drawing, parts of electron microscopes, injector nozzles for diesel engines, *etc.*
5. A micromachining technique known as "Electron beam lithography" is being used in the manufacture of field emission cathodes, integrated circuits and computer memories.
6. It is particularly useful for machining of materials of low thermal conductivity and high melting point.

5.1.12. SOLVED PROBLEMS

Example 1 ***Calculate the thermal velocity acquired by an electron of the work material due to electron bombardment, if the vaporisation temperature of the work material is 3500°C and mass of one atom of workpiece is 9.1×10^{-28} gm.***

Given : Vaporisation temperature, $\theta = 3500°C + 273$

$= 3773\ K$

5.2. LASER BEAM MACHINING

5.2.1. INTRODUCTION

Recent researches in solid state physics have revealed a new device known as 'LASER" which means "Light Amplification by Stimulated Emission of Radiation". It produces a powerful, monochromatic, collimated beam of light in which the waves are coherent.

Like the electron beam, the laser beam is also used for drilling microholes upto 25 μm and for cutting very narrow slots, with dimensional accuracy ± 0.025 mm. It is very costly method and can be employed only when it is not feasible to machine a workpiece through other methods.

5.2.2. PRINCIPLE OF LASER BEAM PRODUCTION

Laser works on the principle of quantum theory of radiation.

Consider an atom in the ground state or lower energy state (E_1) when the light radiation falls on the atom, it absorbs a photon of energy $h\nu$ and goes to the excited state (E_2).

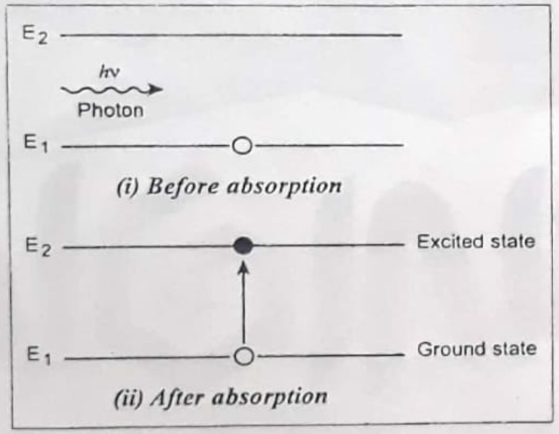

Fig. 5.2.

Normally, the atoms in the excited state will not stay there for a long time. It comes to the ground state by emitting a photon of energy $E = h\nu$. Such an emission takes place by one of the following two methods.

(1) Spontaneous Emission

The atom in the excited state (E_2) returns to the ground state (E_1) by emitting their excess energy ($h\nu$) spontaneously. This process is independent of external radiation. It is shown in Fig.5.3.

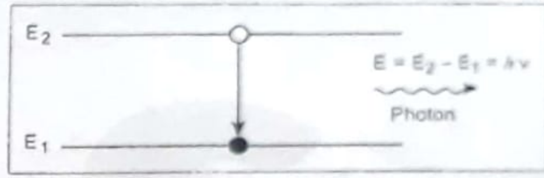

Fig. 5.3. Spontaneous emission

(2) Stimulated Emission

In stimulated emission, a photon having energy E, equal to the difference in energy between the two levels E_2 and E_1, stimulate an atom in the higher state to make a transition to the lower state with the creation of second photon as shown in Fig.5.4.

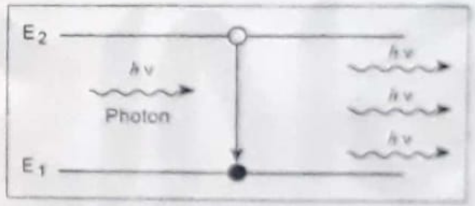

Fig. 5.4. Stimulated emission

5.2.3. PRINCIPLE OF LASER BEAM MACHINING

In laser beam machining process, laser beam (a powerful, monochromatic, collimated beam of light) is focused on the workpiece by means of lens to give extremely high energy density to melt and vaporise the work material.

5.2.4. CONSTRUCTION AND WORKING OF LASER BEAM MACHINING (LBM)

Construction

- The schematic arrangement of laser beam machining process is shown in Fig.5.5.
- There are several types of lasers used for different purposes. *e.g.*, solid state laser, gas laser, liquid laser and semi-conductor laser. In general, only the solid state lasers can provide the required power levels.
- The most commonly used solid state laser is ruby laser. It is the first successful laser achieved by Maiman in 1960. It consists of ruby rod surrounded by a flash tube.
- Synthetic ruby consists of a crystal of aluminium oxide in which a few of the aluminium atoms are replaced by chromium atoms. Chromium atoms have the property of absorbing green light.
- The end surfaces of the ruby rod is made reflective by mirrors. One end of the ruby rod is highly reflective and the other end is partially reflective.
- The flash tube is called the pump and it surrounds the ruby rod in the form of spiral as shown in Fig.5.5. This tube is filled with xenon, argon or krypton gas.
- Since the ruby rod becomes less efficient at high temperatures, it is continuously cooled with water, air or liquid nitrogen.
- Since the laser beam has no effect on aluminium, the workpiece to be machined is placed on the aluminium work table.

(9)

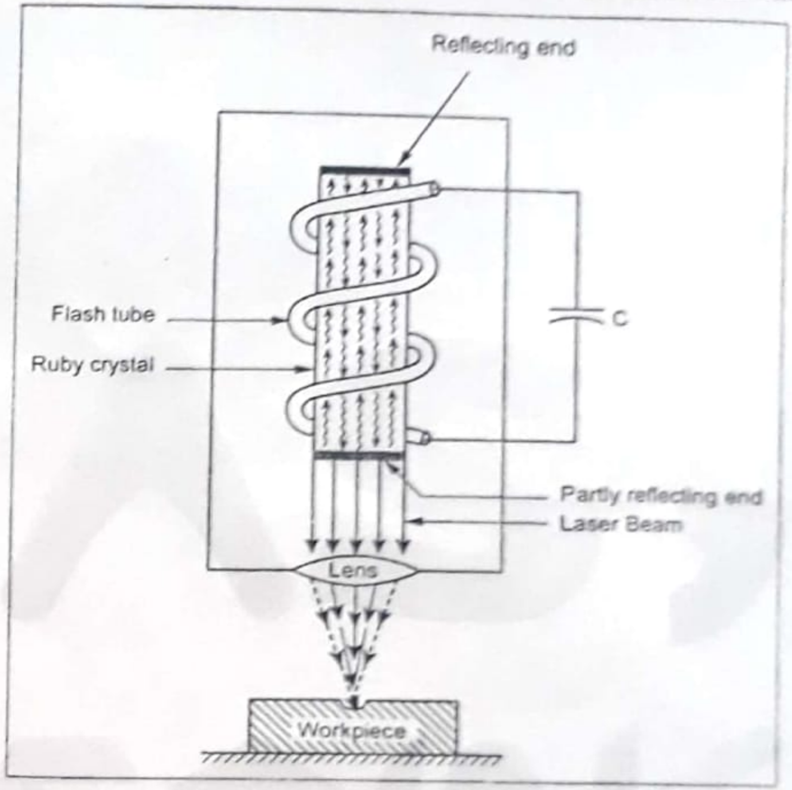

Fig. 5.5. Schematic diagram of LBM

Working

- The xenon or argon gas present in the flash tube is fired by discharging a large capacitor through it. The electric power of 250 to 1000 watts may be needed for this operation.
- This optical energy *i.e.*, light energy from the flash tube is passed into the ruby rod.
- The chromium atoms in the ruby rod are thus excited to high energy levels. The excited atoms are highly unstable in the higher energy levels and it emits energy (photons) when they return to the original levels.

- The emitted photons in the axis of ruby rod are allowed to pass back and forth millions of times in the ruby with the help of mirror at the two ends. The emitted photons other than the axis, will escape out of rod.
- The chain reaction is started and a powerful coherent beam of red light is obtained.
- This powerful beam of red light goes out of the partially reflective mirror at one end of the ruby rod.
- This highly amplified beam of light is focused through a lens, which converges it to a chosen point on the workpiece.
- This high intensity converged laser beam, when falls on the workpiece, melts and vapourise the workpiece material.
- The laser head is traversed over the work material by manually adjusting the control panel and an operator can visually inspect the machining process.
- The actual profile is obtained from a linked mechanism, made to copy the master drawing or actual profile placed on a near-by bench.

5.2.5. ACCURACY

The laser is used for cutting and drilling. In order to achieve the best possible results in drilling, the material should be placed within a tolerance of ± 0.2 mm focal point.

5.2.6. LASING MATERIALS

Many materials exhibit lasing action. But only a limited number is used in metal working. Solids, gases and semi-conductors can be used as lasing materials.

5.2.7. SOLID STATE LASER

Ruby laser, the Neodymium doped Yitrium-Aluminium-Garnet (Nd-YAG) laser, and the Neodymium-doped glass laser (Nd-glass) are examples of solid state lasers. The most commonly used solid state laser is ruby laser.

5.2.8. GAS LASER

The main advantage of gas laser is, it can be operated continuously. The gas laser produce exceptionally a high monochromaticity and high stability of frequency. The output of the laser can be changed to a certain available wavelength. So, the gas lasers are widely used in industries.

Examples : Carbon dioxide (CO_2) laser

Helium-Neon (He-Ne) laser

5.2.9. SEMICONDUCTOR LASER

Lasing action can also be produced in semi-conductors. The most compact type of laser is semiconductor laser. It is also known as injection laser. In its simplest form, the diode laser consists of a *p-n* junction doped in a single crystal of a suitable semi-conductor.

Example : Gallium-arsenide.

5.2.10. PROCESSING WITH LASERS

Lasers give rise to certain advantages in metal cutting processes due to their special characteristics. The following table lists these advantages.

S.No.	Special characteristics of laser beam	Cutting process characteristics
1.	It can be focused to maximum intensity or to minimum intensity as needed.	Metal removal rate is maximum to minimum.
2.	It can be moved rapidly on the workpiece.	Cutting of complex shapes.
3.	It is projected on the workpiece at particular distance from the lens.	Remote cutting over long stand-off distances.
4.	Dedicated to an online process.	Re-routing is not necessary.
5.	Power is shared on a job.	Two or more cuts simultaneously.

5.2.11. MACHINING APPLICATIONS OF LASER

A laser has a wide range of machining applications.

Laser in Metal Cutting

A laser beam can be used for cutting metals, plastics, ceramics, textile, cloth and even glass, when its surface is coated with radiation – absorbing material such as carbon. Normally, laser cutting starts by drilling a hole through the workpiece, then moving along a pre-determined path of the shape to be cut. Steel, titanium, nickel and plastics can be cut easily by using laser beam. But cutting of aluminium metal and copper is very difficult, since these metal tends to absorb the applied heat. The cutting speed of the laser depend on the material being cut, its thickness, physical characteristics and the

output power of the laser beam. Laser has an additional advantage in cutting complex shapes with sharp corners and slots.

Laser in Drilling

Laser drilling was one of the first practical applications of laser technology in industry and the demand for laser drilling is increasing.

Hole drilling by laser is a process of melting and vaporising unwanted materials by means of narrow pulsed laser operating at 3 to 95 pulses/s. Due to melting and vaporization process, high accuracy is not possible in laser drilling. So, laser drilling is not suited for deep hole drilling and for producing perfectly cylindrical holes.

Laser drilling is used in watch jewels, diamond dies and other machine parts for various industries where a particularly high level of precision is not demanded.

Laser drilling is used in aircraft-turbine industry to make holes for air bleeds, air cooling or the passage of other fluids. It is also used for making holes in hypodermic needles, automotive fuel plates, various lubrication devices, holes in tungsten-carbide tool plate, holes in baby bottle nipples, relief holes in pressure plugs, *etc.*

Laser in Welding

In this process, a laser beam is focused on spot where the two parts are to be welded.

Laser beam welding requires more precise control of the input laser power than in the case of drilling.

Laser welding is especially useful when it is essential to control the size of the heat affected zone, to reduce the roughness of the welded surface and to eliminate mechanical effects. It is generally used for welding multilayer materials.

There are two different types of laser welding. They are :

1. Conduction limited welding.
2. Deep penetration welding.

Conduction Limited Welding

In this method, the metal absorbs the laser beam at the work surface, and the area below the surface is heated by conduction. It is used for welding thin components.

Deep Penetration Welding

In this method, the metal absorbs the laser beam from top to bottom of the work surface. Thermal conduction does not limit the penetration. This type of welding require greater power and the CO_2 laser is used for this purpose.

Basic Requirements for Laser Welding

1. The focus of the beam should be adjusted to the thickness of the material.
2. The wavelength of the laser beam must be compatible with the material being welded.
3. Pulse waves are normally better than continuous waves.
4. A pulse shape of the laser beam should be controlled precisely from weld to weld.

Many metals and alloys can be laser welded. Some of the most readily processed are : low carbon steel, stainless steel, titanium, zirconium, silicon bronze and some nickel alloys.

One of the major factor for laser welding is the proper joint preparation. The two surfaces being welded should remain in close contact with each other. Since filler material is not used in laser welding, there should not be any gap in the joint.

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The advantage of the laser weld is the elimination of grinding from the entire process. In conventional welding process, electron beam welding process and plasma welding process excess filler material is removed by grinding.

Laser for Surface Treatment

Gears, saw teeth, valve wear pads, and cylinder liners can be strengthened by using laser beam. The laser is used to deposit a thin layer of cobalt alloy on the turbine blade shroud-contact areas. Argon gas is used for shielding during deposition of the cobalt alloy and for cooling purposes. By using laser, a thin ceramic coatings is applied on metal surface for heat and wear resistance. Laser can also be used to seal microcracks which are usually present in hard-chromium electroplates.

Other Applications

Other applications include steel metal trimming, blanking and resistor trimming. Since laser beam machining is not a mass material removal process, it is used in mass micromachining production.

5.2.12. ADVANTAGES OF LBM

1. Machining of any material including non-metal is possible.
2. Micro-sized holes can be machined.
3. Soft materials like rubber and plastics can be machined.
4. Unlike conventional machining, there is no direct contact between tool and workpiece.
5. There is no tool wear.

6. Laser beam can be sent to long distance without diffraction. It can also be focused at one point thereby generating large amount of heat.
7. Process can be easily automated.
8. Hardness of the material does not affect the process.
9. Dissimilar materials can be easily welded.
10. Heat affected zone is small around the machined surface.
11. Beam configuration and size of exposed area can be easily controlled.
12. Deep holes of very short diameter can be drilled by using unidirectional multiple pulses.

5.2.13. DISADVANTAGES (LIMITATIONS)

1. Initial investment is high.
2. Operating cost is also quite high.
3. Highly skilled operators are needed.
4. Rate of production is low.
5. Possibility of machining only thin sections and where a very small amount of metal removal is involved.
6. Safety procedures to be followed strictly.
7. Overall efficiency is extremely low (10 to 15%).
8. Some materials like fibre glass, reinforced material, phenolics, *etc.*, cannot be machined by laser as these materials burn, char and bubble.
9. Life of flash lamp is short.
10. The machined hole is not round and straight.

5.2.14. CHARACTERISTICS OF LBM

Material removal technique : Heating, melting and vaporisation of material by using high intensity of laser beam.

Work material : All materials except those having high thermal conductivity and high reflectivity.

Tool : Laser beam in wavelength range of 0.3 to 0.6 μm.

Power density : Maximum 10^7 W/mm^2.

Output energy of laser : 20 J

Pulse duration : One millisecond.

Material removal rate : 6 mm^3/min

Dimensional accuracy : ± 0.025 mm

Medium : Atmosphere

Specific power consumption : 1000 W/mm^3/min

Efficiency : 10 to 15%

5.3. PLASMA ARC MACHINING [PAM] OR PLASMA JET MACHINING [PJM]

5.3.1. INTRODUCTION

Solids, liquids and gases are the three familiar state of matter. In general when solid is heated, it turns to liquids and the liquids eventually become gases. When a gas is heated to sufficiently high temperature, the atoms (molecules) are split into free electrons and ions. The dynamical properties of this gas of free electrons and ions are sufficiently different from the normal unionized gas. So, it can be considered a fourth state of matter, and is given a new name, 'PLASMA'. In other words, when a following gas is heated to a sufficiently high temperature of the order of 11,000°C to 28,000°C, it becomes partially ionized and it is known as 'PLASMA'. This is a mixture of free electrons, positively charged ions and neutral atoms. This plasma is used for metal removing process. Plasma arc machining process is used for cutting alloy steels, stainless steel, cast iron, copper, nickel, titanium and aluminium, *etc.*

5.3.2. WORKING PRINCIPLE

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. This high temperature plasma jet melts the material of the workpiece.

5.3.3. CONSTRUCTION AND WORKING OF PAM

Construction

- The schematic arrangement of plasma arc machining is shown in Fig.5.6.
- The plasma arc cutting torch carries a tungsten electrode fitted in a small chamber.
- This electrode is connected to the negative terminal of a DC power supply. So it acts as a cathode.
- The positive terminal of a D.C power supply is connected to the nozzle formed near the bottom of the chamber. So, nozzle act as an anode.
- A small passage is provided on one side of the torch for supplying gas into the chamber.
- Since there is a water circulation around the torch, the electrode and the nozzle remains water cooled.

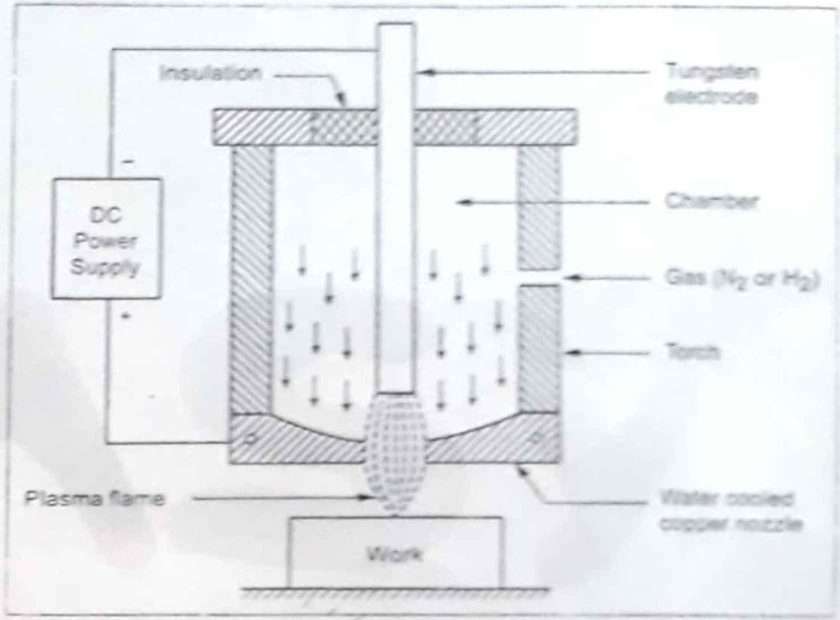


Fig. 5.6. Schematic arrangement of PAM

Working

- When a D.C power is given to the circuit, a strong arc is produced between the electrode (cathode) and the nozzle (anode).
- A gas usually hydrogen (H_2) or Nitrogen (N_2) is passed into the chamber.
- This gas is heated to a sufficiently high temperature of the order of 11,000°C to 28,000°C by using an electric arc produced between the electrode and the nozzle.
- In this high temperature, the gases are ionized and large amount of thermal energy is liberated.
- This high velocity and high temperature ionized gas (plasma) is directed on the workpiece surface through nozzle.
- This plasma jet melts the metal of the workpiece and the high velocity gas stream effectively blows the molten metal away.

- The heating of workpiece material is not due to any chemical reaction, but due to the continuous attack of plasma on the workpiece material. So, it can be safely used for machining of any metal including those which can be subjected to chemical reaction.

5.3.4. ACCURACY

- Plasma arc machining is a roughing operation to an accuracy of around 1.4 mm with corresponding surface finish. Accuracy on the width of slots and diameter of holes is ordinarily from ± 4 mm on 100 to 150 mm thick plates.

5.3.5. GASES USED IN PAM

The selection of a particular gas for use in this process mainly depends on the expected quality of surface finish on the work material and economic consideration. The gases used in this process, should not affect the electrode or the workpiece to be machined. The commonly used gases and gas mixtures are given in the following table.

S.No.	Gas or Gas Mixture	Material to be machined
1.	Nitrogen – Hydrogen, Argon – Hydrogen	Stainless steel and non-ferrous metals.
2.	Nitrogen – Hydrogen, compressed air	Carbon and alloy steels, cast iron.
3.	Nitrogen, Nitrogen – Hydrogen, Argon – Hydrogen	Aluminium, Magnesium

15

5.3.6. TYPES OF PLASMA ARC TORCHES (PLASMATRON)

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

1. Direct arc plasma torches (or) Transferred arc type.
2. Indirect arc plasma torches (or) Non-transferred arc type.

Direct Arc Plasma Torches

In direct arc plasma torches, electrode is connected to the negative terminal (cathode) of a D.C power supply and workpiece is connected to the positive terminal (anode) of a D.C power supply. So, more electrical energy is transferred to the work, thus giving more heat to the work.

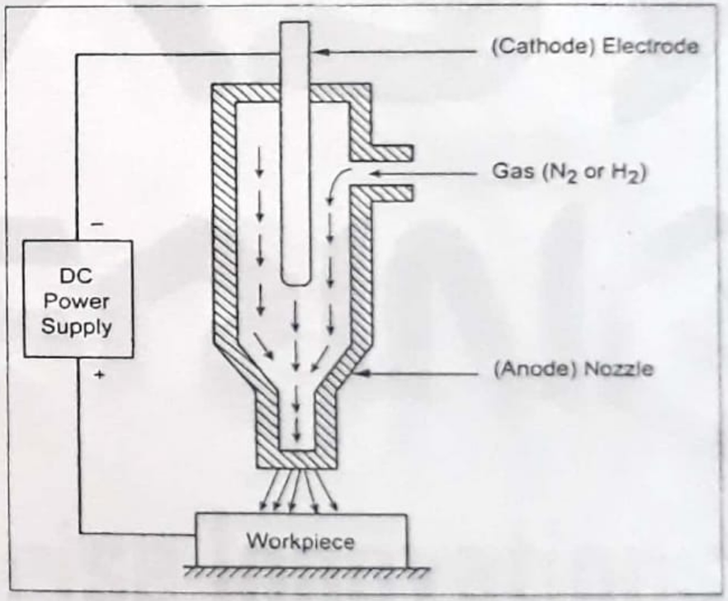


Fig. 5.7. Direct arc plasma torch

Since it is difficult to strike an arc between the electrode and workpiece directly through the narrow torch passage, first an auxiliary arc is commonly produced between the electrode and the nozzle.

When the arc flame reaches the workpiece, it automatically strikes the main arc between the electrode and the workpiece and the auxiliary arc is switched off.

Direct arc torches has higher efficiency and this type of arc is preferred for cutting, welding, depositing, *etc*.

Indirect Arc Plasma Torches

In these type of torches, electrode is connected to the negative terminal (cathode) of a D.C power supply and nozzle is connected to the positive terminal (anode) of a D.C power supply.

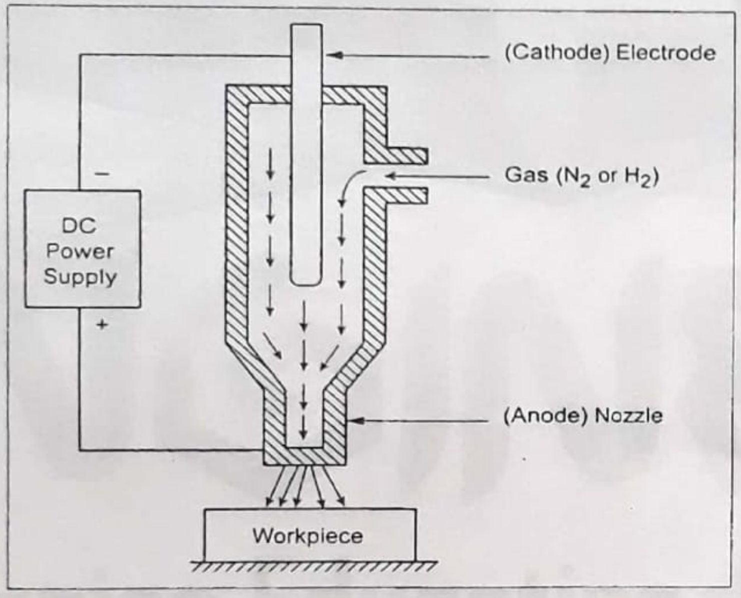


Fig. 5.8. Indirect arc plasma torch

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 are used for non-conducting materials.

In many cases, plasma torches with a double or combined gas flow are used for welding and cutting. Primary and secondary gases can differ in the designation, composition and flow rate. In the cutting process the primary gas (usually inert gas) protects the tungsten electrode from the environment. The secondary gas (usually active gas) is used for forming plasma.

5.3.7. FACTORS AFFECTING THE CUTTING PROCESS OR PROCESS PARAMETERS OF PAM

The metal removal rate mainly depends on thermo-physical and metallurgical properties of the plasma-forming gases. The most commonly used gases are argon, nitrogen, hydrogen and oxygen.

Since hydrogen has high heat conductivity, it is possible to achieve the best conditions for the transfer of plasma power to the metal. Due to high cutting speed of hydrogen, smooth surface is obtained. Hydrogen containing mixtures are used for cutting thick, high alloy steel plates and good heat conductors such as copper and aluminium.

Gas mixture containing hydrogen and argon (Maximum of 20%) is also used for forming plasma. Argon gas is used to protect the tungsten electrode from the environment. But the protection is not sufficiently reliable, since even the small deviation on the column from the axis of the nozzle causes the damage of tungsten electrode. Besides, argon is a scare and expensive gas.

Carbon and alloy steels, cast iron, stainless steel, and aluminium are machined by using nitrogen. The quality of plasma machining by using nitrogen is poor and the cutting speed is considerably less compared to hydrogen-containing gases.

Air plasma is simplest and most economical method for machining. Air contains nitrogen and oxygen. The heat conductivity of air is higher than that of hydrogen. The speed of cutting steels with the air plasma is 1.5 to 2 times greater than the use of nitrogen as the cutting gas. Non-ferrous alloys can be machined by using air plasma. But the quality of the surface finish is poor.

5.3.8. STAND OFF DISTANCE

Stand-off distance is the distance between the nozzle tip and workpiece. When the stand-off distance increases, depth of penetration is reduced. With an excessive reduction of the stand-off distance, the plasma torch can be damaged by the metal spatter. The optimum stand-off distance depends on the thickness of the metal being machined and varies from 6 to 10 mm.

5.3.9. ADVANTAGES OF PAM

1. It can be used to cut any metal.
2. Cutting rate is high.
3. As compared to ordinary flame cutting process, it can cut plain carbon steel four times faster.
4. It is used for rough turning of very difficult materials.
5. Due to the high speed of cutting, the deformation of sheet metal is reduced while the width of the cut is minimum and the surface quality is high.

5.3.10. DISADVANTAGES OF PAM

1. It produces tapered surface.
2. Protection of noise is necessary.
3. Equipment cost is high.

4. Protection of eyes is necessary for the operator and persons working in nearby areas.
5. Oxidation and scale formation takes place. So, it requires shielding.
6. Work surface may undergo metallurgical changes.

5.3.11. APPLICATIONS

1. It is used for cutting alloy steels, stainless steel, cast iron, copper, nickel, titanium, aluminium and alloy of copper and nickel, *etc.*
2. It is used for profile cutting.
3. It is successfully used for turning and milling of hard to machine materials.
4. It can be used for stack cutting, shape cutting, piercing and underwater cutting.
5. Uniform thin film spraying of refractory materials on different metals, plastics, ceramics is also done by plasma arcs.

5.3.12. CHARACTERISTICS OF PAM

Metal removal technique : Heating, melting and vaporising by using plasma.

Work material : All materials which conduct electricity.

Tool : Plasma jet

Velocity of plasma jet : 500 m / s

Power range : 2 to 220 kW

Current : As high as 600 amp.

Voltage : 40 – 250 V

Cutting speed : 0.1 to 7 m / min

Metal removal rate : 145 cm^3 / min

UNIT-4

Electro-chemical Energy Based Processes

* In chemical energy methods, the metal is removed from the workpiece through controlled etching of the workpiece material in contact with a chemical solution

  Example: chemical Machining (CHM)

* In Electro-chemical energy methods, material is removed by ion displacement of the workpiece material in contact with a chemical solution.

  Examples:

1. Electro-chemical Machining (ECM)
2. Electro-chemical Grinding (ECG)
3. Electro-chemical Honing (ECH)
4. Electro-chemical Deburring (ECD)

1. CHEMICAL MACHINING (or) CHEMICAL MILLING:

* Construction and working:

  In this Process, material is removed from the workpiece through a controlled etching (or) chemical attack of the workpiece material.

- Material can be removed from selected area of a workpiece or from the entire surface of the workpiece, according to requirement.
- If selective machining is desired, the areas of the workpiece which are not to be machined are covered with a resistant material, called a resist or maskant.
- The workpiece to be machined is first cleaned in trichlorethylene vapour or in a solution of mild alkaline at 85 to 90°C, followed by washing in a clean water. This removes dust and oil from the workpiece.
- After cleaning, the workpiece is dried and coated with the maskant material.
- The workpiece is then immersed in a chemical reagent as shown in Fig.4.1. So, chemical reaction takes place and the metal is removed from the workpiece. The metal is removed by the chemical conversion of the metal into metallic salt.
- The time of immersion of the workpiece depends upon the amount of material removed by chemical action.
- The chemical etching agent depends upon work material. Caustic soda is used as etching reagent for aluminium, solution of hydrochloric and nitric acids for steel and iron chloride for stainless steels.
- In order to obtain a uniform depth of metal removal, temperature control and stirring of chemical reagent is important.
- After machining, the workpiece should be washed thoroughly to prevent reaction with any chemical etching reagent residues.

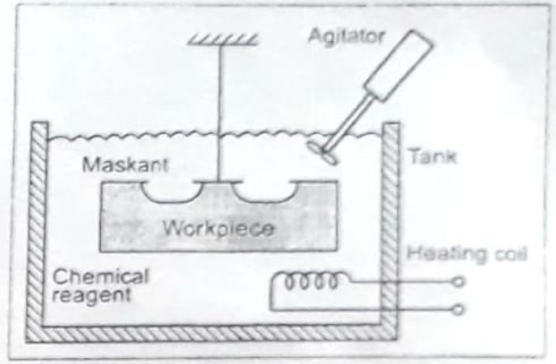


Fig. 4.1.

4.1.2. ETCHANTS

The chemical reagent (etchant) is used to remove the metal from the workpiece. The metal is removed by the chemical conversion of the metal into metallic salt.

The chemical etching reagent depends upon work material. The following table shows the etchant for different materials.

Sl.No.	Material	Etchant
1.	Aluminium	Caustic Soda
2.	Steel	Hydrochloric acid or Nitric acid
3.	Stainless steel	Iron chloride
4.	Magnesium	Nitric acid
5.	Titanium	Nitric acid

4.1.3. MASKANTS

In chemical machining process, the areas of the workpiece which are not to be machined are covered with a resistant material, called a resist or maskant.

The following table shows the maskants for different materials.

Sl.No.	Material	Maskant
1.	Aluminium	Butyl rubber, Neoprene rubber
2.	Magnesium	Polymers
3.	Titanium	Translucent chlorinated polymers
4.	Nickel	Neoprene
5.	Ferrous metals	Polyvinyl chloride, polyethylene

4.1.4. METHODS OF MASKING

The usual methods of masking are :

(*i*) Scribed and Peeled maskants.

(*ii*) Photoresists maskants.

(i) Scribed and Peeled Maskants

In this method, a maskant (like paint) is applied to the entire surface of the workpiece by dip, spray, brush or stencil. After the maskant hardens, it is removed from those surfaces where metal removal is desired. The maskant is removed by scribing with knife and peeling away the desired surfaces. Templates can be used to assist in scribing. This method is used when critical dimensional tolerances are not required.

(ii) Photoresists Maskant

- It is an excellent method of masking, especially for complex work. This method is used for thin sections and components requiring closed dimensional tolerances.

3

- The workpiece to be machined is thoroughly cleaned and decreased by acid or alkalis. The cleaned metal is dried and photoresist material is applied to the workpiece by dipping, spraying, brushing or roller coating.
- The coating is then dried and hardened by heating in an oven upto about 125°C.
- The design of the part to be machined is prepared at a magnification of upto 100 ×. The master drawing is photographed and reduced to the size of the finished part.
- The master photographic negative is placed over the dried photoresist coated surface of the workpiece and exposed to ultraviolet light, which hardens the exposed areas.
- After exposure, the workpiece is then developed by immersing it into a tank which contains an organic solvent bath solution. The unexposed portions are dissolved out during the developing process, while the exposed portions remains on the workpiece.
- Finally the treated workpiece is dipped into the etching solution. After 5 to 15 minutes, the unwanted metal is removed from the workpiece and the finished part is washed thoroughly to eliminate all chemical residues.

4.1.5. METAL REMOVAL RATE

Metal removal rate mainly depends upon the selected etchant. Metal removal rate is fast with certain etchant. It increases undercutting, poor surface finish and more heating takes place. So, etch rate is limited to 0.02 to 0.04 mm/min. Etching rate and depth of cut are high for hard metals (titanium alloys, stainless steel and heat resistant alloys) and low for softer materials (aluminium). With optimum time, temperature and solution control, accuracies of the order of ± 0.01 mm is obtained. Surface finish of the order of 5 microns is produced. The size of the workpiece that can be treated is limited only by the size of the tank in which the workpiece is dipped for etching.

4.1.6. CLASSIFICATION OF CHEMICAL MACHINING PROCESS

The chemical machining process can be classified as follows :

(*i*) Chemical blanking.

(*ii*) Contour machining.

(i) Chemical Blanking

In chemical blanking, the material is etched entirely on the workpiece. It is used for cutting out parts from thin sheet metals or foil sheets.

(ii) Contour Machining

In contour machining, the material is selectively etched from certain areas on the workpiece. It is used for removing metal from thicker workpieces.

4.1.7. APPLICATION OF CHEMICAL MACHINING PROCESS (CHM)

- Chemical machining process is applied in great number of usages where the depth of metal removal is critical to a few microns and the tolerances are close.
- The major application of chemical machining is in the manufacture of burr free components.

4.1.8. ADVANTAGES OF CHM

- Burr-free components are produced.
- Most difficult to machine materials can be processed.
- High surface finish is obtained.
- Any metal can be machined.
- Stress free components are produced.
- Since the process is comparatively simple, there is no need of highly skilled labour.
- Both faces of the workpiece can be machined simultaneously.
- Hard and brittle materials can be machined.
- Tooling cost is very low.
- Complex contours can be easily machined.

4.1.9. DISADVANTAGES OF CHM

- Since the process is slow, metal removal rate is low.
- Manufacturing cost is high.
- Workpiece thickness, that can be machined, is limited.
- Large floor area is needed.
- It is not possible to produce sharp corners.

4.2. ELECTRO-CHEMICAL MACHINING

4.2.1. INTRODUCTION

Electro-Chemical Machining (ECM) is one of the recent and most useful machining process. In this process, electrolysis method is used to remove the metal from the work piece. It is best suited for the metals and alloys which are difficult to be machined by mechanical machining processes.

4.2.2. PRINCIPLE

This process is based on the principle of Faraday's laws of electrolysis which may be stated as follows

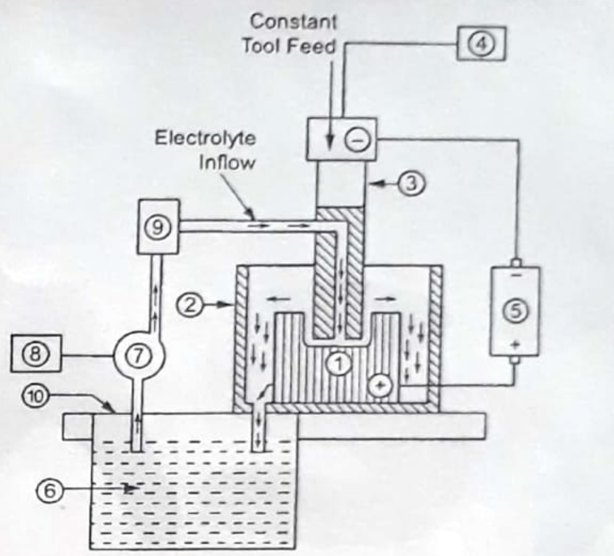
1. The first law states that the amount of any material dissolved or deposited, is proportional to the quantity of electricity passed.
2. The second law proposes that the amount of change produced in the material is proportional to its electrochemical equivalent of the material.

Basically in electroplating, the metal is deposited on the work piece, while in ECM, the objective is to remove the metal from the work piece. So, the reverse of electroplating is applied in ECM process. Therefore, 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.

4.2.3. CONSTRUCTION AND WORKING OF ECM PROCESS

Construction

- The schematic arrangement of ECM process is shown in fig. 4.2.
- It consists of work piece, tool, servomotor for controlled tool feed, D.C power supply, electrolyte, pump, motor for pump, filter for incoming electrolyte and reservoir for electrolyte.
- A shaped tool (electrode) is used in this process, which is connected to negative terminal (cathode) and the workpiece is connected to positive terminal (anode).



1. Workpiece, 2. Tank, 3. Tool (cathode), 4. Servomotor for controlled tool feed, 5. D.C. Power supply, 6. Electrolyte, 7. Pump, 8. Motor for pump, 9. Filter, 10. Reservoir

Fig. 4.2. Arrangement of ECM Process

- The tools used in this process should be made up of the materials which have enough thermal and electrical conductivity, high chemical resistance to electrolyte and adequate stiffness and machinability.
- The widely used tool materials are stainless steel, titanium, brass and copper.
- The tool is of hollow tabular type as shown in fig. 4.2. and an electrolyte is circulated between the work and tool.
- Most widely used electrolyte in this process is sodium nitrate solution. Sodium chloride solution in water is a good alternative but it is more corrosive than the former. Some

other chemicals used in this process are sodium hydroxide, sodium sulphate, sodium flouride, potassium nitrate and potassium chloride.

- Servomotor is used for controlling the tool feed and the filter is used to remove the dust particles from the electrolytic fluid.

Working

- The tool and workpiece are held close to each other with a very small gap (0.05 to 0.5mm) between them by using servo motor.
- The electrolyte from the reservoir is pumped at high pressure and flows through the gap between the work piece and tool at a velocity of 30 to 60 m/s
- A mild D.C. voltage about 5 to 30 volts is applied between the tool and workpiece.
- Due to the applied voltage, the current flows through the electrolyte with positively charged ions and negatively charged ions. The positive ions move towards the tool (cathode) while negative ions move towards workpiece (anode)
- The electrochemical reaction takes place due to this flow of ions and it causes the removal of metal from the workpiece in the form of sludge.

The surface finish in ECM process is of the order 0.2 to 0.8 micron with a tolerance of the order 0.005 mm depending on the work material and the electrolyte used.

4.2.9. ADVANTAGES OF ECM PROCESS

1. The metal removal rate by this process is quite high for high strength-temperature resistant (HSTR) materials compared to conventional machining processes.
2. Wear and tear of tool is negligible.
3. Machining is done at low voltage.
4. Intricate and complex shapes can be machined easily through this process.
5. The machined work surface is free of stresses.
6. No cutting forces are involved in the process .
7. High surface finish, of the order of 0.2 to 0.8 microns, can be obtained.
8. Very thin sections, such as sheet metal, can be easily machined without any damage.
9. It is an accurate process and close tolerances of the order 0.005 mm can be easily obtained.
10. No burrs are produced and this process can be easily automated.
11. Toughness and brittleness of a material has no effect on the machining process.

4.2.10. DISADVANTAGES

1. Non conducting materials cannot be machined
2. Consumption of power is nearly 100 times more than in turning or milling the steel.
3. Machining process is comparatively slow
4. Initial investment is quite high
5. More space is required
6. To vary the tool feed rate and supply of electrolyte, constant monitoring is needed
7. Difficulty in designing a proper tooling system.

4.2.11. APPLICATIONS OF ECM

It is used for

1. Machining complicated profiles, such as jet engine blades, turbine blades, turbine wheels etc.,
2. Drilling small deep holes, such as in nozzles.
3. Machining of cavities and holes of irregular shapes.
4. Machining of blind holes and pockets, such as in forging dies.
5. Machining of hard materials and heat resistant materials.

4.2.12. LIMITATIONS OF ECM

1. Sharp internal corners cannot be obtained.
2. Post machining cleaning is needed to reduce the corrosion of the workpieces.
3. Tool design is very complicated and it requires cut and dry method to achieve the final shape.
4. Complicated control is needed for the maintenance of higher tolerances.

4.3. ELECTRO-CHEMICAL GRINDING (ECG) OR ELECTROLYTIC GRINDING

(8)

4.3.1. INTRODUCTION

The materials which cannot be easily shaped due to their extreme hardness or high tensile strength can be ground by using Electro-chemical grinding process.

Examples : Cemented carbides, hardened steel etc.,

4.3.2. PRINCIPLE

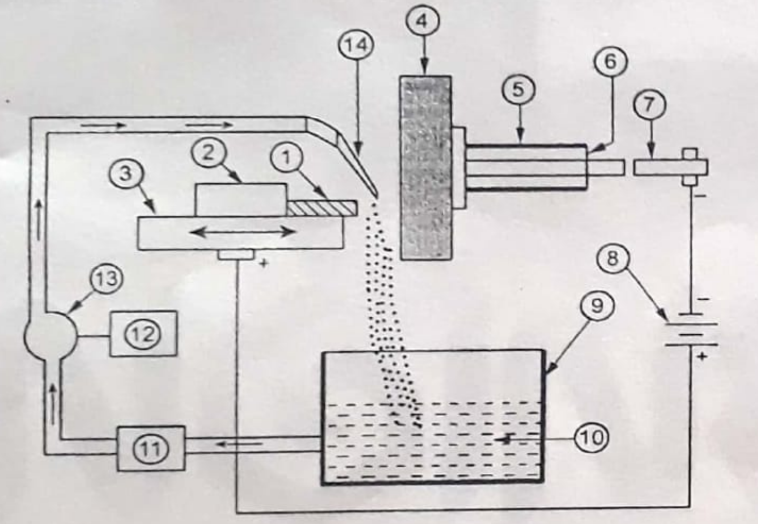
In Electrochemical grinding method, the work is machined by the combined action of electrochemical effect and conventional grinding operation. But the major portion of the metal (about 90%) is removed by electrochemical effect.

4.3.3. CONSTRUCTION AND WORKING OF ECG PROCESS

Construction

- The schematic arrangement of electrochemical grinding process is shown in Fig.4.6.
- It consists of workpiece, work table, grinding wheel, spindle, D.C power source, electrolyte, pump, motor for pump, nozzle, filter for incoming electrolyte, and reservoir for electrolyte.

- The grinding wheel is mounted on a spindle, which rotates inside suitable bearings.
- The workpiece is held on the machine table in suitable fixtures. The table can be moved forward and backward to feed the work or to withdraw it.
- The grinding wheel and spindle are separated from the machine by using an insulating sleeve as shown Fig.4.6.



1. Workpiece, 2. Fixture, 3. Work table, 4. Grinding wheel, 5. Insulation, 6. Sleeve, 7. Spindle, 8. D.C. power source, 9. Tank for electrolyte, 10. Electrolyte, 11. Filter, 12. Motor for pump, 13. Pump, 14. Nozzle.

Fig. 4.6. Arrangement of ECG process

- Sodium nitrate, sodium chloride and potassium nitrate with a concentration of 0.150 to 0.300 kg/ litre of water are usually used as electrolyte.

- The electrolyte from the reservoir is pumped and passed through nozzle in the gap between the wheel and workpiece.
- A constant gap of 0.025 mm is maintained between the grinding wheel and workpiece.
- The grinding wheel is made of fine diamond particles. These particles are slightly projecting out from the surface and come in contact with work surface with very little pressure.
- The grinding wheel runs at a speed of 900 to 1800 m/min
- The workpiece is connected to positive terminal (anode) of battery and grinding wheel is connected to negative terminal (cathode)

Working

- A mild D.C voltage of about 3 to 30 V is applied between the grinding wheel and work piece.
- Due to the applied voltage, the current flows through the electrolyte with positively charged ions and negatively charged ions. The positive ions move towards the grinding wheel (cathode) while the negative ions move towards the work piece (anode).
- The electrochemical reaction takes place due to this flow of ions and it causes the removal of metal from the workpiece.
- It can be seen that the workpiece is fed against the rotation of grinding wheel and the metal is removed from the workpeice surface by the simultaneous abrasive action and electrolytic reaction. In fact, 10% of the workpiece metal is removed by abrasive cutting, and 90% by electrolytic reaction.

- Grinding wheel wear is negligible because the major part of the cutting action is electrolytic, and little dressing of grinding wheel is needed.
- The short-circuit between the wheel and work is prevented due to point contact made by the fine diamond points.

4.3.4. PROCESS PARAMETERS

The following process parameters are involved in the effectiveness of electro-chemical grinding process.

1. Current density

The metal is removed from the work piece based on the current density. It is of the order 100 to 200 A/cm^2. The power supply is D.C voltage of 3 to 30V.

It is clear that the material removal rate increases with current density which leads to better surface finish.

2. Electrolyte

The surface finish, precision and metal removal rate are influenced by the composition of the electrolyte. Sodium nitrate, sodium chloride and potassium nitrate with a concentration of 0.150 to 0.300 kg/litre of water are usually used as electrolyte. It is passed through nozzle in the gap (.25mm) between the wheel and workpiece. Electrolyte is maintained at a temperature between 15°C to 30°C.

3. Feed rate

If the applied feed rate is very slow, it results in poor surface finish and tolerance. If the feed rate is very fast, the abrasive particles will be forced into the workpiece, resulting in excessive wheel wear. The maximum depth of cut for grinding wheel is 2.5 mm.

(10)

4. Grinding wheel speed

The grinding wheel runs at a speed of 900 to 1800 m/min . Higher speed of wheel leads to wear and tear. Accuracy of wheel running and wheel pressure also influences the effectiveness of electro grinding process.

4.3.5. ADVANTAGES OF ECG

1. Since the tool wear is negligible, the life of the grinding wheel is increased. This factor is most valid in the grinding of hard metals such as tungsten carbide, where, costly diamond grinding wheels are used. In ordinary grinding there are high wear rates on these expensive diamond wheels.
2. Work is free of surface cracks and distortion because heat is not generated in the process.
3. As compared to conventional grinding, a very little cutting force is applied to the work piece.
4. Good surface finish is obtained.
5. Work material is not subjected to any structural changes.
6. Intricate parts can be machined without any distortion.
7. The surface finish produced by this process is varied from 0.2 to 0.4 μm.
8. Accuracy of the order of 0.01 mm can be achieved by proper selection of wheel grit size and abrasive particles.
9. Burr free and stress free components are produced.
10. The wheel bond wears very slowly. So, the grinding wheel need not be dressed frequently.

4.3.6. DISADVANTAGES

1. Initial cost is high.
2. Power consumption is high.
3. Metal removal rate is lower than conventional grinding.
4. Non-conducting materials cannot be machined.
5. Preventive measures are needed against corrosion by the electrolyte.
6. Maintenance cost is high.
7. Since the tolerances achieved are slightly low, the workpieces need final abrasive machining.

4.3.7. APPLICATIONS

It is best suited for

1. Very precision grinding of hard metals like tungsten carbide tool tips, high speed steel tools.
2. Cutting thin sections of hard materials without any damage or distortion.

ELECTROSTREAM DRILLING (ESD) UNIT-5

2.1 Introduction

(1)

Electrostream drilling (ESD) is a special version of electro chemical machining adapted for drilling small holes (usually less than 1mm) by using high voltages and acid electrolytes. ESD was first developed in the mid 1960s by the General Electric Company, Aircraft Engine Group. The process was invented to solve the problems associated with drilling thousand of small cooling holes in turbine blades [illegible].

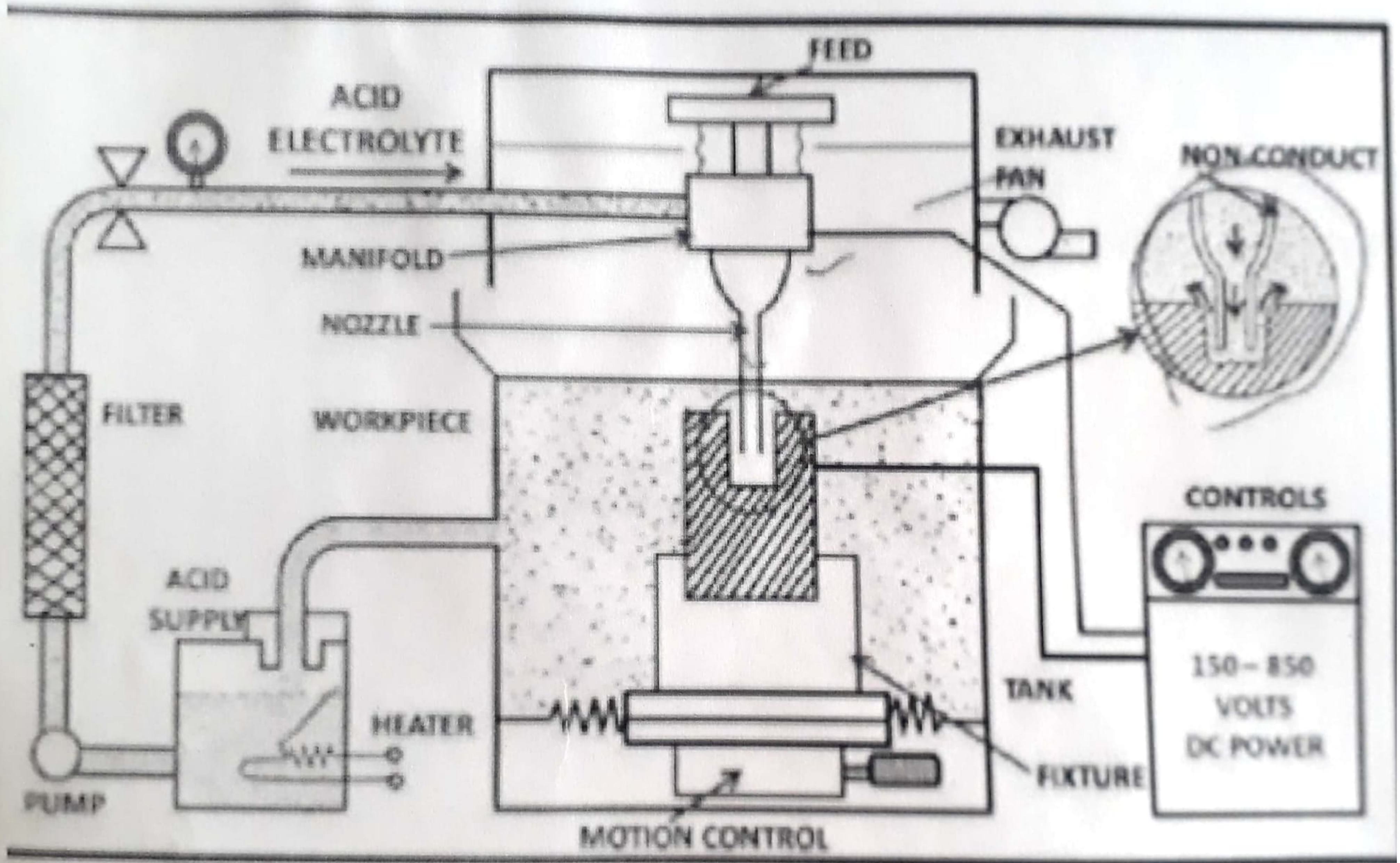
ESD uses acid electrolyte instead of the salt electrolytes normally used in ECM to drill small holes. The use of acid electrolytes ensures that the metal sludge by-products from the electrolytic deplating are dissolved and carried away as metal ions. This eliminates clogging of the electrolyte flow around the electrode [illegible].

The nozzle and electrically conductive workpiece are connected to negative and positive terminal of the DC power supply. As the charged electrolyte stream impinges on the workpiece, material is removed through the electrolytic dissolution and is flushed from the machining area in the form of metal ions in solution. ESD process is effective for drilling brittle or difficult-to-machine metals with small holes at steep angles or curved surfaces [illegible].

Two different ESD techniques are currently used depending upon the requirements of the application. They are known as penetration drilling and dwell drilling. Penetration drilling is used when deep and accurate holes are required and a nozzle in-feed system is available. The drilling cycle for the penetration technique begins when the nozzle is rapidly fed towards the workpiece but with a reduce charging current in the system. A gap-sensing device monitors the current, slow the feed, and triggers full power when the proper nozzle-workpiece gap is detected. During the drilling cycle, the nozzle is fed in to the hole at a constant feed rate to maintain a constant gap through out the drilling cycle [illegible].

Dwelling technique is used when shallow, less accurate holes are required or when machine capabilities or workpiece configuration cannot support a nozzle in feed mechanism. In dwell drilling, fixing the nozzle at the proper gap distance from the work

Electro Stream Drilling Diagram



surface and performing the drilling sequence with out nozzle feed. In this technique, the tip of the nozzle never penetrates into the workpiece, the relatively coherent stream of charged jet is solely responsible for determining both the shape and diameter of the hole. This technique eliminates the need for tool-feed and gap-sensing equipment, it also limits the depth and accuracy capabilities of the process.

Two concepts are generally used for charging the acid electrolyte. They differ in the charging electrode that consists of either a metallic sleeve or a small titanium wire, which is placed inside the large diameter section of the ES nozzle as close to the throat as possible [6].

2.2 Equipment and Tooling

Electrostream drilling is a high voltage process in which a voltage is applied between the workpiece and a cathode wire usually made of titanium placed in glass nozzle (Fig 2.1). The voltage (250-650 V) applied drives the current through an electrolyte column.

This process also requires an extra tank in the electrolyte system. The acid electrolyte is pumped from one tank and, after traveling through the machine, overflows into a separate tank, which is electrically insulated from the first. Thus the current is prevented from making complete circuit around the system. It is important that Electrostream drilling machine must be grounded and guarded to prevent voltage mishaps.

Electrostream drilling uses a nozzle shaped glass tube as a cathode. A platinum wire is inserted in the tube to give supply to the acid electrolyte. Electrostream drilling machines have one feed axis capable of producing constant feed rates between 0.125 to 0.25 mm/min as well as jogging movement. Multi axis machine units allow rotation of the part or allow an array of tubes to be indexed across the part. Feed rates and voltages are programmed by using a computer numerical control [2].

2.3 Power Supply

The power supply used for Electrostream drilling is full wave rectified, D.C power supply. The supply can be designed to have a multi channel output if required, each channel feeding a separate manifold.

2.7 Glass nozzles

Glass tube 3 or 8 mm in diameter, with the front drawn to the necessary cutting tube size of 0.15 to 0.60 mm is used. The length of this small-diameter section of the tube is responsible to drill the hole. The importance of accurate tubes cannot be overemphasized. The tips must be lapped flat with no chip or crack. The concentricity of the outside and inside diameter is critical. The inside diameter must be kept free of obstruction at all times.

2.8 Process Parameters

The key process parameters for ESD include

Voltage: 250 to 650V

Electrolyte: type: a). Type: acid: Sulphuric acid, nitric acid or hydrochloric acid

b). Concentration of 15 to 50% by volume

c). Pressure: 0.275 to 0.40 N/mm^2

d). Temperature: 40°C for sulphuric acid and 20°C for others

Feed rate: 0.75 to 2.5mm/min.

2.9 Process Capabilities

2.9.1 Material removal rates and tolerances

Penetration rates 1.5 to 3.0 mm/min are typical for the super alloys. The electrolytic dissolution follows Faraday's law and current density is limited by the boiling of electrolyte in the nozzle from the resistive heating. Diameter tolerances are typically +/- 0.025 mm or plus or minus 5 percent for sizes above 0.5mm.

2.9.2 Surface roughness

Surface roughness in the holes ranges from 0.4 to 1.6 μm R_a. There are no metallurgical changes when the electrolyte and operating parameters are compatible with the metallurgical state of the workpiece. The holes produced by this process are free from the induced residual stress. Thermal damage is nonexistent.

2.10 Advantages

The advantages of electrostream drilling include the following

- No heat-affected zone.
- No burrs are produced.
- No induced stress in the workpiece.

- Not affected by the hardness of the metal.
- Blind and intersecting holes can be drilled.
- No recast layer.

11 Limitations

Electro stream drilling can be used only on corrosion resistant metals (st obalt, and nickel base turbine engine alloys) and electrically conductive enerally this process can not drill commercially pure titanium and refrac her limitations are [2.3]

- Process is slow when drilling single hole.
- Expensive electrodes.
- Handling of acid requires special workplace and environmental precau
- Chances of nozzle breakage since glass is a fragile material.
- Bell-mouth hole entrance.
- High preventive maintenance cost.

12 Applications

pplications of electrostram drilling include

- Drilling rows of cooling holes in gas turbine blades and vanes.
- Machining of oil passages.
- Machining of fuel nozzles.
- Starting holes for wire EDM cuts, especially where the length of cu mm.
- Drilling oil passages in bearings in which EDM will cause cracks.
- Drilling regular arrays of holes in corrosion resistant metals of low (for example, strainers and dies).

Magnetic Abrasive Finishing

INTRODUCTION

- Traditionally finishing processes are crucial, expensive uncontrolled and a labour intensive phase in the overall production.
- It also include total production cost and time.
- The ever increasing demand from the industry for better quality & cost competitive product with complex design material need to good surface finishing.
- In case of some application like internal finishing of capillary tube, machining of titanium alloy, aircraft application , medical application where high surface finish parts are required.
- Magnetic abrasive finishing (MAF) is the process which capable of precision finishing of such work pieces.
- Since MAF does not require direct contact with the tool, the particles can be introduced into area which are hard to reach by conventional techniques.

CLASSIFICATION OF MAF

BASED ON TYPE OF MAGNETIC FIELD

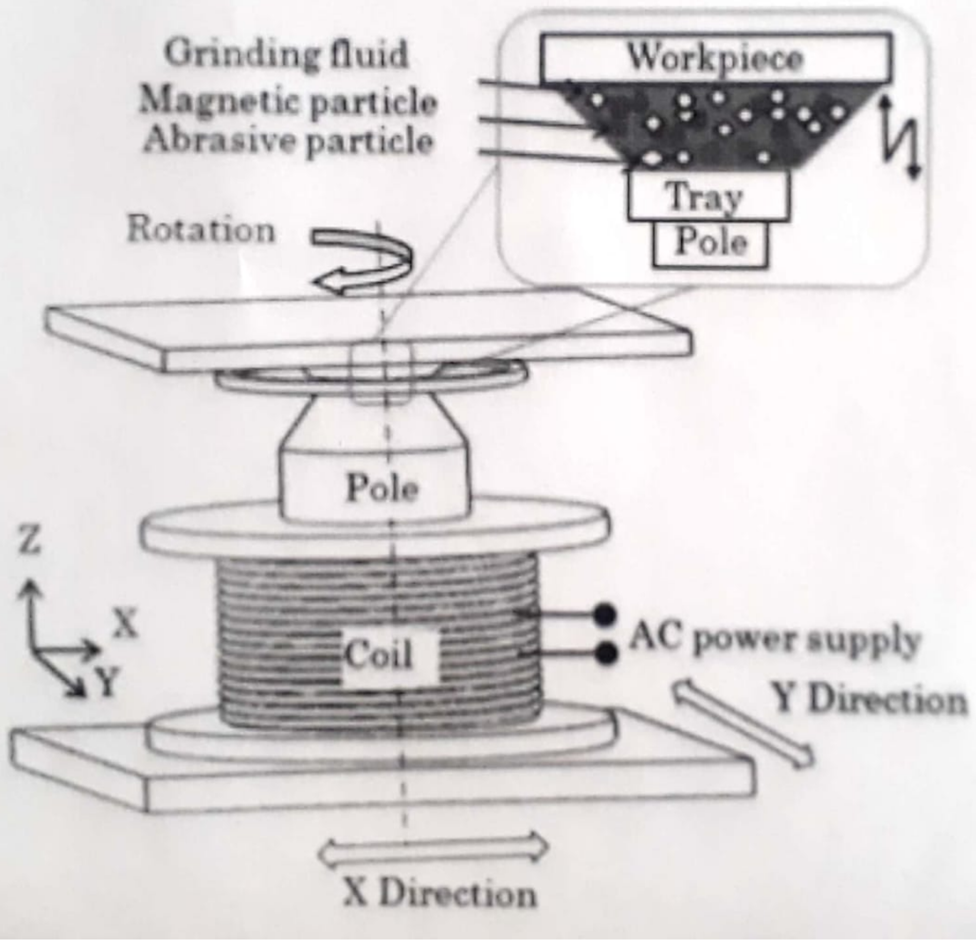
1. Magnetic Abrasive Finishing With Permanent Magnet
2. Magnetic Abrasive Finishing With Direct Current
3. Magnetic Abrasive Finishing With Alternating Current

BASED ON WORKPIECE

1. Lathe based MAF
2. Milling based MAF

WORKING OF MAGNETIC ABRASIVE FINISHING PROCESS

7



ADVANTAGES

- Able to attain wide range of surface characteristics by careful selection of magnetic particles
- Enhance surface characteristics such as wet ability or reducing friction.
- Capability to accessing hard to reach areas.
- Capable of modifying roughness without altering form.
- Setup is independent of work piece material; it can efficiently finish ceramics, stainless steel, brass, coated carbide and silicon.
- Due to the flexible magnetic abrasive brush, it can finish any symmetric work piece shape, if electromagnet designed accordingly.
- It possesses many attractive advantages such as self-adaptability and controllability.
- The finishing tool requires neither compensation nor dressing
- The method can finish ferromagnetic materials but as well as non-ferromagnetic materials.

DISADVANTAGES

- It is difficult to implement Magnetic abrasive finishing in mass production operation.
- Not applicable for some ordinary finishing task where conventional finishing technique can be easily implemented.
- Time consuming process.
- The cost of process is high.

APPLICATION

- Cutting tools
- Turbine blades
- Air foils
- Optics
- Sanitary pipes
- Food industry
- Capillary tubes, needles, biopsy needles in ,medical field
- Curved pipes

CONCLUSION

- Magnetic abrasive finishing process can be used for surface finishing as well as surface modification of hard to finish surfaces such as brass, stainless steel, etc.
- Magnetic abrasive finishing can be successfully used for finishing of internal as well as external surfaces of complicated design.
- In magnetic abrasive finishing process, magnetic force is affected by the material, shape and size of work, work-pole gap distance, and composition of magnetic abrasives.
- The MAF-processed improves tribological properties, reduces the friction on the chip-tool interface, and results in extended tool life. Smoothing with minimal material removal and negligible changes in cutting edge geometry.

Shaped tube Electrolytic Machining :

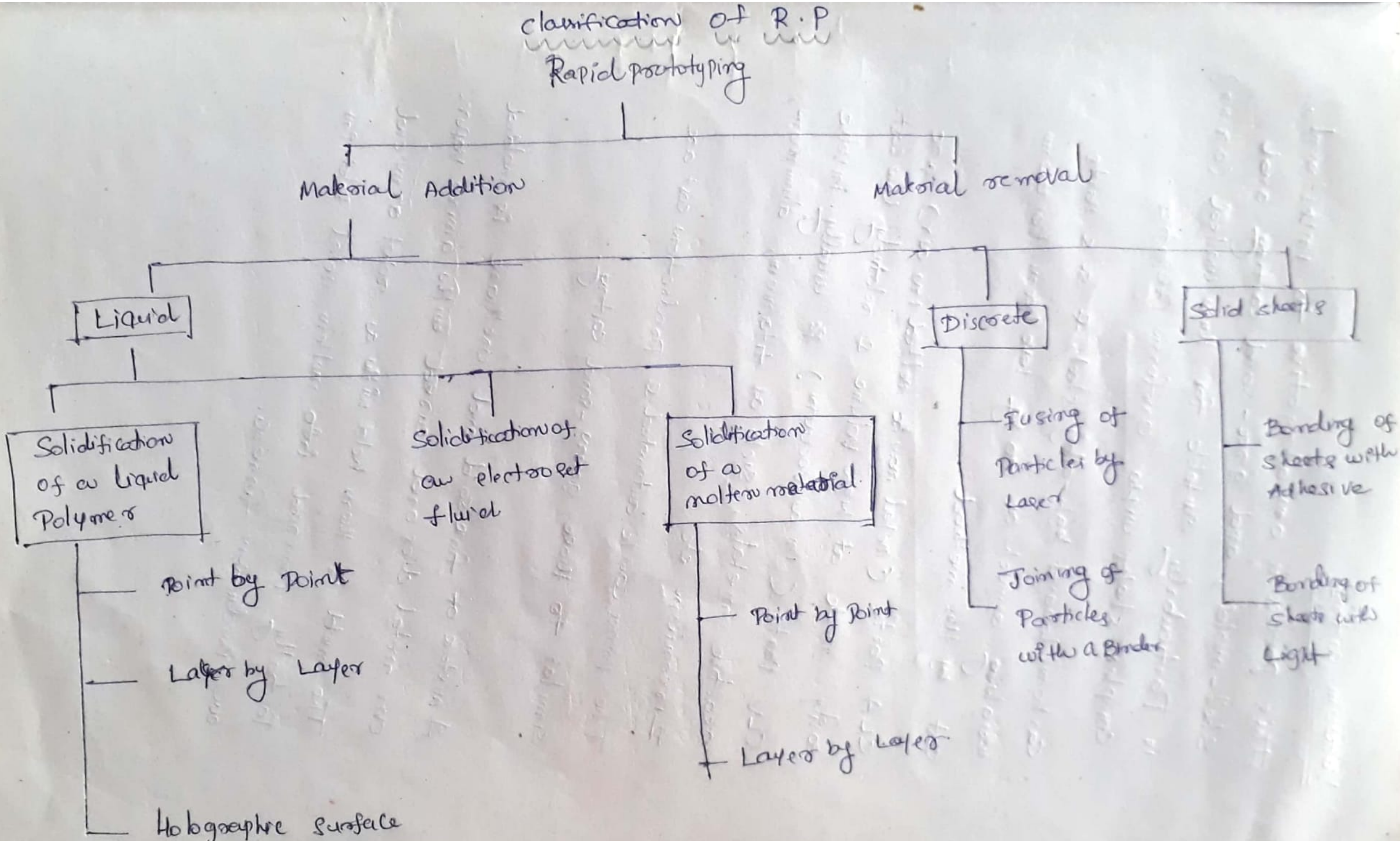
* Shaped tube electrolytic machining (STEM) is a modified electrochemical machining (ECM) process that uses an acid electrolyte so that the removed metal goes into the solution instead of forming a precipitate.

* In shaped tube electrolytic machining, the machining current passes through the electrolytic solution that fills the gap between an anodic workpiece and a preshaped cathodic tool.

* The electrolyte removes the dissolution products, such as metal hydroxides, heat and gas bubbles, generated in the ~~interelectro~~ interelectrode gap.

Applications :

* Because the process uses acid electrolytes, its use is limited to drilling holes in stainless steel (or) other corrosion resistance materials in Jet engines and gas turbine parts ~~such~~ such as,
  * Turbine blade cooling holes
  * Fuel nozzles
  * starting holes for wire EDM
  * Any holes where EDM recast is not desirable.


Classification of R.P
Rapid prototyping
Material Addition
Material removal
Liquid
Discrete
Solid sheets
Solidification of a liquid Polymer
Solidification of an electroset fluid
Solidification of a molten material
Point by Point
Layer by Layer
Holographic surface
Point by Point
Layer by Layer
Fusing of Particles by Laser
Joining of Particles with a Binder
Bonding of sheets with Adhesive
Bonding of sheets with Light

Stereolithography :

- The stereolithography Process is based on the Principle of curing (hardening) a liquid photo Polymer into a specific shape.
- A Vat Containing mechanism where by a Platform can be lowered and raised, is filled with a photo curable liquid acrylate Polymer.
- The liquid is a mixture of acrylic monomers, oligomers, and a photo initiator.
- When the Platform is at its highest Position, depth a, the layer of liquid above it is shallow.
- A laser, generating an ultraviolet beam, is now focused upon a selected surface area of the photo Polymer and then moved in X-Y direction.
- The beam cures that Portion of the photo Polymer (say, a ring-shaped portion) and there by Produces solid body.
- The plat form is then lowered sufficiently to cover the cured Polymer with another layer of liquid Polymer, and the sequence is repeated.
- The Process is repeated until level b is reached

→ Thus far we have generated a cylindrical Part with a constant wall thickness.

→ Note that the platform is now lowered by a vertical distance ab.

→ At level b, the x-y moments of the beam are wider, so that we now have a flange shaped portion that is being produced over the previously formed part.

→ After the proper thickness of the liquid has been cured the process is repeated, producing another cylindrical section b/w levels b and c.

Application Range:

→ Parts used for functional tests

→ manufacturing of medical models

→ Form-fit functions for assembly tests.

→ Patterns for investment casting, sand casting and molding.

→ Parts for prototype tooling and low volume production tooling.

→ Prototype for design, analysis, verification and functional testing.

→ Tools for fixture, tool design and producti tooling

Selective laser sintering (SLS):

* Selective laser sintering is an additive manufacturing technique that uses a laser as the power source to sinter powdered material (nylon (or polyamide), aiming the laser automatically at points in space defined by a 3D model, binding the material together to create a solid structure.

* It is similar to selective Laser Melting (SLM), the two are instantiations of the same concept but differ in technical details.

* ~~SL In~~ SLS is a relatively new technology that so far has mainly been used for rapid prototyping and for low volume production of component parts.

* SLS involves the use of a high power laser (Carbon dioxide laser) to fuse small particles of plastic, metal, ceramic (or) glass powders into a mass that has a desired 3-D shape.

* The laser selectively fuses powdered material by scanning cross-sections generated from a 3-D digital description of the part (from a CAD file (or) scan data) on the surface of a powder bed.

* After each cross-section is scanned, the powder bed is lowered by one layer thickness, a new layer of material is applied on top, and the process is repeated until the part is completed.

Applications: Prototype parts early in the design cycle such as for

* Investment casting patterns
* Automotive hardware
* Wind tunnel models
* end-use parts for aerospace, military, medical and electronics hardware.
* manufacturing of tooling, jigs etc.