Program : **B.Tech**

Subject Name: **Manufacturing Technology**

Subject Code: **ME-405**

Semester: **4th**

Introduction:

Machining is one of the most important process of metal forming and shaping. Mostly, it is used in all manufacturing processes. In the convention machining processes, **tool** is in direct contact with work piece. There are many disadvantages and limitations of conventional machining like tool wear, cannot machine complex surface efficiently, gives lower surface finish etc. Conventional machining processes are limited due to hardness of work piece. For machining hard surface through conventional machining, we require a harder tool material which is sometime uneconomical and sometimes unavailable. These limitations of traditional machining can be eliminated by non-traditional machining process. In these machining processes some other unconventional energy sources are used like laser, chemical, electron, hydraulic energy etc. 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.

Why unconventional machining processes are used?

The answer is simple. 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 workpiece) or the workpiece material is damaged (while machining brittle workpiece). This is because, in conventional machining, there is a direct contact between the tool and the workpiece. Large cutting forces are involved and material is removed in the form of chips. Huge amounts of heat are produced in the workpiece. This induces residual stresses, which degrades the life and quality of the workpiece 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.

Some of the major requirements of developing non-tradition machining processes are as follow.

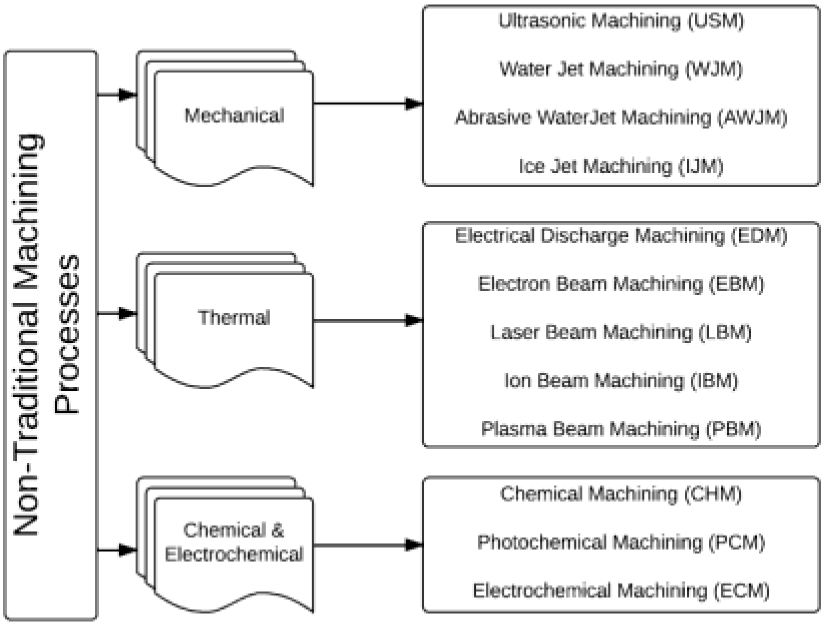
- Machining too hard material.
- Forming complex parts.
- Required better surface finish and negligible tolerance.
- Work piece is heat sensitive or temperature can change internal properties of work piece.
- Work piece is too slender and flexible to clamp.

Classification:

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

- Based on type of energy used.
- Based on source of energy used.
- Based on the medium of energy transfer.
- Based on the mechanism of material removal.

- Based on **type of energy** used.



- Based on **source of energy** used.
  - Current
  - Voltage
  - Hydraulic Pressure
  - Pneumatic Pressure
  - Ionized Particles
  - Light
- Based on the **medium of energy transfer.**
  - Electrons
  - Chemical reagent
  - Atmosphere
  - Radiation
  - Ions
  - Laser
  - Electrolyte
  - Pressurized gas
  - Water
  - Ultrasonic waves
  - Plasma
- Based on the **mechanism of material removal.**
  - Erosion
  - Blasting
  - Electric
  - Discharge
  - Shear
  - Chemical Etching
  - Vaporization
  - Melting
  - Ion Displacement

Classification of Unconventional Machining Processes based on Energy Used.

1. Mechanical Energy based Unconventional Machining Processes:

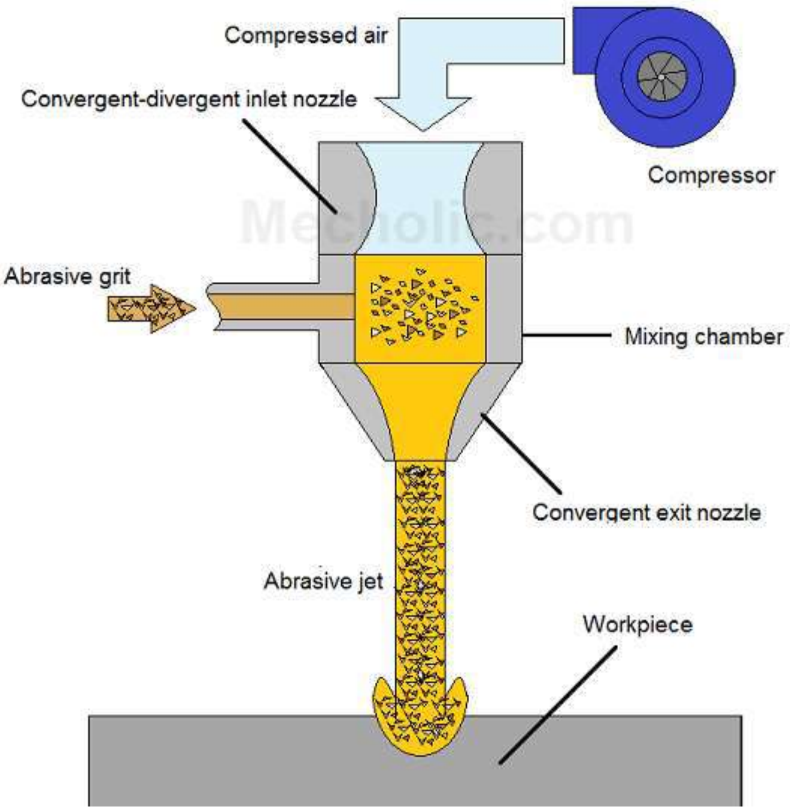
In these processes, unwanted material in the workpiece is removed by mechanical erosion. The mechanical erosion can be facilitated by using any medium. For example, in abrasive jet machining, high velocity abrasive jet is used for eroding material from the workpiece. In water jet machining, high velocity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

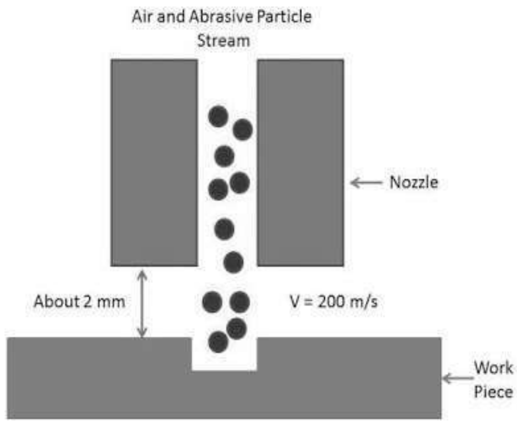
- Abrasive Jet Machining
- Water Jet Machining or Water Jet Cutting
- Abrasive Water Jet Machining
- Ultrasonic Machining

Abrasive Jet Machining

Abrasive Jet Machining (AJM), also known as micro-abrasive blasting, is a mechanical energy based unconventional machining process, used to remove unwanted material from a given workpiece. The process makes use of an abrasive jet with high velocity, to remove material and provide smooth surface finish to hard metallic workpieces. In this machining process, a high stream of abrasive particles forced towards work piece, this will remove metal from striking surface due to erosion. The metal removal process takes place due to brittle fracture and micro cutting action of abrasive particles. The abrasive particles carried by high velocity gas which act as transportation medium for abrasive particles. This machining is mostly used for machining hard material.

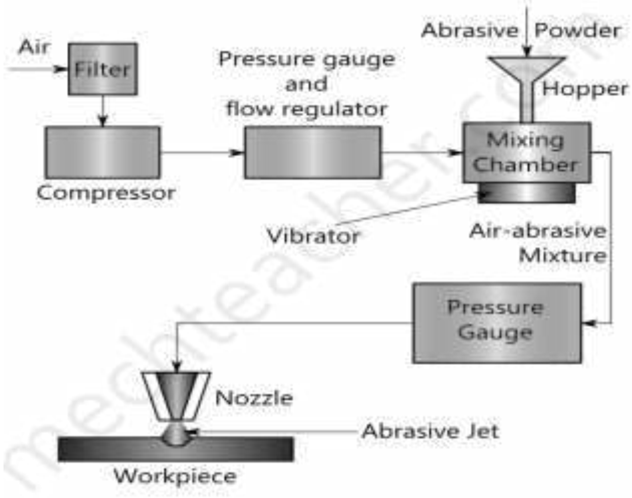
Abrasive Jet Machining: *Principle*





This machining process works on the basic principle of abrasive erosion. If a high velocity abrasive particles strike on a hard or brittle work piece, it remove some metal at the striking surface. This metal removal process takes place due to brittle fracture of metal and also due to micro cutting by abrasive particle. This is principle process of abrasive jet machining.

Abrasive Jet Machining: *Construction*



The constructional requirements of Abrasive Jet Machining (AJM) are listed and described below:

- **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.
- **Mixing chamber:** It is used to mix the gas and abrasive particles.
- **Filter:** It filters the gas before entering the compressor and mixing chamber.
- **Compressor:** It pressurizes the gas.
- **Hopper:** Hopper is used for feeding the abrasive powder.
- **Pressure gauges and flow regulators:** They are used to control the pressure and regulate the flow rate of abrasive jet.
- **Vibrator:** It is provided below the mixing chamber. It controls the abrasive powder feed rate in the mixing chamber.
- **Nozzle:** It forces the abrasive jet over the workpiece. Nozzle is made of hard and resistant material like tungsten carbide.

Abrasive Jet Machining: *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.

Abrasive Jet Machining: *Applications*

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

- Drilling
- Boring
- Surface finishing
- Cutting
- Cleaning
- Deburring
- Etching
- Trimming
- Milling

Abrasive Jet Machining: *Advantages*

- 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.

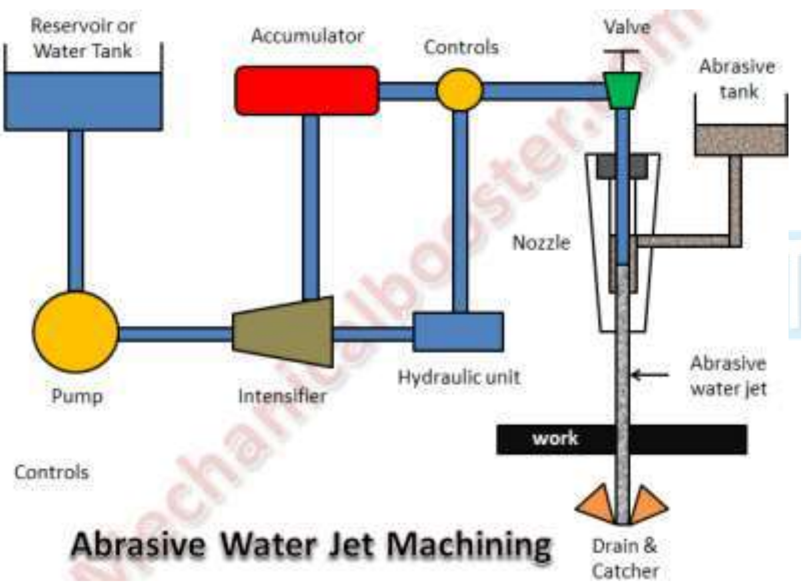
Abrasive Jet Machining: Dis*advantages*

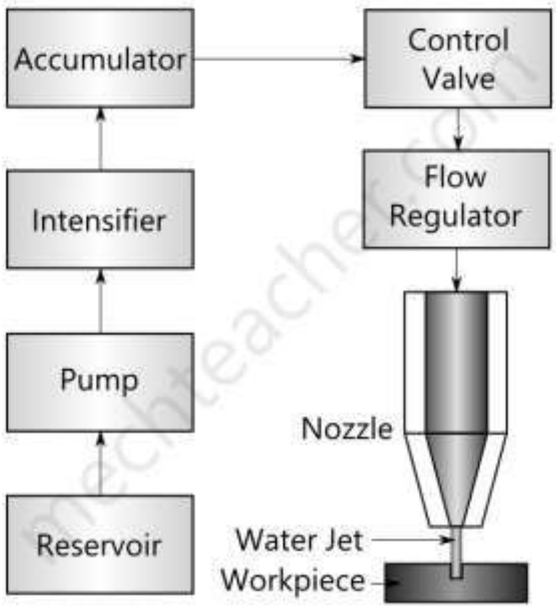
- Metal removal rate is low.
- In certain circumstances, abrasive particles might settle over the workpiece.
- Nozzle life is less.
- Nozzle should be maintained periodically.
- Abrasive Jet Machining cannot be used to machine soft materials.

Water Jet Machining:

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.

Water Jet Machining: *Construction*





The apparatus of water jet machining consists of the following components:

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.

Water Jet Machining: *Working*

- 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.

Water Jet Machining: *Applications*

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

Water Jet Machining: *Advantages*

- Water jet machining is a relatively fast process.
- It prevents the formation of heat affected zones on the workpiece.
- It automatically cleans the surface of the workpiece.
- WJM has excellent precision.
- Tolerances of the order of ±0.005" can be obtained.
- It does not produce any hazardous gas.
- It is eco-friendly.

Water Jet Machining: Dis*advantages*

- Only soft materials can be machined.
- Very thick materials cannot be easily machined.
- Initial investment is high.

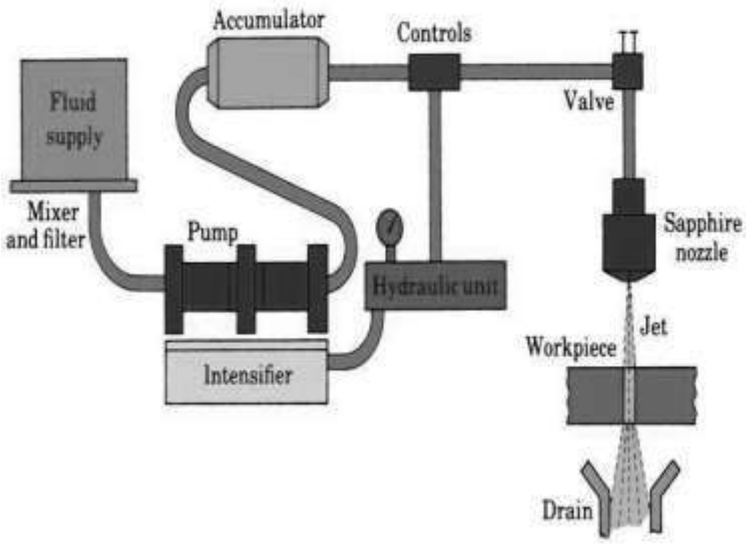
Abrasive Water Jet Machining:

It uses water jet working as a tool to cut the metal. It is same as **abrasive jet machining** except working medium is water. In this machining process a high speed steam of water jet impinge on the work piece which removes metal from contact surface by erosion. For machining hard materials like carbide, ceramic, etc. abrasive particles added in water steam which increases its machining quality. This process is known as abrasive water jet machining. It is mostly used in mining industries, aerospace industries for cutting required shape.

Abrasive Water Jet Machining: *Principle*

This process works on basic principle of water erosion. In this process, a high speed well concentrated water jet is used to cut the metal. It uses kinetic energy of water particle to erode metal at contact surface. The jet speed is almost 600 m/s. It does not generate any environmental hazards. For cutting hard materials, abrasive particles are used in water jet These abrasive particles erode metal from contact surface.

Abrasive Water Jet Machining: *Construction*



Hydraulic Pump: In the water jet machining process a **hydraulic pump** is used to pump the water from storage tank for machining process. It is connected by an electric motor of about 100 Horse power.
Hydraulic Intensifier: As the name implies, it is used to increase the water pressure for further process. Hydraulic intensifier accept water from pump at a small pressure about 4 bar. The water pressure at outlet of intensifier is about 3000-4000 bars.
Hydraulic Accumulator: Hydraulic accumulator is used when large amount of pressure energy is required for an instant. It used to eliminate pressure fluctuation It supplies fluid at high pressure when required.
Tubing System: Tubes are used to supply high pressure water to the nozzle for further cutting process. It increase the kinetic energy of fluid. It diameter is about 10-14 mm. It provide flexible movement and does not allow any significant loses.
Flow regulator: Flow regulators are used to regulate the flow according to cutting requirement. For high cutting load, high pressurized water is supplied at high rate.
Abrasive: Abrasive particles are used in abrasive water jet machining for machine hard material. Generally Aluminium oxide, Silicon carbide etc. used as abrasive particles.
Nozzle: As we know, **nozzles** are used to convert pressure energy into kinetic energy. This nozzle convert high pressure of water into high velocity jet. This high speed water jet strikes at work surface which is used for machining. There is possibility of erosion at orifice of the nozzle due to high pressure water jet. Therefor high wear resistance material is used for nozzle. The size of nozzle is about 0.2 – 0.4 mm. If abrasive water jet machining is used, abrasive particles mixed in water stream before entering into nozzle.
Drain and Catcher : The drain and catcher system is used to remove debris and other machined particle form water. It separate metal particle from water and this water is further send to reservoir. It also used to reduce noise associate with WJM.

Abrasive Water Jet Machining: ***Working***
First water is filled in water reservoir. It provides water for cutting operation. A pump sucks water from water reservoir and send it to intensifier. Intensifier increases the water pressure from 4 bar to 4000 bars. It sends water to accumulator which store some pressurize water. This high pressure water now sends through tubing system to nozzle. The water passes through flow regulator valve which regulate the flow. Now this high pressure water enters into nozzle. Nozzle converts some pressure energy of water into kinetic energy. A high speed high pressurize water jet is available at nozzle exit. This water jet send to strike at work surface. It erode metal from the contact surface. Thus metal removal take place.

Abrasive Water Jet Machining: ***Applications***
- It is used in aerospace industries.
- Abrasive water jet machining is used to cut hard metal like stainless steel, titanium, Inconel etc.
- It is used to machining or cutting reinforced plastic.
- Use to cut stone which reduce dust in environment.
- Used to machining PCB.

Abrasive Water Jet Machining: ***Advantages***
- It does not change mechanical properties of work piece. It is useful for machining heat sensitive material.
- It is environment friendly because it does not form any dust particle and used water as cutting fluid.

- Good surface finish.
- No physical tool is required.
- It can cut both soft and hard material. For machining soft materials, water jet machining is used and for machining hard materials, abrasive water jet machining is used.

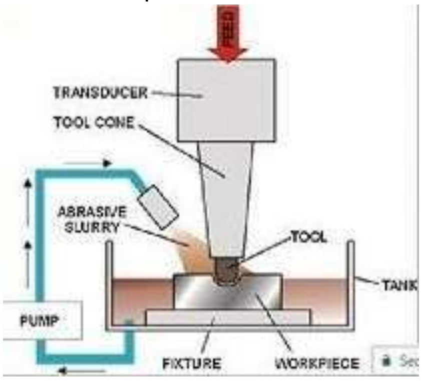
Abrasive Water Jet Machining: Dis*advantages*

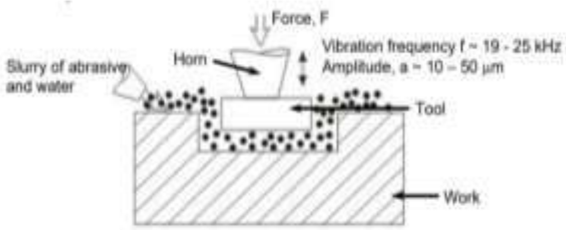
- It cannot used for machining material which degrade in presence of water.
- Low metal removal rate.
- High initial cost.
- Thick material cannot be machined easily.

Ultrasonic Machining:

Ultrasonic machining is a non-traditional machining process. USM is grouped under the mechanical group NTM processes.

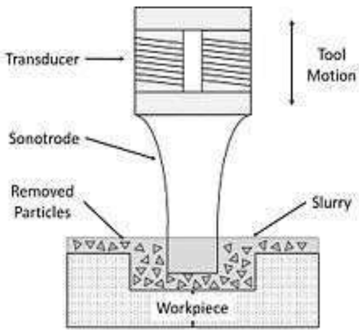
Fig. briefly depicts the USM process.





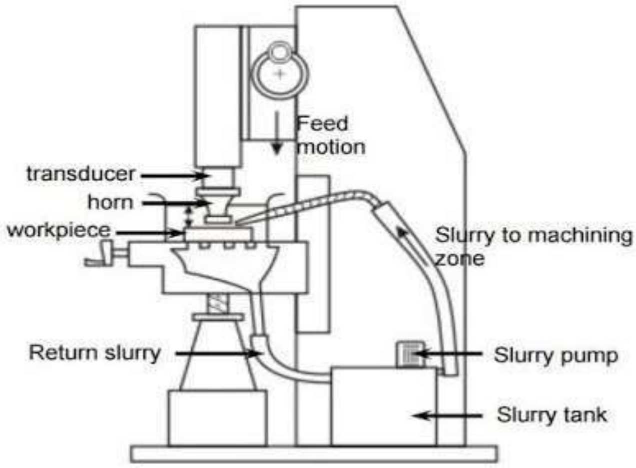
In ultrasonic machining, a tool of desired shape vibrates at an ultrasonic frequency (19 ~ 25 kHz) with an amplitude of around 10 – 50 μm over the workpiece. Generally the tool is pressed downward with a feed force, F. Between the tool and workpiece, the machining zone is flooded with hard abrasive particles generally in the form of a water based slurry. As the tool vibrates over the w/p, the abrasive particles act as the indenters and indent both the work material and the tool. The abrasive particles, as they indent, the work material, would remove the same, particularly if the work material is brittle, due to crack initiation, propagation and brittle fracture of the material. Hence, USM is mainly used for machining brittle materials {which are poor conductors of electricity and thus cannot be processed by Electrochemical and Electro-discharge machining (ECM and ED)}.

Ultrasonic Machining: Principle



It works on the same principle of ultrasonic welding. This machining uses ultrasonic waves to produce high frequency force of low amplitude, which act as driving force of abrasive. Ultrasonic machine generates high frequency vibrating wave of frequency about 19000 to 25000 Hz and amplitude about 10-50 micron. This high frequency vibration transfer to abrasive particle contains in abrasive slurry. This leads indentation of abrasive particle to brittle work piece and removes metal from the contact surface.

Ultrasonic Machining: *Construction*



- **Power Source:**

As we know, this machining process requires high frequency ultrasonic wave. So a high frequency high voltage power supply require for this process. This unit converts low frequency electric voltage (60 Hz) into high frequency electric voltage (20k Hz).

- **Magnetostrictive transducer:**

As we know, transducer is a device which converts electric single into mechanical vibration. In ultrasonic machining magnetostrictive type transducer is used to generate mechanical vibration. This transducer is made by nickel or nickel alloy.

- **Booster:**

The mechanical vibration generated by transducer is passes through booster which amplify it and supply to the horn.

- **Tool:**

The tool used in ultrasonic machining should be such that indentation by abrasive particle, does not leads to brittle fracture of it. Thus the tool is made by tough, strong and ductile materials like steel, stainless steel etc.

- **Tool holder or Horn:**

As the name implies this unit connects the tool to the transducer. It transfers amplified vibration from booster to the tool. It should have high endurance limit.

- **Abrasive Slurry:**

A water based slurry of abrasive particle used as abrasive slurry in ultrasonic machining. Silicon carbide, aluminum oxide, boron carbide are used as abrasive particle in this slurry. A slurry delivery and return mechanism is also used in USM.

Ultrasonic Machining: ***Working***

First the low frequency electric current passes through electric supply. This low frequency current converts into high frequency current through some electrical equipment. This high frequency current passes through transducer. The transducer converts this high frequency electric single into high frequency mechanical vibration. This mechanical vibration passes through booster. The booster amplifies this high frequency vibration and send to horn. Horn which is also known as tool holder, transfer this amplified vibration to tool which makes tool vibrate at ultrasonic frequency. As the tool vibrates, it makes abrasive particle to vibrate at this high frequency. This abrasive particle strikes to the work piece and remove metal form it.

Ultrasonic Machining: ***Applications***

- This machining is used to machine hard and brittle material like carbide, ceramic, glass etc.
- This is used in machining of die and tool of drill, wire drawing machine etc.
- Used in fabrication of silicon nitrite turbine blade.
- It is used to cut diamond in desire shape.
- It is used machining of machining non-conductive hard material which cannot be machined by ECM or EDM due to poor conductivity.

Ultrasonic Machining: ***Advantages***

- Hard material can be easily machined by this method.
- No heat generated in work so there is no problem of work hardening or change in structure of work piece.
- Non-conductive metals or non-metals, which cannot be machined by ECM of EDM can be machined by it.
- It does not form chips of significant size.

Ultrasonic Machining: Dis*advantages*

- It is quite slower than other mechanical process.
- Tool wear is high because abrasive particle affect both work-piece and tool.
- It can machine only hard material. Ductile metal cannot be machine by this method.
- It cannot used to drill deep hole.

2. Electrical Energy based Unconventional Machining Processes:

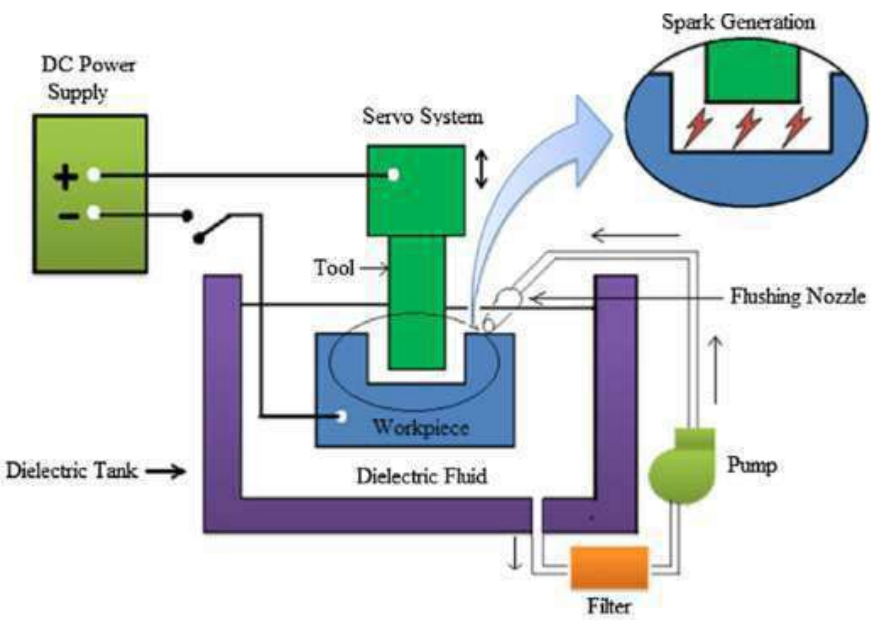
Here, electric spark discharge is used to cut and machine the workpiece. In electrical energy based processes thousands of sparks are produced every second. These sparks increase the temperature of the workpiece, melt the unwanted portions and vaporizes those portions. A dielectric fluid is used for cleaning the workpiece and facilitating a smooth spark discharge. Processes that come under this category are:

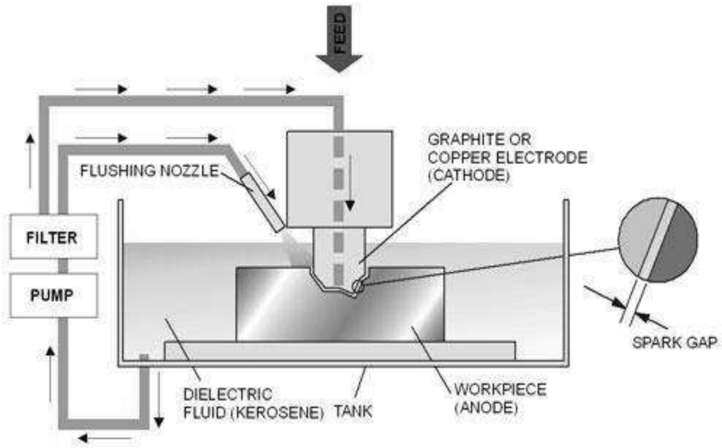
- Electrical Discharge Machining
- Wire Cut Electrical Discharge Machining

Electrical Discharge Machining (EDM)

Electrical Discharge Machining (EDM) is a nontraditional machining and electro thermal process in which material from the workpiece is removed by using electrical discharges (sparks). In EDM machine the material is removed by rapidly recurring (repeating) discharges of current in between the electrodes. The electrodes are separated by dielectric liquid and a high voltage is applied across it. It is used to machine those materials which are difficult to machine and have high strength temperature resistance. EDM can be used to machine only electrically conductive materials. Otherwise it cannot be used. One of the electrodes is called as tool and other is called as workpiece. Here the tool is connected with the negative terminal of the power supply and the workpiece is connected with the positive terminal.

Electrical Discharge Machining (EDM): *Principle*

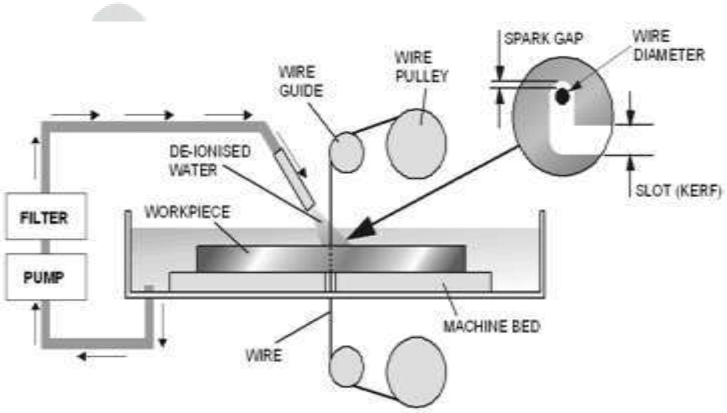




In Electrical discharge machining; a potential difference is applied across the tool and w/p in pulse form. The tool and workpiece must be electrically conductive and a small gap is maintained in between them.
The tool and workpiece is immersed in a dielectric medium (kerosene or deionized water). As the potential difference is applied, electrons from the tool start to move towards the workpiece. Here the tool is negative and w/p is positive.
The electrons moving from the tool to the w/p collide with the molecules of dielectric medium. Due to the collision of electrons with the molecule, it gets converted into ions. This increases the concentration of electrons and ions in the gap between the tool and w/p. The electron moves towards the w/p and ions towards the tool. An electric current is set up in between the tool and w/p and called as plasma. As the electrons and ions strikes the w/p and tool, its kinetic energy changes to heat energy.
The temperature of the heat produced is about 10000 degree Celsius. This heat vaporizes and melts the material from the workpiece. As voltage is break down, the current stops to flow between the tool and w/p and the molten material in the w/p is flushed by circulating dielectric medium leaving behind a crater.The spark generation is not continuous because constant voltage is not applied across the electrodes. The voltage is applied in pulse form.

Electrical Discharge Machining (EDM): ***Types***
(i) Ram/Sinker EDM :
This EDM machine consists of tool and workpiece immersed in a dielectric medium. It consists of ram type tool and it may be created according to the shape or form required to produce on the workpiece. It is also called as cavity type or volume EDM.
(ii) Wire EDM:
In wire EDM, thin single-strand wire is used to cut the material from the workpiece. The wire is usually made of brass. A constant gap is always maintain between the wire and w/p. The wire is continuously fed through the workpiece submerged in a tank with dielectric medium. Here spark is generated in the gap between the wire and workpiece.
It is used to cut metal as thick as 300 mm and to make punches, dies, and tools from hard metals that are difficult to cut from other methods.

Electrical Discharge Machining (EDM): ***Equipment.***



Dielectric Reservoir, Pump and Circulating system:
Pump is used to circulate the dielectric medium between the two electrodes (tool and workpiece). Kerosene or deionized water is used as dielectric medium.
Power Generator and Control Unit:
Generator is used to apply potential difference. The voltage used in this machining process is not constant but it is applied in pulse form. A control unit is used to control the different operation during machining process.
Working Tank with Work Holding Devices:
It has working tank with a work holding device. The workpiece is hold in the work holding devices. The tank contains dielectric medium.
Tool Holder:
It is used to hold the tool.
Servo System to Move the Tool:
A servo system is used to control the tool. It maintains the necessary gap between the electrodes (tool and workpiece).

Electrical Discharge Machining (EDM): ***Working***
In EDM, first the tool and w/p is clamped to the machine. After that with the help of a servo mechanism a small gap (of human hair) is maintain in between the tool and workpiece. The tool and workpiece is immersed in dielectric medium (kerosene of deionised water). A potential difference is applied across the Electrode. An electric spark is generated in

between the tool and workpiece. This spark generates a heat of about 10000 degree Celsius. And due to this heat the material from the workpiece starts to vaporize and melts. As the voltage breaks, the dielectric fluid flushes away the molten materials leaving behind a crater. This process keep continue and machined the workpiece.

Electrical Discharge Machining (EDM): *Applications*

- It is mostly used by mold making and dies industries.
- It is used in prototype manufacturing in aerospace, automobile and electronic industries.
- It is used for coinage die making.
- It is used to create small holes in variety of application.
- It is used to disintegrate parts which cannot be disintegrate easily such as broken tools (studs, bolts drill bit and taps) form the workpiece.

Electrical Discharge Machining (EDM): *Advantages*

- It can be used to machine any material that is electrically conductive.
- It can easily machine thin fragile sections such as webs or fins without deforming the part.
- Complex dies sections and molds are produced accurately, faster and at lower price.
- It is burr-free process.
- It does not involve contact between the tool and workpiece. So delicate sections and work material can be machined easily without any distortion.
- It can machined complex shapes which is not manufactured by the conventional machine tools.
- It can produce tapered holes.

Electrical Discharge Machining (EDM): *Disadvantages*

- It can machine only electrically conductive materials.
- Low rate of metal removal.
- More tool wear during machining.
- Takes extra cost and time for the preparing electrodes for ram/sinker EDM.
- High power consumption.
- Overcut is formed in EDM.

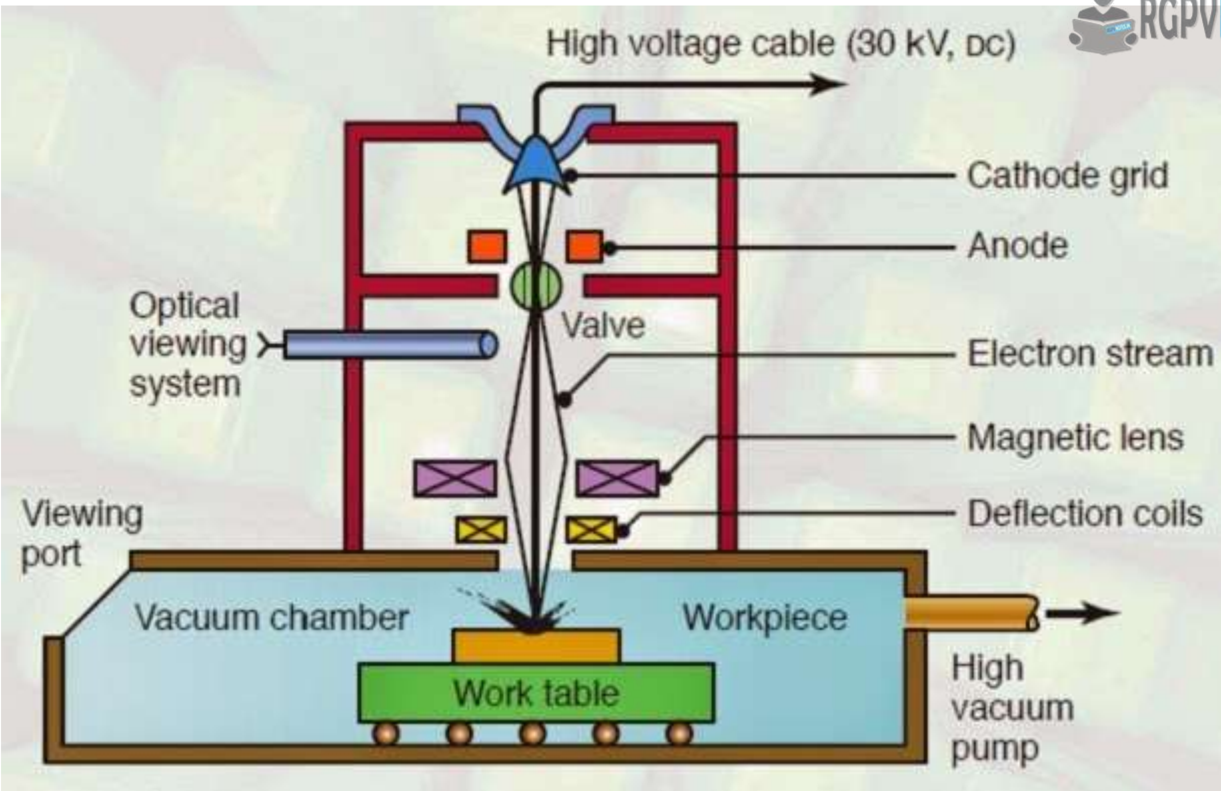
Electron Beam Machining (EBM):

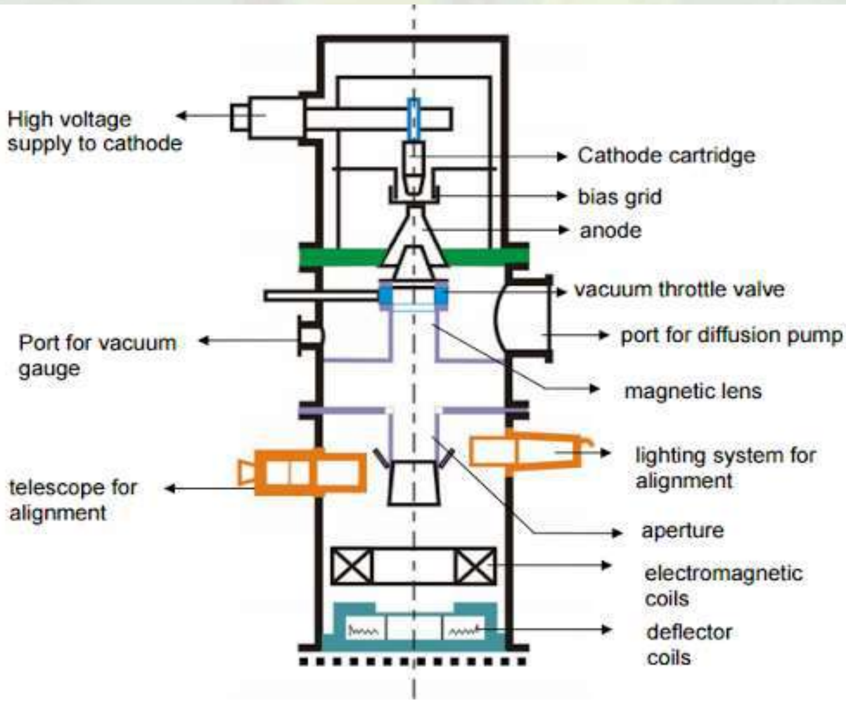
Electron Beam Machining is process in which high velocity electrons are concentrated in a narrow beam and then directed towards the workpiece for machining. When this high velocity electron strikes the workpiece, it melts and vaporizes the material from the workpiece.

Electron Beam Machining (EBM) Working Principle :

In an electron beam machining, the electrons strike the workpiece with a high velocity. As the electron strikes the workpiece, the kinetic energy of the electron changes into heat energy. The heat energy so produced is used to melt and vaporize the materials from the w/p. The whole process takes place in vacuum. Vacuum environment is used to prevent the contamination and avoid collision of electrons with air molecules. If the electrons collide with the air molecules, it will lost its Kinetic energy.

Electron Beam Machining (EBM) : Equipment/Construction





The various parts of the equipment used in EBM machine are

1. Cathode

The cathode is negatively charged and it is used to produce Electrons.

2. Annular Bias Grid

It is present next to the cathode. Annular bias grid is a circular shaped bias grid and prevents the diversion of electrons produced by the cathode. It works as a switch and makes the electron gun to operate in pulse mode.

3. Anode

It is placed after the annular bias grid. It is positively charged. Annular anode attracts the beam of electron towards it and gradually the velocity of the electron increases. As the electron beam leave the anode section, its velocity becomes half of the velocity of light.

4. Magnetic Lenses

The magnetic lenses reduce the divergence of electron beam and shape them. It allows only convergent electrons to pass and captures the low energy divergent electrons from fringes. It improves the quality of the beam.

5. Electromagnetic Lens

It helps the Electron beam to focus on the desired spot.

6. Deflector Coils

The deflector coil carefully guides the high velocity electron beam to a desired location on the workpiece and improves the shape of the holes.

Electron Beam Machining (EBM): Working

In EBM, first the electron is generated by the cathode and an annular biased grid does not allows the electron to diverge. From the annular bias grid, the electron produced by the cathode is attracted towards the anode and gradually its velocity increases. As the electron beam leaves the anode section, its velocity reaches to half of the velocity of the light. After that, it passes to the series of magnetic lenses. The magnetic lenses allows only convergent beam to pass through it and captures the divergent beam from the fringes. And then a high quality electron beam is made to pass through the electromagnetic lens and deflector coils. The electromagnetic lens focuses the electron beam to the desired spot on the workpiece. The deflector carefully guides the beam to the desired locations and improves the shape hole.

Electron Beam Machining (EBM) : Characteristics

- The Electron Beam machine is operated in pulse mode and this is achieved by the biasing annular biased grid.
- The beam current can be as low as 200 µamp to 1 amp.
- The pulse duration achieved in the EBM machine is 50 µs to 15 ms.
- The energy possessed by the pulse is 100 j/pulse.
- It utilizes voltage in the range of 150 kV to 200 kV. And this voltage is used to accelerate Electrons to about 200,000km/s.

Electron Beam Machining (EBM) : Applications

- It is used to produce very small size hole about 100 micro meters to 2 millimeter.
- It is used to produce holes in diesel injection nozzle.
- Used in aerospace industries for producing turbine blade for supersonic engines and in nuclear reactors.

Electron Beam Machining (EBM) : Advantages

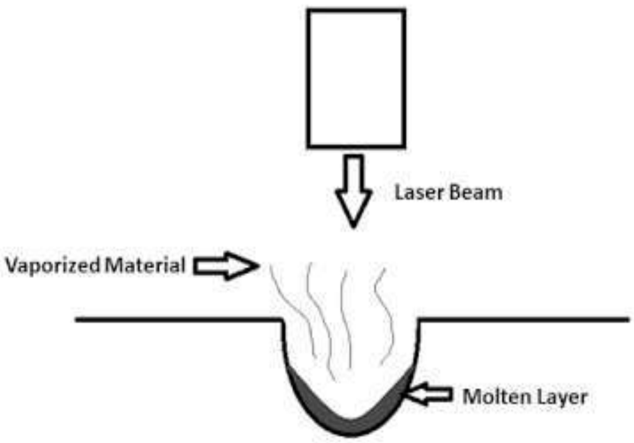
- It can produce bolts of small sizes.
- High accuracy and better surface finish.
- Almost all types of materials can be machined.
- Highly reactive metals such as Al and Mg can be machined easily.
- As it does not apply any mechanical cutting forces on the workpiece, so cost of work holding and fixtures is reduced.

Electron Beam Machining (EBM) : Disadvantages

- High equipment cost.
- Low metal removal rate.
- High skilled operator is required.
- High power consumption.
- Not applicable to produce perfectly cylindrical deep holes.

Laser Beam Machining (LBM)

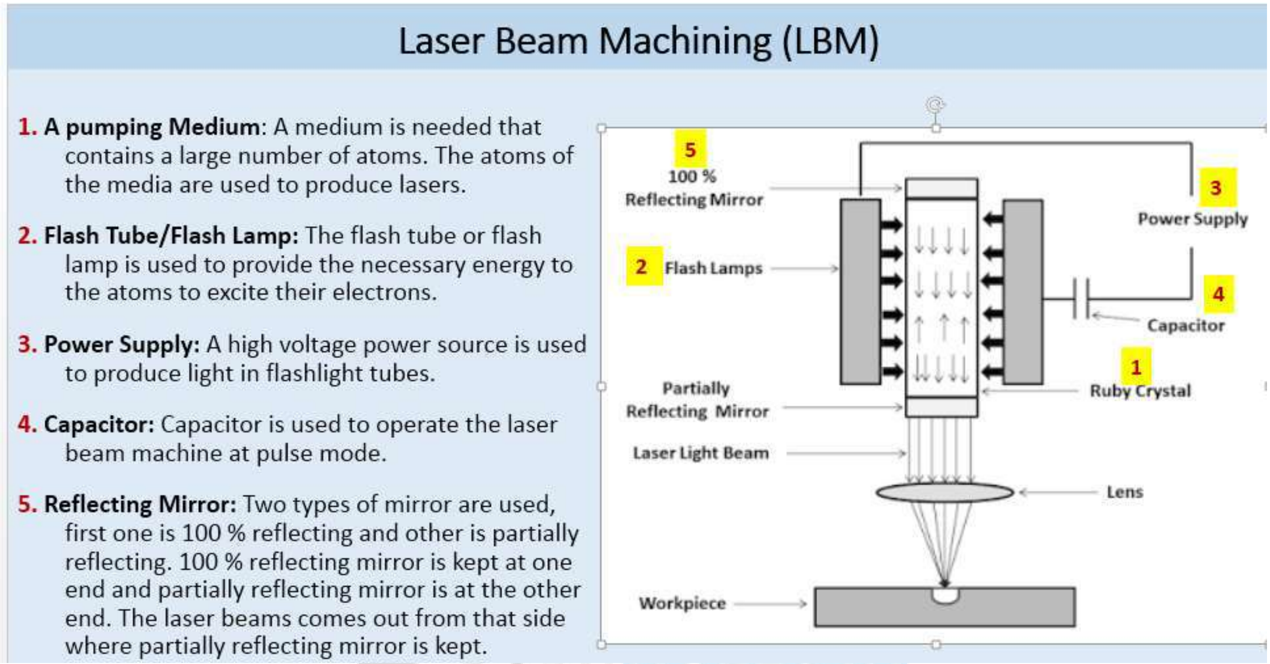
Laser Beam Machining (LBM) is a form of machining process in which laser beam is used for the machining of metallic and non-metallic materials. In this process, a laser beam of high energy is made to strike on the workpiece, the thermal energy of the laser gets transferred to the surface of the w/p (workpiece). The heat so produced at the surface heats, melts and vaporizes the materials from the w/p. Light amplification by stimulated emission of radiation is called **LASER**.



Laser Beam Machining (LBM) : Working Principle

It works on the principle that when a high energy laser beam strikes the surface of the workpiece. The heat energy contained by the laser beam gets transferred to the surface of the w/p. This heat energy absorbed by the surface heat melts and vaporizes the material from the w/p. In this way the machining of material takes place by the use of laser beam.

Laser Beam Machining (LBM) : Equipment/Construction



Laser Beam Machining (LBM) : How Laser is Produced
A high voltage power supply is applied across the flash tube. A capacitor is used to operate the flash tube at pulse mode. As the flash is produced by the flash tube, it emits light photons that contain energy. These light photons emitted by the flash tube are absorbed by the ruby crystal. The photons absorbed by the atoms of the ruby crystals excite the electrons to the high energy level and population inversion (situation when the number of exited electrons is greater than the ground state electrons) is attained. After short duration, this excited electrons jumps back to its ground state and emits a light photon. This emission of photon is called spontaneous emission. The emitted photon stimulates the excited electrons and they starts to return to the ground state by emitting two photons. In this way two light photons are produced by utilizing a single photon. Here the amplification (increase) of light takes place by stimulated emission of radiation. Concentration of the light photon increases and it forms a laser beam. 100 % reflecting mirror bounces back the photons into the crystal. Partially reflecting mirror reflects some of the photons back to the crystal and some of it escapes out and forms a highly concentrated laser beam. A lens is used to focus the laser beam to a desired location.

Laser Beam Machining (LBM) : Working
- A very high energy laser beam is produced by the laser machines.
- This laser beam produced is focused on the workpiece to be machined.
- When the laser beam strikes the surface of the w/p, the thermal energy of the laser beam is transferred to the surface of the w/p.
- This heats, melts, vaporizes and finally removes the material form the workpiece.
- In this way laser beam machining works.

Laser Beam Machining (LBM) : Application
- The laser beam machining is mostly used in automobile, aerospace, shipbuilding, electronics, steel and medical industries for machining complex parts with precision.
- In heavy manufacturing industries, it is used or drilling and cladding, seam and spot welding among others.
- In light manufacturing industries, it is used for engraving and drilling other metals.
- In the electronic industry, it is used for skiving (to join two ends) of circuits and wire stripping.

- In medical industry, it is used for hair removal and cosmetic surgery.

Laser Beam Machining (LBM) : Advantages

- It can be focused to a very small diameter.
- It produces a very high amount of energy, about 100 MW per square mm of area.
- It is capable of producing very accurately placed holes.
- Laser beam machining has the ability to cut or engrave almost all types of materials, when traditional machining process fails to cut or engrave any material.
- Since there is no physical contact between the tool and workpiece. The wear and tear in this machining process is very low and hence it requires low maintenance cost
- This machining process produces object of very high precision. And most of the object does not require additional finishing
- It can be paired with gases that help to make cutting process more efficient. It helps to minimize the oxidation of w/p surface and keep it free from melted of vaporized materials. Produces a very high energy of about 100 MW per square mm of area.
- It has the ability to engrave or cut almost all types of materials. But it is best suited for the brittle materials with low conductivity.

Laser Beam Machining (LBM) : Disadvantages

- High initial cost. This is because it requires many accessories which are important for the machining process by laser.
- Highly trained worker is required to operate laser beam machining machine.
- Low production rate since it is not designed for the mass production.
- It requires a lot of energy for machining process.
- It is not easy to produce deep cuts with the w/p that has high melting points and usually cause a taper.
- High maintenance cost.

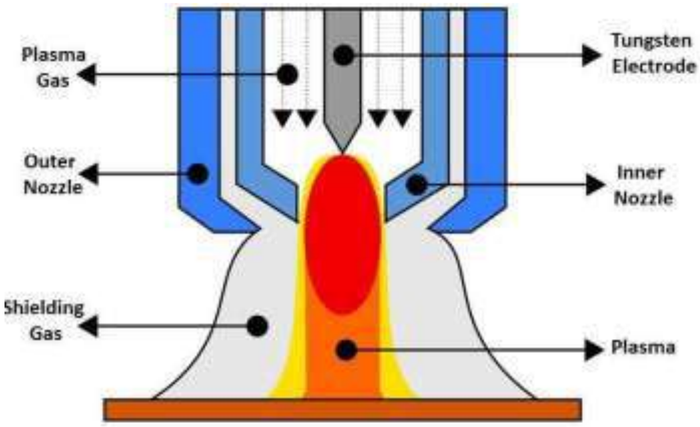
Plasma Arc Machining (PAM)

What is Plasma?

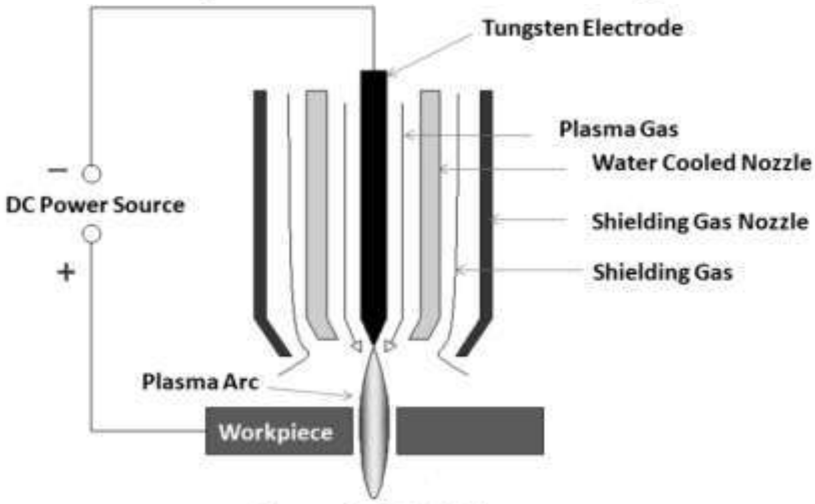
When a gas or air heated at high temperatures, the number of collisions between atoms increases. When you heat the gas above 5500ºC, it partially ionizes into positive ions, negative ions and neutral ions. When you further heat the gas above 11000ºC then, it completely ionizes. Such a completely ionized gas is called as Plasma. Plasma State lies in between temperatures 11,000ºC to 28,000ºC.

Basically, Plasma Arc Machining (PAM) is a metal cutting process where metals are cut with plasma arc, tungsten-inert-gas arc or a torch. It is mostly used for the metals that cannot be cut by an oxyacetylene torch. PAM was introduced in the industries in 1964 as a method that would help in the arc welding and that would require less current supply .Plasma Arc machining is also referred as PAM. In PAM, different gases are used according to different material. Different material means a workpiece. Your workpiece may be made up of aluminum, iron or steel. For example, for aluminum nitrogen is used, for argon hydrogen is used. In most of the cases, nitrogen and hydrogen are used. Plasma Arc Machining employs a high-velocity jet of high-temperature gas to melt and displace material in its path.

Plasma Arc Machining (PAM) : Construction



Principle of Plasma Arc Welding



Plasma Arc Machining

- Plasma arc machining consists of a Plasma gun. Plasma gun has an electrode made up of tungsten situated in the chamber.
- Here, this tungsten electrode is connected to the negative terminal of DC power supply.
- Thus, the tungsten acts as a cathode.
- While the positive terminal of DC power supply is connected to the work piece.
- Thus, work piece acts as an anode.

Plasma Arc Machining (PAM) : *Working*

As we give the power supply to the system, an electric arc develops between the cathodic tungsten electrode and the workpiece. As the gas comes in contact with the arc, there is a collision between the atoms of a gas and electrons of an electric arc and, as a result we get an ionized gas That, means we get the plasma state that we wanted for Plasma Arc machining. Now, this plasma is targeted towards the workpiece with a high velocity and the machining process starts.
One thing to note down is that a high potential difference is applied in order to get the plasma state. In the whole process, high temperature conditions are required. As hot gases come out of nozzle there are chances of overheating. In order to prevent this overheating, a water jacket is used.

Plasma Arc Machining (PAM) : *Process Parameters*

- Current: Up to 500A
- Voltage: 30-250V
- Cutting speed: 0.1-7.5 m/min.
- Plate thickness: Up to 200mm
- Power require: 2 to 200 KW
- Material removal rate: 150 cm^3/min
- Velocity of Plasma: 500m/sec
- Material of workpiece: We can use any metal as material of workpiece. For instance, aluminum and stainless steel are highly recommended for this process.
-

Plasma Arc Machining (PAM) : *Applications*

- It is mostly used for cryogenic, high temperature corrosion resistant alloys.
- It is also used in case of titanium plate up to 8mm thickness.
- PAM is used in nuclear submarine pipe system and for welding steel rocket motor case.
- PAM is prominent for the applications related to stainless tube and tube mills.

Plasma Arc Machining (PAM) : *Advantages*

- In Plasma Arc Machining, hard as well as brittle metals can be easily machined.
- It can be applied to almost all types of metals.
- The best part of this process is that we get high cutting rate.
- We get a better dimensional accuracy in case of machining small cavities.
- It is a simple process to carry out and a very efficient process.
- It takes a big part in automatic repair of jet engine blades.

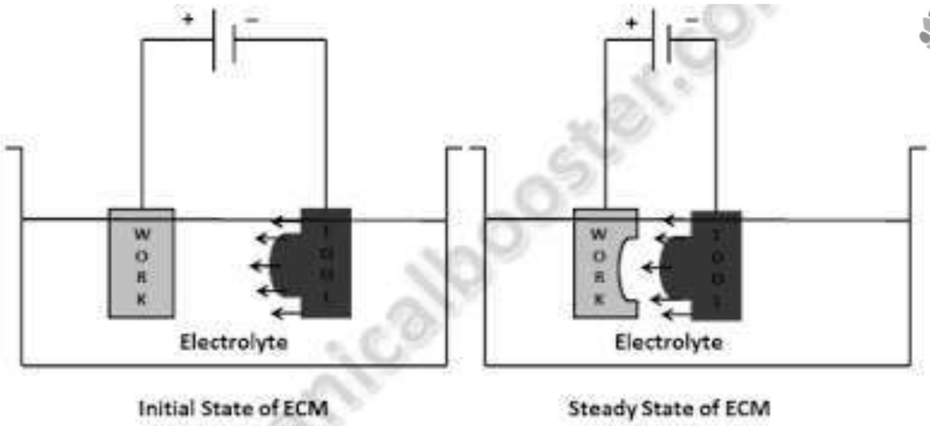
Plasma Arc Machining (PAM) : Dis*advantages*

- PAM involves various equipment but the cost of this equipment is very high.
- This entire machining process consumes high amount of inert gases.
- Production of narrower surfaces takes place which is unnecessary.
- The most harmful part of PAM is that metallurgical changes takes place on the surface.
- The operator or person handling whole process must take proper precautions. This process can affect human eyes so a proper goggles or helmet must be wear by an operator.

Electrochemical Machining (ECM)

Electrochemical machining (ECM) is a machining process in which electrochemical process is used to remove materials from the workpiece. In the process, workpiece is taken as anode and tool is taken as cathode. The two electrodes workpiece and tool is immersed in an electrolyte (such as NaCl). When the voltage is applied across the two electrodes, the material removal from the workpiece starts. The workpiece and tool is placed very close to each other without touching. In ECM the material removal takes place at atomic level so it produces a mirror finish surface. This process is used to machine only conductive materials.

Electrochemical Machining (ECM) : *Principle*



Working Principle of Electrochemical Machining

During electrochemical machining process, the reactions take place at the electrodes i.e. at the anode (workpiece) and cathode (tool) and within the electrolyte. Let's take an example of machining low carbon steel which is mainly composed of ferrous alloys (Fe). We generally use neutral salt solution of sodium chloride (NaCl) as the electrolyte to machine ferrous alloys. The ionic dissociation of NaCl and water takes place in the electrolyte as shown below.

$$NaCl \rightarrow Na^+ + Cl^-$$

$$H_2O \rightarrow H^+ + OH^-$$

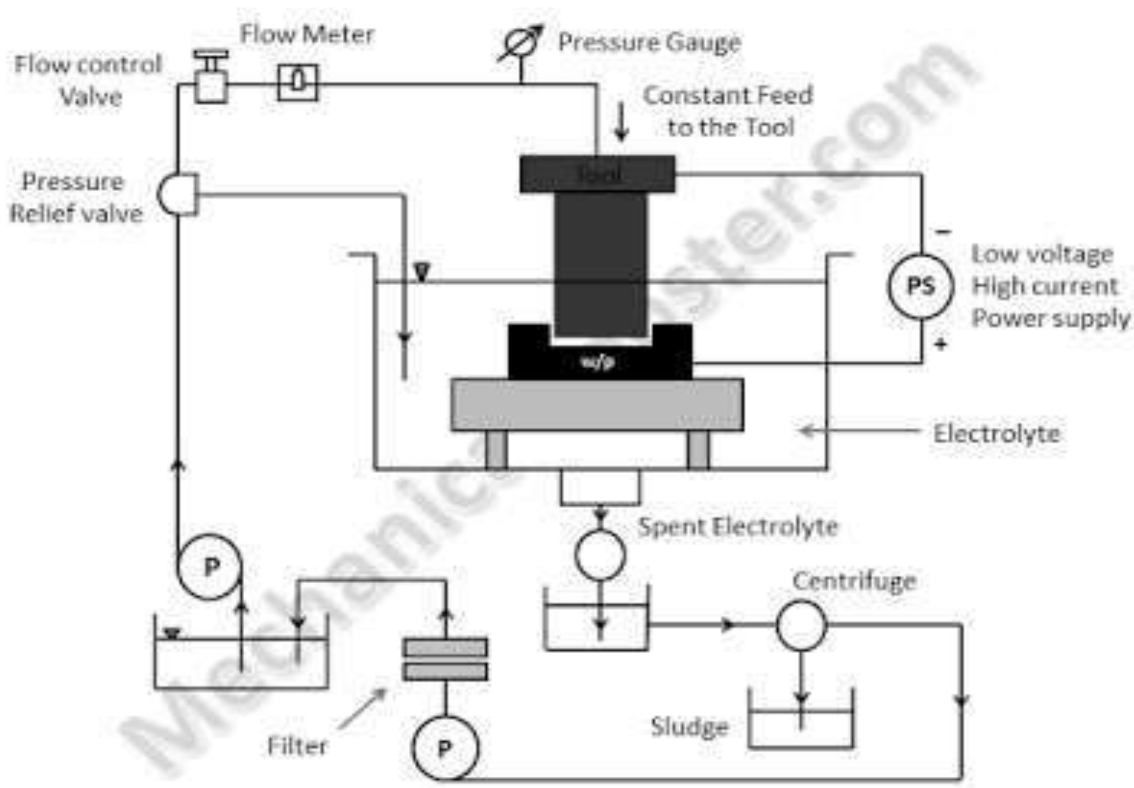
As the potential difference is applied across the electrode, the movement of ions starts in between the tool and w/p. The positive ions moves towards the tool (cathode) and negative ions move towards the workpiece. At cathode the hydrogen ions takes electrons and gets converted into hydrogen gas.

$$2H^+ + 2e^- \rightarrow H_2 \uparrow$$

In the same way the iron atoms comes out from the anode (w/p) as Fe++ ions.

$$Fe \rightarrow Fe^{++} + 2e^-$$

Electrochemical Machining (ECM) : *Equipment/Construction*



Schematic Diagram of Electrochemical Drilling Unit

The ECM system has the following modules-

- Power Supply
- Electrolyte filtration and delivery system
- Tool Feed system
- Working Tank

Electrochemical Machining (ECM): *Working*

First the workpiece is assembled in the fixture and tool is brought close to the workpiece. The tool and workpiece is immersed in a suitable electrolyte. After that, potential difference is applied across the w/p (anode) and tool (cathode). The removal of material starts. The material is removed as in the same manner as we have discussed above in the working principle. Tool feed system advances the tool towards the w/p and always keeps a required gap in between them. The material from the w/p is comes out as positive ions and combine with the ions present in the electrolyte and precipitates as sludge. Hydrogen gas is liberated at cathode during the machining process. Since the dissociation of the material from the w/p takes place at atomic level, so it gives excellent surface finish. The sludge from the tank is taken out and separated from the electrolyte. The electrolyte after filtration again transported to the tank for the ECM process.

Electrochemical Machining (ECM): *Applications*

- ECM is used to machining disk or turbine rotor blade.
- It can be used for slotting very thin walled collets.
- ECM can be used to generate internal profile of internal cam.
- Production of satellite rings and connecting rod, machining of gears and long profile etc.

Electrochemical Machining (ECM): *Advantages*

- It can machine very complicated surface.
- A single tool can be used to machining large number of work-piece. Theoretically no tool wear occur.
- Machining of metal is independent on strength and hardness of tool.
- ECM gives very high surface finish.

Electrochemical Machining (ECM): Dis*advantages*

- High initial cost of machine.
- Design and tooling system is complex.
- Fatigue property of machined surface may reduce.
- Nonconductive material cannot be machined.
- Blind hole cannot be machined form ECM.
- Space and floor area requirement is high compare to conventional machining.

NON DESTRUCTIVE TESTING

Nondestructive testing (NDT) is the process of inspecting, testing, or evaluating materials, components or assemblies for discontinuities, or differences in characteristics without destroying the serviceability of the part or system. In other words, when the inspection or test is completed the part can still be used. In contrast to NDT, other tests are destructive in nature and are therefore done on a limited number of samples ("lot sampling"), rather than on the materials, components or assemblies actually being put into service. These destructive tests are often used to determine the physical properties of materials such as impact resistance, ductility, yield and ultimate tensile strength, fracture toughness and fatigue strength, but discontinuities and differences in material characteristics are more effectively found by NDT. Today modern nondestructive tests are used in manufacturing, fabrication and in-service inspections to ensure product integrity and reliability, to control manufacturing processes, lower production costs and to maintain a uniform quality level. During construction, NDT is used to ensure the quality of materials and joining processes during the fabrication and erection phases, and in-service NDT inspections are used to ensure that the products in use continue to have the integrity necessary to ensure their usefulness and the safety of the public.

NDT Test Methods

Current NDT methods are:

- Acoustic Emission Testing (AE),
- Electromagnetic Testing (ET),
- Guided Wave Testing (GW),
- Ground Penetrating Radar (GPR),
- Laser Testing Methods (LM),
- Leak Testing (LT),
- Magnetic Flux Leakage (MFL),
- Microwave Testing,
- Liquid Penetrant Testing (PT),
- Magnetic Particle Testing (MT),
- Neutron Radiographic Testing (NR),
- Radiographic Testing (RT),
- Thermal/Infrared Testing (IR),
- Ultrasonic Testing (UT),
- Vibration Analysis (VA) and
- Visual Testing (VT).
- **The six most frequently used test methods are MT, PT, RT, UT, ET and VT**

Visual Testing

Visual testing is the most commonly used test method in industry. Because most test methods require that the operator look at the surface of the part being inspected, visual inspection is inherent in most of the other test methods. As the name implies, VT involves the visual observation of the surface of a test object to evaluate the presence of surface discontinuities. VT inspections may be by Direct Viewing, using line-of sight vision, or may be enhanced with the use of optical instruments such as magnifying glasses, mirrors, boroscopes, charge-coupled devices (CCDs) and computer-assisted viewing systems (Remote Viewing). Corrosion, misalignment of parts, physical damage and cracks are just some of the discontinuities that may be detected by visual examinations. Visual inspection is commonly defined as "the examination of a material, component, or product for examination of a material, component, or product for conditions of nonconformance using light and the eyes, conditions of nonconformance using light and the eyes, alone or in conjunction with various aids. Visual inspection often also involves, shaking, listening, feeling, and sometimes even smelling the component being inspected.

Visual inspection consists of at least two major processes. The first is a **search process**. The second is a process of combining relevant knowledge, sensory input, and pertinent logical processes to provide an identification that some anomaly or pattern represents a flaw that poses a risk to the performance of the part. Visual inspection is commonly employed to support other NDT methods. Digital detectors and computer technology have made it possible to automate some visual inspections, this is known as "machine vision inspection." Visual inspection is the most basic and most commonly employed NDT method. It is applicable to a wide variety of material types and product forms. Several characteristics about the part being examined may be determined, which include dimensional conformance, the presence of discontinuities, general fit and wear, and simple discontinuities, and simple cosmetic compliance. It can be performed by direct or indirect methods during various stages of manufacturing or after the component has been placed in-service. The quality of an inspection are affected by four factors

- The quality of the detector (eye or camera).
- The lighting conditions.
- The capability to process the visual data.

- The level of training and attention to detail.

The majority of visual inspections are completed by an inspector, but machine vision is becoming more common. The primary advantage of an inspector is his ability to quickly adapt variety of lighting and other non-typical conditions, and their ability to use other senses. The primary advantage of a machine vision inspection system is their ability to make very consistent and rapid inspections of specific details of a component. Machine vision is primarily used in production applications where a large number of components require inspection.

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