

UNIT - 1

Unconventional Machining Processes

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Important Repeated Questions:

1. Classify Unconventional Machining Processes based on the type/source of energy used. (W23 - Q1a, 03; S22 - Q1a, 03; W24 - Q1b, 04)
2. Explain the need/requirement/importance of Unconventional/Advanced Manufacturing Processes. (S22 - Q1a, 03; S23 - Q1a, 03; W24 - Q1a, 03; W22 - Q1a, 03)
3. Explain the Abrasive Jet Machining (AJM) process in detail with a neat diagram/sketch. (S23 - Q1c, 07; W23 - Q2c, 07; W22 - Q1c, 07)
4. Explain the Electric Discharge Machining (EDM) process in detail with a neat diagram/sketch and its working principle. (S23 - Q1c, 07; W23 - Q2c, 07; S22 - Q2b, 04)
5. Distinguish/Differentiate between Conventional and Non-Conventional Machining Processes. (S23 - Q2b, 04; S22 - Q1c, 07; W24 - Q2b, 04)
6. Explain the mechanism of material removal in AJM. (S25 - Q1b, 04; S24 - Q2b, 04; W24 - Q3b, 04)
7. Explain the Water Jet Machining (WJM) process with a neat sketch. (W24 - Q1c, 07; W23 - Q3c, 07)
8. What are the applications of Laser Beam Machining (LBM)? (S22 - Q2a, 03; S24 - Q1b, 04)
9. Enlist/Discuss the process parameters of Electrochemical Machining (ECM) and their effect on Material Removal Rate (MRR). (S22 - Q2c, 07; S23 - Q2c, 07; W24 - Q3b, 04)
10. Explain the Ultrasonic Machining (USM) process with a neat sketch. (S25 - Q2c, 07; W24 - Q3c, 07)

Legends: W- Winter, S- Summer, Q- Question and 03/04/07- Marks of Question

1.1 Introduction

1.1.1 Traditional Machining

- Machining removes certain parts of the workpieces to change them to final parts.
- Traditional, also termed conventional, machining requires the presence of a tool that is harder than the workpiece to be machined.
- This tool should be penetrated in the workpiece to a certain depth.
- Moreover, a relative motion between the tool and workpiece is responsible for forming or generating the required shape.
- The absence of any of these elements in any machining process such as the absence of tool-workpiece contact or relative motion, makes the process a nontraditional one.

1.1.2 Requirement of Non Traditional Machining

- The greatly improved thermal, chemical, and mechanical properties of the new engineering materials made it impossible to machine them using the traditional machining processes of cutting and abrasion.
- This is because traditional machining is most often based on the removal of material using tools that are harder than the workpiece.
- The high cost of machining ceramics and composites and the damage generated during machining.
- In addition to the advanced materials, more complex shapes, low-rigidity structures, and micromachined components with tight tolerances and fine surface quality are often needed. Traditional machining methods are often ineffective in machining these parts. To meet these demands, new processes are developed.
- These methods play a considerable role in the aircraft, automobile, tool, die, and mold making industries.

1.1.3 Comparision between conventional and Non Conventional Machining

Conventional Machining	Non Conventional Machining
Direct contact of tool and workpiece.	Tools are made with non-conventional technique like Laser beam, electric arc etc.
Cutting tool is always harder than work piece.	Tool may not be harder and it may not be physical presence.
Tool life is less due to high wear.	Tool life is more.
Generally Macroscopic chip formation.	Material removal occur with or without chip formation.
Material removal takes place due to application of cutting force.	It uses different energy like electrical, Thermo-Chemical etc. to provide machining.
Capital cost and maintenance cost is low.	Capital cost and maintenance cost is High.
It cannot be used to make prototype parts very effectively.	It can be used to produce prototype parts very effectively.

1.2 Classification of Unconventional Machining Process

Mechanical Energy Based Process: In this Process metal is removed by mechanical erosion of workpiece material.

- Abrasive Jet Machining
- Water Jet Machining
- Abrasive Water Jet Machining
- Ultrasonic Machining

Electrical Energy Based Process: With the aid of current a high power spark is produced between wire-electrode and work piece. Due to this high amount of heat is produced this heat energy used to melt and vaporize the work material.

- Electric Discharge Machining
- Wire Cut EDM

Chemical and Electro Chemical Process: Material is removed by microscopic electrochemical cell action, as occurs in corrosion or chemical dissolution of a metal.

- Chemical and Electrochemical Machining
- Electro Chemical Grinding
- Electro Chemical Honing

Thermal Energy Based Process: Thermal machining removes the machining allowance by melting or vaporizing the workpiece material.

- Laser Beam Machining
- Plasma Arc Machining
- Electro Beam Machining

1.3 Mechanical Energy Based Process

1.3.1 Abrasive Jet Machining (AJM)

- In abrasive jet machining (AJM) a focused stream of abrasive grains of Al_2O_3 or SiC carried by high- pressure gas or air at a high velocity is made to impinge on the work surface through a nozzle of 0.3- to 0.5-mm diameter.
- The process differs from sandblasting (SB) in that AJM has smaller diameter abrasives and a more finely controlled delivery system.
- AJM machining is best suited for machining holes in super hard materials. It is typically used to cut, clean, peen, deburr, deflash, and etch glass, ceramics, or hard metals

Working Principal

- The workpiece material is removed by the mechanical abrasion (MA) action of the high-velocity abrasive particles.

Construction:

- It consist of Compressor (To pressurize the gas), Filter, mixing chamber, Hopper, Vibrator, Nozzle, Pressure gauge and flow regulator.
- The nozzle is made of a hard material like tungsten carbide.
- Abrasive used are aluminum oxide, Silicon carbide, or Sodium bicarbonate.
- The gases commonly used are air, N_2 , CO_2 .
- Hopper is placed above mixing chamber for feeding purpose.
- Vibrating device placed below mixing chamber to vibrate mixture of abrasive and gas.

Working:

- First dry air or gas is filtered and then it compressed by compressor.
- A pressure gauge and flow regulator controls the pressure and regulate the flow of the compressed air.
- Compressed air entered into the mixing chamber where it mixed with abrasive particles.
- Then mixture passes through nozzle where high velocity fine abrasive jet is produced.

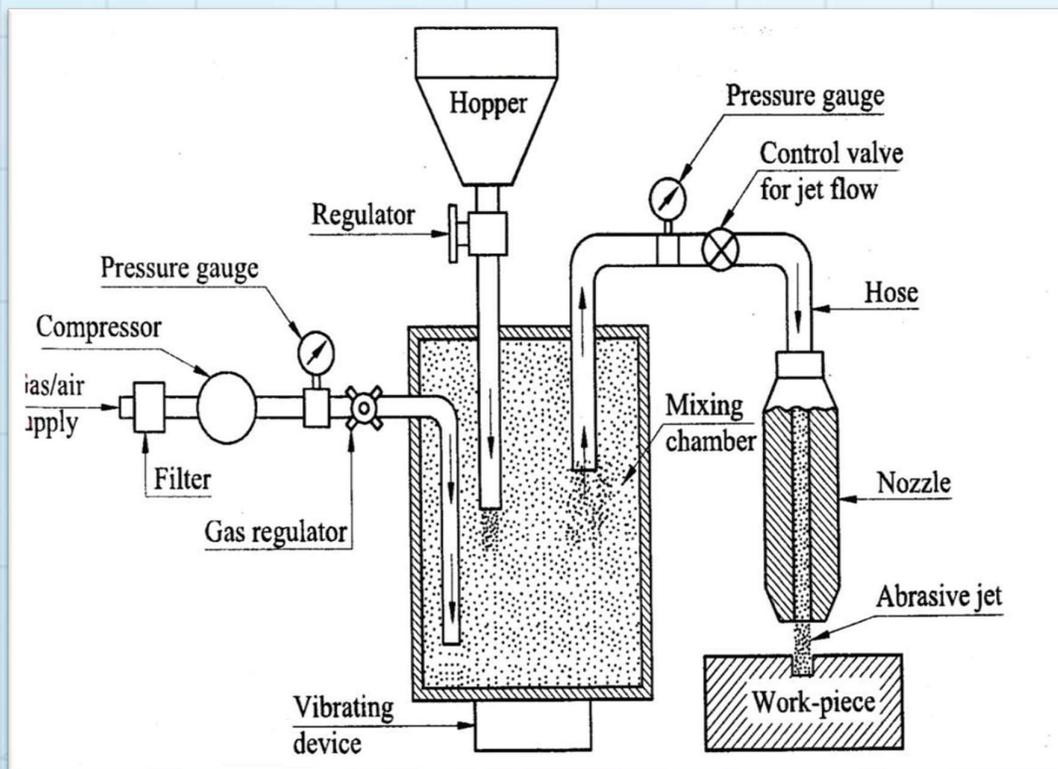


Fig.1.1 Abrasive Jet Machining

- The nozzle increases velocity about 200 to 400 m/s at the expense of it's pressure.
- As a result of repeated impact material removed from work due to erosion. Again new surface exposing and so on material removed by erosion.

AJM Process Parameter:

- Abrasive size: 25 μ m
- Nozzle diameter: 0.13 to 1.2 mm
- MRR: 0.8 mm³/min
- Surface Finish: 0.5-1.2 μ m

Application:

- Drilling, Cleaning, and polishing of hard surface.
- To machine intricate shapes which is difficult to machine.
- Aircraft fuel system, Medical appliances and Hydraulic valves.

Advantage of Abrasive Jet Machining:

- No heat is generated in work. So it is suitable for heat sensitive materials.
- No physical contact between tool and work.
- Thin and fragile materials also machined.
- Low investment.
- Smooth surface finish.

Disadvantage:

- Low MRR.
- Abrasive powder cannot be reused.
- Nozzle life is less and maintenance of nozzle required.

Factors affecting performance of AJM :

- Abrasive grain size and It's mass flow rate
- Mixing ratio.
- Velocity of abrasive particles.
- Gas pressure.
- Nozzle tip distance.

1.3.2 Water Jet Machining (WJM)

- Key element in WJM is a jet of water.
- Water jet travels at velocities as high as 900 m/s (approximately Mach 3).
- When the water stream strikes a work piece surface, the erosive force of water removes the material rapidly.
- The water, in this case, acts like a saw and cuts a narrow groove in the work piece material.
- True cold cutting process – no HAZ (Heat Affected Zones), mechanical stresses or operator and environmental hazards

Working Principal

- The water jet machining involves directing a high pressure, high, velocity water jet to the surface to be machined.
- The kinetic energy of water jet after striking the work surface is reduced to zero.
- The bulk of kinetic energy of jet is converted into pressure energy. q
- If the local pressure caused by the water jet exceeds the strength of the surface being machined, the material from the surface gets eroded and a cavity is thus formed.
- Water is the most common fluid used, but additives such as alcohols, oil products and glycerol are added when they can be dissolved in water to improve the fluid characteristics.

Construction

- Typical work materials involve soft metals, paper, cloth, wood, leather, rubber, plastics, and frozen food.
- If the work material is brittle it will fracture, if it is ductile, it will cut well.

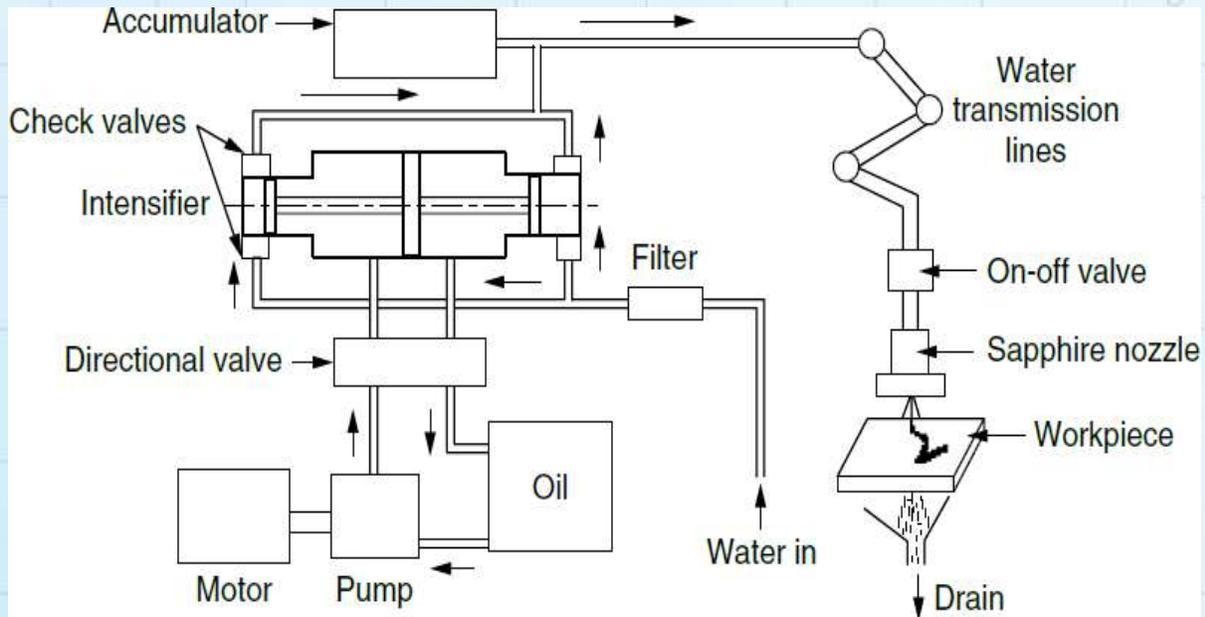


Fig.1.2 Water Jet Machining

- Water jet Machining consists of:

Hydraulic Pump

- Powered from a electric motor.
- Supplies oil at pressures as high as up to 117 bars.
- The hydraulic pump offers complete flexibility for water jet cutting and cleaning applications.
- It also supports single or multiple cutting stations for increased machining productivity.

Intensifier

- Accepts the water at low pressure and expels it, through an accumulator, at higher pressures.
- The intensifier converts the energy from the low-pressure hydraulic fluid into ultrahigh pressure water.

Accumulator

- Maintains the continuous flow of the high-pressure water and eliminates pressure fluctuations.
- It relies on the compressibility of water (12 percent at 3800 bar) in order to maintain a uniform discharge pressure and water jet velocity, when the intensifier piston changes its direction.

High Pressure Tubing

- Transports pressurized water to the cutting head.
- Typical tube diameters are 6 to 14 mm.
- The equipment allows for flexible movement of the cutting head.
- The cutting action is controlled either manually or through a remote-control valve specially designed for this purpose.

Jet Cutting Nozzle

- Nozzle provides a coherent water jet stream for optimum cutting of low-density, soft material that is considered unmachinable by conventional methods.
- Nozzles are normally made from synthetic sapphire.
- About 200 h of operation are expected from a nozzle, which becomes damaged by particles of dirt and the accumulation of mineral deposits on the orifice due to erosive water hardness.

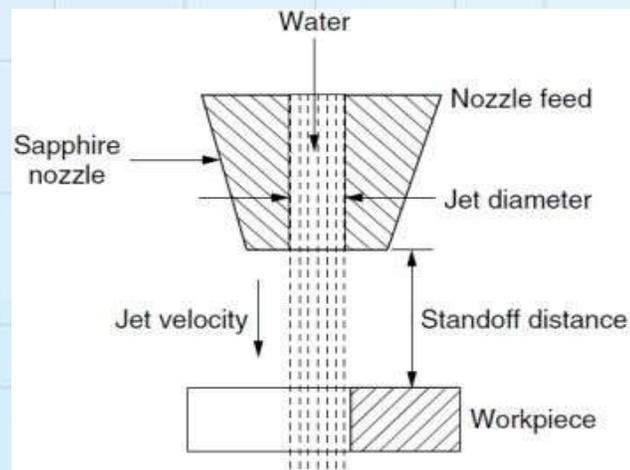


Fig.1.3 Jet Cutting Nozzle

Catcher

- Acts as a reservoir for collecting the machining debris entrained in the water jet.
- Moreover, it reduces the noise levels [105 decibels (dB)] associated with the reduction in the velocity of the water jet from Mach 3 to subsonic levels.

Jet Nozzle

- Standoff distance - Gap between the jet nozzle (0.1–0.3 mm diameter) and the workpiece (2.5 – 6 mm).
- However for materials used in printed circuit boards, it may be increased to 13 to 19 mm.
- But larger the standoff distance, smaller would be the depth of cut.

Jet Fluid

- Typical pressures used are 150 to 1000 MPa to provide 8 to 80 kW of power.
- For a given nozzle diameter, increase in pressure allows more power to be used in the machining process, which in turn increases the depth of the cut.
- Jet velocities range between 540 to 1400 m/s.
- The quality of cutting improves at higher pressures by widening the diameter of the jet and by lowering the traverse speed.
- Under such conditions, materials of greater thicknesses and densities can be cut.
- Moreover, the larger the pump pressure, the greater will be the depth of the cut.
- The fluid used must possess low viscosity to minimize the energy losses and be noncorrosive, nontoxic, common, and inexpensive

Work Piece

- Brittle materials will fracture, while ductile ones will cut well.
- Material thicknesses range from 0.8 to 25 mm or more.

Applications

- WJM is used on metals, paper, cloth, leather, rubber, plastics, food, and ceramics.
- It completely eliminates heat-affected zones, toxic fumes, recast layers, work hardening and thermal stresses.
- The process drills precision-angled and -shaped holes in a variety of materials.
- Machining or cutting of fiber reinforce plastics.
- Cutting of Rocks.
- Deburring.
 - Cutting of Printed circuit board.
 - Surface treatments.

Advantages

- It has multidirectional cutting capacity.
- No heat is produced.
- Cuts can be started at any location without the need for predrilled holes.
- There is no deflection to the rest of the workpiece.
- The burr produced is minimal.

- The tool does not wear and, therefore, does not need sharpening.
- The process is environmentally safe.
- Hazardous airborne dust contamination and waste disposal problems that are common when using other cleaning methods are eliminated.
- There is multiple head processing.
- Grinding and polishing are eliminated, reducing secondary operation costs
- It is ideal for roughing out material for near net shape.
- It is ideal for laser reflective materials such as copper and aluminum.
- It allows for more accurate cutting of soft material.
- It cuts through very thick material such as 383 mm in titanium and 307 mm in Inconel.

Limitations

- Hourly rates are relatively high.
- It is not suitable for mass production because of high maintenance requirements.

1.3.3 Ultrasonic Machining (USM)

- It is mechanical material removal process in which material is removed by repetitive impact of abrasive slurry on work surface, by using high frequency oscillation of shaped tool.

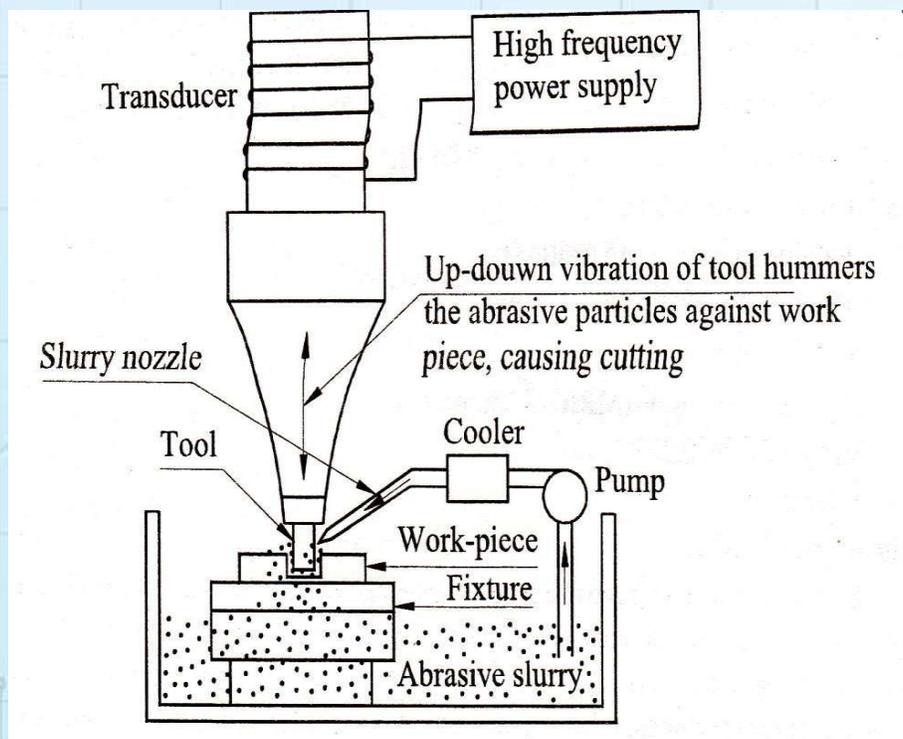


Fig.1.4 Ultrasonic Machining

Construction:

- It consists of Ultrasonic generator and transducer, Concentrator, tool, Abrasive slurry and its feed mechanism, and tool feed mechanism.
- Concentrator is tool cone which is made from titanium or SS.
- Tool is attached to base of concentrator by means of silver brazing or screws. Tool is shaped as approximate mirror image of cavity desired.
- The gap between tool and work is about 0.02 to 0.1 mm.
- Abrasive slurry is mixture of abrasive grains and carrier fluid which is provided between tool and work-piece. Generally water is used as carrier fluid.

Working:

- The ultrasonic transducer converts electrical energy into ultrasonic waves or vibrations using magnetostrictive effects.
- Tool vibrates longitudinally at 20 to 30 kHz with amplitude 0.02 mm pressed on the work surface with light force.
- Concentrator increases the amplitude of vibration in order to give required force amplitude ratio.
- The abrasive particle in form of abrasive slurry is continuously circulates between tool and work. The tool performs hammering action on abrasive particles.
- The vibration of tool tip accelerates the abrasive particles at high rate and it imparts the necessary force for cutting action.
- The tool is gradually moved down by means of tool feed mechanism to maintain constant gap.

USM Process Parameter:

- Vibration frequency: 15 to 30 kHz
- Vibration amplitude: 25 to 100 μ m
- Gap: 0.02 to 0.1 mm
- Surface finish: 0.2 to 0.8 μ m (CLA)
- MRR: 300 mm³/min

Application of USM:

- It is used for machining of hard and brittle material like ceramics, boron carbide, titanium carbide.
- USM enables a dentist to drill a hole of any shape on teeth painlessly.

Advantage of USM:

- Non-conductive materials can also be machined.
- There is no change in microstructures, physical or chemical properties.
- Better surface finish and higher structure integrity.
- Noiseless operation.
- Work piece harder than 60 HRC like carbide, Ceramics machined by USM.
-

Disadvantage of USM:

- Low MRR.
- High power consumption.
- High tooling cost and it wears rapidly.
- Not suitable for soft materials

Factors affecting MRR and surface finish in USM:

- Tool amplitude and frequency.
- Tool shape.
- Abrasive grain size.
- Abrasive concentration.
- Work hardness-tool hardness ratio.
- Feed force.

1.4 Electrical Energy Based Process

1.4.1 Electrical Discharge Machine (EDM)

Principle of EDM:

- The main attraction of EDM over conventional machining is that this technique use thermoelectric process to erode undesired material from the w/p.

Construction

- System consist of Shaped tool, Power supply source, Dielectric fluid and its circulation line, Servo controlled tool feed mechanism and work.
- Tool: Cathode (Negative terminal)
- Work: Anode (Positive terminal)
- Terminals are connected to DC power supply to create potential difference between work and tool.
- Distance between work and tool is known as Spark gap and it is filled by dielectric fluid.

Working:

- High voltage is applied between terminals and it induce electrical field in spark gap.
- Free electrons on tool are subjected to electrostatic force and hence they are emitted from tool and accelerate towards work. There would be collision between electrons and molecules in dielectric. It causes further generation of electrons because of ionization of dielectric molecules.
- This cyclic process increase concentration of electrons in spark gap and when potential difference is sufficiently high dielectric break down and large no. of electrons will flow from tool to job and ions from job to tool.
- This movement of electrons visually seen as Spark and electrical energy is dissipated as thermal energy of spark.

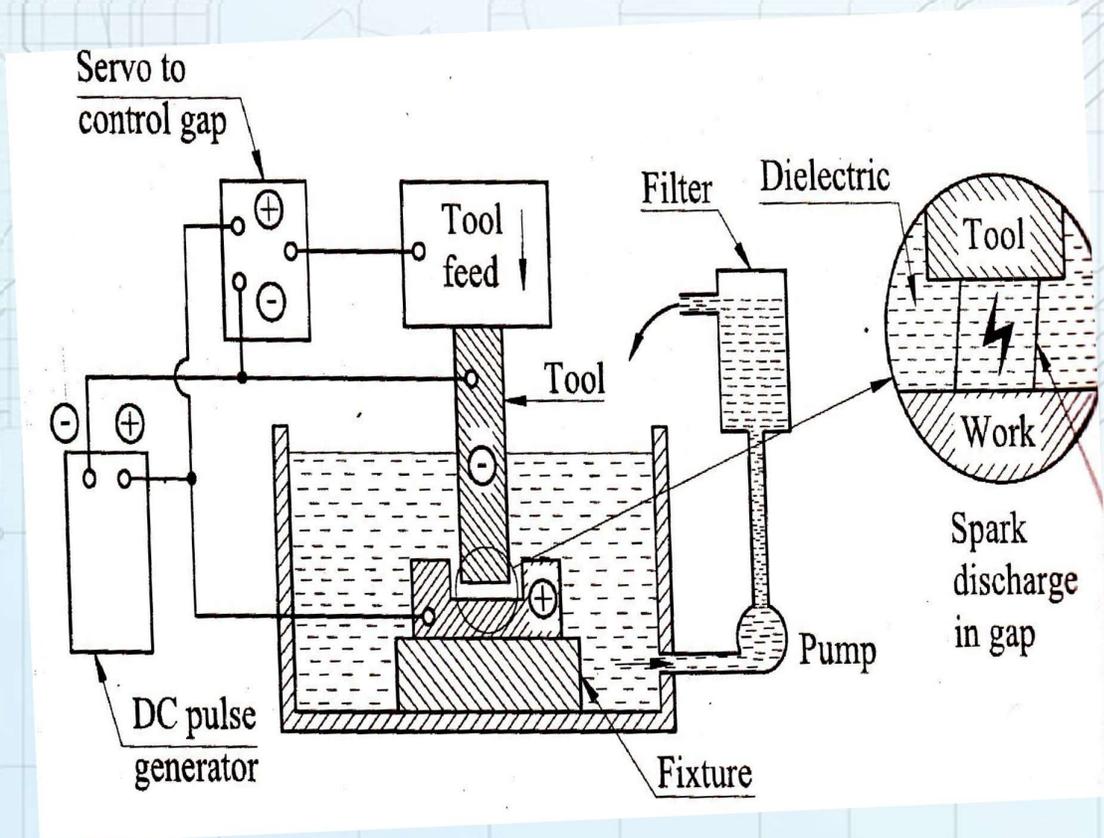


Fig.1.5 Electrical Discharge Machining

- With a very short duration of spark , temperature of electrodes raised locally to more than their normal boiling point and this heat of spark melt a tiny bit of metal from work.
- The melted metal cools and solidifies as tiny particles in dielectric.
- The metal is carried away due to circulation of dielectric by means of pump and the process continues.

Process Parameter:

- Voltage: 40 to 300 V
- Current: 0.5 to 400 A
- Spark gap: 0.0125 to 0.125 mm
- Pulse duration: 2 to 2000 microsecond
- MRR: 800 mm³ – 5000 mm³

Application of EDM:

- EDM Drilling to drill very small holes and EDM milling to machine complex shapes.
- EDM can be used to make parts with irregular shape with precision for forging press tool, extrusion dies, cutting tool dies etc.

1.4.2 Wire Cut EDM

- Wire EDM use Electro thermal mechanism to cut electrically conductive materials.

Construction:

- EDM consist NC unit to control counter movement of work, wire feeding mechanism to move wire at constant tension, power supply and dielectric fluid supply.
- Wire of 0.02 to 0.3 mm diameter
- Tool: Cathode (Negative terminal)
- Work: Anode (Positive terminal)
- Dielectric is de-ionized water applied as localized stream rather than submerging the whole work.
- Wire for EDM is made of Brass, copper, tungsten, and Zinc or brass coated wire. The wire should have high tensile strength and good electrical conductivity.

Working:

- During operation wire moves along prescribed path and removes material from work.
- Same as EDM process material is removed due to series of discrete discharge between Anode and Cathode in presence of dielectric fluid.
- The place of discharge heated to extremely high temperature and that surface is melted and material removed.
- Removed particles flushed away by flowing dielectric fluids.

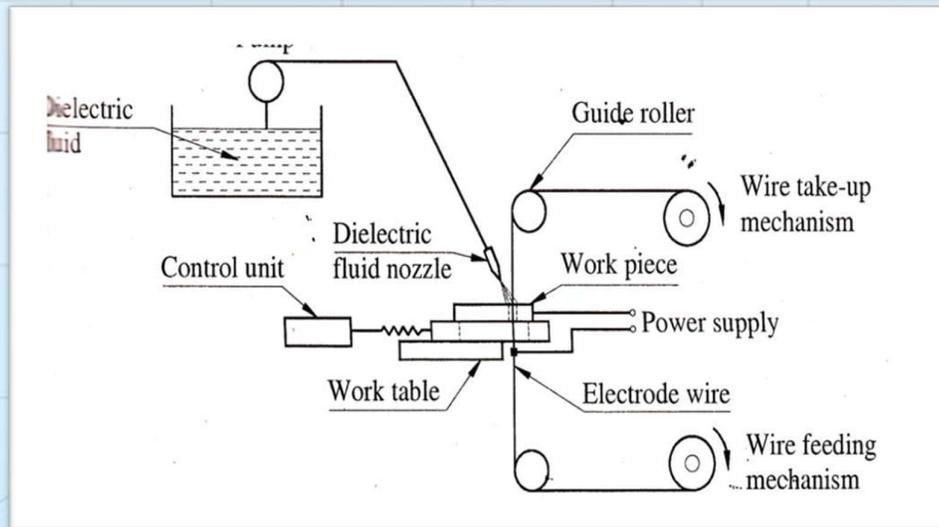


Fig.1.6 Wire Cut Electric Discharge Machining

Advantage of Wire cut EDM:

- Smooth machine surface and polishing not required.
- Forming electrode to product shape is not required.
- Wear of electrode is negligible.
- Production rate is high machine can be easily operated for long time.

Application of Wire cut EDM:

- Intricate components for electrical and aerospace industries.
- Machining of sheet metal die, extrusion dies and prototype parts.
- Cylindrical objects are cut with high precision.

1.5 Thermal Energy Based Process:

1.5.1 Chemical Machining (CM)

- In Chemical Machining process material is removed by chemical dissolution using chemical reagents or etchants (Acids or Alkaline solutions).
- Chemical reaction takes place between work surface and etchants resulting into removal of material from surface.
- The surface which etched away, exposing the lower layers and process is continued till the desired amount of material removed.
- Classification of Chemical Machining:

- a) Chemical blanking.
- b) Chemical Milling.
- c) Chemical engraving

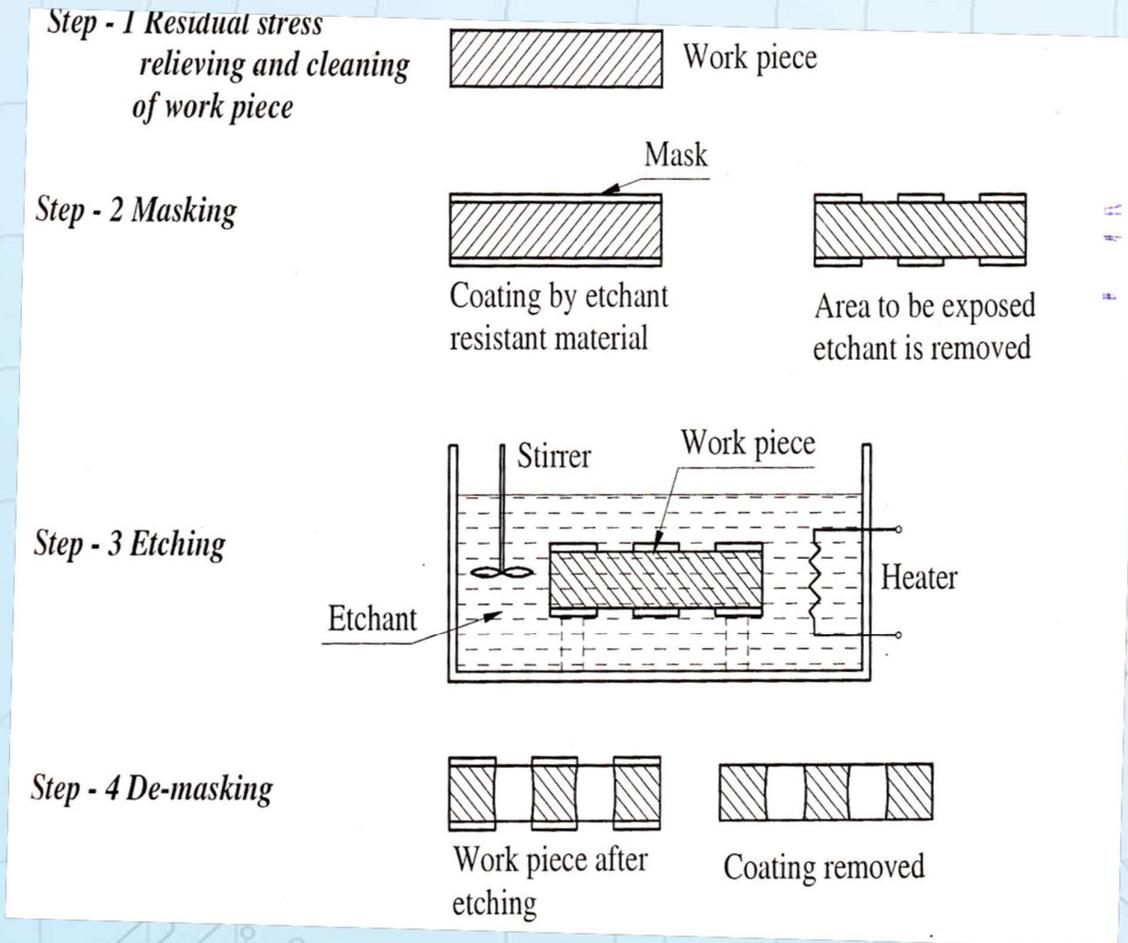


Fig.1.7 Chemical Machining

Steps for CM:

- Residual stress relieving
- Cleaning the work piece
- Masking
- Etching
- De-masking

Application of CM:

- CM is used as chemical blanking for burr free etching of printed chemical printed circuit boards, decorative panels.
- Chemical milling is commonly used in aerospace industry to remove shallow layers of material from large aircraft components like missile skin panels and airframe parts.

Advantage:

- It doesn't distort the work and all the faces of work machined simultaneously.
- Low setup, maintenance and tooling cost.
- It can be used to machine complex profiles of delicate and intricate design parts.
- Improves productivity.

Disadvantage:

- Large tank and large floor area required.
- High operation cost.
- Chemicals used in process may be dangerous to health.

1.5.2 Electro Chemical Machining (ECM)

- ECM is metal removal process based on principle of reverse electroplating.

Construction:

- It consist cathode (tool), Anode (work), Servomotor to control tool feed, Electrolyte tank and it's circulation arrangement, DC power supply.
- Servomotor controlled the feed of tool.
- Pump is placed for providing strong stream of electrolyte.

Working:

- DC power supply provides current 50 to 40000 A at 5 to 30 V for across the gap of 0.05 to 0.07 mm between tool and work. Electrolyte flows through this gap at velocity 30 to 60 m/s.
- Current started flowing through electrolyte having positively charged ions attracted towards the tool and negatively charged ions attracted towards work.
- Due to this flow electrochemical reaction takes place and metal removes in form sludge.
- This sludge is taken away from gap by strong stream of electrolyte.

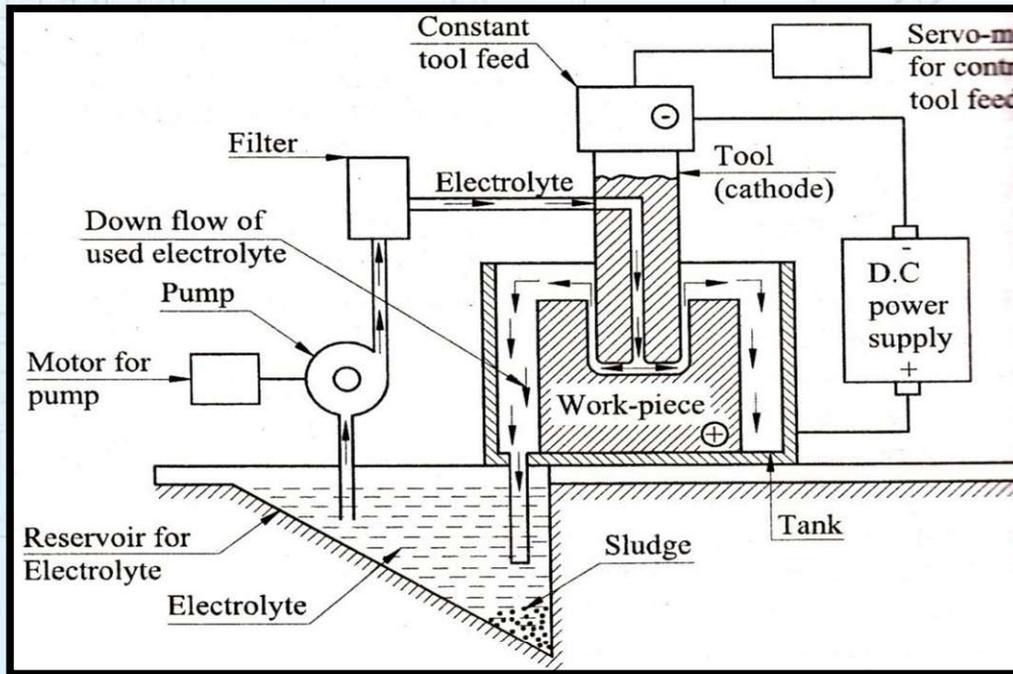
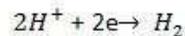
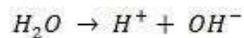
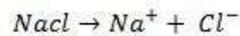
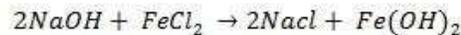
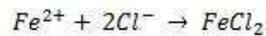
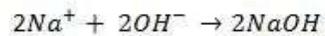


Fig.1.8 Electro Chemical Machining

- Following reactions takes place while machining of pure iron through ECM using NaCl+H₂O as electrolyte.



Material Removal:



ECM Process Parameter:

- Voltage: 4 to 30 V
- Current: 50 to 40000 A
- MRR: 1600 mm³/min
- Surface Finish: 0.1-2.5 μm (CLA)
- Gap: 0.025 to 0.75 mm

Properties of Electrolyte:

- Electrolyte provides several functions like complete the circuit, Remove material from cutting region by pressure, Carry away heat to be generated.
- High thermal and Electrical Conductivity

- Low viscosity
- Cheaper and Available
- Non corrosive and Non toxic
- Chemically Stable at process temperature

1.5.3 Electrochemical Grinding (ECG)

- It is combination of conventional mechanical grinding and electrochemical machining in which material removed by electrolytic activity. In this process mostly material removed by electrochemical decomposition and remaining material is removed by abrasion of metal.

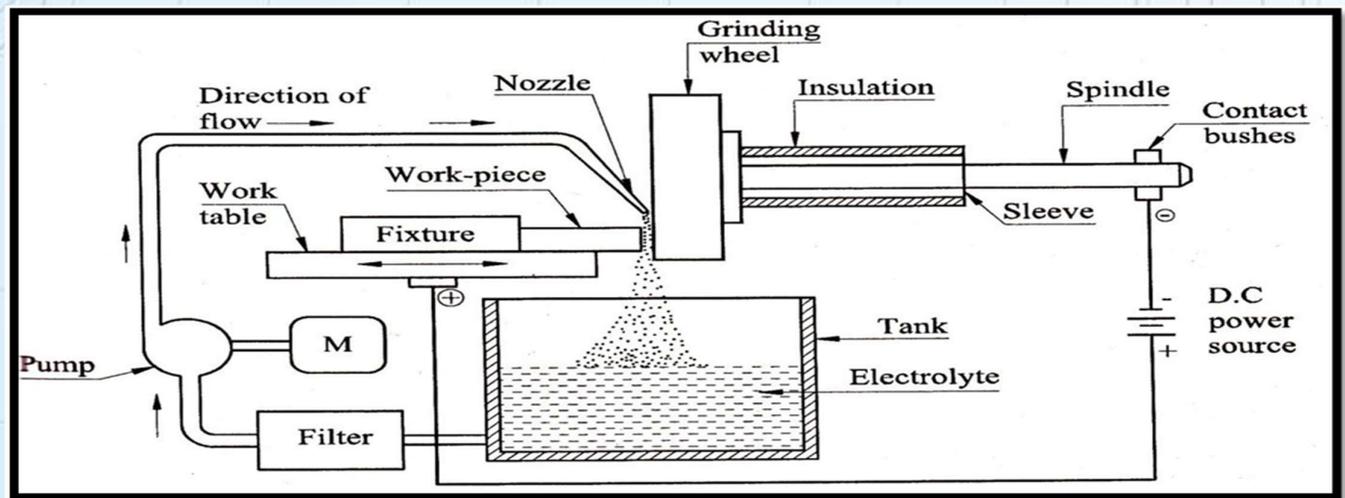


Fig.1.9 Electro Chemical Grinding

- ECG is widely used because it gives burrs free surface without producing heat and after ECG, any secondary machining operation not required.

Construction:

- It consist of metallic grinding wheel as cathode, Work-piece as anode, Electrolyte tank and circulation system.
- Grinding wheel is maid such that diamond or aluminum oxide particles embedded in it and it slightly projecting out from the surface so that they touch work surface with a very little pressure. This abrasive particles preventing direct contact between wheel and work piece.
- As Electrolyte, non corrosive salt solution is used with water. It works as both Electrolyte and coolant.

Working:

- DC power is supplied between electrodes and Grinding wheel start rotating by means of motor.
- Pump circulating electrolyte From reservoir tank to machining place. When electrolyte entrapped in small cavities between work and abrasive particles it forms electrolyte cell.
- Current started flowing grinding wheel (Cathode) to work (Anode).

- Oxide film forms on surface of work due to electro chemical oxidation and this film is removed by projecting abrasive particles, which results in accurate surface finish.

Application:

- For grinding Carbide tools, refractory metals and Cobalt based alloy ECG is used.

Advantage:

- Process is independent of material hardness and strength.
- Not completely depends on abrasive process.
- Work is not subjected to any mechanical distortion and no heat generation.
- High surface finish and tool wear is negligible.
- Rapid MRR.

Disadvantage:

- Power consumption is more and High Capital cost.
- Not applicable for non-conductive work-piece.
- It is not suitable for soft materials.

1.6 Thermal Energy Based Process:

1.6.1 Laser Beam Machining (LBM)

- It is thermal metal removal process which uses LASER beam to melt and vaporize particles on the surface of metallic and non-metallic work-pieces.

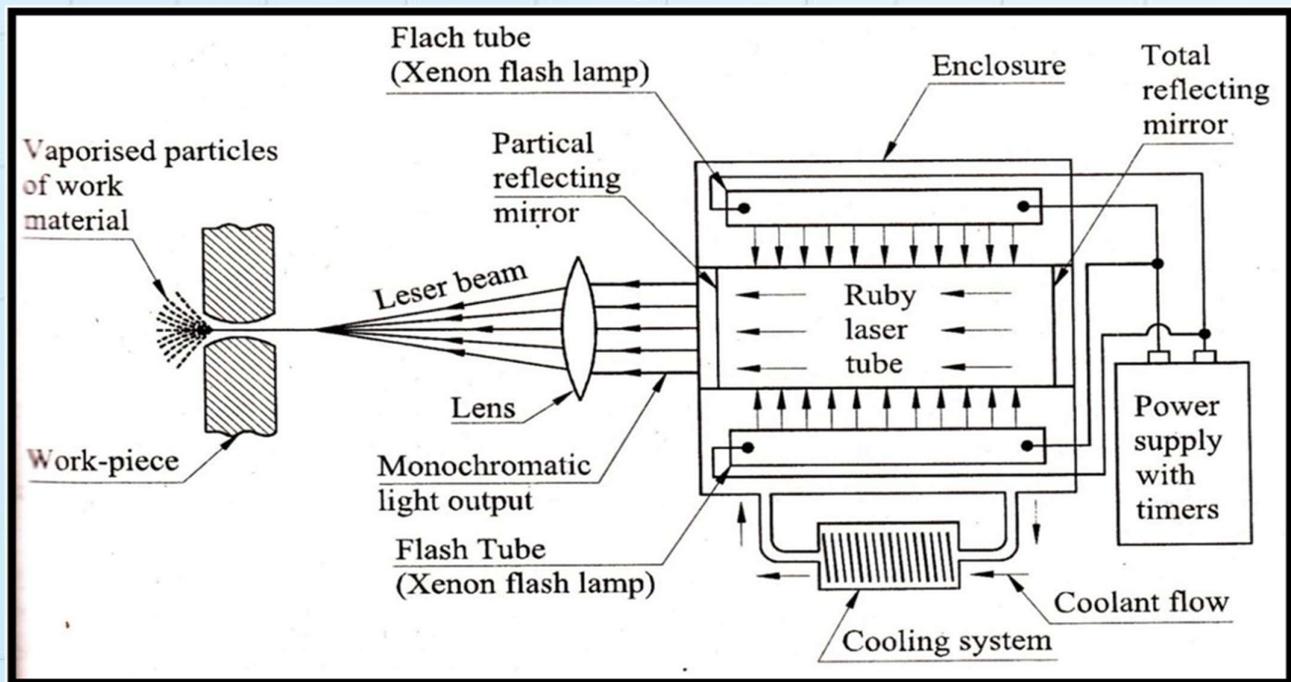


Fig.1.10 Laser Beam Machine

Construction:

- It consist cylindrical crystal ruby tube, flash tube, focusing lens, power supply source, total and partial reflecting mirror and cooling system.
- Ruby is Aluminum oxide with 0.05% Cr dispersed and it's one end is blocked with total reflective mirror while other end having partially reflected mirror.
- Flash tube is placed outside ruby crystal.

Working:

- Capacitor bank is charged by high voltage energy supplied which energize flash tube by triggering system.
- Flash tube flashes white light and Cr atoms in ruby crystal absorb this energy and get excited.
- These atoms pumped to high energy level and drop back to original state. When atoms jump from one to another level it emits photons (Red fluorescent light). This phenomenon is known as lasing action or stimulation effect.
- Due to reflection this effect is enhanced and finally photons will come out from partially reflected mirror with great intensity called LASER.
- Laser beam is focused with the help of lens and work is placed near focal point of lens. Due to high temperature work material will melt and vaporize.
- Ruby rod becomes high efficient at low temperature. Thus it is continuous cooled with water or liquid Nitrogen.

LBM Process parameters:

- Voltage: 4500 V
- Pulse duration: 100 microsecond
- MRR: 0.1 mm³/min
- Surface Finish: 0.5-1.2 μ m (CLA)

APPLICATION of LBM:

- LASER drilling
- LASER metal cutting
- LASER welding

ADVANTAGE of LBM:

- Small, complex and micro sized holes.
- No direct contact between tool and work.
- Accuracy is high and doesn't require filler material.
- Dissimilar material can be easily welded.
- Automated easily.

DISADVANTAGE:

- It can't be used to drill deep holes.
- Highly reflective material can't be effectively machined.
- Initial investment is high.

- Safety must be followed strictly and skilled operator required.

1.6.2 Plasma Arc Machining (PAM)

- It is method of metal cutting with arc of plasma (jet of high velocity ionized gas) that removes material from work-piece.
- At very higher temperature atoms of gas become ionized and this stage of gas is known as Plasma.

Construction:

- Plasma torch makes plasma and direct it for cutting.
- Plasma torch consist gas chamber, Nozzle as Anode and Tungsten electrode as Cathode and power supply.
- Argon, nitrogen, hydrogen, or compressed air introduced around cathode.

Working Principle:

- In gas chamber high velocity arc is generated between Anode and Cathode. Gas molecules are collide with high velocity electrons of arc and due to this gas gets ionized and large amount of heat energy librated.

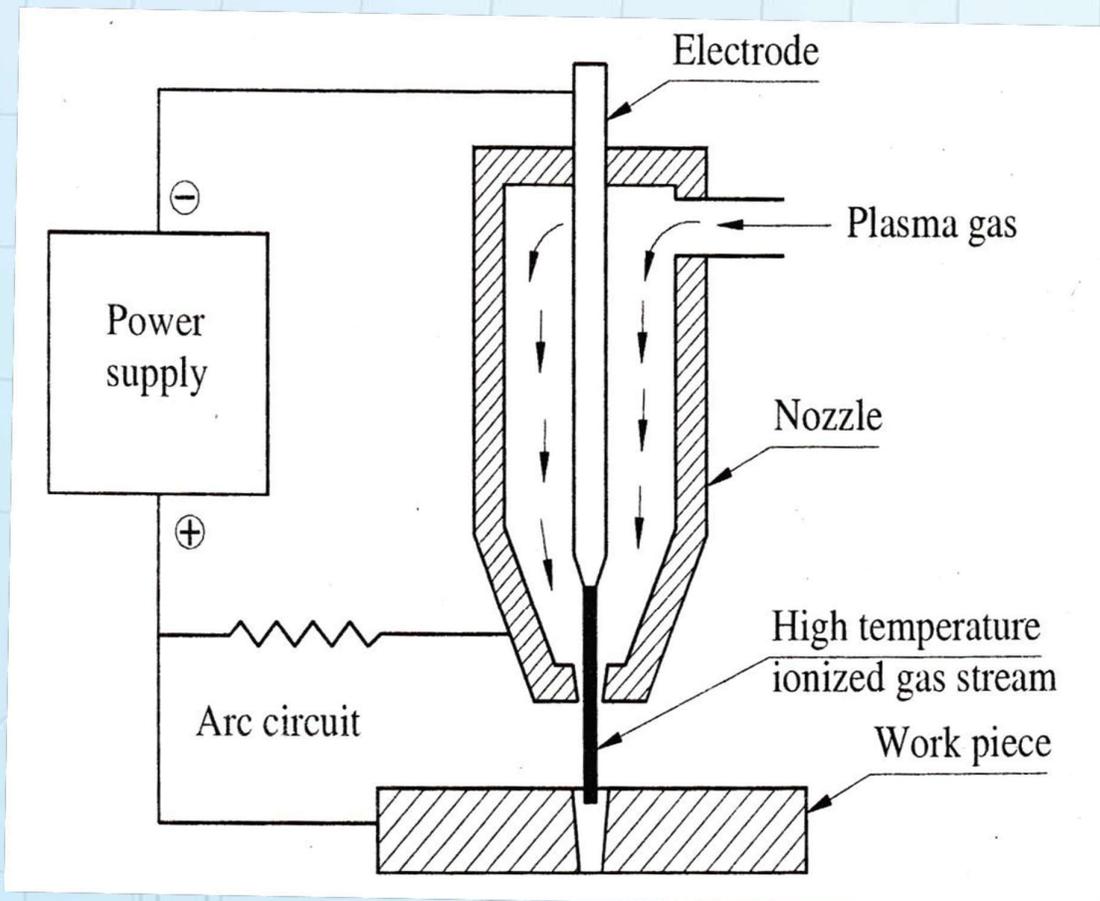


Fig.1.11 Plasma Arc Machining

- This high velocity stream of hot ionized gas (Plasma) is directed on the work-piece to melt the material.

PAM Process Parameter:

- Voltage: 30-250 V
- Current: Up to 600 A
- Power: 2-200 KW
- Velocity of plasma jet: 500 m/s
- MRR: 1,50,000 mm³/min

Advantages:

- Any electrically conductive material machined regardless it's hardness.
- Doesn't require any surface preparation.
- It has high cutting rate.

Disadvantage:

- Power consumption is very high.
- High equipment cost.
- It produced tapered surface.
- Noise protection is required.

1.6.3 Electro Beam Machining (EBM)

- EBM is thermo Electrical process in which material is removed by high velocity electron beam emitted from tungsten filament. Kinetic energy of beam transferred to work, producing heat and melts or vaporize material locally.

Construction:

- It consist vacuum chamber, electron gun, magnetic lens to focus beam, deflecting coil, and work table for holding.
- Electron gun consist grid cup, tungsten filament (cathode), Anode. The filament and anode are connected with DC power supply.

Working:

- The tungsten filament is heated about 2500-3000 °C by high voltage DC supply in order to emit electrons. Grid cup direct electrons to travel towards the work.
- Electrons are attracted by the Anode, and passed through already placed hole without colliding with it.
- Due to high potential difference electrons accelerated and it's velocity reaches near 2/3 of light velocity.
- Electron beam is refocused by electromagnetic lens system so that beam is directed with control (typically 0.25 mm diameter) towards work.
- For controlling path of cut deflector coil is used to deflect electron beam.

- Kinetic energy of high velocity beam is transmitted into heat and temperature of work increased above boiling point.

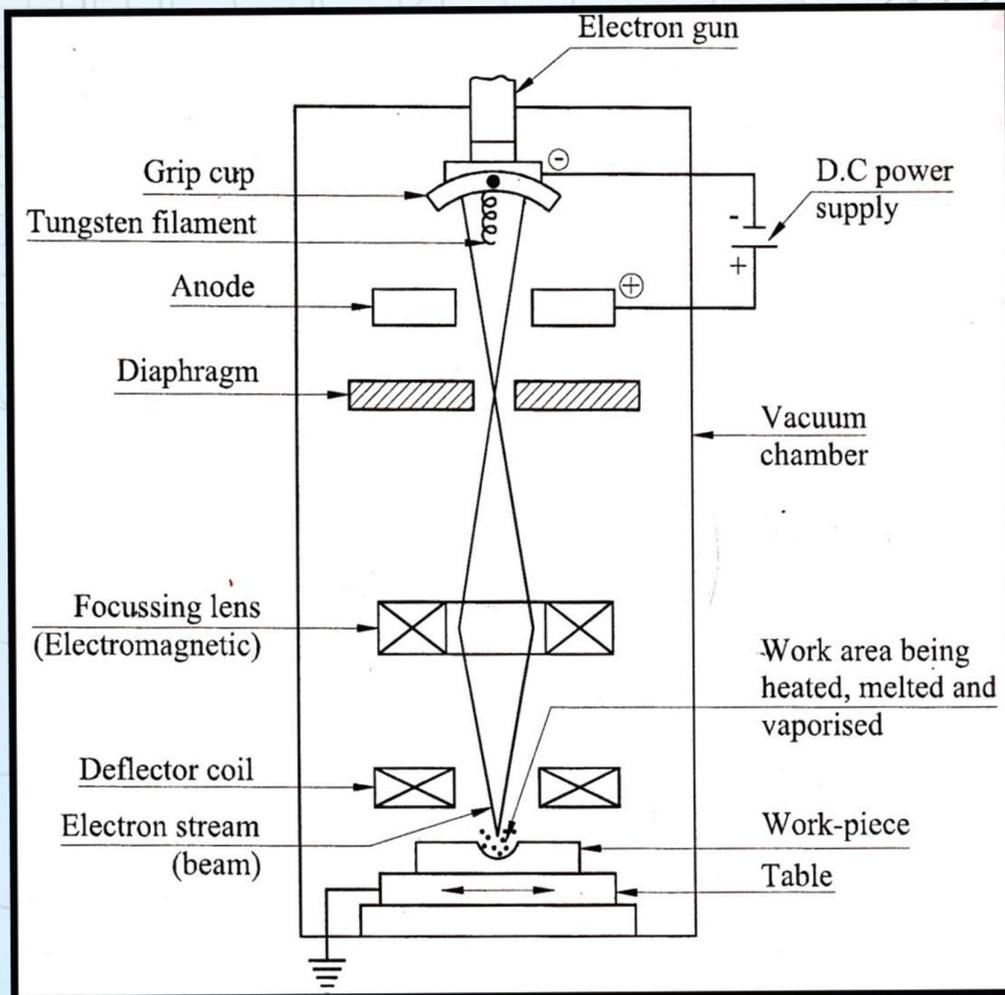


Fig.1.12 Plasma Arc Machining

EBM process parameter:

- Voltage: 1,50,000 V
- Vacuum requirement: $133 \times 10^{-6} \text{ N/m}^2$
- MRR: $1.6 \text{ mm}^3/\text{min}$
- Surface Finish: $0.4\text{-}2.5 \mu\text{m (CLA)}$

Application:

- To drill holes in pressure differential device and to machine low thermal conductive and high melting point materials.
- Advantage:
 - Drill very small hole with high accuracy.
 - Brittle material can be easily machined.
 - Set up can be automated easily.

Disadvantage:

- Vacuum chamber is essential
- Equipment cost is high.
- Low MRR and skilled operator required.

1.7 Comparison between various Non-conventional Machining Process

Process	Medium	Surface finish	MRR	Power consumption	Tooling Cost	Investment cost	Efficiency
EDM	Liquid dielectric	0.2-1.2	800	Low	High	Medium	High
ECM	Electrolyte	0.1-2.5	1500	Medium	Medium	Very high	Low
CM	Liquid chemical	0.5-2.5	15	High (Chemical cost)	low	Medium	Medium
LBM	Air	0.5-1.2	0.1	Very low	Low	Low	Very high
EBM	Vacuum	0.5-2.5	1.6	Low	Low	High	Very high
PAM	Argon	Rough	75000	Very low	Low	Very low	Very low
USM	Abrasive in water	0.2-0.5	300	Low	Low	Low	High
AJM	Abrasive in gas	0.5-1.2	0.8	low	low	Very low	High

1.8 Reference

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