SYLLABUS

ME8073 UNCONVENTIONAL MACHINING PROCESSES

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OBJECTIVE:

- To learn about various unconventional machining processes, the various process parameters and their influence on performance and their applications

UNIT I INTRODUCTION AND MECHANICAL ENERGY BASED PROCESSES 9

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

UNIT II THERMAL AND ELECTRICAL ENERGY BASED PROCESSES 9

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

UNIT III CHEMICAL AND ELECTRO-CHEMICAL ENERGY BASED PROCESSES 9

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

UNIT IV ADVANCED NANO FINISHING PROCESSES 9

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

UNIT V RECENT TRENDS IN NON-TRADITIONAL MACHINING PROCESSES 9

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

TOTAL: 45 PERIODS

OUTCOMES:

Upon the completion of this course the students will be able to

CO1 Explain the need for unconventional machining processes and its classification

CO2 Compare various thermal energy and electrical energy based unconventional machining processes.

CO3 Summarize various chemical & electro-chemical energy based unconventional machining processes.

CO4 Explain various nano abrasives based unconventional machining processes.

CO5 Distinguish various recent trends based unconventional machining processes.

TEXT BOOKS:

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

REFERENCES:

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

UNIT-1

INTRODUCTION AND MECHANICAL ENERGY BASED PROCESSES

An unconventional machining process (or non-traditional machining process) is a special type of machining process in which there is no direct contact between the tool and the workpiece. In unconventional machining, a form of energy is used to remove unwanted material from a given workpiece.

Need of unconventional machining processes

In several industries, hard and brittle materials like tungsten carbide, high speed steels, stainless steels, ceramics etc., find a variety of applications. For example, tungsten carbide is used for making cutting tools while high speed steel is used for making gear cutters, drills, taps, milling cutters etc.

If such materials are machined with the help of conventional machining processes, either the tool undergoes extreme wear (while machining hard work piece) or the work piece material is damaged (while machining brittle work piece). This is because, in conventional machining, there is a direct contact between the tool and the work piece. Large cutting forces are involved and material is removed in the form of chips. Ahuge amount of heat is produced in the workpiece. This induces residual stresses, which degrades the lifeand quality of the work piece material.

Hence, conventional machining produces poor quality workpiece with poor surface finish (if the workpiece is made of hard and brittle material). To overcome all these drawbacks, we use unconventional machining processes to machine hard and brittle materials. We also use unconventional machining processes to machine soft materials, in order to get better dimensional accuracy.

Classification of unconventional machining processes:

Unconventional machining processes can be broadly classified into several types based on four main criteria. The classification of unconventional machining processes is given below:

1. **Based on the type of energy used**
   1. Mechanical Energy based Unconventional Machining Processes (e.g. Abrasive Jet Machining, Water Jet Machining)
   2. Electrical Energy based Unconventional Machining Processes (e.g. Electrical Discharge Machining)
   3. Electrochemical Energy based Unconventional Machining Processes (e.g. Electrochemical Grinding)
   4. Chemical Energy based Unconventional Machining Processes (e.g. Chemical Machining)
   5. Thermo-electrical (or Electro-thermal) Energy based Unconventional Machining Processes (e.g. Plasma Arc Machining)
2. **Based on the source of energy**
   1. Current
   2. Voltage

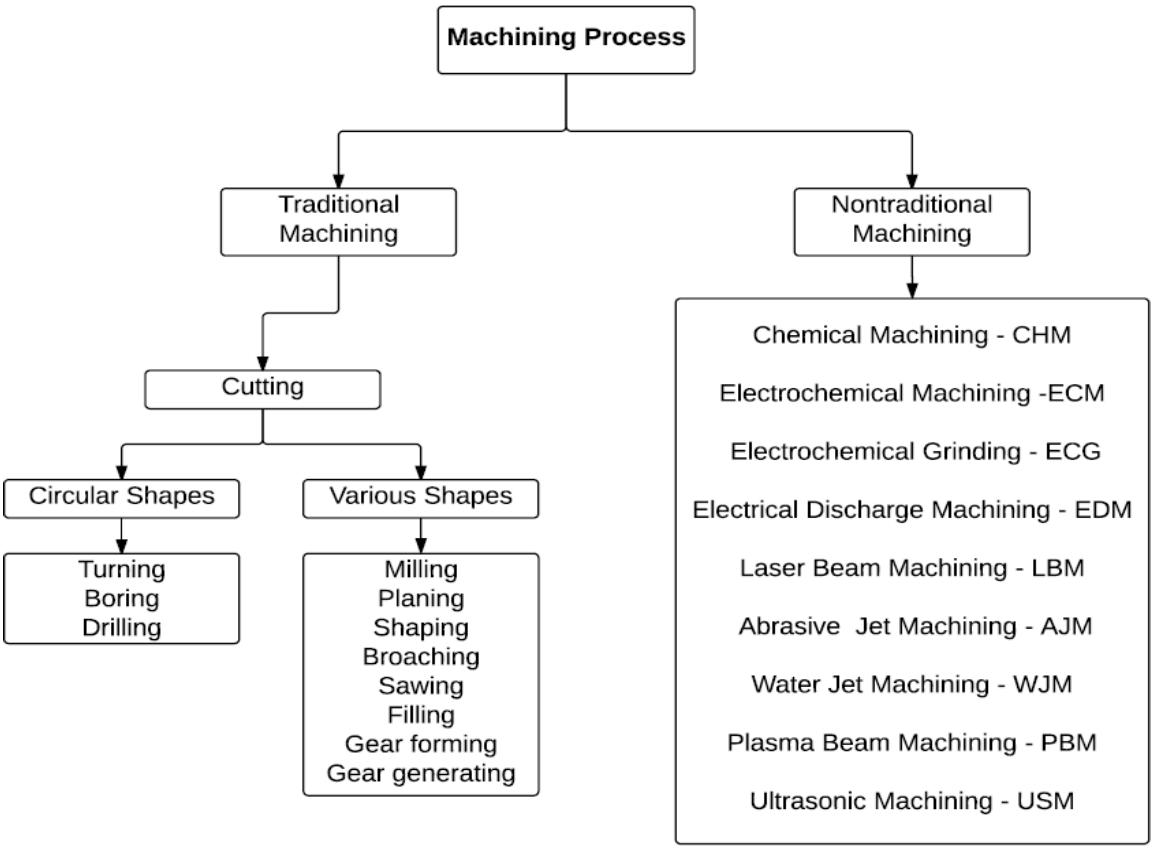
3. Hydraulic Pressure
4. Pneumatic Pressure
5. Ionized Particles
6. Light

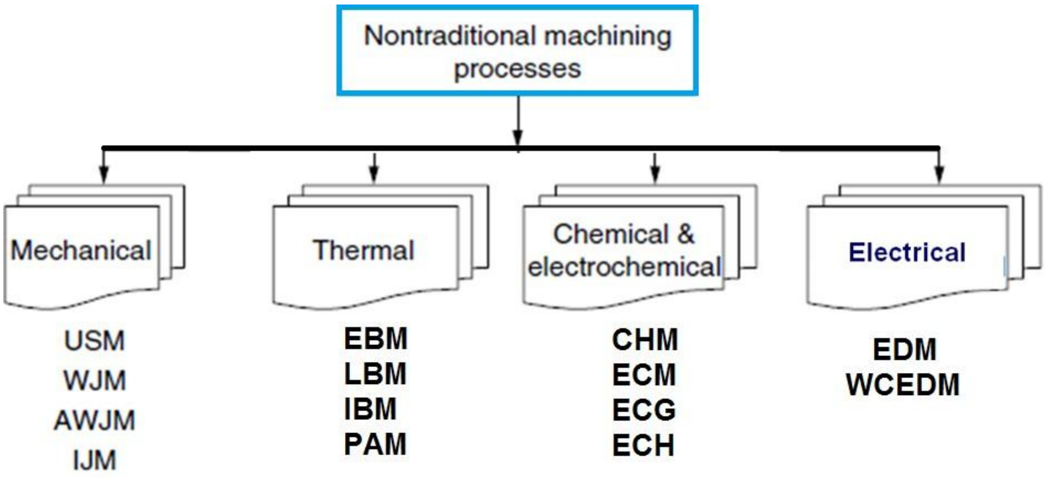
3. Based on the medium of energy transfer

1. Electrons
2. Atmosphere
3. Ions
4. Electrolyte
5. Pressurized gas
6. Water
7. Ultrasonic waves
8. Plasma
9. Laser
10. Chemical reagent
11. Radiation

4. Based on the mechanism of material removal

1. Erosion
2. Electric Discharge
3. Shear
4. Chemical Etching
5. Vaporization
6. Melting
7. Ion Displacement
8. Blasting





1. Mechanical Energy based Unconventional Machining Processes:

In these processes, unwanted material in the workpiece is removed by mechanical erosion. The mechanical erosion can be facilitated by using any medium. For example, in abrasive jet machining, high velocity abrasive jet is used for eroding material from the workpiece. In water jet machining, high velocity water jet is used for cutting the workpiece material.

The four main mechanical energy based unconventional machining processes are:

1. Abrasive Jet Machining
2. Water Jet Machining or Water Jet Cutting
3. Abrasive Water Jet Machining
4. Ultrasonic Machining

2. Electrical Energy based Unconventional Machining Processes:

Here, electric spark discharge is used to cut and machine the workpiece. In electrical energy based processes, no arc is produced (as in arc welding). Instead, thousands of sparks are produced every second. These sparks increase the temperature of the workpiece, melt the unwanted portions and vapourise those portions. A dielectric fluid is used for cleaning the workpiece and facilitating a smooth spark discharge.

Processes that come under this category are:

1. Electrical Discharge Machining
2. Wire Cut Electrical Discharge Machining

3. Electrochemical Energy based Unconventional Machining Processes:

In these processes, unwanted portions of the workpiece are removed by electrochemical effect. The workpiece (in contact with an electrolyte) is machined by ion dissolution. Processes that come under this category are:

1. Electrochemical Machining
2. Electrochemical Grinding
3. Electrochemical Honing

4. Chemical Energy based Unconventional Machining Processes:

Here, chemical energy is used to remove material from the workpiece.

We know that metal can be easily converted to metallic salt, if suitable reagent is used. Chemical energy based processes exploit this principle.

Material is removed by controlled etching of the workpiece in the presence of a reagent known as enchant.

Chemical machining, chemical milling and photochemical milling (PCM) are the processes that come under this category.

5. Thermo-electrical (or Electro-thermal) Energy based Unconventional Machining Processes:

Unwanted portions of a metal can be easily removed, if it is melted or vaporized. Thermo-electrical energy based unconventional machining processes make use of this principle.

In these processes, electrical energy is converted to a huge amount of heat by some means. This heat is applied on a small region of the workpiece. That particular region is either melted or vaporised. By this way, material is removed.

The following are some of the important thermo-electrical energy based unconventional machining processes:

1. Plasma Arc Machining
2. Electron Beam Machining
3. LASER Beam Machining
4. Ion Beam Machining

Material and Method of Machining

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

Based on the following points:

1. Physical Parameters
2. Shapes to be machined
3. Process Capability or Machining Characteristics
4. Economic Considerations

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, kW	100	2.70	0.15	20	220	2.4	0.22
Gap, mm	0.5	0.05	100	150	7.5	0.25	0.75
Medium	Electro -lyte	Dielectric Fluid	Vacuum	Air	Argon or Hydrogen or Nitrogen	Abrasive grains & water	N_2 or Co_2 or Air
Work Material	Difficult to machine materials	Tungsten carbides and electrically conductive materials	All materials	All materials	All materials which conduct electricity	Tungsten carbide, glass, quartz etc.,	Hard and brittle materials

Shapes to be machined

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.

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 etching small portions

- ECM and EDM are well suited.

Process Capability or Machining Characteristics

1. Material Removal rate
2. Tolerance Maintained
3. Surface Finish
4. Depth of surface Damage
5. Power required for machining

Process	Process Capability			
	Metal removal Rate (mm^3/s) (MRR)	Surface Finish (μm, CLA)	Accuracy (μm)	Specific power ($kW/cm^3/min$)
LBM	0.10	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	0.90
USM	14	0.2-0.7	7.5	9.0
AJM	0.014	0.5-1.2	50	312.5

Process Economy

Process	Capital Cost	Tooling and fixtures	Power requirement -	Efficiency	Total consum -ption
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
Conventio -nal machining	V.Low	Low	Low	V.Low	Low

Advantages of UCM

- High Accuracy and surface finish in process
- Less Rejected pieces
- Increase productivity
- Tool material need not be harder than work piece material.
- Easy to machine harder and brittle materials
- There is no residual stresses in the machined material

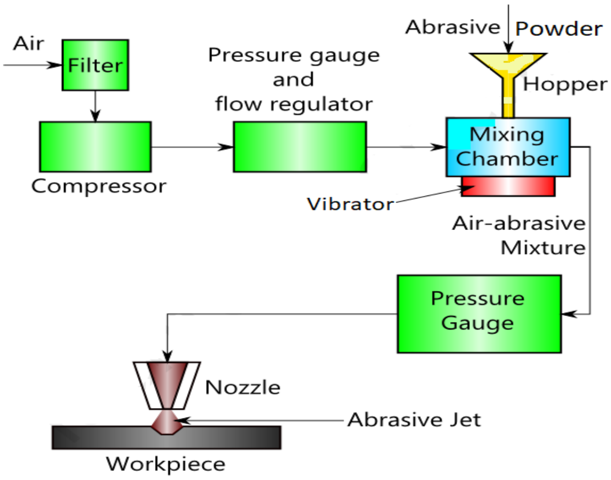
Dis-Advantages of UCM

1. More expensive process
2. Low Material Removal Rate (MRR)
3. AJM, CHM , PAM and EBM are not commercially economical Process

MECHANICAL BASED MACHINING PROCESSES

ABRASIVE JET MACHINING

Abrasive Jet Machining (AJM), is a mechanical energy based unconventional machining process used to remove unwanted material from a given work piece. The process makes use of an abrasive jet with high velocity, to remove material and provide smooth surface finish to hard metallic work pieces.



Parts & Usages

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

Working:

Dry air or gas is filtered and compressed by passing it through the filter and compressor. A pressure gauge and a flow regulator are used to control the pressure and regulate the flow rate of the compressed air. Compressed air is then passed into the mixing chamber. In the mixing chamber, abrasive powder is fed. A vibrator is used to control the feed of the abrasive powder. The abrasive powder and the compressed air are thoroughly mixed in the chamber. The pressure of this mixture is regulated and sent to nozzle.

The nozzle increases the velocity of the mixture at the expense of its pressure. A fine abrasive jet is rendered by the nozzle. This jet is used to remove unwanted material from the workpiece.

Operations that can be performed using Abrasive Jet Machining (AJM)

The following are some of the operations that can be performed using Abrasive Jet Machining:

1. Drilling
2. Boring
3. Surface finishing
4. Cutting
5. Cleaning
6. Deburring
7. Etching
8. Trimming
9. Milling

Advantages of Abrasive Jet Machining:

- Surface of the workpiece is cleaned automatically.
- Smooth surface finish can be obtained.
- Equipment cost is low.
- Hard materials and materials of high strength can be easily machined.

Disadvantages of Abrasive Jet Machining:

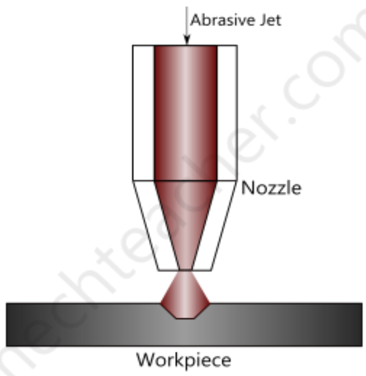
- Metal removal rate is low
- In certain circumstances, abrasive particles might settle over the workpiece.
- Nozzle life is less. Nozzle should be maintained periodically.
- Abrasive Jet Machining cannot be used to machine soft materials.

Process parameters

Process parameters of Abrasive Jet Maching (AJM) are factors that influence its Metal Removal Rate (MRR). In a machining process, Metal Removal Rate (MRR) is the volume of metal removed from a given workpiece in unit time.

Some of the important process parameters of abrasive jet machining:

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



Abrasive mass flow rate:

Mass flow rate of the abrasive particles is a major process parameter that influences the metal removal rate in abrasive jet machining.

In AJM, mass flow rate of the gas (or air) in abrasive jet is inversely proportional to the mass flow rate of the abrasive particles. Due to this fact, when continuously increasing the abrasive mass flow rate, Metal Removal Rate (MRR) first increases to an optimum value (because of increase in number of abrasive particles hitting the workpiece) and then decreases. However, if the mixing ratio is kept constant, Metal Removal Rate (MRR) uniformly increases with increase in abrasive mass flow rate.

Nozzle tip distance:

Nozzle Tip Distance (NTD) is the gap provided between the nozzle tip and the workpiece. Up to a certain limit, Metal Removal Rate (MRR) increases with increase in nozzle tip distance. After that limit, MRR remains constant to some extent and then decreases. In addition to metal removal rate, nozzle tip distance influences the shape and diameter of cut. For optimal performance, a nozzle tip distance of 0.25 to 0.75 mm is provided.

Gas pressure:

Air or gas pressure has a direct impact on metal removal rate. In abrasive jet machining, metal removal rate is directly proportional to air or gas pressure.

Velocity of abrasive particles:

Whenever the velocity of abrasive particles is increased, the speed at which the abrasive particles hit the workpiece is increased. Because of this reason, in abrasive jet machining, metal removal rate increases with increase in velocity of abrasive particles.

Mixing ratio:

Mixing ratio is a ratio that determines the quality of the air-abrasive mixture in Abrasive Jet Machining (AJM). It is the ratio between the mass flow rate of abrasive particles and the mass flow rate of air (or gas). When mixing ratio is increased continuously, metal removal rate first increases to some extent and then decreases.

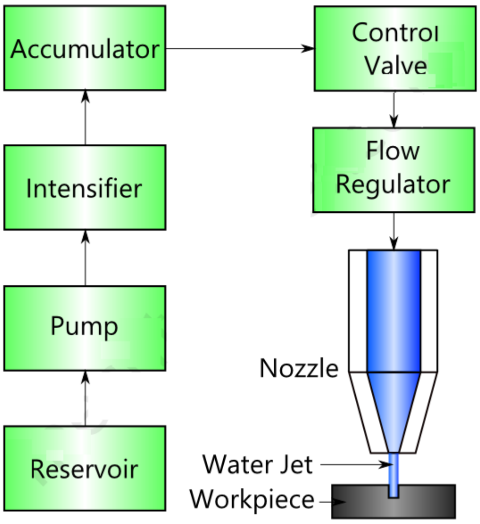
Abrasive grain size:

Size of the abrasive particle determines the speed at which metal is removed. If smooth and fine surface finish is to be obtained, abrasive particle with small grain size is used. If metal has to be removed rapidly, abrasive particle with large grain size is used.

WATER JET MACHINING (WJM)

Water Jet Machining (WJM) is a mechanical energy based non-traditional machining process used to cut and machine soft and non-metallic materials. It involves the use of high velocity water jet to smoothly cut a soft workpiece. It is similar to Abrasive Jet Machining (AJM).

In water jet machining, high velocity water jet is allowed to strike a given workpiece. During this process, its kinetic energy is converted to pressure energy. This induces a stress on the workpiece. When this induced stress is high enough, unwanted particles of the workpiece are automatically removed.



Reservoir: It is used for storing water that is to be used in the machining operation.
Pump: It pumps the water from the reservoir.
Intensifier: It is connected to the pump. It pressurizes the water acquired from the pump to a desired level.
Accumulator: It is used for temporarily storing the pressurized water. It is connected to the flow regulator through a control valve.
Control Valve: It controls the direction and pressure of pressurized water that is to be supplied to the nozzle.
Flow regulator: It is used to regulate the flow of water.
Nozzle: It renders the pressurized water as a water jet at high velocity

Working of Water Jet Machining (WJM):

- Water from the reservoir is pumped to the intensifier using a hydraulic pump.
- The intensifier increases the pressure of the water to the required level. Usually, the water is pressurized to 200 to 400 MPa.
- Pressurized water is then sent to the accumulator. The accumulator temporarily stores the pressurized water.
- Pressurized water then enters the nozzle by passing through the control valve and flow regulator.
- Control valve controls the direction of water and limits the pressure of water under permissible limits.
- Flow regulator regulates and controls the flow rate of water.
- Pressurized water finally enters the nozzle. Here, it expands with a tremendous increase in its kinetic energy. High velocity water jet is produced by the nozzle.
- When this water jet strikes the workpiece, stresses are induced. These stresses are used to remove material from the workpiece.
- The water used in water jet machining may or may not be used with stabilizers. Stabilizers are substances that improve the quality of water jet by preventing its fragmentation.
- For a good understanding of water jet machining, refer the schematic diagram above.

Advantages of Water Jet Machining (WJM):

1. Water jet machining is a relatively fast process.
2. It prevents the formation of heat affected zones on the workpiece.

3. It automatically cleans the surface of the workpiece.
4. WJM has excellent precision. Tolerances of the order of ±0.005″ can be obtained.
5. It does not produce any hazardous gas.
6. It is eco-friendly.

Disadvantages of Water Jet Machining:

1. Only soft materials can be machined.
2. Very thick materials cannot be easily machined.
3. Initial investment is high.

Applications of Water Jet Machining:

1. Water jet machining is used to cut thin non-metallic sheets.
2. It is used to cut rubber, wood, ceramics and many other soft materials.
3. It is used for machining circuit boards.
4. It is used in food industry.

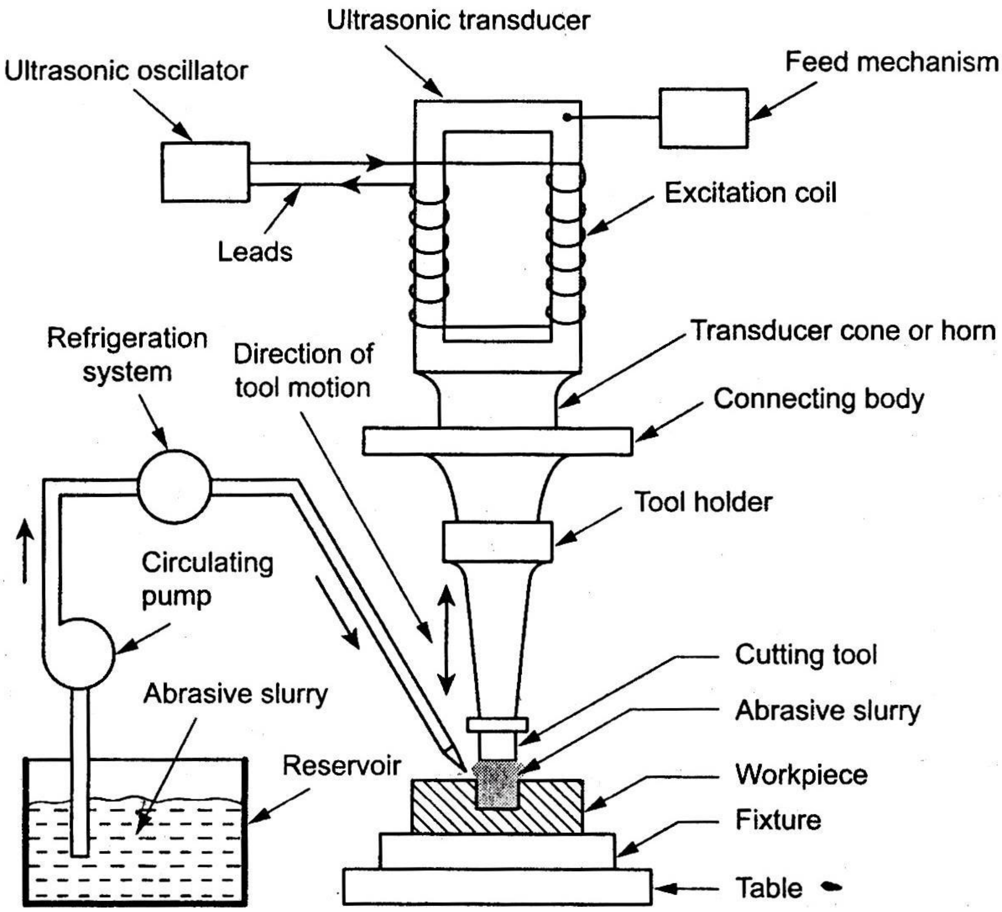
ULTRASONIC MACHINING (USM)

Principles

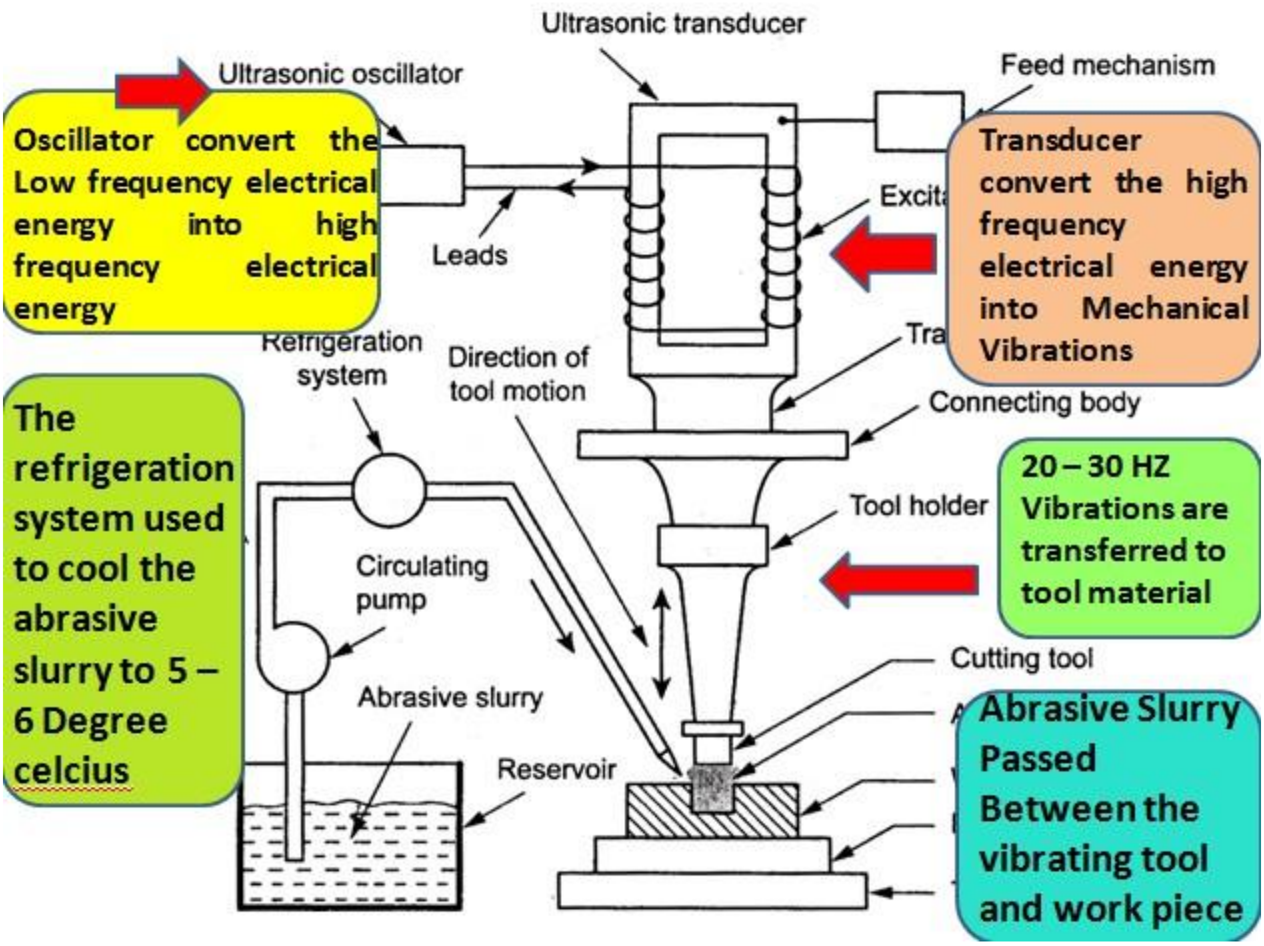
Working principle of Ultrasonic Machining or Ultrasonic Impact Grinding is described with the help of a schematic diagram. The shaped tool under the actions of mechanical vibration causes the abrasive particles dipped in slurry to be hammered on the stationary work piece. This causes micro-indentation fracture on the material. Small abraded particles are removed along the surface which is perpendicular to the direction of the tool vibration. When the material is removed a cavity of the same profile of the tool face is formed. The abrasive particles gradually erode as the machining process continues. As a result fresh abrasive particles are needed to be supplied in the machining zone. Abrasive particles associated with the liquid are fed to the m/c zone and it ensures the removal of the worn out grains and material.

Machining Time

The machining time of the ultrasonic grinding depends on the frequency of the vibration, material properties and grain size. The amplitude of the vibration may vary from 5 to 75 μm and frequency may vary from 19~25 kHz. Ample static force is also required to hold the job against the machining tool. A continues flow of abrasives suspension is also mandatory.



Ultrasonic transducer
Ultrasonic oscillator
Feed mechanism
Excitation coil
Leads
Refrigeration system
Direction of tool motion
Transducer cone or horn
Connecting body
Tool holder
Circulating pump
Cutting tool
Abrasive slurry
Abrasive slurry
Reservoir
Workpiece
Fixture
Table



Ultrasonic transducer
Ultrasonic oscillator
Feed mechanism
Oscillator convert the Low frequency electrical energy into high frequency electrical energy
Leads
Transducer convert the high frequency electrical energy into Mechanical Vibrations
Refrigeration system
Direction of tool motion
Connecting body
The refrigeration system used to cool the abrasive slurry to 5 – 6 Degree celcius
Tool holder
20 – 30 HZ Vibrations are transferred to tool material
Circulating pump
Cutting tool
Abrasive slurry
Abrasive Slurry Passed Between the vibrating tool and work piece
Reservoir

Process parameters

1. Amplitude of vibration (15 to 50 microns), Frequency of vibration (19 to 25 kHz).
2. Feed force (F) related to tool dimensions, Feed pressure
3. Abrasive size, Abrasive material ** Al203, SiC, B4C, Boron silicon Carbide, Diamond.
4. Flow strength of the work material, Flow strength of the tool material
5. Contact area of the tool, Volume concentration of abrasive in water slurry
6. Tool ----------------------a. Material of tool
   b. Shape
   c. Amplitude of vibration
   d. Frequency of vibration
   e. Strength developed in tool
7. Work material -------- a. Material b. Impact strength c. Surface fatigue strength
8. Slurry --------------------a. Abrasive – hardness, size, shape and quantity of abrasive flow
   b. Liquid – Chemical property, viscosity, flow rate
   c. Pressure
   d. Density

Advantages of USM:

1. It can be used to drill circular or non-circular holes on very hard materials like stones, carbides, ceramics and other brittle materials.
2. Non-conducting materials like glass, ceramics and semi precious stones can also be machined.

Disadvantages of USM:

1. It can be proved slower than the conventional machining processes.
2. Creating deep holes is difficult because of the restricted movement of the suspension.
3. It is arduous to select the perfect tool geometry for creating hole of certain dimension. The holes created may be of larger sizes because of side cutting.
4. High tool wear because of continues flow of abrasive slurry.

Applications:

1. Hard and brittle materials can be machined like tungsten carbide, diamond and glass. These are difficult to machine in conventional m/c-ing process.
2. Wire drawing dies of tungsten carbide can be drilled by this process.
3. Circular as well as non-circular holes can be done with straight or curved axes.
4. It has been proved successful in machining geranium, silicon quartz and synthetic ruby etc.

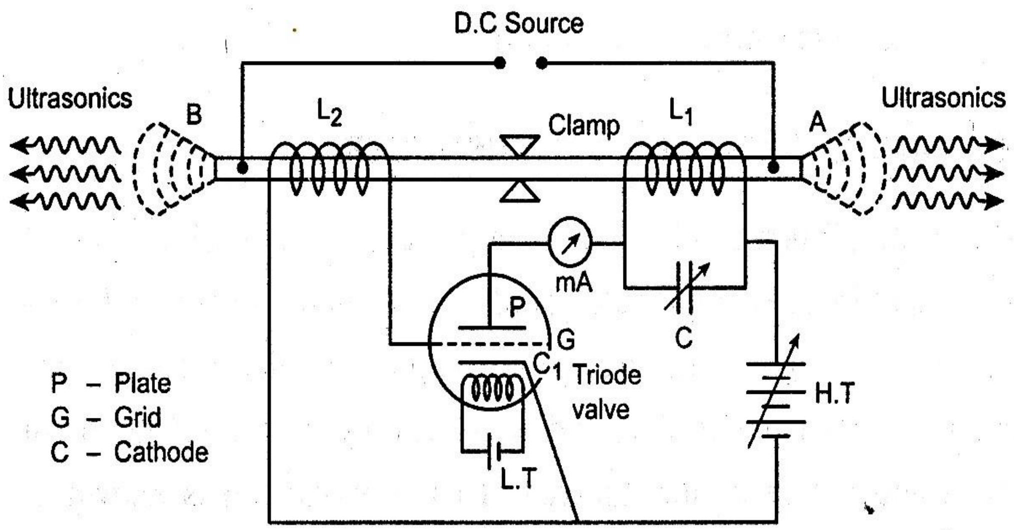
TRANSDUCER

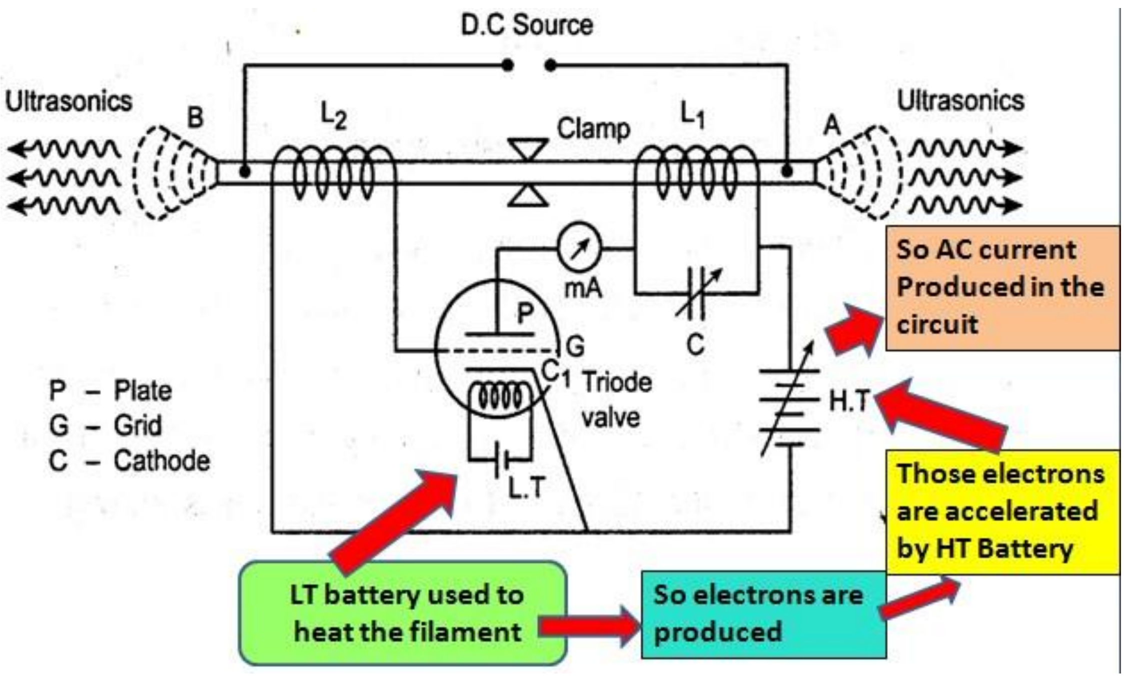
Transducer is a device which is used to convert one form of energy in to another form of energy.

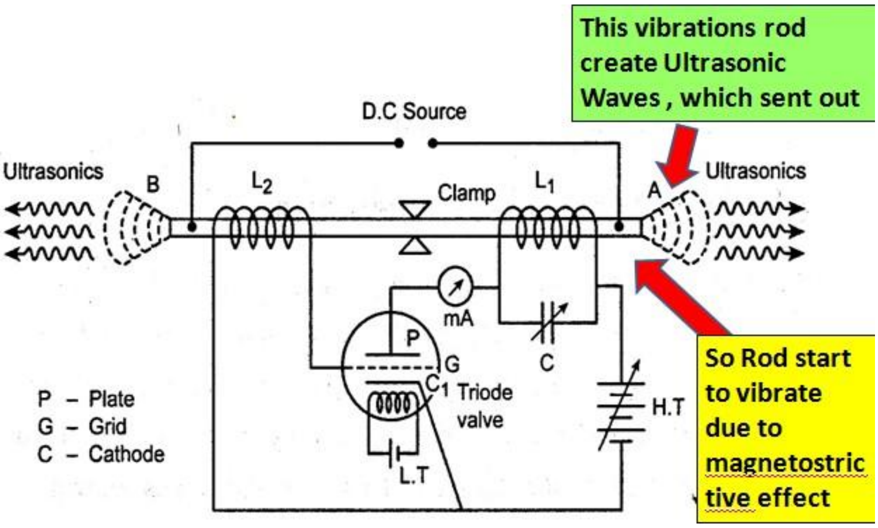
Types - Magnetostrictive transducer and piezoelectric transducer

Magnetostrictive transducer

Principle : **When a rod of ferromagnetic material such as iron or nickel is kept in a magnetic field parallel to its length, the rod suffers a change in its length. The change in length is independent of the direction of the magnetic field and depends only on the magnitude of the field and nature of the material. This phenomenon is known as *Magnetostriction effect.***







The Longitudinal Extension and contraction of the Rod AB produce an EMF in the coil L2

Resonance will occur when

Frequency of the oscillatory circuit = **Frequency of Vibrating Rod**

At resonance , the rod vibrates vigorously and ultrasonic waves are produced at high frequencies

$$\left.\begin{matrix}\text{Frequency of the}\\ \text{oscillatory circuit}\end{matrix}\right\} = \left\{\begin{matrix}\text{Frequency of the}\\ \text{vibrating rod}\end{matrix}\right.$$

$$\frac{1}{2\pi\sqrt{L_1 C_1}} = \frac{1}{2l}\sqrt{\frac{E}{\rho}}$$

where,

E – Young's modulus of the rod material, N/m^2,

l – Length of the rod, m,

ρ – Density of the rod material, kg/m^3.

Advantages – Magnetostrictive Transducer

1. Production cost is low.
2. Very simple design.
3. At low ultrasonic frequencies, large power output is possible without any damage to the oscillatory circuit.

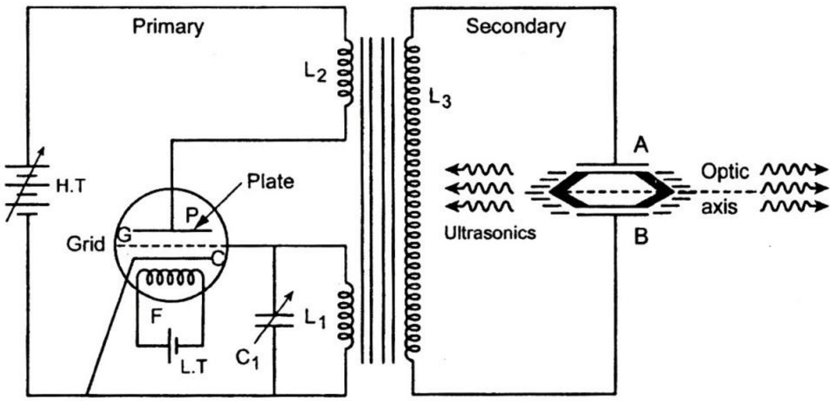
Dis-advantages – Magnetostrictive Transducer

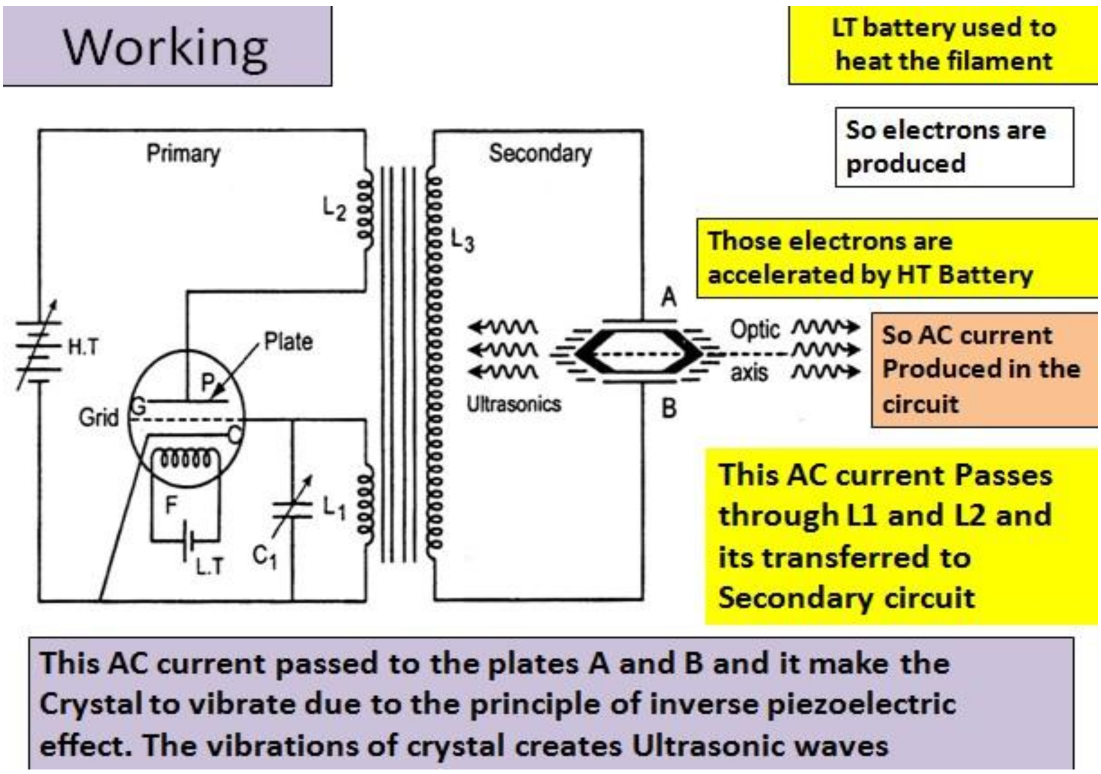
1. It cannot produces ultrasonic waves of frequency above 3000 kHz.
2. The frequency of oscillations depends on temperature. So, it is not possible to get a constant single frequency.
3. There will be losses of energy due to hysteresis and eddy current.

PIEZOELECTRIC TRANSDUCER

Piezoelectric transducers are a type of electro acoustic transducer that convert the electrical charges produced by some forms of solid materials into energy. The word "piezoelectric" literally means electricity caused by pressure.

- It consists of primary and secondary circuits. The primary circuit is arranged with coils L_1 and L_2.
- Coil L_1 is connected to the grid circuit and the coil L_2 is connected to the plate circuit. The frequency of the oscillatory circuit is varied by using the capacitor C_1.
- The quartz crystal is placed between two metal plates A and B. The plates are connected to the secondary (L_3) of the transformer.





Resonance

When the frequency of the oscillatory circuit is equal to the frequency of the vibrating crystal, resonance occurs. At resonance, the crystal vibrates vigorously and ultrasonic waves are produced with very high frequencies.

$$\left.\begin{array}{r}\text{Frequency of the}\\ \text{oscillatory circuit}\end{array}\right\} = \left\{\begin{array}{l}\text{Frequency of the}\\ \text{vibrating crystal}\end{array}\right.$$

$$\frac{1}{2\pi\sqrt{L_1 C_1}} = \frac{P}{2l}\sqrt{\frac{E}{\rho}}$$

where,

l – Length of the crystal, m,

E – Young's modulus of the crystal, N/m^2,

ρ – Density of the crystal, kg/m^3,

P = 1, 2, 3, 4, ……, *etc.*, for fundamental first over tone, second over tone respectively.

Advantages – Piezoelectric transducer

1. It is more efficient than magnetostriction transducer.
2. It can produce frequency upto 500 MHz.
3. It is not affected by temperature and humidity.

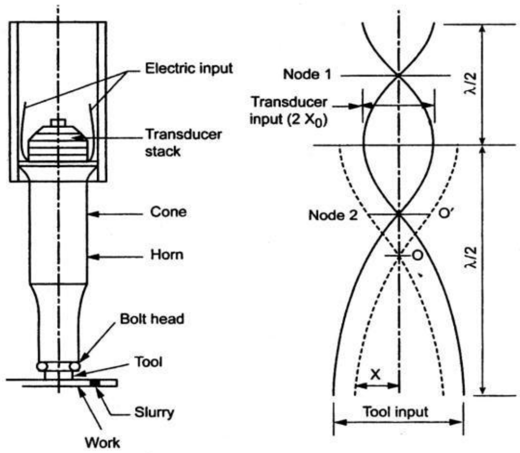
Disadvantages – Piezoelectric transducer

1. Piezoelectric quartz is high cost

2. Cutting and shaping of crystal is very complex.

TOOL HOLDER OR HORN.

The tool holder holds and connects the tool to the transducer. It virtually transmits the energy and in some cases, amplifies the amplitude of vibration. Material of tool should have good acoustic properties, high resistance to fatigue cracking. Due measures should be taken to avoid ultrasonic welding between transducer and tool holder. Commonly used tool holders are Monel, titanium, stainless steel. Tool holders are more expensive, demand higher operating cost.



TOOL FEED MECHANISM

The feed mechanism of an ultrasonic machine must perform the following functions:

1. Bring the tool slowly to the work piece to prevent breaking.

2. The tool must provide adequate cutting force and sustain it during the machining operation.

3. The cutting force must be decreased when the specified depth is reached.

4. Overrun a small distance to ensure the required hole size at the exit.

5. The tool has to come back to its initial position after machining is done.

Types

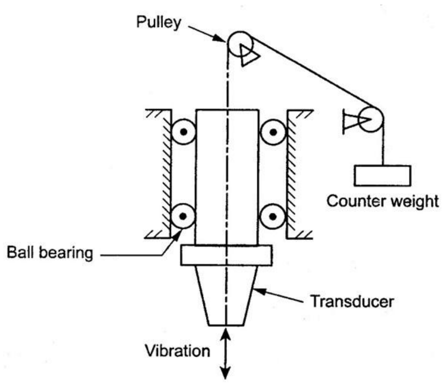
There are four types of feed mechanism which are commonly used in USM:

1. Gravity feed mechanism

2. Spring loaded feed mechanism

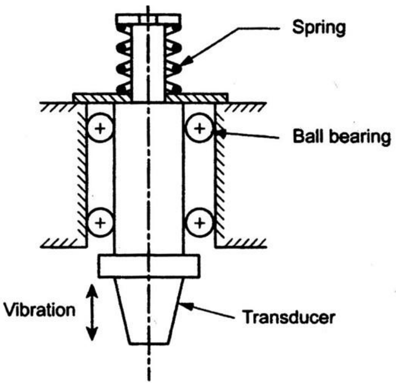
3. Pneumatic or hydraulic feed mechanism

4. Motor controlled feed mechanism.



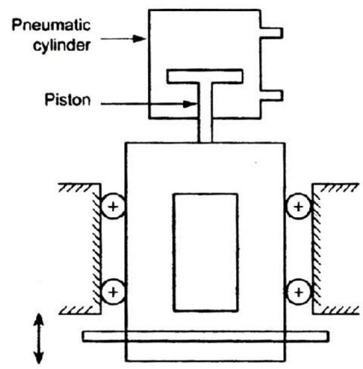
Gravity feed mechanism

balancing or adjusting the counter weight , we can achieve the require feed level in the tool during operation



Spring loaded feed mechanism

A spring effect is used to control the feed movement of tool. its highly sensitive and compact in size



Pneumatic feed mechanism

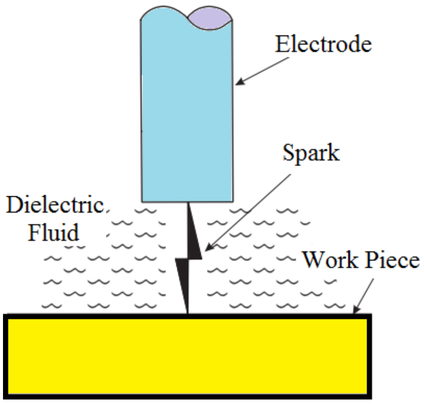
Here , they using a compressed air through piston and cylinder arrangement. by which we control the tool movement

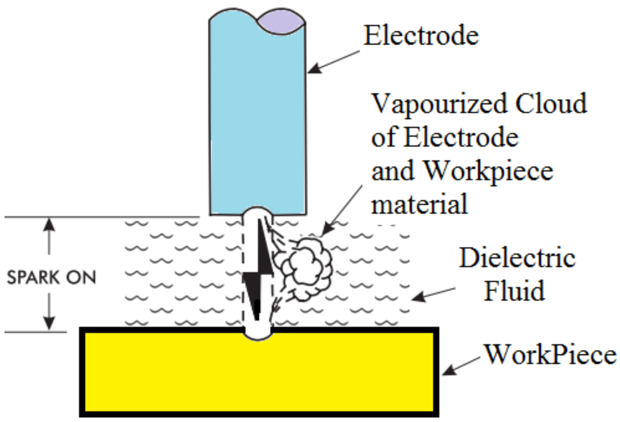
UNIT-II
THERMAL AND ELECTRICAL ENERGY BASED PROCESSES

ELECTRICAL DISCHARGE MACHINING (EDM)

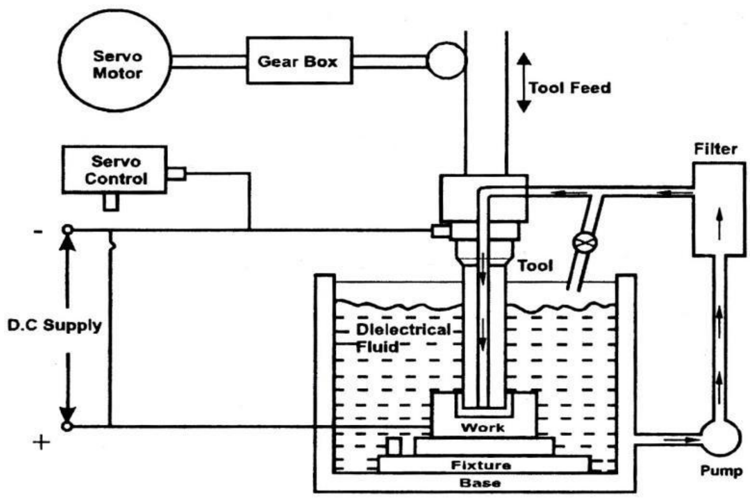
Introduction

EDM is a non-conventional machining technique uniquely used for cutting metals which are not possible to cut with traditional methods. EDM only works with materials which are electrically conductive. Delicate cavities and intricate contours which are difficult to produce with a grinder or other machines can be done with **Electrical Discharge Machining** or EDM. The cutting tool for EDM may be made of hardened too steel, titanium carbide. EDM is also known as "Spark Machining”. Such name has been given for the fact that it removes the metal by applying a rapid series of repetitive electrical discharges. An electrode and the work piece are used for the conducting path of these electrical discharges. A continuously flowing fluid is always flowing to flush away the little amount of material that is removed. Repetitive discharge gives the work piece a desired shape.





WORKING PRINCIPLE OF EDM



Schematic layout of EDM

Working principle of EDM As shown in Figure, at the beginning of EDM operation, a high voltage is applied across the narrow gap between the electrode and the work piece. This high voltage induces an electric field in the insulating dielectric that is present in narrow gap between electrode and work piece. This cause conducting particles suspended in the dielectric to concentrate at the points of strongest electrical field. When the potential difference between the electrode and the work piece is sufficiently high, the dielectric breaks down and a transient spark discharges through the dielectric fluid, removing small amount of material from the work piece surface. The volume of the material removed per spark discharge is typically in the range of 10^{-6} to 10^{-6} mm^3.

Advantages of EDM

The main advantages of EDM are:

By this process, materials of any hardness can be machined;

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

Limitations of EDM

The main limitations of this process are:

This process can only be employed in electrically conductive materials;

- Material removal rate is low and the process overall is slow compared to conventional
- Machining processes; unwanted erosion and over cutting of material can occur;
- Rough surface finish obtained, when at high rates of material removal.

Specifications

Voltage = 250 V

GAP = 0.005 – 0.05 mm

Temperature = 10000 degree celcius

Spark occur = 10 – 30 micro seconds

Current density = 15 – 500 A

Process Parameters

1. Operating Parameters
2. Taper
3. Surface finish
4. Current Density

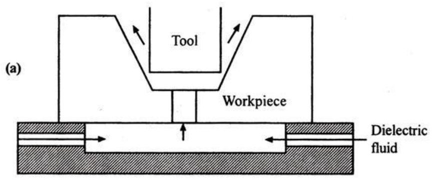
Dielectric Fluid Requirements

- Should not be toxic
- Should not be corrosive
- Should not be hazardous
- Should be circulate freely
- Should be flushed out
- Should be act as coolant
- Should be filtered before use
- Should be less cost

Di electric Fluid – Flushing Method

1. Pressure Flushing

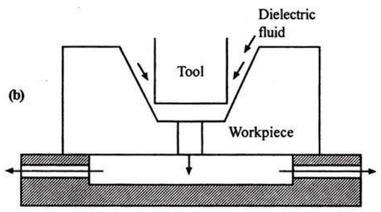
Pressure Flushing



Here a pressurized fluid enters from the bottom, so the eroded particles are flushed away from the working zone easily.

Suction Flushing

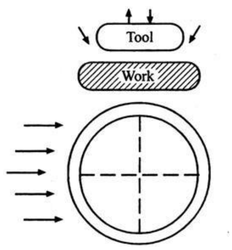
Suction Flushing



Here the pressurized fluid enters in to the cutting zone from top due to the suction pressure created at the bottom portion of machining. So the fluid flush away the eroded particles and moves down.

Side Flushing

Side Flushing



Here the pressurized fluid enters in to the cutting zone in side direction as shown in figure. So it flushed away the eroded particles from the cutting zone.

Functions of Dielectric Fluid

Act as an insulator between the tool and the work piece.

- Act as coolant.
- Act as a flushing medium for the removal of the chips.

Electrode (Tool)

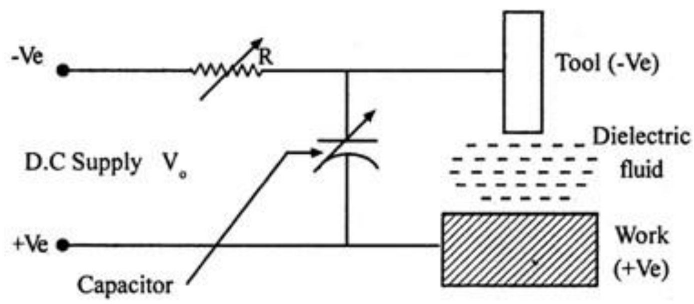
- Graphite (Non Metallic) , Copper (Metallic) , Coppre – Tungsten

POWER GENERATING CIRCUITS

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

1. Relaxation Circuit

- Commonly used
- Simplicity
- Less cost



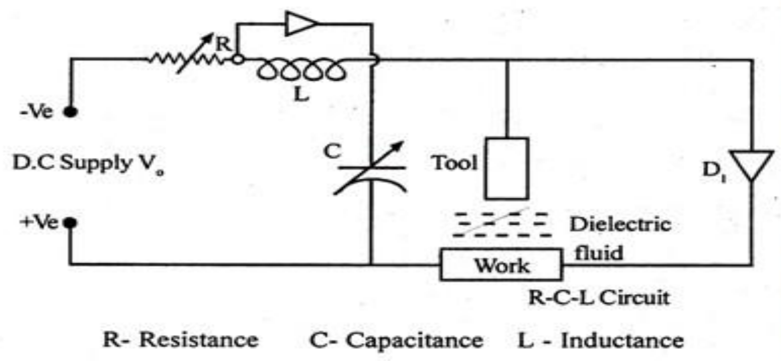
In this system, Direct Current (D.C) is flowing through a resistor (R) and it charges the capacitor (C). The charged capacitor is connected to the machine. When the voltage across the capacitor is sufficiently high (50 to 200V), dielectric medium breakdown occurs. So, the dielectric medium between the 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)

Dis-advantages

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.

2. R-C-L Circuit

- **MRR** increases with the **decrease** of R

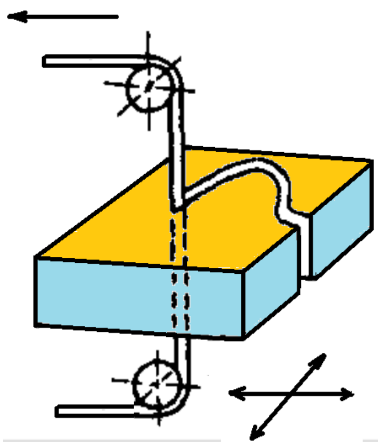


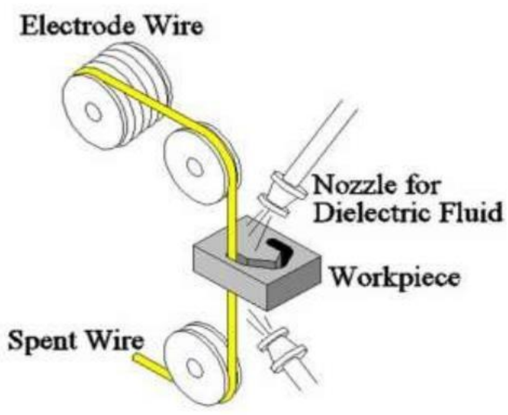
Capacitor charging time is the problem in R-C circuit.

So to overcome this , inductance (L) is introduced in the circuit

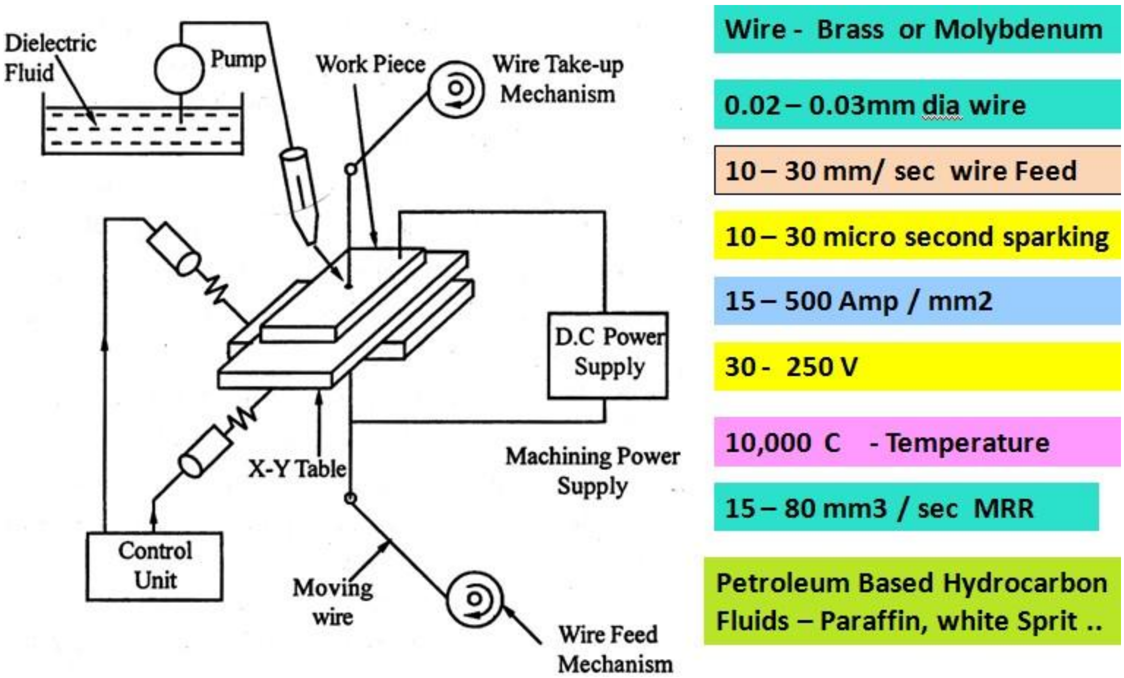
WIRE CUT EDM (WCEDM)

Wire EDM machining (Electrical Discharge Machining) is an electro thermal production process where a thin single strand metal wire, along with de-ionised water (used to conduct electricity) allows the wire to cut through metal by the use of heat from electrical sparks, while preventing rust.





A very thin wire of diameter ranging from 0.02 to 0.3 mm is used as an electrode in wire cut EDM. It cuts the work piece with electrical discharge just like a band saw. In this process either work piece or the wire is moved. The spark discharge phenomenon is used for eroding the metal which is same as the conventional EDM. In wire cut EDM the wire acts as an electrode as a result complicated shapes can be cut easily without forming electrode. Basically the wire-cut EDM consists of a machine which has a work piece contour movement control unit (NC tension: a power supply which supplies electrical energy to the wire and has a unit).



It also has work piece mounting table and a wire driver section. The wire driver section is use for moving the wire accurately at a constant tension. Another important part is the dielectric fluid (distilled water) supplier having constant specific resistance. Wire EDM has the following features -

- No forming electrode is necessary, Electrode wear is very negligible.
- Smooth machined surface, Tight geometrical and dimensional tolerances.
- Extremely high tolerances between punch and die. Extended die life.
- Straight holes are possible to produce, No skill is needed to run the machine.
- Machine can be operated without any regular supervision for long time at high operating rates.

- **Advantages**

- Because of the absence of the split lines in the die, savings of the stages in the sequential tools occurs. It permits more punch opening per stage.
- There will no flashes on the moulded parts because the moulds with draught can be arranged without vertical divisions.
- To necessity for tool manufacturing and storing.
- Work pieces are hardened before cutting, so no heat treatment distortion is present.
- Whole work is done in one machine. So die manufacturing cycle time is short.
- Lesser inspection time because of single piece construction of dies with high accuracy.
- Time is utilized perfectly as the wire cut EDM can cut throughout the day.
- Very economical even for small batch production, Low thermally affected zone. High surface finish.
- Numbers of rejected work piece are very small.

THERMAL ENERGY BASED PROCESSES

Principle

Here the machining is done by usage of heat energy.The heat energy is focused on a particular portion for melt & Vaporize the work material.

Example :

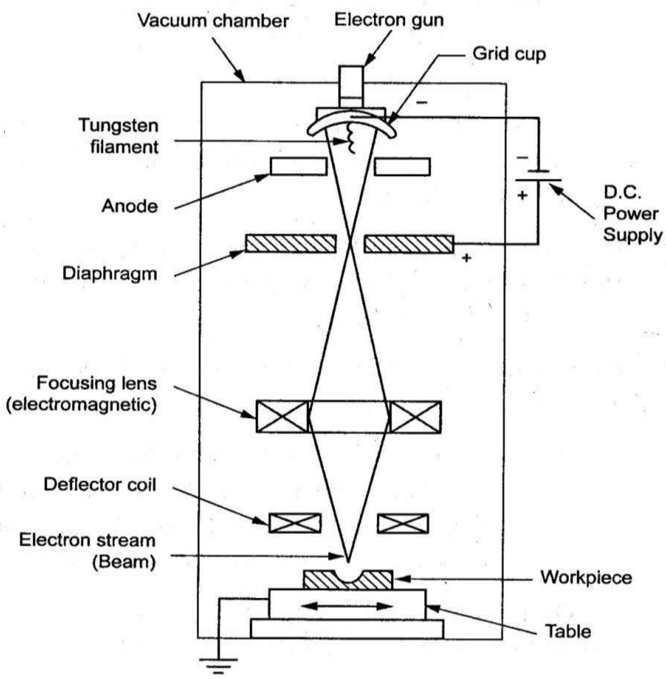
1. Electron Beam Machining (EBM)
2. Laser Beam Machining (LBM)
3. Plasma Arc Machining (PAM)

ELECTRON BEAM MACHINING (EBM)

Principle

In this, a high velocity focused beam of electrons are used to remove the metal from the work piece. These electrons are travelling at half the velocity of light. i.e 1.6 x 10^8m/sec. this process is best for micro cutting of materials.

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

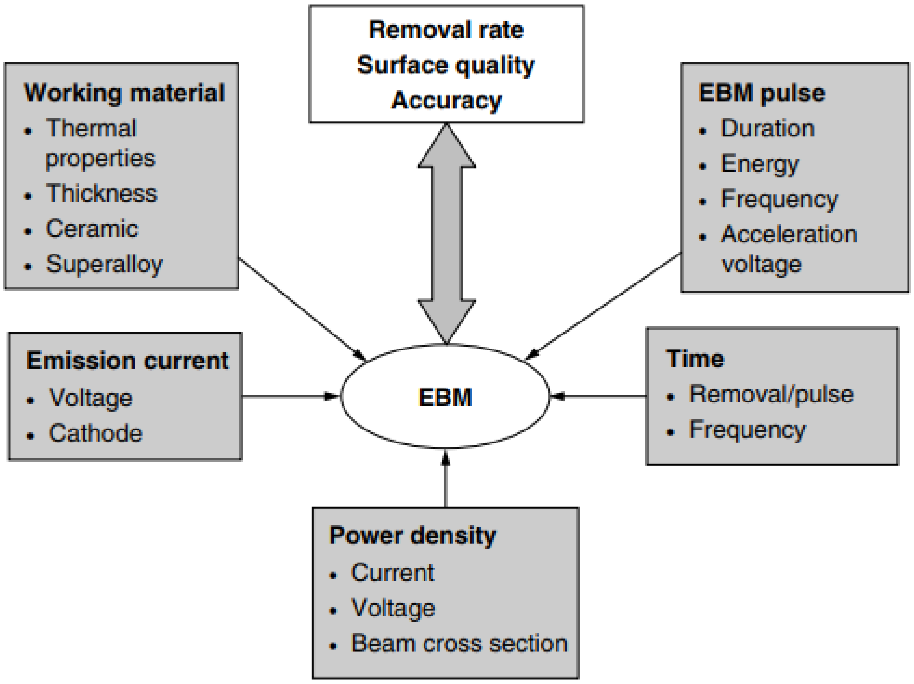


Arrangement of Electron Beam Machining

Working

The main components of EBM installation, shown in Fig. are housed in a vacuum chamber, evacuated to about 10–4 torr. The tungsten filament cathode is heated to about 2500 to 3000°C in order to emit electrons. A measure of this effect is the emission current, the magnitude of which varies between 20 and 100 mA. Corresponding current densities lie between 5 and 15 A/cm^2 . Emission current depends on the cathode material, temperature, and the high voltage that is usually about 150 kV. Such a high voltage accelerates a stream of electrons in the direction of the workpiece. After acceleration, electrons, focused by the field, travel through a hole in the anode. The electron beam is then refocused by a magnetic or electronic lens system so that the beam is directed under control toward the workpiece. The electrons maintain the velocity (228 × 10^3 km/s) imparted by the acceleration voltage until they strike the workpiece, over a well-defined area, typically 0.25 mm in diameter. The kinetic energy of the electrons is then rapidly transmitted into heat, causing a corresponding rapid increase in the temperature of the workpiece, to well above its boiling point, thus causing material removal by evaporation.

Factors Affecting Performance of EBM



EBM Process Parameters and Capabilities

Acceleration voltage	50–60 kV
Beam current	100–100 μA
Beam power	0.5-50 kW
Pulse time	4-64,000 μs
Pulse frequency	0.1-16,000 Hz
Vacuum	0.01-0.0001 mm mercury
Spot size	0.013-0.025 mm
Deflection range	6.4 mm^2
Beam intensity	1.55×10^5–1.55×10^9 W/cm^2
Depth of cut	Up to 6.4 mm
Narrowest cut	0.025 mm in 0.025-mm-thick metal
Hole range	0.025 mm in 0.02-mm-thick metal 1.0 mm in 5-mm-thick metal
Hole taper	1°–2° typical
Hole angle to surface	20°–90°
Removal rate	40 mm^3/s
Penetration rate	0.25 mm/s
Perforation rate	Up to 5000 holes/s
Tolerance	± 10% depth of cut
Surface roughness	1 μm R_a

Advantages

- Drilling is possible at high rates (up to 4000 holes per second).
- No difficulty is encountered with acute angles.
- Drilling parameters can easily be changed during machining.
- No limitation is imposed by work piece hardness, ductility, and surface reflectivity.

■ No mechanical distortion occurs to the work piece since there is no contact.

■ The process is capable of achieving high accuracy and repeatability of 0.1 mm for position of holes and 5 percent for the hole diameter.

■ The process produces the best surface finish compared to other processes.

■ The cost is relatively small compared to other processes used to produce very small holes.

Disadvantages

■ High capital equipment cost

■ Long production time due to the time needed to generate a vacuum

■ The presence of a thin recast layer

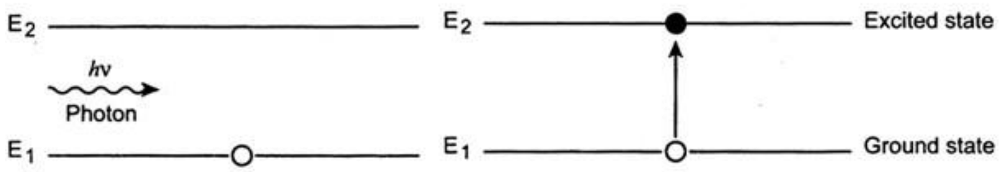
■ Need for auxiliary backing material

LASER BEAM MACHINING (LBM)

'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.

Laser works on the principle of quantum theory of radiation.

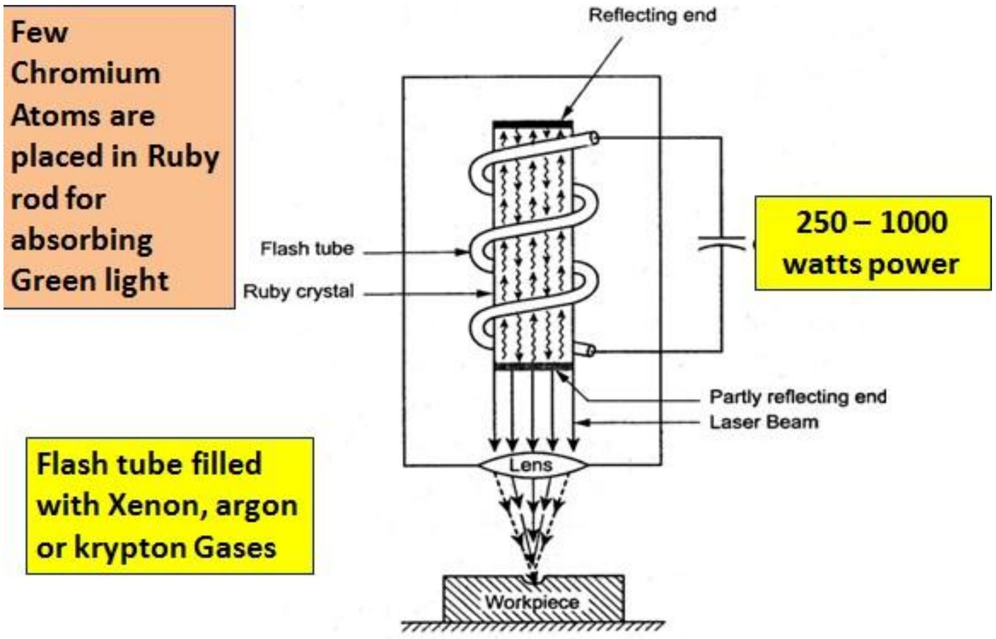
Consider an atom in the ground state or lower energy state (E_1) when the light radiation falls on the atom, it absorbs a photon of energy $h\nu$ and goes to the excited state (E_2).



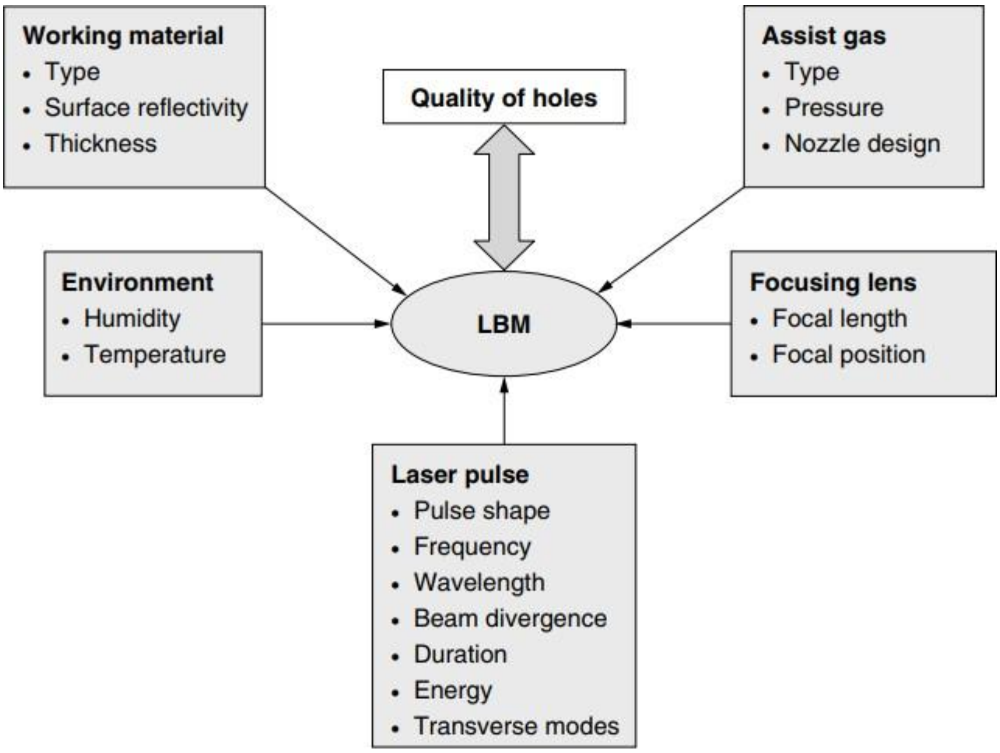
(i) Before absorption *(ii) After absorption*

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
2. Stimulated Emission



Schematic diagram of LBM



Working

A flash light of 1000watts wound around the ruby rod as shown in figure. When a switch is ON the light energy from the flash tube passed into the ruby rod and it triggers the chromium atom in the rod. So the excited atoms emit photons. These photons are reflected so many times due t the presence of mirror arrangement in the construction. Due to this a powerful coherent beam of red light is obtained. This red light is focused on work piece through converging lenses. So this red light heat and vaporise the pointed metal portion in the work piece. Likewise the machining continued.

TYPES OF LASER

1. Gas lasers
2. Solid lasers
3. Liquid lasers
4. Semi Conductor lasers

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.

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

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.

Applications of Laser

1. Laser in Metal Cutting
2. Laser in Drilling
3. Laser in Welding
4. Laser in Surface Treatment
5. Trimming
6. Blanking
7. Micromachining applications

Laser in Surface Treatment

- A thin layer of cobalt alloy coating is applied on Turbine blade for heat and Wear Resistance.

- A thin Ceramic coating is applied on metal Surface for heat and Wear Resistance.
- It's also used to seal the micro cracks which are usually present in hard – Chromium electroplates

Advantages of LBM

1. All Kind of metals are machined, Micro holes are possible
2. Soft materials like rubber can be machined
3. No tool wear and contact with w/p
4. Automated process, Controlling of beam is easy

Disadvantages of LBM

1. High initial Cost, Operating cost is high
2. Required skilled labours
3. Rate of production is low
4. Need safety equipments, Life of flash lamp is low
5. The machined holes are not straight and round

PLASMA ARC MACHINING (OR) PLASMA JET MACHINING

Introduction

When a gas is heated to a sufficiently high temperature of the order of 11000 – 28000 degree Celsius, it becomes partially ionized it's known as PLASMA.

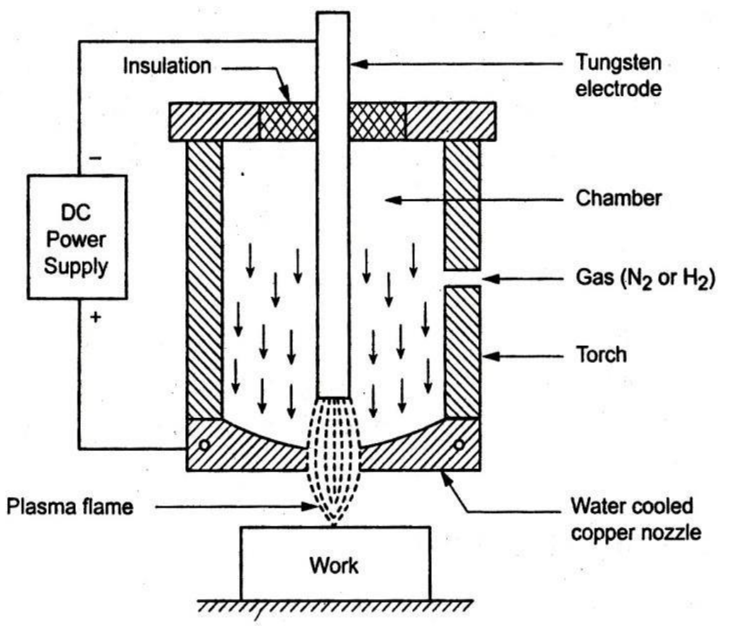
PLASMA

It's a mixture of free electrons + partially ionized gas and Neutral Atoms

Working Principle

The material is removed by directing a high velocity jet of high temperature (11000°C – 28000°C) ionized gas on the work piece. This high temperature plasma jet melts the material of the work piece.

In plasma machining a continuous arc is generated between a hot tungsten cathode and the water-cooled copper anode. A gas is introduced around the cathode and flows through the anode.



Schematic arrangement of PAM

The temperature, in the narrow orifice around the cathode, reaches 28,000°C, which is enough to produce a high-temperature plasma arc. Under these conditions, the metal being machined is very rapidly melted and vaporized. The stream of ionized gases flushes away the machining debris as a fine spray creating flow lines on the machined surface.

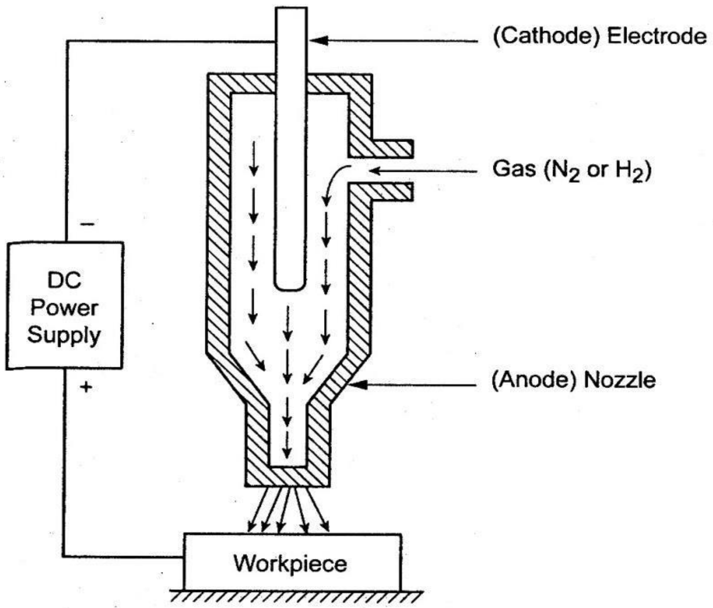
Types of Torches

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

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

Direct Arc Plasma Torch

- The arc is formed between the electrode(-) and the work piece(+).
- In other words, arc is transferred from the electrode to the work piece.
- A transferred arc possesses high energy density and plasma jet velocity. For this reason it is employed to cut and melt metals. Besides carbon steels this process can cut stainless steel and nonferrous metals also where oxyacetylene torch does not succeed. Transferred arc can also be used for welding at high arc travel speeds.

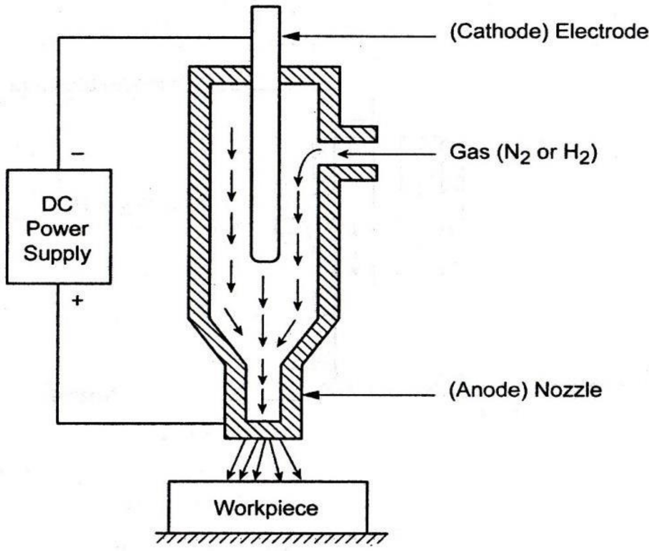


Direct arc plasma torch

A pilot arc is established between the electrode and the nozzle. As the pilot arc touches the job main current starts flowing between electrode and job, thus igniting the transferred arc. The pilot arc initiating unit gets disconnected and pilot arc extinguishes as soon as the arc between the electrode and the job is started. The temperature of a constricted plasma arc may be of the order of 8000 - 25000^0C.

In-Direct Arc Plasma Torch

- The arc is formed between the electrode(-) and the water cooled nozzle(+).
- Arc plasma comes out of the nozzle as a flame.
- The arc is independent of the work piece and the work piece does not form a part of the electrical circuit. Just like an arc flame (as in atomic hydrogen welding), it can be moved from one place to another and can be better controlled. The non transferred plasma arc possesses comparatively less energy density as compared to transferred arc plasma and it is employed for welding and in applications involving ceramics or metal plating (spraying). High density metal coatings can be produced by this process. A non-transferred arc is initiated by using a high frequency unit in the circuit.



Indirect arc plasma torch

UNIT-III
CHEMICAL AND ELECTRO-CHEMICALENERGY BASED PROCESSES

Introduction

The metal is removed from the work piece through controlled etching or chemical attack of the work piece material in contact with a chemical solution

CHEMICAL MACHINING PROCESS

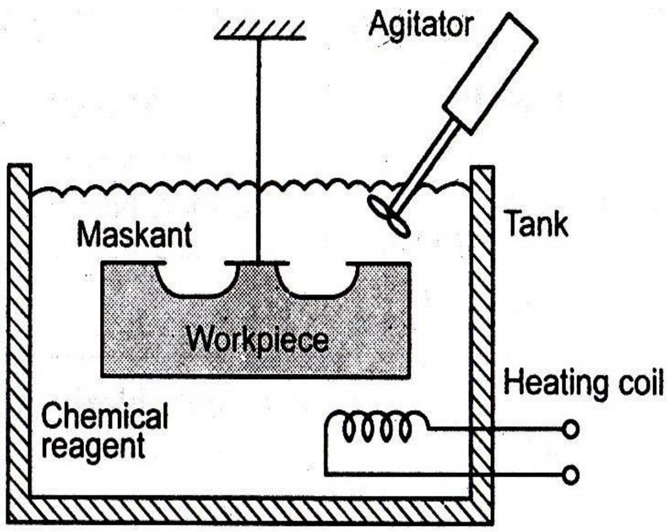
In this method, the metal is removed by ion displacement of the work piece material in contact with a chemical solution.

Examples

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

Chemical Machining

Chemical machining (CM) is the controlled dissolution of workpiece material (etching) by means of a strong chemical reagent (etchant). In CM material is removed from selected areas of workpiece by immersing it in a chemical reagents or etchants; such as acids and alkaline solutions. Material is removed by microscopic electrochemical cell action, as occurs in corrosion or chemical dissolution of a metal. This controlled chemical dissolution will simultaneously etch all exposed surfaces even though the penetration rates of the material removal may be only 0.0025–0.1 mm/min.



Processes in Machining

- Maskant coating
- Cleaning ,Drying
- Dipping in chemical solution
- Stirring & Heating – For uptain Uniform Depth, Washing

Steps in chemical machining

Residual stress relieving: If the part to be machined has residual stresses from the previous processing, these stresses first should be relieved in order to prevent warping after chemical milling.

Preparing: The surfaces are degreased and cleaned thoroughly to ensure both good adhesion of the masking material and the uniform material removal.

Masking: Masking material is applied (coating or protecting areas not to be etched).

Etching: The exposed surfaces are machined chemically with etchants.

Demasking: After machining, the parts should be washed thoroughly to prevent further reactions with or exposure to any etchant residues. Then the rest of the masking material is removed and the part is cleaned and inspected.

Applications:

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

MASKANTS

The process essentially involves bathing the cutting areas in a corrosive chemical known as an etchant, which reacts with the material in the area to be cut and causes the solid material to be dissolved; inert substances known as maskants are used to protect specific areas of the material as resists.

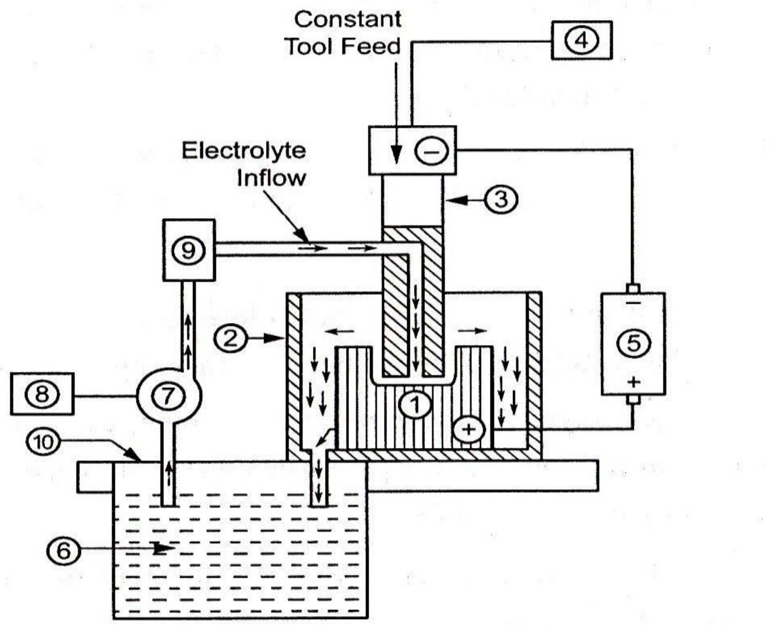
Sl.No.	Material	Maskant
1.	Aluminium	Butyl rubber, Neoprene rubber
2.	Magnesium	Polymers
3.	Titanium	Translucent chlorinated polymers
4.	Nickel	Neoprene
5.	Ferrous metals	Polyvinyl chloride, polyethylene

Methods of Maskants

- Scribed and Peeled Maskants
- Photo resists Maskants

Electrochemical Machining (ECM)

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



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

Arrangement of ECM Process

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

Advantages of ECM

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

Limitations of ECM

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

Material removal rate, MRR, in electrochemical machining:

MRR = C .I. h (cm^3 /min)

C: specific (material) removal rate (e.g., 0.2052 cm^3 /amp-min for nickel);

I: current (amp);

h: current efficiency (90–100%).

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

ELECTRO-CHEMICAL GRINDING (ECG)
OR
ELECTROLYTIC GRINDING

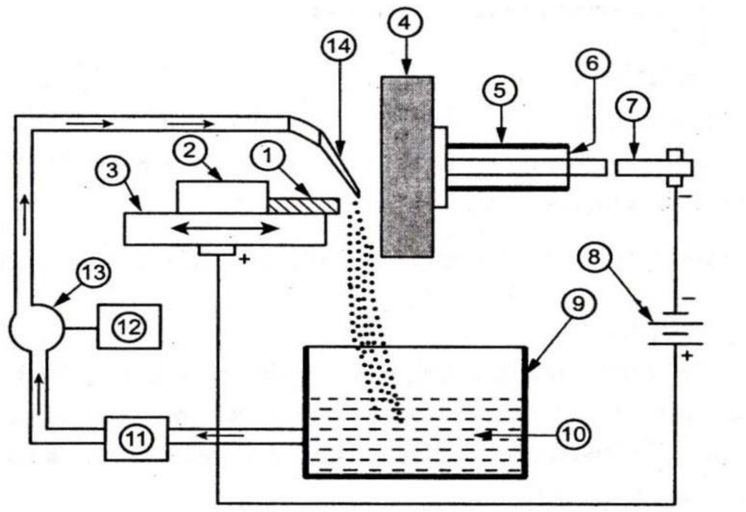
Principle

Machining operation by the combined action of Electro-chemical effect and conventional grinding operation

90 % - Metal removed by chemical Action

10 % -Metal removed by Grinding Action

ECG also called electrolytic grinding is similar to ECM, except that the cathode is an electrically conductive abrasive grinding wheel instead of a tool shaped like the contour to be machined • Used primarily to machine difficult to cut alloys such as stainless steel, Hastelloy, Inconel, Monel, Waspally and tungsten carbide, heat treated workpeices, fragile or therm-sensitive parts, or parts for which stress-



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.

Arrangement of ECG process

free and burr-free results are required. ECG removes metal by a combination of electrochemical (responsible for 90% of material removal) and grinding actions. The grinding action removes the buildup of oxide film on the surface of the workpiece . Less power is needed for ECG than for ECM since the machining area is smaller and the abrasive in the wheel is removing the oxide film – current ranges from 5 to 1000A are most common, with a voltage of 3 to 15V over an electrolyte gap of approximately 0.25mm or less and wheel speeds of 1100 to 1800m/min. Many similarities between ECG and conventional grinding make this one of the easiest ECM based processes to both understand and implement – grinding wheel closely resemble their conventional counterparts with the exception that ECG wheels use an electrically conductive abrasive bonding agent; electrolyte is introduced to the work area in the same manner that coolant is introduced in conventional grinding.

Process parameters

ECG exhibits MRRs that are up to 10 times faster than conventional grinding on materials harder than 60HRC; although MRRs are high, ECG cannot obtain the tolerances achieved by conventional grinding.

The removal rate for ECG is governed by the current density, just as in ECM: as with ECM, the higher the current density, the faster the removal rate and the better the resulting surface finish.

Feed rates vary with different parameters, depending on the grinding method: if the feed rate is running too slowly for the application, a large overcut will be produced that will result in poor surface finishes and tolerances and if the feed rate is too fast, the abrasive particles will be prematurely forced into the workpiece, resulting in excessive wheel wear.

Advantages

- No thermal damage to workpiece
- Elimination of grinding burn , Absence of work hardening
- Long-lasting wheels – less truing
- Higher MRR;
- Single pass grinding - reduced cost of grinding;
- Absence of burrs on the finished surface; Improved surface finish with no grinding scratches;
- Reduced pressure of work against the wheel – no distortion;
- In ECG, the ECM action is efficient

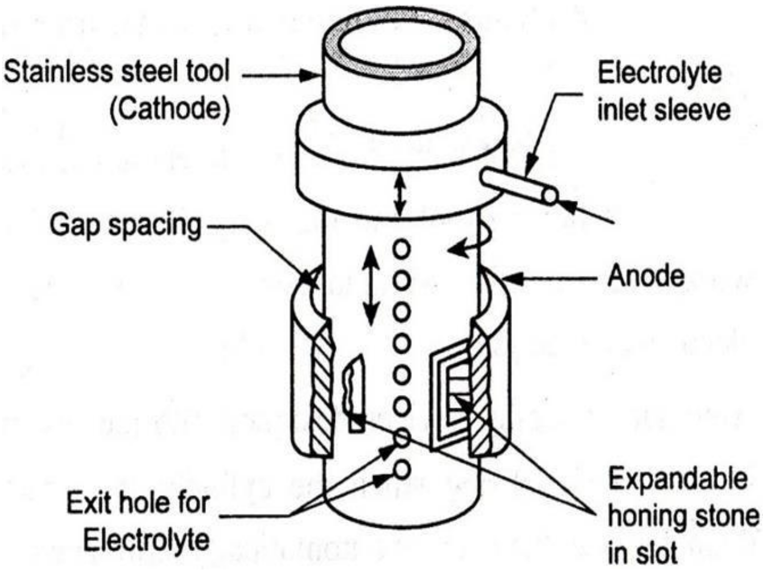
Dis advantages

- High capital cost / Higher cost of grinding wheel;
- Corrosive environment
- High preventive maintenance cost
- Tolerances achieved are low.

- Difficult to optimize due to the complexity of the process;
- Non-conductive materials cannot be machined
- Not economical for soft materials – noncompetitive removal rates compared to conventional methods for readily machinable metals
- Requires disposal and filtering of electrolytes

ELECTRO-CHEMICAL HONING (ECH)

It is a process in which it combines the high removal characteristics of **Electrochemical** Dissolution (ECD) and Mechanical Abrasion (MA) of conventional **Honing**.



Tool consists of a hollow stainless steel body that has expandable, nonconductive honing stones protruding from at least three locations around the circumference. The honing stones are identical with those used in conventional honing operations, except that they must resist the corrosiveness of the electrolyte. The honing stones are mounted on the tool body with a spring-loaded mechanism so that each of the stones exerts equal pressure against the workpiece.

Working

At the beginning of the ECH cycle, the stones protrude only 0.075-0.127mm from the stainless steel body, establishing the gap through which the electrolyte flows. The electrolyte enters the tool body via a sliding inlet sleeve from which it exits into the tool-workpiece gap through small holes in the tool body . After passing through the gap, the electrolyte flows from the workpiece through the gap at the top and bottom of the bore. The mechanical action of the tool is the same as with conventional honing; the tool is rotated and reciprocated so that the stones abrade the entire length of the bore. Electrolytes used in ECH are essentially the same as those used in ECM, although the control of pH, composition and sludge is less critical because the abrasive action of the stones tends to correct any resulting surface irregularities. As in ECM, the electrolytes are recirculated and reused after passing through appropriate filtration, and the most commonly used electrolytes are sodium chloride and sodium nitrate.

Process parameters

• Machines are available that deliver up to 6000 amp

• Current density at the workpiece can range from 12 to 47amp/cm2

• Working voltages are 6-30VDC

• The electrolyte is delivered to the work area at pressures of 0.5-1MPa

• ECH can remove materials at rates up to 100% faster than conventional honing, the gain being more pronounced as the material hardness increases

• Machine capacities are currently able to accommodate bore lengths up to 600mm and bore diameters from 9.5 to 150mm

Advantages

- Increased MRR particularly on hard materials
- Since most of the material is removed electrochemically, honing stone life is greatly extended
- Burr-free operation
- Unlike conventional honing, no micro-scratches are left on the work surface
- Less pressure required between stones and work
- Reduced noise and distortion when honing thin walled tubes
- Cooler action leading to increased accuracy with less material damage
- As with all ECM-based processes, ECH imparts no residual stresses in the work piece
- Capable of achieving surface finishes of 0.05μ and dimensional accuracies of ±0.012mm

Dis-advantages

- More number of equipments used
- Cost of machine is high
- Required Skilled labours
- Hard materials only machined.

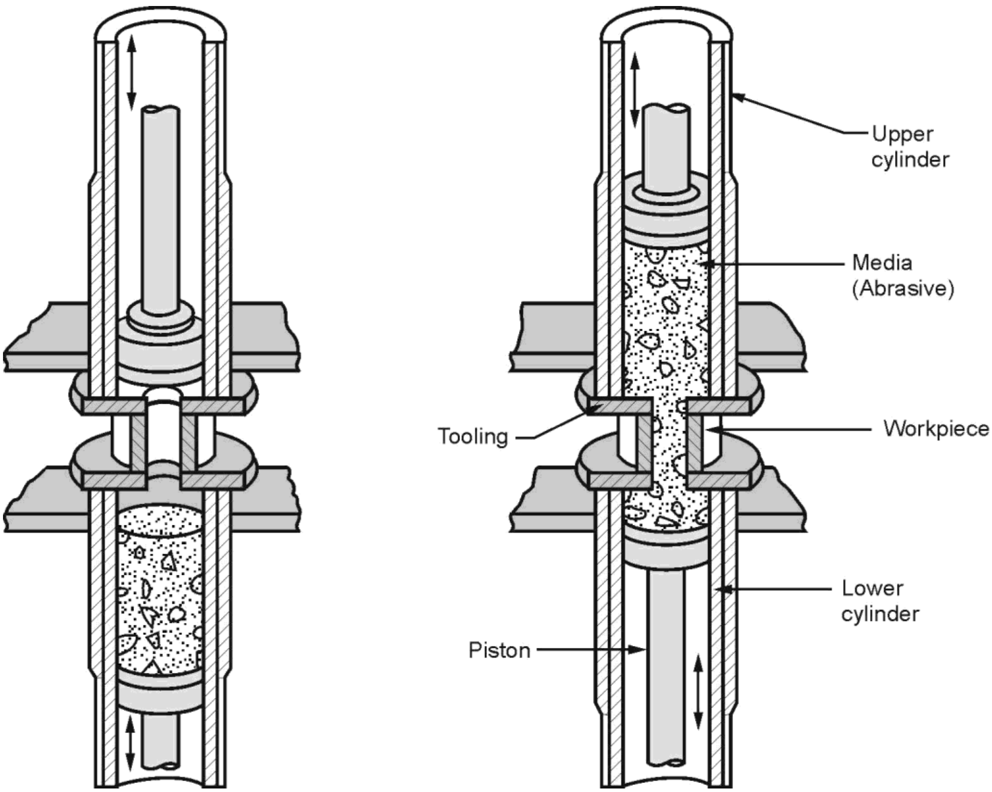
UNIT - IV

Abrasive Flow Finishing (AFF)

- Now - a - days developments in the field of material science are taking place but at the same time the demand for better quality and low cost products is also increases.
- There is a consistent demand for a decreased lead time from design to production.
- In a production cycle, finishing operations usually cost almost 15 % of the total cost. Also, a need of automated finishing operations instead of manual is felt.
- Therefore, a non - traditional finishing process called as **Abrasive Flow Machining (AFM)** or **Abrasive Flow Finishing (AFF)** has been developed.
- This method provides better accuracy and high efficiency, economically and consistently.

Working principle :

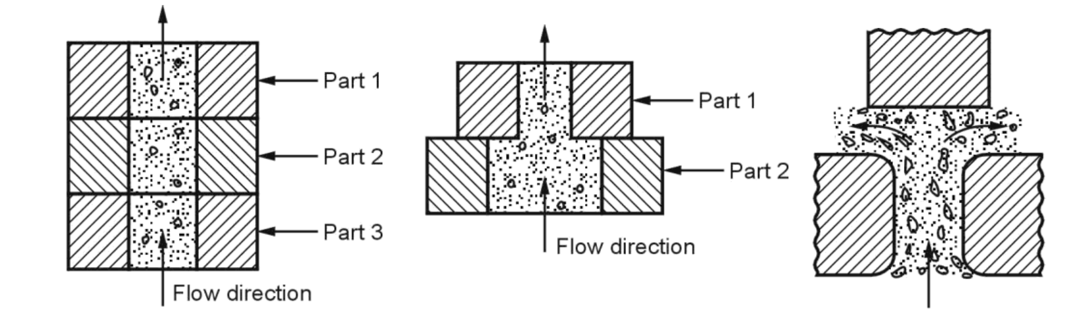
- AFF is a kind of finishing process in which small quantity of material is removed by flowing a semisolid abrasive slurry (putty) over the surface to be machined.
- The abrasive media has high viscosity. The common types of abrasives are aluminium oxides (Al_2O_3), silicon carbide (SiC), cubic boron nitride and diamond dust.
- The process consists of two vertically opposed cylinders which extrude abrasive media back and forth through the passage formed either by workpiece and tooling (fixture) or by workpiece alone. Refer Fig. 4.1.
- This process is suitable for operations like deburring, radiusing, polishing, removing recast layer, etc.
- The process can be used to machine multiple parts at the same time to increase the productivity.
- Also, the machine has high flexibility i.e. the same machine can be used for different workpieces by altering the toolings, machining parameters, media and abrasives.
- The semisolid abrasive media is forced through the workpiece (restricted passage) formed by workpiece and tooling together.



(a) **(b)**

Fig. 4.1 Working principle of AFF

- The force may be applied either hydraulically or mechanically. Also, the flow velocity of media is governed by the cross-section area of passage.
- To maintain a constant viscosity of media, in some cases, coolers are also used to lower the temperature of the media. Manual or computer control machines are also available.
- The basic purpose of tooling is to hold the parts in position and to contain the media and direct its flow.
- As the process has low MRR (Material Removal Rate), the maximum machining takes place wherever there is a maximum restriction to the flow of abrasive.
- Fig. 4.2 (a), (b) and (c) shows the finishing of internal surfaces.



(a) Finishing of multiple parts of same configuration   **(b) Finishing of two parts of different configurations**   **(c) Finishing and radiusing of internal hole**

Fig. 4.2 Finishing of internal surfaces

- Fig. 4.3 shows the finishing of external surfaces in which the designer of tooling decides the extent of restriction.

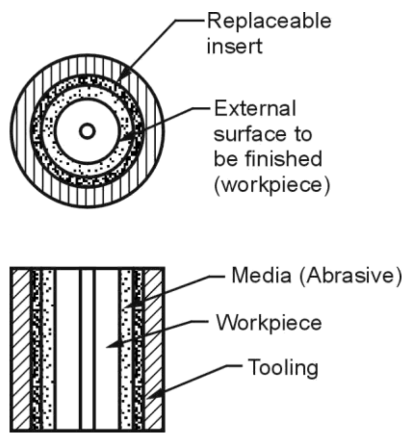


Fig. 4.3 Tooling for external surface to be finished

- After machining the parts should be cleaned properly by air or vacuum.

Process variables

- The important factors that affect the performance of the process and the quality of product are as follows :
  - Workpiece material (Hardness and composition)
  - Machine and tooling (fixture design, cylinder size, clamping pressure, etc.)
  - Geometry of component (passage shape, length, diameter, etc.)
  - Media (Viscosity and its change during the process, flow rate, type and size of abrasive, etc.)
  - Adjustable parameters (Pressure and number of strokes)

Applications :

- It is very useful for finishing of the following parts :
  - Extrusion dies (improves die performance and life)
  - Nozzle of flame cutting torch
  - Airfoil surfaces of impellers of turbine
  - Deburring of aircraft valve bodies and spools.
  - Removing recast layer after EDM or LBM.
- It is used for finishing operations mainly in the industries related to the manufacturing of aerospace, automotive, semiconductor, medical parts, etc.
- It also improves the mechanical fatigue strength of blades, disks, hubs, shafts, etc.

Advantages :

- By using AFF deburring, polishing and radiusing are conducted in one operation.
- This process can finish in accessible area.
- AFF is suitable for batch production.
- It is a very fast method.
- This method provides better accuracy and high efficiency.
- Media temperature control generally not required.
- Excellent process control and quick change tooling.

Disadvantages :

- Tooling or fixtures required are expensive.
- Initial cost of the machine is high.
- This process is not suitable for blind holes.

- Demands for high quality surface finish, dimensional and form accuracy are required for optical surfaces and it is very difficult to achieve this using conventional grinding methods.
- ELPD is new and efficient method that uses a metal bonded diamond grinding wheel to achieve a mirror surface finish especially on hard and brittle materials.

Working principle :

- The basic elements of ELID grinding are shown in Fig. 4.4. ELID cell comprises of a metal bonded grinding wheel, cathode electrode, DC power supply and electrolyte.

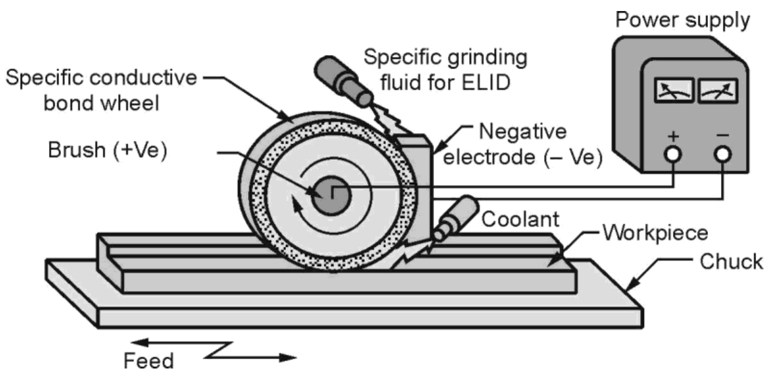


Fig. 4.4 Basic elements of ELID grinding

- The grinding wheel is connected to the positive terminal of DC supply by a carbon brush, whereas electrode is connected to the negative terminal of DC supply.
- Generally, alkaline liquids are used as electrolyte as well as coolant for grinding.
- An electrolyte is injected into the gap between the wheel and electrode by using a nozzle. Usually, this gap is 0.1 to 0.3 mm.
- Due to electrochemical reaction an anodic oxide layer is formed on the circumference of the grinding wheel.
- It is soft and brittle in nature as compared to original metal bond and easily gets worn off because of the excessing grinding force.
- Fig. 4.5 shows the basic mechanism of ELID grinding.

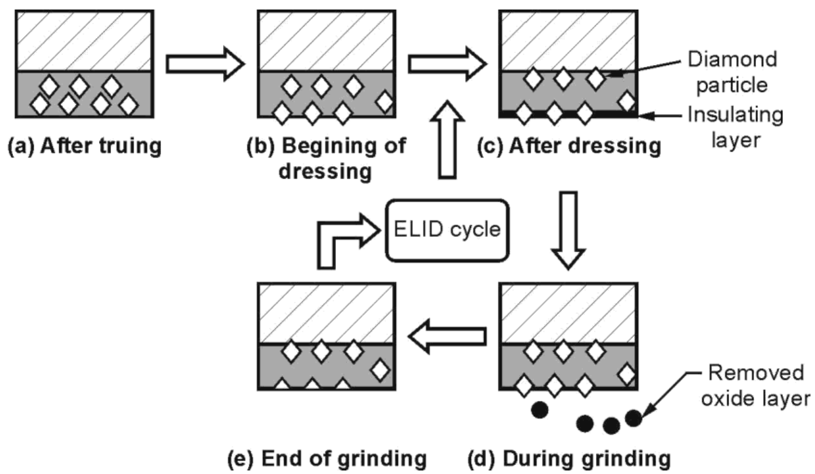


Fig. 4.5 Basic mechanism of ELID grinding

- After truing, the grains and bonding material (metal) of the wheel surface are flattened. Refer Fig. 4.5 (a).

- For the trued wheel it is necessary to be electrically predressed to protrude the grains on the wheel surface and the dressing continues during the grinding operation.
- When predressing starts as shown in Fig. 4.5 (b), the bonding material flows out from the grinding wheel and an insulating layer composed of the oxidized bonding material is formed on the wheel surface. Refer Fig. 4.5 (c).
- This insulating layer reduces the conductivity of the wheel surface and prevents excessive flow out of the bonding material from the wheel. At the same time, the grits are held by the bonding material and oxide layer.
- The oxide layer is soft and brittle in nature and easily wears off when it comes in contact with the workpiece during the grinding. Refer Fig. 4.5 (d).
- As grinding continues, diamond grains wear out and cutting force increases. This force will cause falling off the blunt grits which is held by the brittle insulating material. Refer Fig. 4.5 (e).
- Due to breakage of insulating layer, electrical conductivity of wheel surface increases and electrolytic dressing restarts with the flow out of bonding material from grinding wheel.
- Thus, the profrusions of new diamond grains from the grinding wheel remains constant.

Advantages :

- Good surface finish
- High surface accuracy
- Low subsurface damage

Applications :

- This process is used for grinding of silicon surfaces in semiconductor industry.
- This process produces nano surface finish on glass and ceramics.
- It also helps in production of aspherical surfaces for lenses and moulding dies in optical industry.
- It is used for precision grinding of bearing steel.
- Finishing of internal cylindrical holes in a hard and brittle material is performed by ELID.

Magnetic Abrasive Finishing (MAF)

- We know that, every magnet has two poles [north pole (N) and south pole (S)] and magnetic lines of force (magnetic field) travels from north pole to south pole.

- This magnetic principle is used in the Magnetic Abrasive Finishing (MAF) process.
- This process is suitable for finishing of cylindrical workpieces (external and internal surfaces) and for flat workpieces also.
- It is used for internal finishing of tubes, external finishing of rods, finishing of flat surfaces, etc.
- The workpiece may be made of ferromagnetic or non -ferromagnetic materials.

Working Principle :

- In MAF process, granular magnetic abrasive composed of ferromagnetic material (as iron particles) and abrasive grains like Al_2O_3, SiC or diamond dust are used as cutting tools and the finishing pressure is applied by electro - magnetically generated field.
  Refer Fig. 4.6.

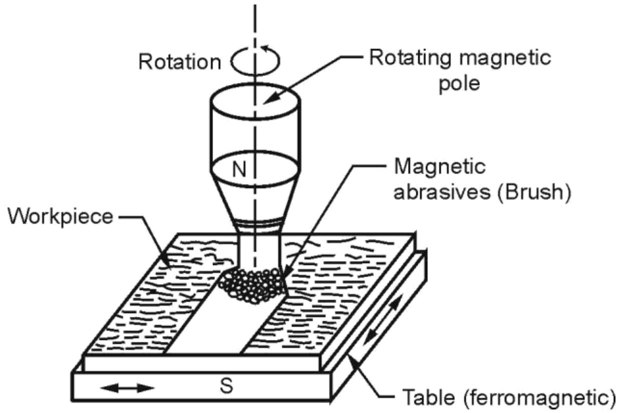


Fig. 4.6 : Working principle of MAF

- The magnetic particles are joined to each other magnetically between magnetic poles along the lines of magnetic force forming **Flexible Magnetic Abrasive Brush (FMAB)**.
- When a cylindrical workpiece with rotary, vibratory and axial movement is inserted in such a magnetic field, the finishing of surface and edges is performed by the magnetic abrasive brush.
- If the workpiece is of non - magnetic material, the lines of magnetic field go around it (through magnetic abrasives) and if it is of magnetic material then they pass through the workpiece.
- The magnitude of magnetic force between the two poles is also affected by the material, shape and size of workpiece as well as magnetic poles.
- The pressure exerted by the magnetic abrasives is decreased as the gap between the magnetic pole and workpiece is increased.
- The magnetic abrasives have been used in the form of either a mixture (unbounded) of abrasive and ferromagnetic particles or abrasive held in a ferromagnetic matrix (bonded) form by sintering.
- The unbounded magnetic abrasives yield higher metal removal rates whereas bonded magnetic abrasive give better surface finish.

Process Variables

The process variables of MAF process are as follows :

- Type and size of magnetic abrasives
- Mixing ratio of abrasive grains with ferromagnetic particles
- Working clearance
- Rotational speed and vibration (both amplitude and frequency)
- Material properties of workpiece
- Flux density and relative speed of magnetic abrasive to the workpiece surface.

Advantages :

- MAF process can finish ferromagnetic as well as non - ferromagnetic materials.
- The finishing tool requires neither compensation nor dressing.
- This process has capability to access hard to reach areas.
- The process is capable of modifying roughness without changing the form.
- MAF is able to attain wide range of surface characteristics by careful selection of magnetic particles.
- The set - up of process is independent of workpiece material. It can easily finish ceramics, stainless steel, brass, coated carbide and silicon.
- Due to flexible magnetic abrasive brush, it can finish any symmetric workpiece shape.

Disadvantages

- This process is not suitable for mass production.
- It is a time consuming process.
- The cost of process is very high.
- The process is not applicable for some ordinary finishing task where conventional finishing technique can be easily applied.

Applications

- MAF is used for finishing of internal surfaces of capillary tubes and other small gauge needles.
- It is suitable for finishing of cutting tools, airfoils, optics, turbine blades, prosthetics, etc.
- Also suitable for internal finishing of sanitary pipes, food industry, curved pipe, medical field (stents, catheter shafts, needles, etc.).

Magneto Rheological Finishing

- Traditional methods of finishing high precision lenses, ceramics and semiconductor wafers are very expensive and labor intensive.
- Lenses are usually made of brittle materials such as glass, which tends to crack while it is machined, and every device that uses either lasers or fiber optics requires at least one high precision lens, increasing its demand higher than ever.
- The lens manufacturer generally uses its in-house opticians for the finishing process, which makes it an arduous, labor- intensive process.
- Lens manufacturing can be classified into two main processes : **grinding and finishing**.
- Grinding gets the lens close to the desired size, while finishing removes the cracks and tiny surfaces imperfections that the grinding process either over looked or created.
- Perhaps the biggest disadvantage to manual grinding and finishing is that it is nondeterministic
- To overcome these difficulties, Center for Optics Manufacturing (COM) in Rochester, N.Y. has developed a technology to automate the lens finishing process known as Magneto Rheological Finishing (MRF).
- The MRF process relies on a unique "smart fluid", known as Magnetorheological (MR) fluid.
- MR-Fluids are suspensions of micron sized magnetizable particles such as carbonyl iron, dispersed in a non- magnetic carrier medium like silicone oil, mineral oil or water.
- In the absence of a magnetic field, an ideal MR-fluid exhibits Newtonian behaviour.
- On the application of an external magnetic field to a MR- suspension, a phenomenon known as Magneto Rheological Effect, shown in Fig. 4.7 is observed.

Magneto Rheological Effect

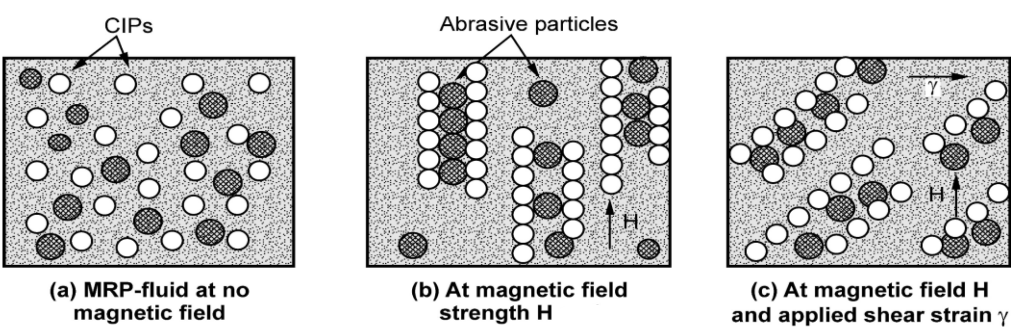


Fig. 4.7 Magnetorheological effect

- Fig. 4.7 (a) shows the random distribution of the particles in the absence of external magnetic field.
- Fig. 4.7 (c) shows an increasing resistance to an applied shear strain, γ due to this yield stress.
- When the field is removed, the particles return to their random state and the fluid again exhibits its original Newtonian behavior.
- In Fig. 4.7 (b) particles magnetize and form columns when external magnetic field is applied.
- The particles acquire dipole moments proportional to magnetic field strength and when the dipolar interaction between particles exceeds their thermal energy, the particles aggregate into chains of dipoles aligned in the field direction.
- Because energy is required to deform and rupture the chains, this micro-structural transition is responsible for the onset of a large "controllable" finite yield stress.

Magneto Rheological Finishing Process

- In the Magneto rheological finishing process, a convex, flat, or concave work piece is positioned above a reference surface.
- A MR fluid ribbon is deposited on the rotating wheel rim. By applying magnetic field in the gap, the stiffened region forms a transient work zone or finishing spot.

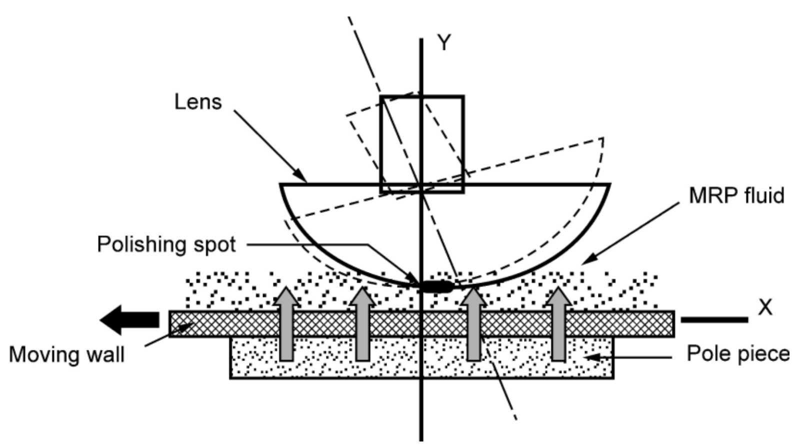


Fig. 4.8 Magnetorheological finsishing process

- Surface smoothing, removal of sub-surface damage, and figure correction are accomplished by rotating the lens on a spindle at a constant speed while sweeping the lens about its radius of curvature through the stiffened finishing zone.
- Material removal takes place through the shear stress created as the Magneto Rheological polishing ribbon is dragged into the converging gap between the part and

carrier surface.

- Deterministic finishing of flats or spheres can be done by mounting the part on rotating spindle and sweeping it through the spot under computer control, such that dwell time determines the amount of material removal.
- The zone of contact is restricted to a spot which conforms perfectly to the local topography of the part.

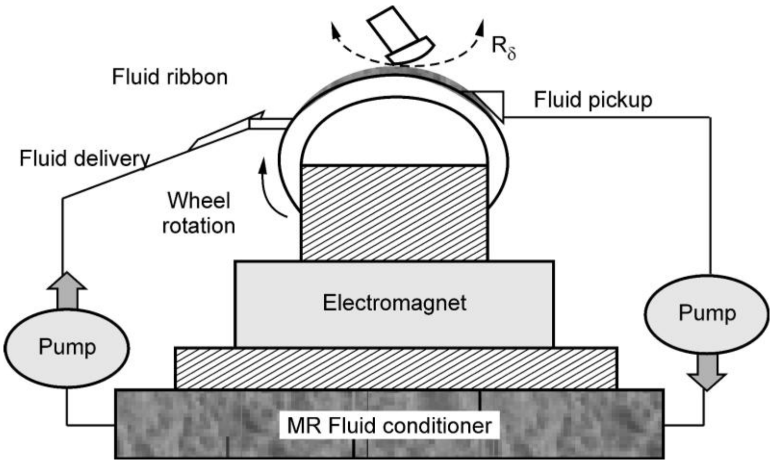


Fig. 4.9 Vertical MRF machine

MRP Fluid

- Magneto rheological polishing fluid comprises of MR-fluid with fine abrasive particles dispersed in it.
- On the application of magnetic field the carbonyl iron particles (CIP) form a chain like columnar structure with abrasives embedded in between.
- The magnetic force between iron particles encompassing abrasive grain provides bonding strength to it and its magnitude is a function of iron concentration, applied magnetic field intensity, magnetic permeability of particles and particle size.

The MR-polishing fluid has following merits:-

1. Its compliance is adjustable through the magnetic field.
2. It carries heat and debris away from the polishing zone.
3. It does not load up as in grinding wheel.
4. It is flexible and adapts the shape of the part of the work piece which is in its contact.

Advantages

- Resistance to applied shear strain by chains is responsible for material removal
- Zone of finishing is restricted to a spot
- Most efficient and for high precision finishing of optics
- MRF makes finishing of free form shapes possible for first time.

Applications

- High precision lenses include medical equipment such as endoscopes
- Military's night vision equipment like infrared binoculars.

Magneto Rheological Abrasive Flow Finishing (MRAFF)

- In AFM, the polishing medium acts as compliant lap and overcomes shape limitation inherent in almost all traditional finishing processes.
- As abrading forces in AFM process mainly depend on rheological behavior of polymeric medium, which is least controllable by external means, hence lacks determinism.
- The process magneto rheological finishing, uses magnetically stiffened ribbon to deterministically finish optical flats, spheres and aspheres.
- In order to maintain the versatility of Abrasive Flow Machining process and at the same time introducing determinism and controllability of rheological properties of abrasive laden medium, a new hybrid process termed as Magnetor heological Abrasive Flow Finishing (MRAFF) is used.
- This process relies on smart behavior of magneto rheological Fluids whose Rheological properties are controllable by means of external magnetic field.

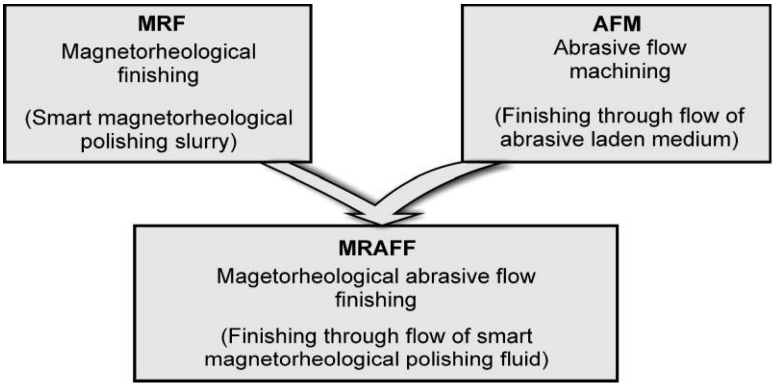


Fig. 4.10 Development of magneto rheological abrasive flow finishing process

Mechanism of MRAFF Process

- In MRAFF process, a magnetically stiffened slug of magneto rheological polishing fluid is extruded back and forth through or across the passage formed by work piece and fixture.

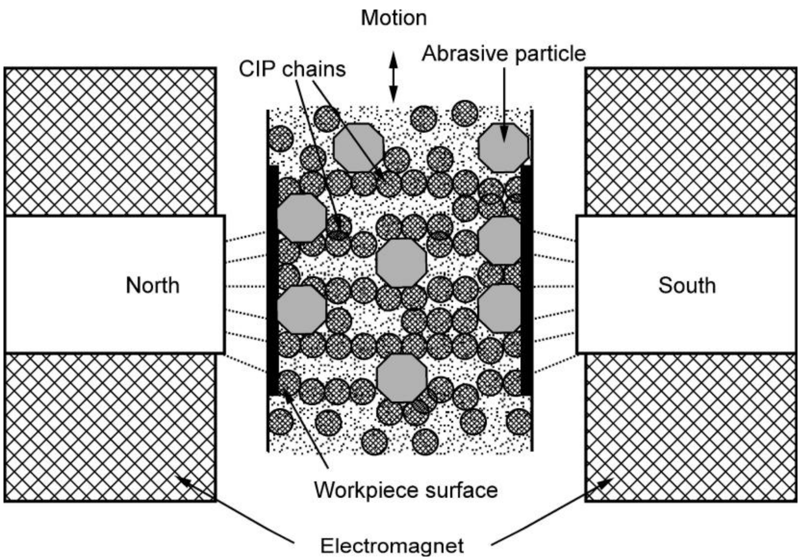


Fig. 4.11 Mechanism of MRAFF process

- Abrasion occurs selectively only where the magnetic field is applied across the work piece surface, keeping the other areas unaffected. The mechanism of the process is shown in Fig. 4.11.
- The rheological behaviour of polishing fluid changes from nearly Newtonian to Bingham plastic upon entering and Bingham to Newtonian upon exiting the finishing zone.

MRAFF Machine

- A hydraulically powered experimental setup is designed to study the process characteristics and performance.
- The setup consists of two MR-polishing fluid cylinders, two hydraulic actuators, electromagnet, fixture and supporting frame.
- Experiments were conducted on stainless steel workpieces at different magnetic field strength to observe its effect on final surface finish.
- No measurable change in surface roughness is observed after finishing at zero magnetic field.

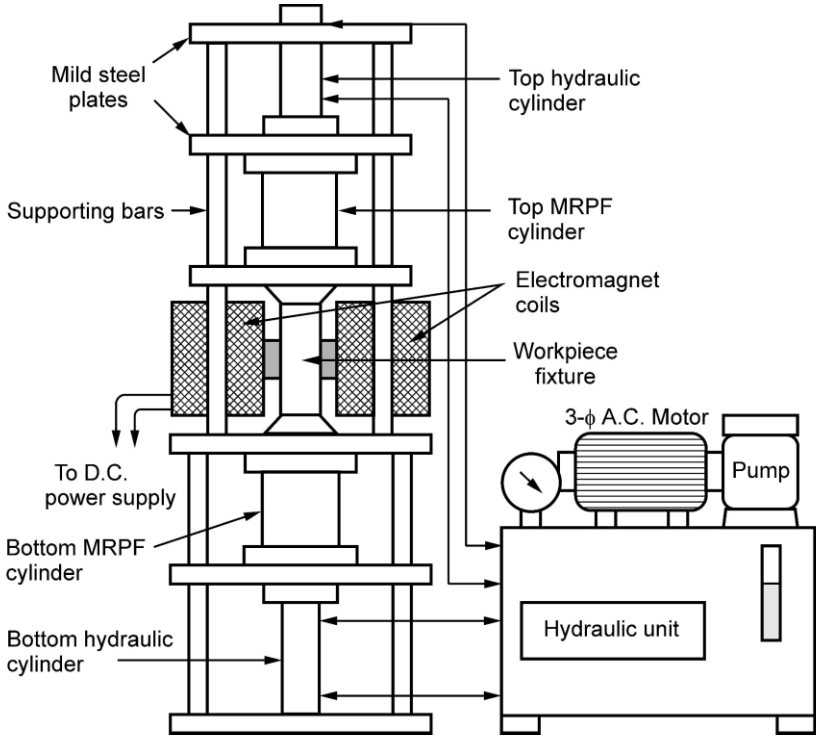


Fig. 4.12 Schematic of MRAFF machine

- In MRAFF process, MRPF is extruded through the workpiece passage to be finished utilizing two opposed cast iron cylinders under the presence of external magnetic field.
- The viscosity of smart magnetorheological polishing fluid (MRPF) is a function of applied magnetic field strength, and it is varied according to the desire finishing characteristics.
- The shearing of the Bingham plastic polishing fluid near the workpiece surface contributes to the material removal and hence finishing.
- Extrusion of the MRP-fluid through the passage formed in the workpiece fixture is accomplished by driving two opposed pistons in MRPF cylinders using hydraulic actuators operated in desired manner with the help of designed hydraulic circuit.
- The MRAFF setup consists of MRPF cylinders with pistons, workpiece fixture, electromagnet, hydraulic drive and controls, and supporting frame.

Advantages

- High machining versatility
- The surface finish improvement by this process is several times better than that of the original surface finish.
- The cutting activity can be easily controlled
- Process is simple
- Complex structures can be easily machined.
- Localized finishing is possible
- Negligible thermal distortion

Disadvantage

- Machining setup is complex and cost is high.

UNIT-V

Electro Chemical Deburring (ECD)

- When the component is processed by a conventional machining method, it is left with burrs, specifically along the two intersecting surfaces.
- Such burrs are undesirable from the viewpoint of performance of a component as well as safety of an operator or other person.
- Such burrs can be removed by one of the deburring processes.
- The problems of burrs are still persisting and unsolved in many industries. Different attempts are made to reduce the burr level by various means.
- Deburring is an important phase for manufacturing quality products, mainly in large scale industries.
- In a modern industrial technology, the deburring process has attained great importance because of rigid quality standards. However, the cost of deburring should not be very high.
- The deburring process can be classified as follows :

i) **Mechanical deburring :** It is performed by using cutting tools, brushes, belt sanders, etc.

ii) **Abrasive deburring :** In this technique tumbling, barrel finishing, vibratory deburring, sand blasting, etc. methods are used.

iii) **Thermal deburring :** In this technique, the components are placed in the chamber which is filled with combustible gas mixture of oxygen and hydrogen. After ignition by spark plug, the heat wave is generated and burrs or sharp edges are removed.

iv) **Electrochemical deburring :**

- This process makes use of flowing electrolyte for conducting electric current for the electrochemical reaction to take place.
- The current rating and current duration for a particular component are found after extensive trials for each type of component.
- The commonly used electrolytes are sodium chloride (NaCl) and sodium nitrate ($NaNO_3$).
- Due to corrosive nature of electrolyte and ferrous hydroxide released by the process, the machines are built with non - corrosive materials.
- This technique is generally used for far away located and inaccessible places where other deburring processes are not effective.

Working Principle of ECD

- It consists of the following elements or sections :
    - Electrolyte system (to provide high velocity to the flow)
    - Electrical power system (to supply current)
    - Mechanical structure (to locate and provide movement or mounting of the electrodes)
    - Separator (to separate the sludge)
- During the process when a voltage is applied between two metal electrodes immersed in an electrolyte, current flows through the electrolyte from one electrode to another electrode. Also, ions (electrically charged atoms) physically migrate through the electrolyte. Refer Fig. 5.1.

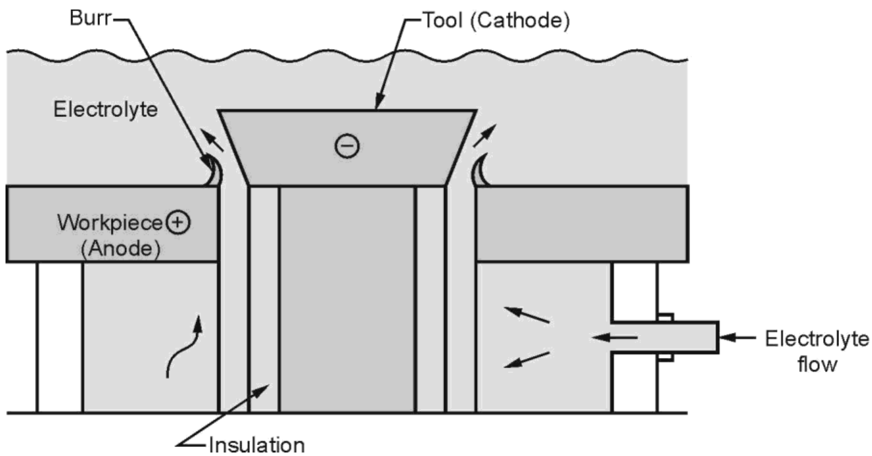


Fig. 5.1 Electromechanical deburring

- The transfer of electrons between the ions and electrodes completes the circuit and brings the phenomenon of metal dissolution at the positive electrode or anode (workpiece).
- Metal detached atom by atom from the anode surface appears in the main body of the electrolyte as positive ions or as precipitated semi - solid of the metal hydroxide. The dissolved burrs in the form of hydroxides settle down and the electrolyte is regenerated.
- Generally, the tool is insulated on all surfaces, except a part of which is adjacent to the burr or burrs.
- But, the setting of dimensions of the bare part of the tool, machining time and other conditions are decided by trial and error method.
- The electrolyte is made to flow through the inter-electrode gap which is generally 0.1 to 0.3 mm.

- The electrolyte is properly filtered out before its recirculation and the hydroxide is disposed through outlet drain.
- The hydroxide removed from the drain valve is extensively used as a raw material for lapping paste.
- Before deburring, the components should be free from loose burrs which damage the electrodes, and also from grease/ oil which contaminates the electrolyte.
- Hence, workpiece should be thoroughly washed out before deburring. After deburring, it should be immediately dipped in running water followed by dewatering fluid which protects against the corrosion.

Advantages

- During the process there are no mechanical loads or thermal loads on the workpiece.
- Both workpiece roughing and finishing can be completed in a single pass. Because ECD is a dissolution process, no primary or secondary burrs are generated.
- ECD is a highly productive process. The process time is fast as compared to conventional methods and multiple parts per cycle can be machined. This results in low unit cost of production.
- It is a highly stable process with good process control which ensures accuracy, quality, consistency and the highest repeatability.
- It is an ideal deburring process for parts where burns are difficult to reach or machine using conventional methods. It also eliminates the problem of secondary burr formation.

Disadvantages

- The acidic electrolyte can corrode the tool, workpiece or equipments.
- Only electrically conductive materials can be machined.
- High specific energy consumption.

Applications

- ECD has applications in industries like consumer appliances, biomedical, aerospace, automobile, etc.
- It is used for the components like gears, splines, drilled holes, milled parts, fuel supply and hydraulic system components, etc.
- Also used in cases where two holes cross each other like crank shaft.

Electrolyte Jet Machining (EJM)

- EJM is an advance version of Electrochemical Machining (ECM).
- In EJM a workpiece is machined only in the area hit by the electrolyte jet which is ejected from a nozzle.
- By translating the jet over the workpiece, intricate patterns can be fabricated without using the special mask.
- Even 3D shapes can be machined by adjusting the current and dwelling time of the jet over the workpiece.
- As EJM is an electrochemical process, there are no burns, cracks or heat affected zones generated by the process.
- This process is used for removing processes by anodic dissolution as well as for coloring processes by anodic oxidation.
- Both glossy surface and considerably rough surface can be obtained by controlling the current density.

Working Principle :

- It is carried out by jetting electrolytic aqueous solution from the nozzle towards the workpiece while applying voltage to the gap as shown in Fig. 5.2.
- Fig. 5.2 shows the electric potential distribution in the electrolyte flow ejected from a cylindrical nozzle and current density distribution over the workpiece surface.
- When the electrolyte jet hits the workpiece at high flow rate, the electrolyte flows rapidly outward in a fast thin layer. This suddenly changes its thickness in area far away from the nozzle due to hydraulic jump phenomenon.

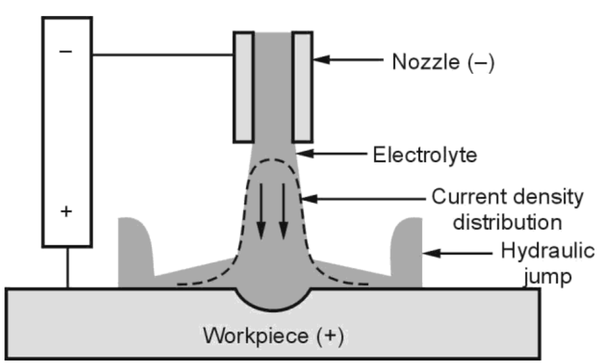


Fig. 5.2 : Working principle of EJM

- A platinum wire is inserted in a glass tube nozzle. When electrolyte pass through this, it acts as cathode and workpiece acts as anode. By electrolytic dissolution metal removal takes place. Metal ions are carried out by flow of electrolyte.

- Fig. 5.3 shows the set - up of EJM. The workpiece is mounted on a table which is placed in a work sink to drain the electrolyte.
- The work sink and nozzle are installed on a platform which can be numerically controlled.
- The electrolyte is supplied from a gear pump whose flow rate can be controlled by varying the pump speed.

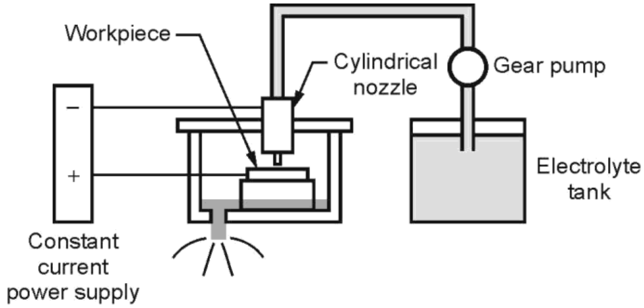


Fig. 5.3 Set - up of EJM

Advantages :

- There are no heat affected zones in the process.
- No residual stresses in the component.
- Tool wear is minimum.
- Additional masking is not required.
- Good surface finish can be obtained.
- It is a non - contact type machining process.

Applications :

Applications of electrolytic jet machining :

- This process is used for drilling small holes in aircraft turbine blades.
- It is used for producing maskless patterns for microelectronics parts.
- It is used to machine hard alloys.
- This process is used to make surface glossy.
- It has large applications in biomedical field as well as in Micro Fluidic systems.

Laser Surface Treatments

Laser based heat treatment

- Heating the steel upto it's melting point and then quickly quenching it leads to hardening.
- In laser based heat treatment, surface layer of workpiece is heated upto a temperature to form austenite.
- Specimen is moved away from laser at constant feed rate. At the moment it moves down from exposure to the laser it is quenched by cooler region rapidly.

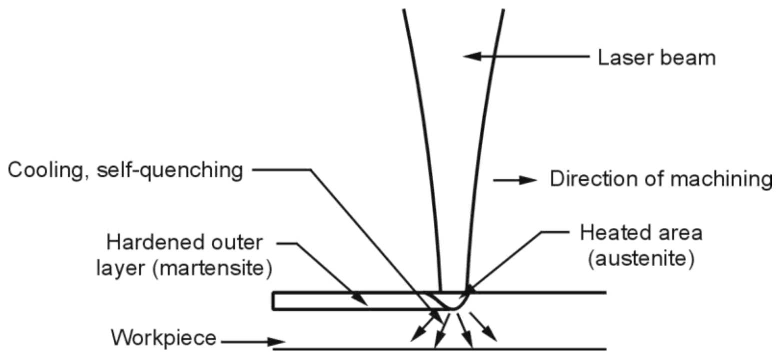


Fig. 5.4

- As the temperature drops rapidly, austenite becomes mechanically unstable and rearrange to form a body centered crystal structure which is harder than the original material.
- The factors affecting this are, nature of metal coating, wavelength and shape of laser beam.
- The lasers used in laser based heat treatment can be gas lasers or state lasers.
- Carbon dioxide lasers are used in this process but their absorption by metals is difficult.
- Yttrium Aluminium Garnet lasers used in the process have high absorption properties but less electrical efficiency.
- High power diode lasers are used, which are most significant. They have higher efficiency as well as better absorption properties.

Factors Affecting the Performance of Laser based Heat Treatment

- Factors which affect the performance of laser-based heat treatment are :

i) **Power Density :** Higher the power density, deeper is the case depth. However, if all the variables are fixed a maximum depth can be achieved.

ii) Travel Speed : If the travel speed is increased, case depth will be decreased until there is no reaction with the material. Decreased travel speed will result into significant surface melting or a lower hardness.

iii) Requirement of Hardness : When a maximum hardness is required for a certain carbon content, then the case depth is controlled by the cooling condition of the part. If the hardness requirement is lower, then we can lower the power density and reduce the travel speed.

iv) Cooling Condition : At least six or seven times the case depth thickness of material is needed beneath the surface to insure reaching the required case depth and hardness. Air jets, water mist or oil can be untilized for this purpose.

Comparison of Advanced Machining Processes

Sr. No.	Parameter	EDM	ECM	AJM
1.	Mechanism of process	Controlled erosion through a series of electric sparks.	Controlled removal of metal by anodic dissolution in an electrolytic medium.	Removal of metal by erosion using high velocity abrasive articles.
2.	MRR	5000 mm^3/min	1600 mm^3/min	16 mm^3/min
3.	Tool material	Brass, copper, graphite, tungsten, etc.	Copper, brass or steel.	Abrasive of Al_2O_3 or SiC are used.
4.	Workpiece material	All conducting metals and alloy.	All conducting metals and alloys.	Hard and brittle materials like glass, ceramic, mica, etc.
5.	Specific power consumption	2-10 W/mm^3/min	7 W/mm^3/min	-
6.	Applications	For producing micro-holes, narrow slots, blind complex cavities, etc.	Used for machining difficult to machine materials and complex shaped parts	For cutting intricate holes in hard and brittle materials, fragile and heat sensitive materials without damage.
7.	Limitations	Non-conducting materials cannot be machined and high power consumption	Non-conducting materials cannot be machined and high power consumption	Low MRR and low accuracy. Sometimes, abrasives get embedded in the material.

Sr. No.	Parameter	LBM	USM
1.	Mechanism of process	Heating, melting and then vapourisation.	It involves both fracture and plastic deformation by impact of grains using vibrating tool.
2.	MRR	5 mm^3/min	800 mm^3/min
3.	Tool material	Laser beams	Soft steel
4.	Workpiece material	All materials except those having high thermal conductivity.	All materials.
5.	Specific power consumption	1000 W/mm^3/min	800 W/mm^3/min
6.	Applications	For drilling small holes in hard materials and cutting very narrow slots.	Machining of hard meterials can be done. Also used for machining of very precise and intricate shaped articles.
7.	Limitations	Holes drilled may have slight taper, high cost of the system and largepower consumption.	High rate of tool wear, softer materials are difficult to machine, size of cavity is limited and high cost of machine.

Recent Developments in EDM

1. Adaptive control

The purpose of the adaptive control in an EDM is to read the conditions of the EDM spark and translate these conditions into digital signals that are fed into the machine's controller. The controller translates these signals, determines the efficiency of the EDM cut and makes adjustments accordingly. One of the conditions monitored by the machine's adaptive control technology is contamination in the gap. If excess contamination in the gap is present, this creates the potential for an EDM arc or diminished performance. The controller must then make adjustments that do not affect the over burn or surface integrity of the workpiece. This generally involves changes in the gap voltage, increasing the off-time, altering the jump cycle or a combination of any of these.

2. Research progress in vibration rotary and Vibro-Rotary EDM

It was proved that the electrode rotation served as an effective gap flushing technique, yielding better material removal. combination of ultrasonic vibration in EDM the MRR and surface finish improved and TWR increased. Vibration, rotary and vibro-rotary mechanism makes the equipment simple and increases the material removal rate, provide better surface finish ejection from work piece. Better circulation of dielectric fluid and debris removal from work piece.

3. Water In EDM

Water as dielectric is an alternative to hydro carbon oil. The approach is taken to promote a better health and safe environment while working with EDM. This is because hydrocarbon oil such as kerosene will decompose and release harmful vapour (CO and CH_4). Water-based dielectric can replace hydrocarbon oils since it is environmentally safe. Water based EDM is more eco friendly, reduced harmful agent, toxic fumes dangerous for human & economically low cost machining as compared to conventional oil based dielectric. The material removal rate enhanced with use of water.

4. Dry EDM

Dry EDM is a green environment friendly Electric discharge machining Technique in which the liquid dielectric is replaced by a gaseous dielectric. Gas at high pressure as used as the dielectric medium. Dry EDM is eco-friendly machining. Pollution is reduced by use of gas instead of oil based dielectric. Harmful & toxic fumes are not generated during machining. Material removal rate &electrode wear ratio also get enhanced by dry EDM.

5. Powder Mixed EDM

Powder mixed electric discharge machining (PMEDM) is one of the new innovations for the enhancement of capabilities of electric discharge machining process. In this process, a suitable material in fine powder is properly mixed into the dielectric fluid. The added powder improves the breakdown characteristics of the dielectric fluid.

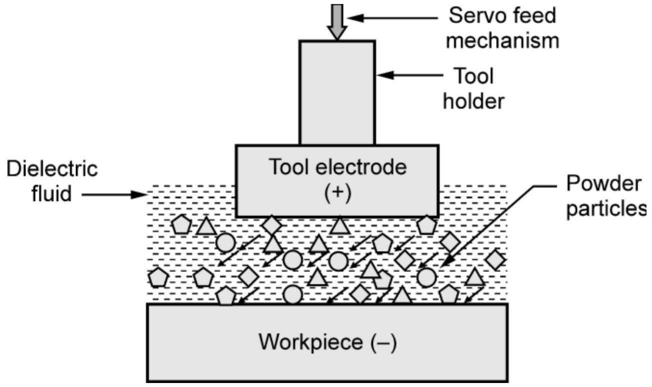


Fig. 5.5

Recent Developments in Wire Cut EDM

1. Wire EDM with Coated Electrodes

Wire electrodes coated with low vaporization temperature metal or alloy gives more protection to the core of the wire from thermal shock. high performance coated wires, having high conductivity and better flushability have been developed and used for machining, resulting in better surface finish and improved cutting speeds. But these wire are costly as well as cause many impurities in dielectric fluid and also some environmental hazards.

2. Wire EDM With Multi- Layered Electrodes

A wire electrode, which includes a steel core coated with copper or some other materials. Large amount of work has been reported in various patents for multi layered steel core wire electrodes and majority of these multi layered wire electrodes results in accuracy and precision problems with increased tool life. It may be therefore concluded that coating is done on the steel wires to achieve high strength and rigidity.

3. Wire EDM with Advance Power Supply

The supply is transistor controlled and composed of a full bridge circuit, two snubber circuits and a pulse control circuit, to provide the functions of anti-electrolysis, high frequency and very low energy pulse control.

4. New Control System to Improve Machining Accuracy

A closed loop wire tension control system for WEDM to improve the machining accuracy. Dynamic performance of the closed loop wire tension system was examined by Proportional Integrate (P.I.) controller and one step ahead controller. Further in order to reduce the vibration of the wire electrode, dynamic dampers were employed.

5. Wire Electrodes with Cryogenic Treatment

In electronics industries, Aluminum, Brass, Copper, Tin, Lead shows better wear resistance after cryogenic treatment. EN 31 steel, when machined with cryogenic treated brass wire, with three process parameters namely type of wire electrode, pulse width, and wire tension, shows a significant improvement in Surface Roughness than the untreated wire electrode.

6. Stratified wires

Properties of the wire used in this process have an impact on MRR and quality of the cut surface. Now a days stratified wires are used as electrodes. These wires are made of copper core within a thin layer of zinc over it. Such a current carry more current hence gives high MRR. This wire is used only once and then scrapped because it is not very expensive. A wire