UNITV

Unconventional Machining Processes

- Principles and process parameters electro-chemical machining (ECM)
- Principles and process parameters Laser beam machining (LBM)
- Principles and process parameters plasma arc machining (PAM)
- Principles and process parameters electron beam machining
- Principles and process parameters of Abrasive jet machining (AJM)
- Principles and process parameters water jet machining
- Principles and process parameters ultrasonic machining
- Principle and processes parameters Electrical discharge machining (EDM)

INTRODUCTION:

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

- In this process, tool and work piece are in direct contact with each other.
- In other words, the conventional machining processes involve removal of metal by compression shear chip formation.

Disadvantages of conventional machining processes:-

- In conventional machining , metal is removed by chip formation which is an expensive and difficult process.
- Removal of these chips and their disposal and recycling is a very tedious procedure , involving energy and money.
- Very large cutting forces are involved in this process. so, proper holding of the work piece is most important.

Disadvantages of conventional machining processes:-

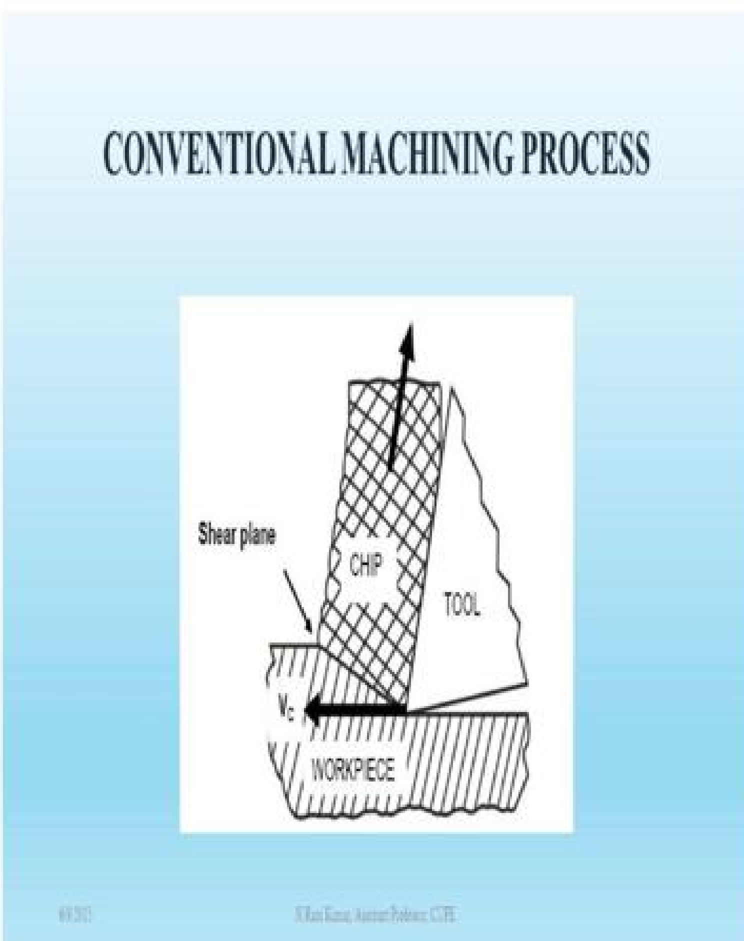
- Due to the large cutting forces and large amount of heat generated between the tool and the work piece interface, undesirable deformation and residual stresses are developed in the work piece.

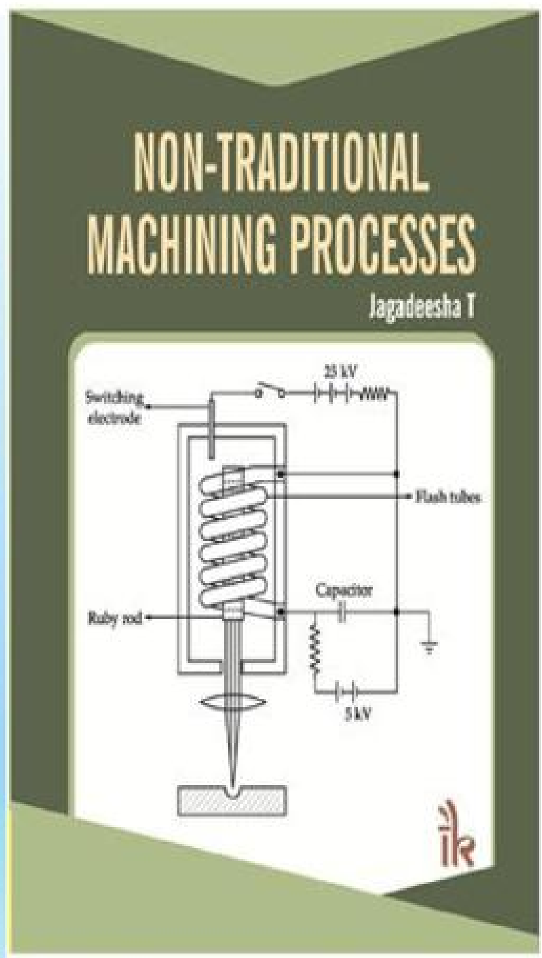
- It is not possible to produce chips by conventional machining process for delicate components like semi conductor.

TO OVERCOME THESE ALL DIFFICULTIES WE ARE GOING FOR UNCONVENTIONAL MACHINING PROCESS.

The unconventional machining:

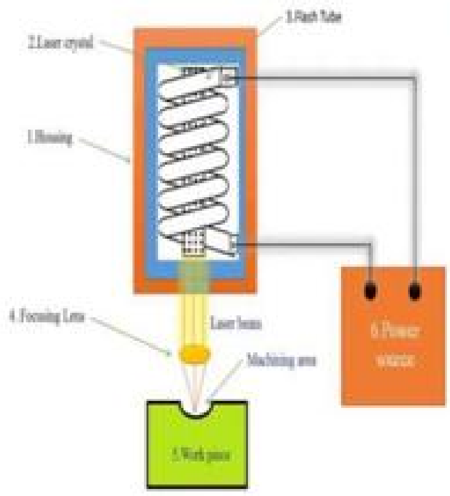
- The unconventional machining processes do not employ a conventional or traditional tool for metal removal, instead they directly **utilize some form of energy** for metal machining.
- In this process, there is no direct physical contact between the tool and the work piece. There fore the tool material need not be harder than the work piece material as in conventional machining.





CONVENTIONAL (Traditional) UNCONVENTIONAL (Nontraditional)

Vs.



Comparison between Conventional and Non-conventional machining :

Sr. No	Conventional	Non-Conventional
1	Direct contact of tool and workpiece.	Tools are non-conventional technique like Laser beam, electric arc etc.
2	Cutting tool is always harder than w/p.	Tool may not be harder and it may not be physical presence.
3	Tool life is less due to high wear.	Tool life is more.
4	Generally Macroscopic chip formation.	Material removal occur with or without chip formation .
5	Material removal takes place due to application of cutting force.	It uses different energy like electrical, Thermo-Chemical etc. to provide machining.
6	Suitable for all material	Not suitable for all material.
7	It cannot be used to make prototype parts very effectively.	It can be used to produce prototype parts very effectively.

NEED FOR UNCONVENTIONAL MACHINING PROCESS

The Need for Advanced Machining Processes

- Traditional machining processes
  - Material removal by mechanical means, such as chip forming, abrasion, or micro-chipping
- Advanced machining processes
  - Utilize chemical, electrical, and high-energy beams
- The following cannot be done by traditional processes:
  - Workpiece **strength and hardness** very high, >400HB
  - Workpiece material too **brittle**, glass, ceramics, heat-treated alloys
  - Workpiece too **slender and flexible**, hard to clamp
  - Part shape **complex**, long and small hole
  - Special **surface and dimensional tolerance** requirements

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Needs for Non Traditional Machining

- Extremely hard and brittle materials are difficult to machine by traditional machining processes.

- When the work piece is too flexible or slender to support the cutting or grinding forces.

- When the shape of the part is too complex.

- Intricate shaped blind hole – e.g. square hole of 15 mm x15 mm with a depth of 30 mm .

- Deep hole with small hole diameter – e.g. φ 1.5 mm hole with l/d = 20 .
- Machining of composites.

Classification of Non-traditional Machining Processes

This classification is carried out depending on nature of energy used for material removal:

Mechanical	Thermo-electric	Chemical	Electro-chemical
• USM • AJM • WJM • AWJM	• EDM • EBM • LBM • PAM	• CHM • PCM	• ECG • EJD • ECM

1. MECHANICAL ENERGY METHODS:

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

Ex:

1. ABRASIVE JET MACHINING (AJM)
2. WATER JET MACHINING (WJM)
3. ULTRASONIC MACHINING (USM)
4. ABRASIVE WATER JET MACHINING (AWJM)

2. THERMAL ENERGY METHODS:

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

Ex:

1. LASER BEAM MACHINING (LBM)

2. PLASMA ARC MACHINING (PAM)

3. ELECTRON BEAM MACHINING (EBM)

3. ELECTICAL ENERGY METHODS:

In these methods electrical energy is directly used to cut the material to get the final shape and shape and size.

Ex:

1. ELECTRO DISCHARGE MACHINING(EDM)
2. WIRE CUT ELECTRICAL DISCHARGE MACHINING(WCEDM)

4. ELECTRO CHEMICAL ENERGY METHODS:-

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

Ex:

ELECTRO CHEMICAL MACHINING(ECM)

ELECTRO CHEMICAL GRINDING(ECG)

5. CHEMICAL ENERGY METHODS:-

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

Ex:

1. CHEMICAL MACHINING.

SUPER ALLOY MEANING:

excellent mechanical strength, resistance to thermal creep deformation, good surface stability, and resistance to corrosion or oxidation

PROCESS SELECTION:- The following points must be considered for the correct selection of the unconventional machining process.

1.Physical Parameters

Physical Parameters of various unconventional machining processes

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	10,000	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	Electrolyte	Dielectric Fluid	Vacuum	Air	Argn 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	Hard and brittle materials

2. SHAPES TO BE MACHINED

Shapes to be Machined by the various machining

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
For grinding	AJM and EDM are best suited
For deburring	USM and AJM are well suited
For threading	EDM is best suited
For clean, rapid cuts and profiles	PAM is well suited
For shallow pocketing	AJM is well suited

3. PROCESS CAPABILITY (OR) MACHINING CHARACTERISTICS

Various Machining Processes Capability

Process	Process Capability			
	Material Removal Rate (mm^3/s) MRR	Surface Finish (μm, CLA)	Accuracy	Specific Power ($KW/cm^3/min$)
LBM	0.10	0.4 to 6.0	25	2700
EBM	0.15 to 40	0.4 to 6.0	25	450
EDM	15 to 80	0.25	10	1.8
ECM	27	0.2 to 0.8	50	7.5
PAM	2500	Rough	250	0.90
USM	14	0.2 to 0.7	7.5	9.0
AJM	0.014	0.5 to 1.2	50	312.5

4. PROCESS ECONOMY

Various Processing Economy

Process	Capital Cost	Tooling and	Power requirement	Efficiency	Total Consumption
EDM	Medium	High	Low	High	High
CHM	Medium	Low	High	Medium	Very low
ECM	Very High	Medium	Medium	Low	Very Low
AJM	Very Low	Low	Low	High	Low
USM	High	High	Low	High	Medium
EBM	High	Low	Low	Very High	Very Low
LBM	Medium	Low	Very Low	Very High	Very Low
PAM	Very Low	Low	Very Low	Very Low	Very Low
Conventional Machining	Very low	Low	Low	Very Low	Low

ADVANTAGES OF UCM

(i)Increases productivity

(ii)Reduces no. of rejected components

(iii)Close tolerance is possible

(iv)Toll material need not be harder than work piece

(v)Machined surface does not have residual stress

LIMITATIONS OF UCM

1. More expensive.
2. Metal removal rate is slow.

1.Electro chemical machining

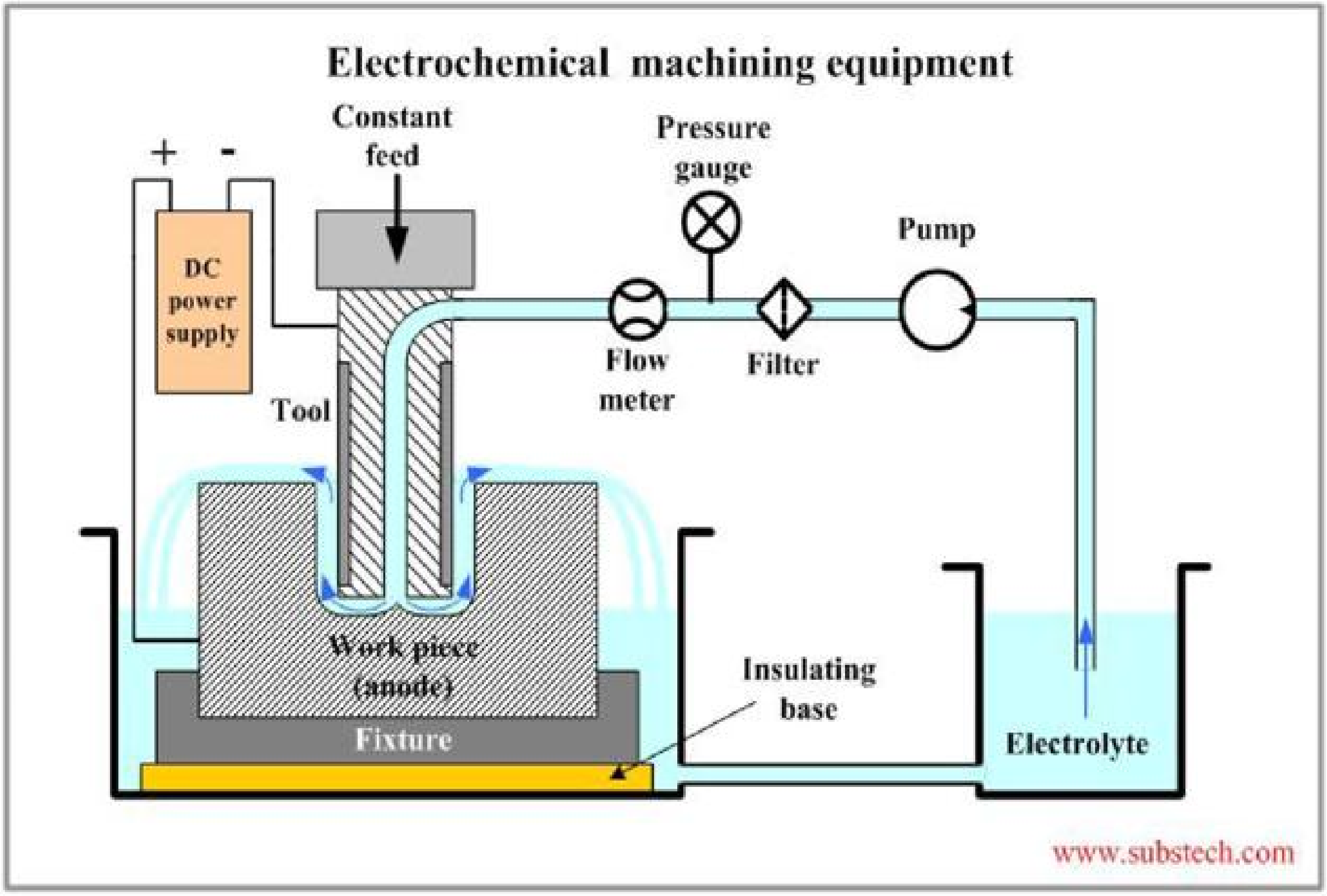
INTRODUCTION:-

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

PRINCIPLE:-

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

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


Electrochemical machining equipment
Constant feed
Pressure gauge
Pump
DC power supply
Flow meter
Filter
Tool
Work piece (anode)
Insulating base
Fixture
Electrolyte
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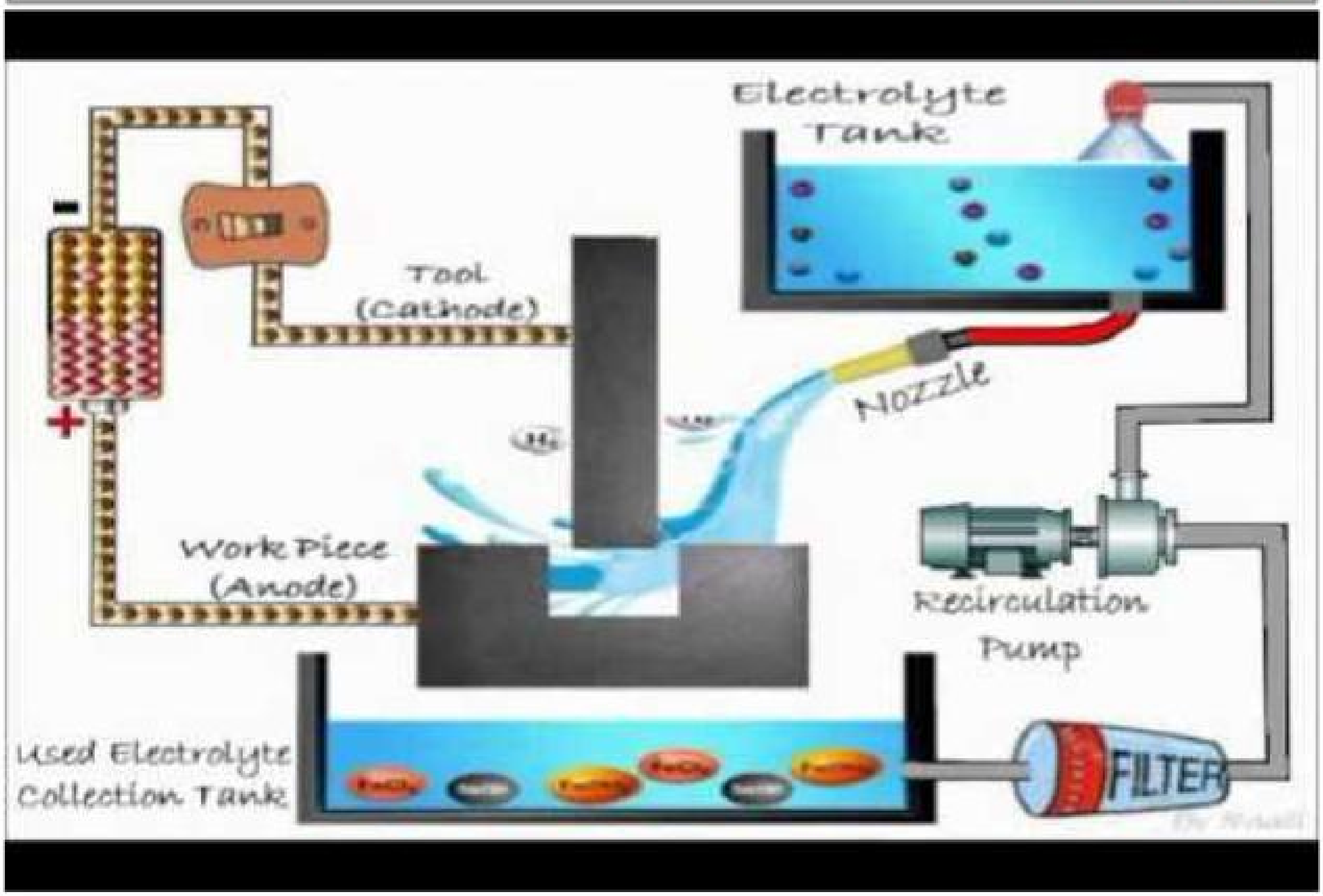
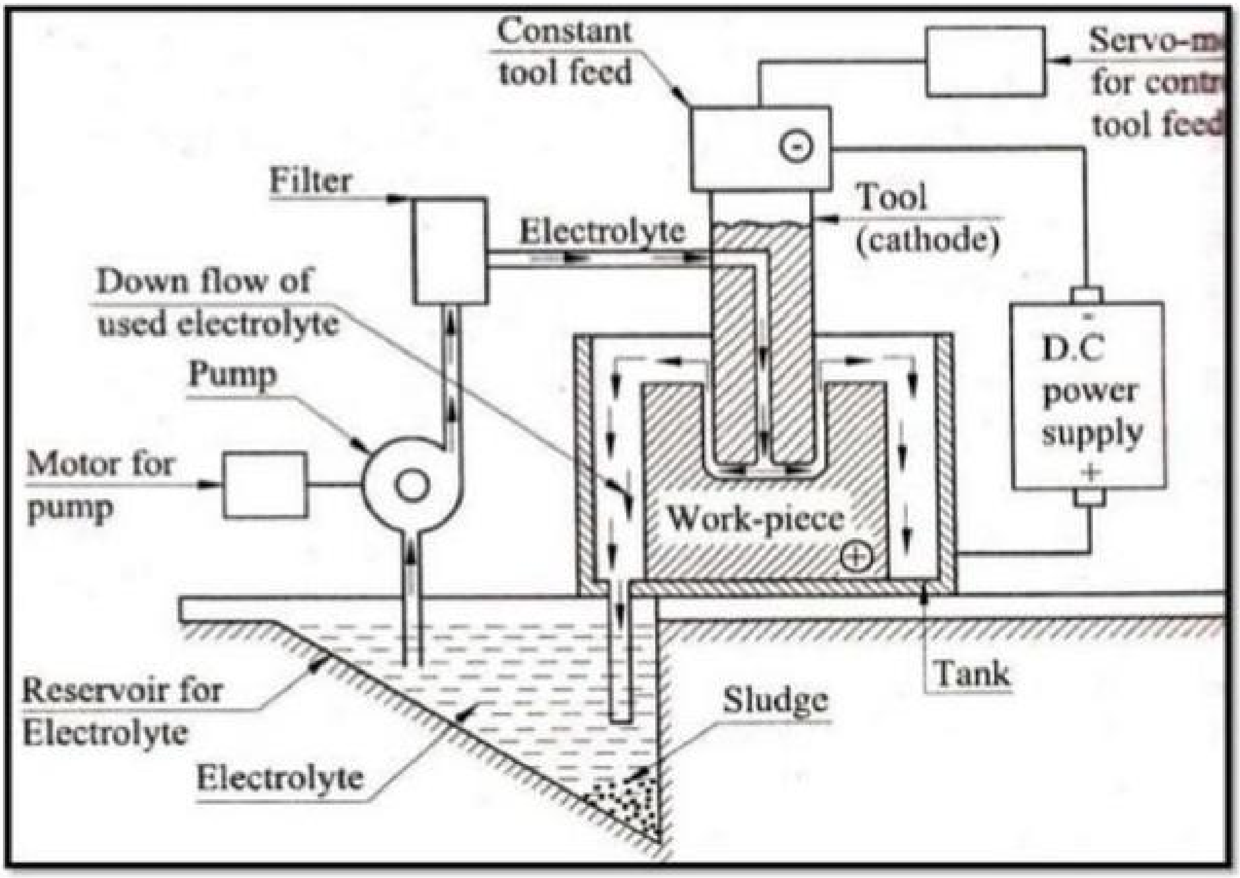

Electrolyte Tank
Tool (Cathode)
Nozzle
Work Piece (Anode)
Recirculation Pump
Used Electrolyte Collection Tank
FILTER



CONSTRUCTION:-

- The schematic arrangement of ECM process is shown in fig.
- It consist of work piece, tool ,servomotor for controlled tool feed , D.C power supply, electrolyte, pump, motor for pump, filter for incoming electrolyte and reservoir for electrolyte.
- A shaped tool (electrode) is used in this process, which is connected to negative terminal (cathode) and the work piece is connected to positive terminal (anode).
- The tools used in this process should be made up of the materials which have enough thermal and electrical conductivity , high chemical resistance to electrolyte and adequate stiffness and machinability.
- The widely used tool materials are stainless steel, titanium, brass and copper.
- The tool is of hollow tabular type as shown in fig . And an electrolyte is circulated between the work and tool.
- Most widely used electrolyte in this process is sodium nitrate solution . Sodium chloride solution in water is a good alternative but it is more corrosive than the former. Some

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

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

WORKING:-

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

> Following reactions takes place while machining of pure iron through ECM using $NaCl+H_2O$ as electrolyte.

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

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

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

Material Removal:

$2Na^+ + 2OH^- \rightarrow 2NaOH$

$Fe^{2+} + 2Cl^- \rightarrow FeCl_2$

$2NaOH + FeCl_2 \rightarrow 2Nacl + Fe(OH)_2$

Advantage of ECM

Advantages:

1. MRR is not dependent on mechanical or physical properties of WP.
2. No surface damage, no burr, low tool wear,
3. **High MRR** for hard-to machine materials
4. Hard to soft materials made of conductive material can be m/ced.
5. Cutting tool can be made from soft material.
6. **Low** heat generated during process.
7. No cutting forces.
8. Excellent surface finish.

Disadvantages:

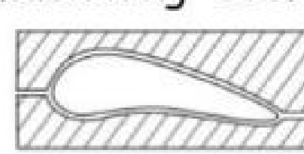
1. Since ECM depends on atomic weight & valency of work material therefore work material should be **electrically conductive**.
2. Low machining accuracy due to its wider machining gap.

Applications of ECM

Application:

1. ECM can machine any electrically conductive work material irrespective of their hardness, strength or even thermal properties.
2. Moreover as ECM leads to atomic level dissolution, the surface finish is excellent with almost stress free machined surface and without any thermal damage so **fragile and thin** section can be machined.
3. ECM is used for : Die sinking, Profiling and contouring, Trepanning , Grinding , Drilling , Micro-machining etc.

Die sinking



3D Profiling

ECM Process Parameter:

- Voltage: 4 to 30 V
- Current: 50 to 40000 A
- MRR: 1600 mm^3/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.

2.LASER BEAM MACHINING

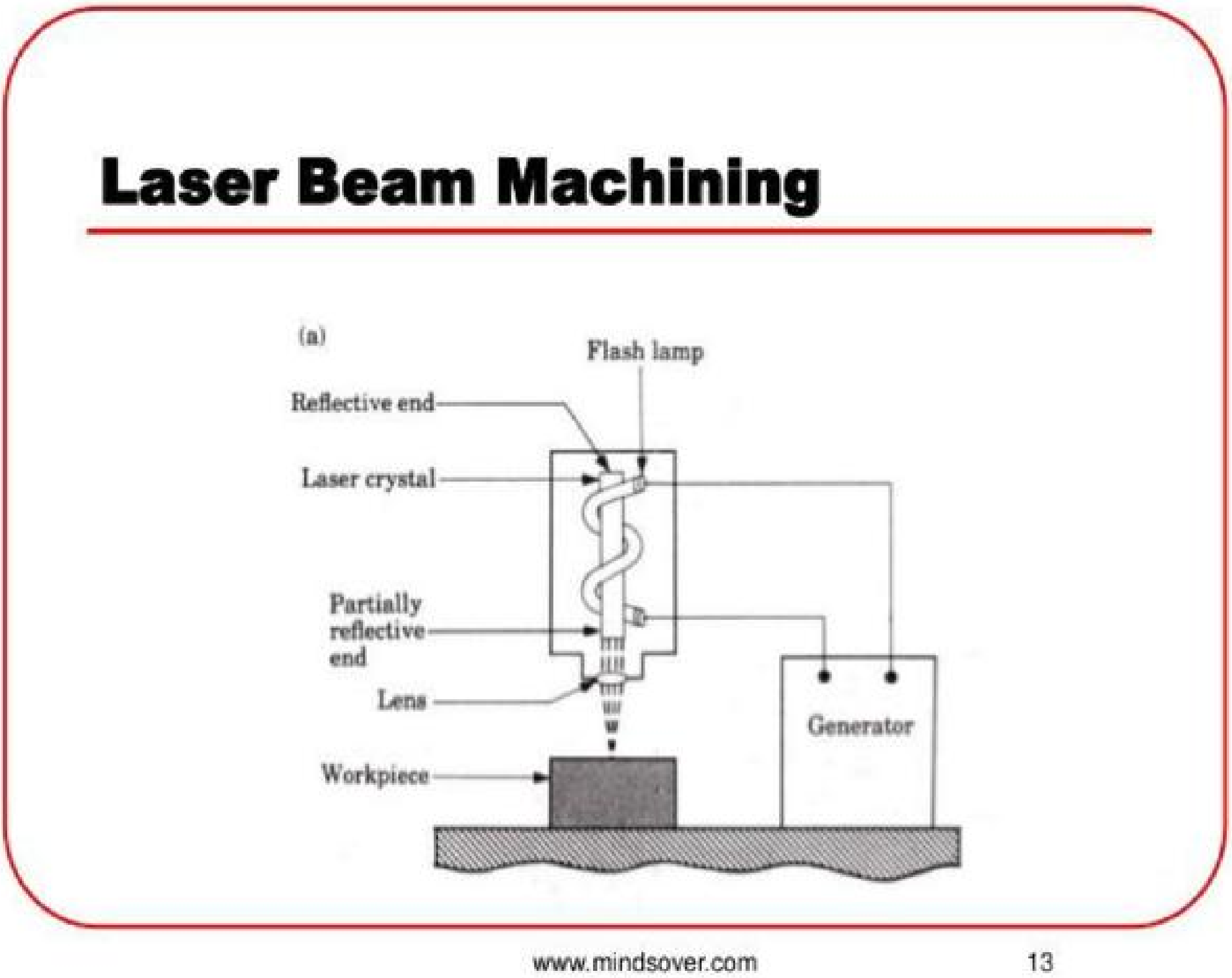
INTRODUCTION:-

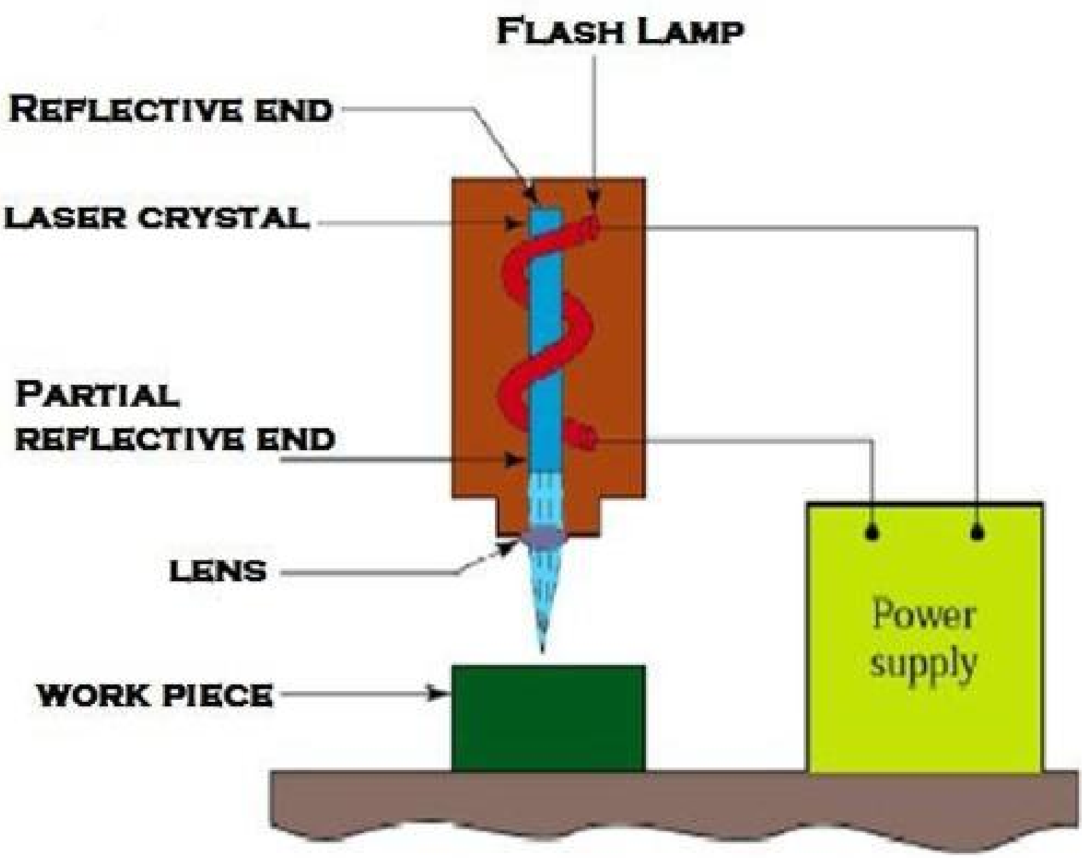
Recent researches in solid state physics have revealed a new device known as "LASER" which means " light amplification by stimulated emission of radiation" . It produces a powerful, monochromatic, collimated beam of light in which the waves are coherent.

Like the electron beam , the laser beam is also used for drilling micro holes up to 25 micro meter and for cutting very narrow slots , with dimensional accuracy +- 0.025 mm . It is very costly method and can be employed only when it is not feasible to machine a work piece through other methods.

PRINCIPLE OF LASER BEAM MACHINING:-

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





LASER BEAM MACHINING PROCESS

CONSTRUCTION:-

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

WORKING:-

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

higher energy levels and it emits energy (photons) when they return to the original levels.

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

LBM Process parameters:

- Voltage: 4500 V
- Pulse duration: 100 microsecond
- MRR: 0.1 mm^3/min
- Surface Finish: 0.5-1.2 μm (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 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.

INTRODUCTION:-

Solids , liquids and gases are the three familiar state of matter. In general when solid is heated, it turns to liquids and the liquids eventually become gases. When a gas is heated to sufficiently high temperature , the atoms (molecules) are spit in to free electrons and ions. The dynamical properties of this gas of free electrons and ions are sufficiently different from the normal unionizes gas. So, it can be considered a fourth state of matter , and is given a new name , PLASMA in other words, when a following gas is heated to a sufficiently high temperature of the order of 11000oc to 28000oc ,it becomes partially ionized and it is known as PLASMA. This is a mixture of free electrons , positively charged ions and neutral atoms. This plasma is used for metal removing process.

WORKING PRINCIPLE:-

In plasma arc machining process, material is removed by directing a high velocity jet of high temperature (11,000oc to

28,000 oc) ionized gas on the work piece . This temperature plasma jet melts the material of the work piece.

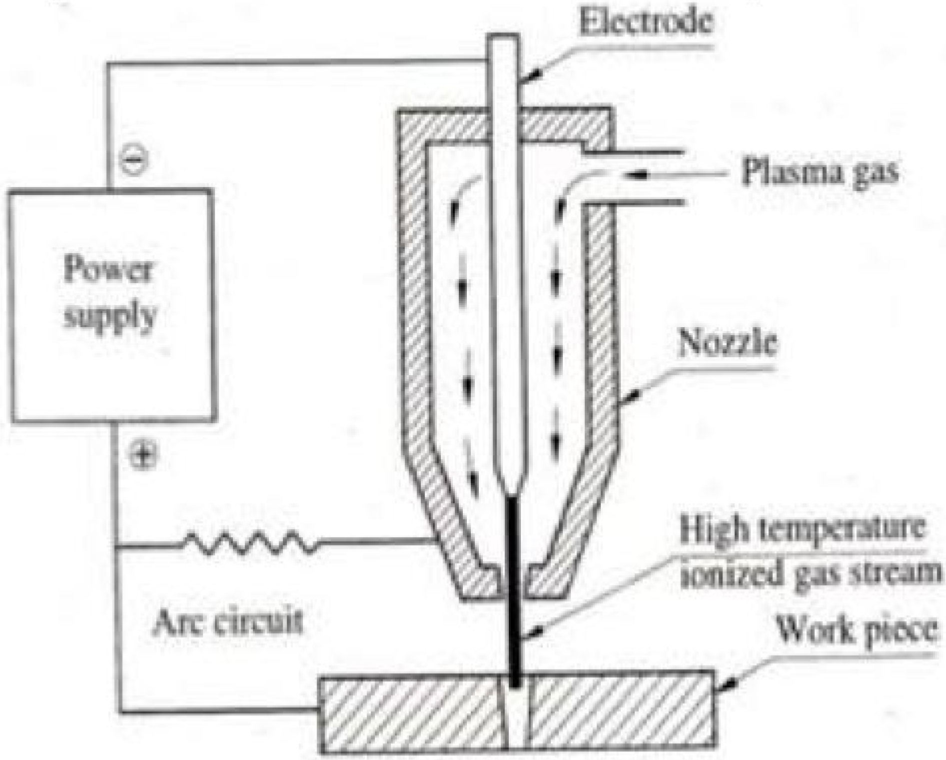


Fig. Schematic arrangement of PAM

CONSTRUCTION:-

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

WORKING:-

- When a D.C power is given to the circuit, a strong arc is produced between the electrode (cathode) and the nozzle (anode).
- A gas usually hydrogen(H2) or Nitrogen (N2) is passed in to the chamber.
- This gas is heated to a sufficiently high temperature of the order of 11,000oc to 28,000 oc by using an electric arc produced between the electrode and the nozzle.
- In this high temperature, the gases are ionized and large amount of thermal energy is liberated.
- This high velocity and high temperature ionized gas (plasma) is directed on the work piece surface through nozzle.
- This plasma jet melts the metal of the work piece and the high velocity gas stream effectively blows the molten metal away.
- The heating of work piece material is not due to any chemical reaction, but due to the continuous attack of plasma on the work piece material. So, it can be subjected to chemical reaction.

PAM Process Parameter:

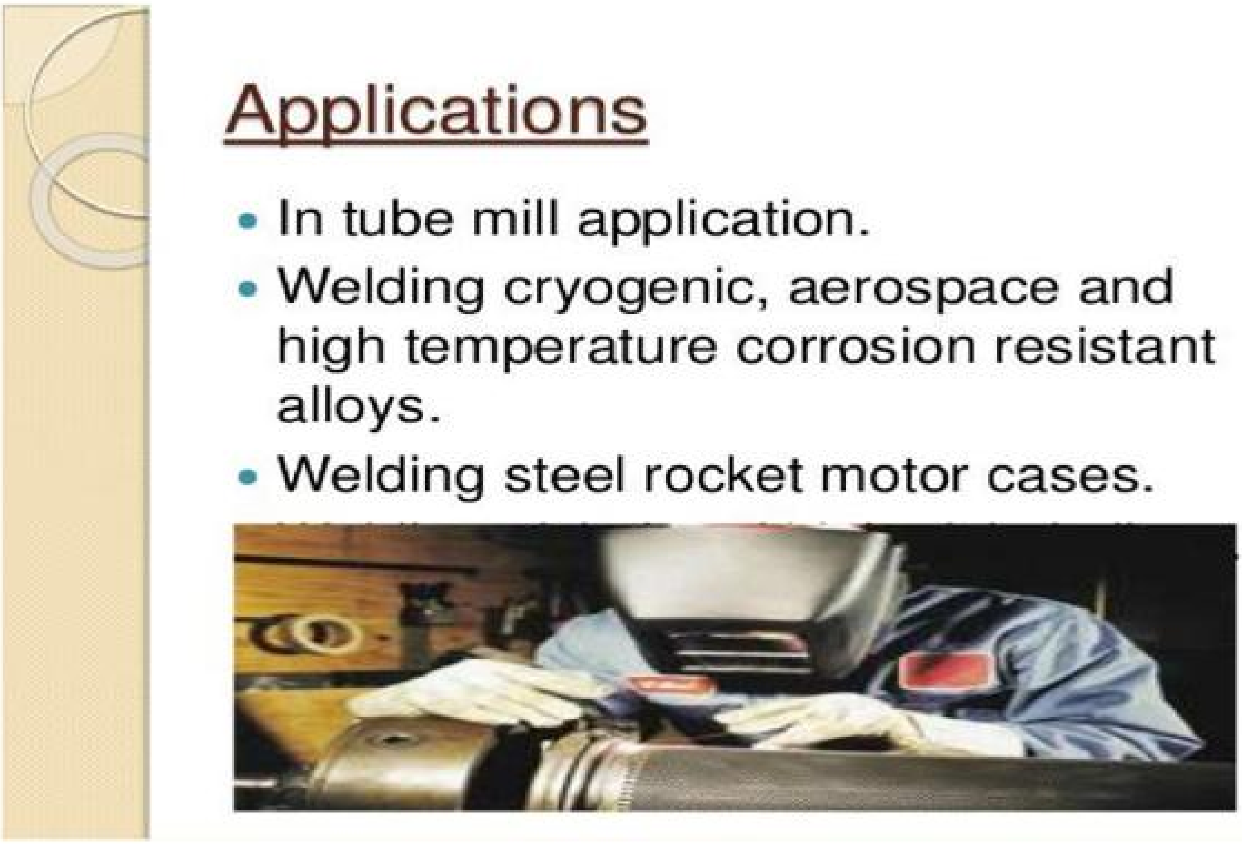
- Voltage: 30-250 V
- Current: Up to 600 A
- Power: 2-200 KW
- Velocity of plasma jet: 500 m/s
- MRR: 1,50,000 mm^3/min

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.



4.WORKING PRINCIPLE OF EDM:-

IN ELECTRICAL DISCHARGE MACHINING , METAL IS REMOVED BY PRODUCING POWERFUL ELECTRIC SPARK DISCHARGE BETWEEN THE TOOL (CATHODE) AND THE WORK MATERIAL (ANODE).

CONSTRUCTION OF EDM:-

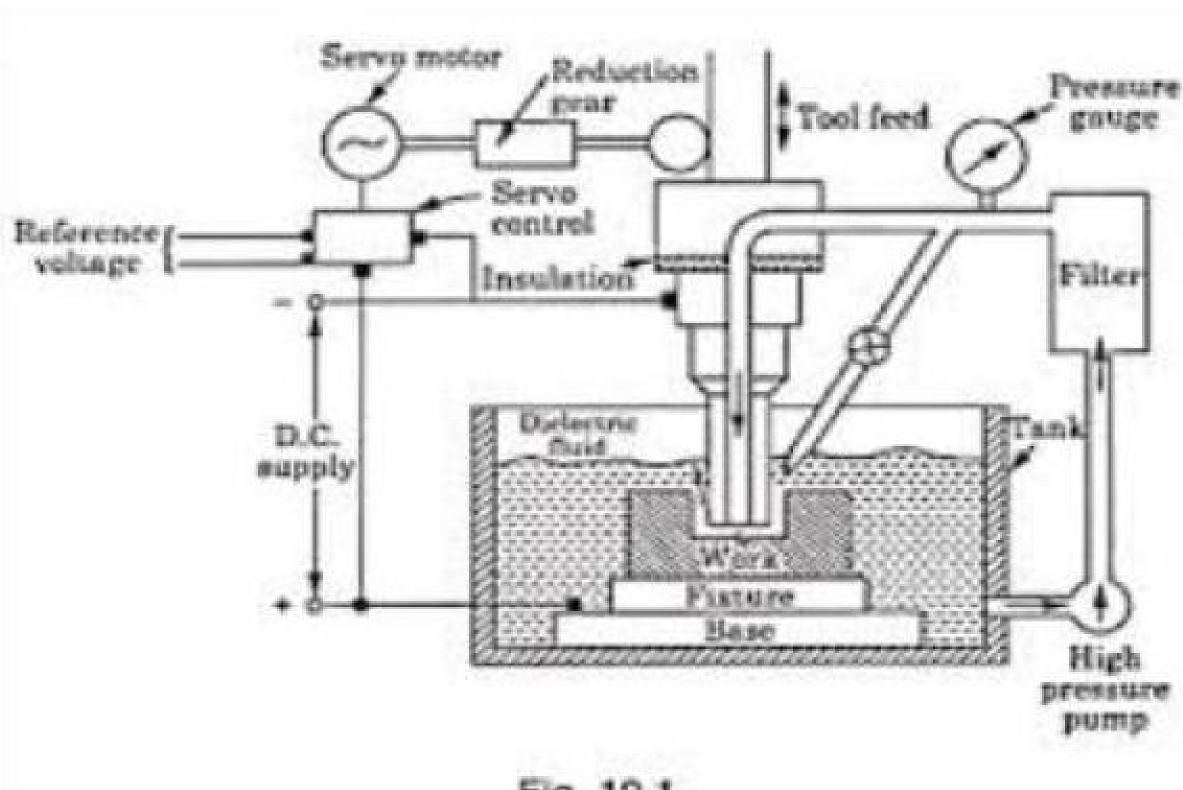


Fig. 10.1

- THE FIG SHOWS THE SCHEMATIC LAY OUT OF THE ELECTRIC DISCHARGE MACHINING PROCESS.
- THE MAIN COMPONENTS ARE THE ELECTRIC POWER SUPPLY, DIEELECTRIC MEDIUM , WORK PIECE , TOOL AND SERVO CONTROL MECHANISM.
- THE WORKPIECE AND THE TOOL ARE ELECTRICALLY CONNECTED TO A D.C POWER SUUPLY.

- THE WORKPIECE IS CONNECTED TO THE POSITIVE TERMINAL OF THE ELECTRIC SOURCE, SO THAT IT BECOMES THE ANODE. THE TOOL IS CONNECTED TO THE NEGATIVE TERMINAL OF THE ELECTRIC SOURCE, SO THAT IT BECOMES THE CATHODE.
- THE TOOL AND WORK PIECE ARE SUBMERGED IN A DIELECTRIC FLUID MEDIUM SUCH AS PARAFFIN , WHITE SPIRIT OR TRANSFER OIL HAVING POOR ELECTRICAL CONDUCTIVITY.

- THE FUNCTION OF THE SERVO MECHANISM IS TO MAINTAIN A VERY SMALL GAP , KNOWN AS ' SPARK GAP' RANGES OF 0.005 TO 0.05 MM BETWEEN THE WORKPIECE AND THE TOOL.

WORKING OF EDM:-

- WHEN THE D.C SUPPLY IS GIVEN TO THE CIRCUIT , SPARK IS PRODUCED ACROSS THE GAP BETWEEN THE TOOL AND THE WORKPIECE.
- WHEN THE VOLATAGE ACROSS THE GAP BECOMES SUFFICIENTLY LARGER (MORE THAN 250 V) , THE HIGH POWER SPARK IS PRODUCED. SO , THE DIE ELECTRIC BREAKS DOWN AND ELECTRONS ARE EMITTED FROM THE CATHODE (TOOL) AND THE GAP IS IONIZED.
- THIS SPARK OCCURS IN AN INTERVAL OF 10 TO 30 MICROSECONDS AND WITH A CURRENT DENSITY OF 15 – 500 A PER MM2 APPROXIMATELY. SO , THOUSANDS OF SPARK – DISCHARGE OCCUR PER SECOND ACROSS THE GAP BETWEEN THE TOOL AND THE WORK , WHICH RESULTS IN INCREASING TEMPERATURE OF ABOUT 1000O DEGREE CENTIGRADES.
- AT THIS HIGH PRESSURE AND TEMPERATURE , WORK PIECE METAL IS MELTED , ERODED AND SOME OF IT IS VAPORISED. IN THIS WAY THE METAL IS REMOVED FROM THE WORKPICE.

THE REMOVED FINE MATERIAL PARTICLES ARE CARRIED AWAY BY DIELECTRIC FLUID CIRCULATED AROUND IT.

ADVANTAGES

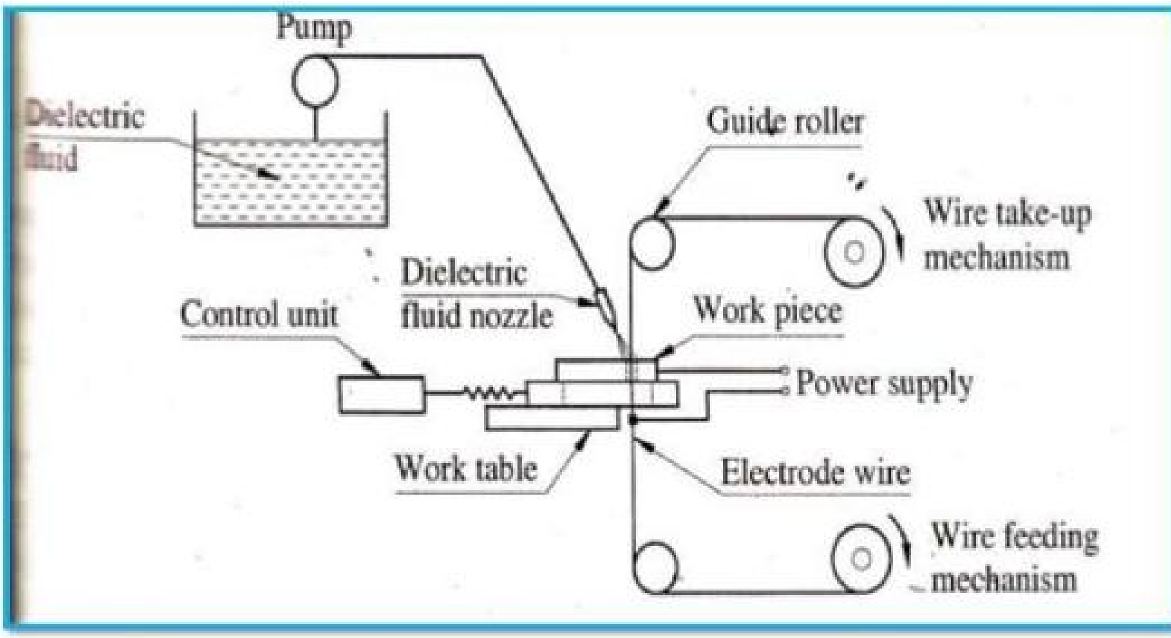
1) Hard & tough metals can be machined with better surface finish.
2) Complex & internal shapes can be machined.
3) No cutting force due to no contact b/w metal and w/p.
4) The surface finish is non-directional.
5) No effects of material hardness and tool wear.
6) Tolerance upto 0.4 micro meter is achieved.
7) Secondary finishing operation can be neglect.
8) No need of Heat treatment before machining.

Disadvantages of EDM

- The slow rate of material removal.
- The additional time and cost used for creating electrodes.
- Reproducing sharp corners on the workpiece is difficult due to electrode wear.
- Power consumption is very high.
- Excessive tool wear occurs during machining.
- Electrically non-conductive materials can´t be machined.

CONSTRUCTION:-

Wire Cut EDM



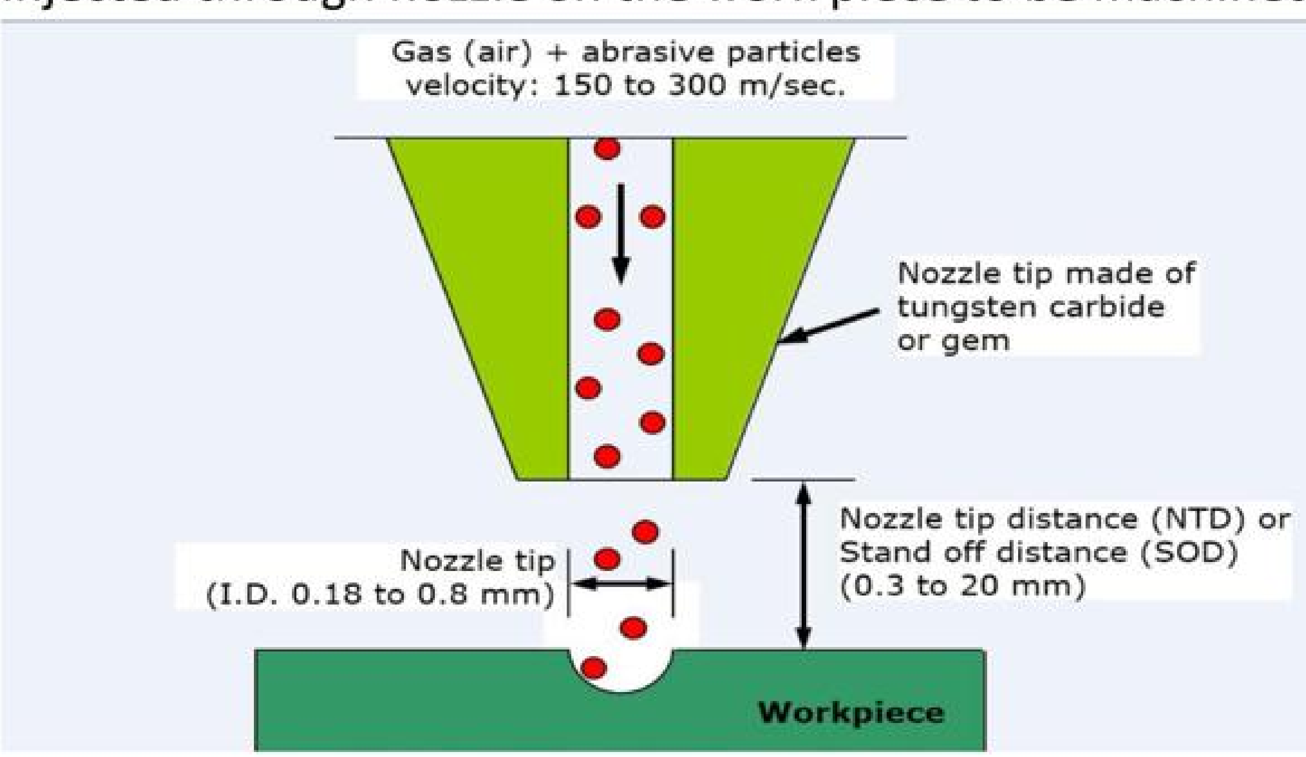
5.abrasive jet machining

INTRODUCTION:-

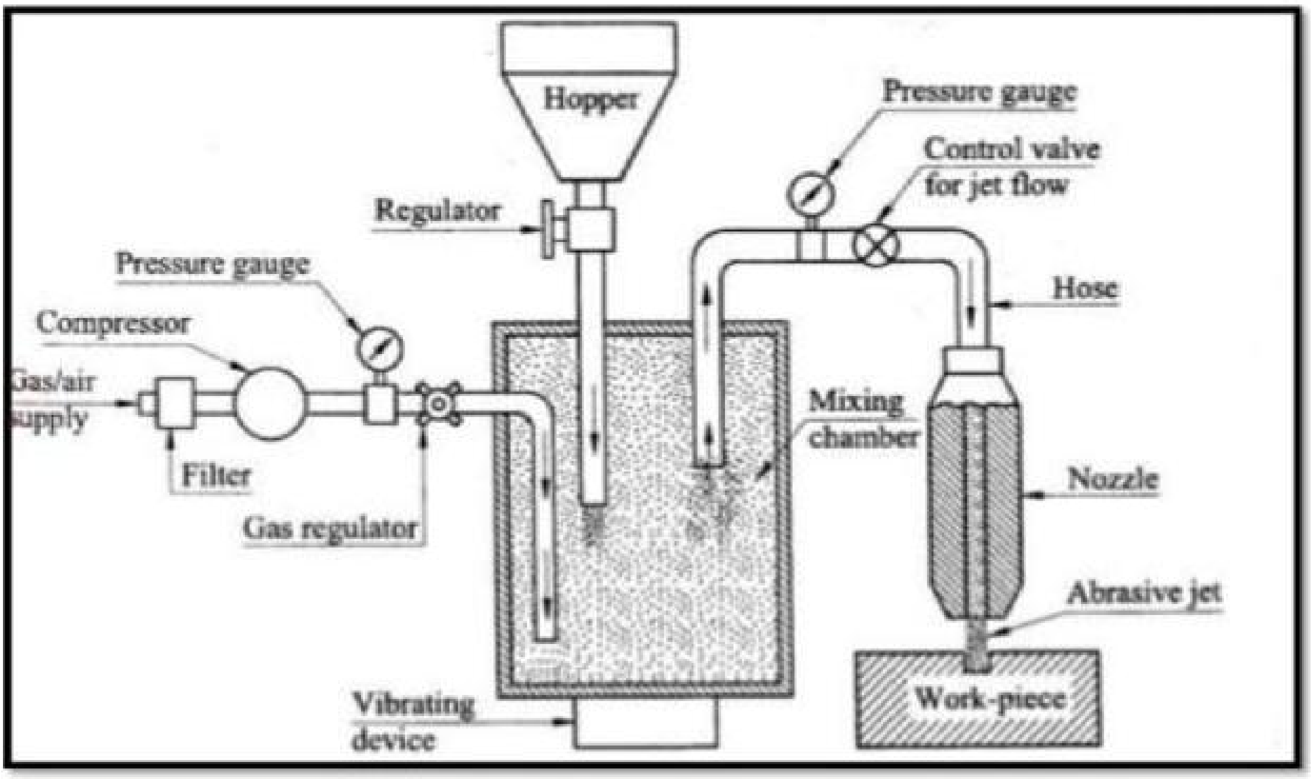
In mechanical energy methods ,the material is removed mechanical erosion of the work piece material.

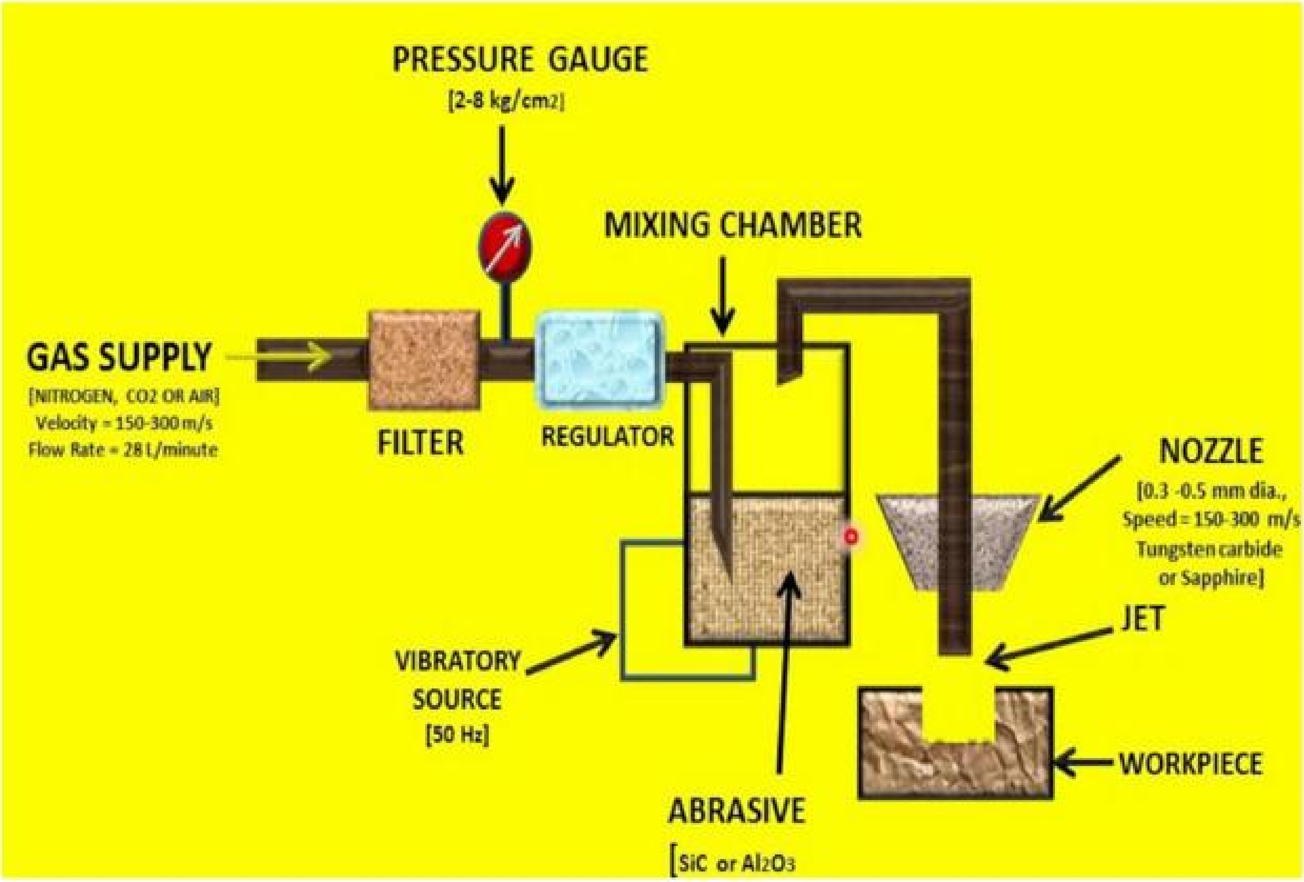
PRINCIPLE OF AJM:-

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



CONSTRUCTION AND WORKING OF AJM





CONSTRUCTION:-

The schematic arrangements of abrasive jet machine is shown in fig

It consists of mixing chamber, nozzle, pressure gauge, hopper, filter, compressor, vibrating device, regulator, etc.

- The gases generally used in this process are nitrogen, carbon dioxide or compressed air.

- The various abrasive particles used in this process are aluminum oxide, silicon carbide, glass powder, dolomite and specially prepared sodium bicarbonate.
- Aluminum oxide(Al_2O_3) is general purpose abrasive and it used in sizes of 10, 25, and 50 micron. Silicon carbide (Sic) is used for faster cutting on extremely hard materials. It is used in sizes of 25 and 50 microns. Dolomite of 200 grit size is found suitable for light cleaning and etching. Glass powder of diameter 0.30 to 0.60 mm are used for light polishing and deburring.
- As the nozzle is subjected to a great degree of abrasion wear , it is made up of hard materials such as tungsten carbide, synthetic sapphire(ceramics), etc ., to reduce the wear rate.
- Nozzles made of tungsten carbide have an average life of 12 to 20 hours ,where as synthetic sapphire nozzle have an average life of 300 hours . Nozzle tip clearance from work is kept at a distance of 0.25 to 0.75 mm.
- The abrasive powder feed rate is controlled by the amplitude of the vibration of mixing chamber. A pressure regulator controls the gas or air flow and pressure. To control the size and shape of the cut , either the work piece or the nozzle is moved by a well designed mechanism such as cam mechanism , pantograph mechanism, etc.

WORKING:-

- Dry air or gas (N_2 or CO_2) is entered in to the compressor through a filter where the pressure of air or gas increased.
- The pressure of the air varies from 2 kg/cm2 to 8kg/cm2.
- Compressed air or high pressure gas is supplied to the mixing chamber through a pipe line. This pipe line carries a pressure gauge and a regulator to control the air or gas and its pressure.
- The fine abrasive particles are collected in the hopper and fed into the mixing chamber. A regulator is incorporated in the line to control the flow of abrasive particles.

- The mixture of pressurized air and abrasive particles from the mixing chamber flows in to the nozzle at a considerable speed.
- Nozzle is used to increase the speed of the abrasive particles and it is increased up to 300 m/s.
- This high speed stream of abrasive particles from the nozzle, impact the work piece to be machined. Due to repeated impacts , small chips of material get loosened and a fresh surface is exposed.
- a vibrator is fixed at the bottom of the mixing chamber. When it vibrates, the amplitude of the vibrations controls the flow of abrasive particles.
- This process is widely used for machining hard and brittle materials, non metallic materials (germanium, glass ,ceramicsand mica) of thin sections. This process is capable of performing drilling, cutting, deburring ,etching and cleaning the surfaces.

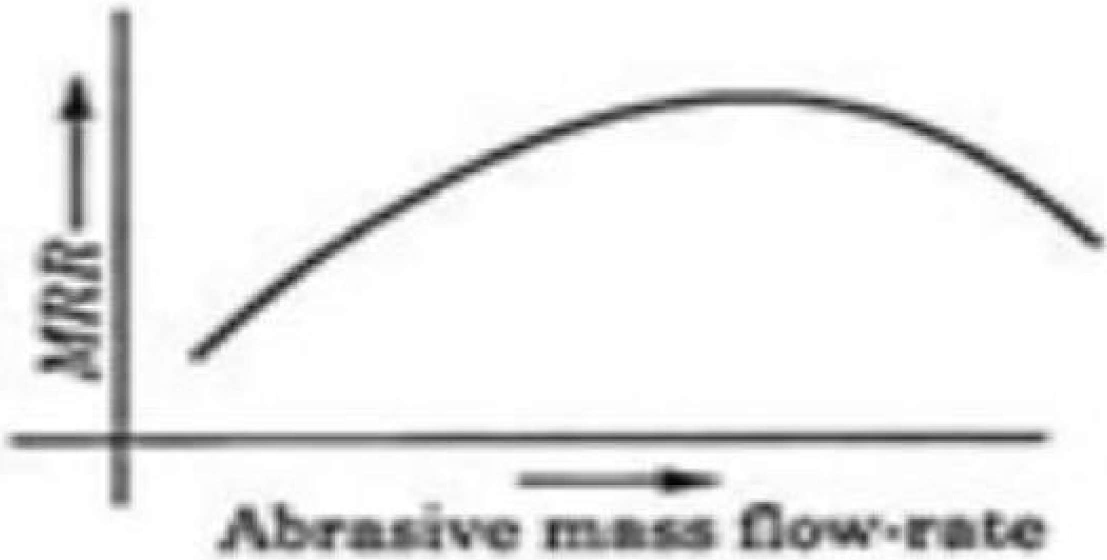
METAL REMOVAL RATE PROCESS PARAMETERS:-

The metal removal rate depends upon the following parameters.

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

1. MASS FLOW RATE:-

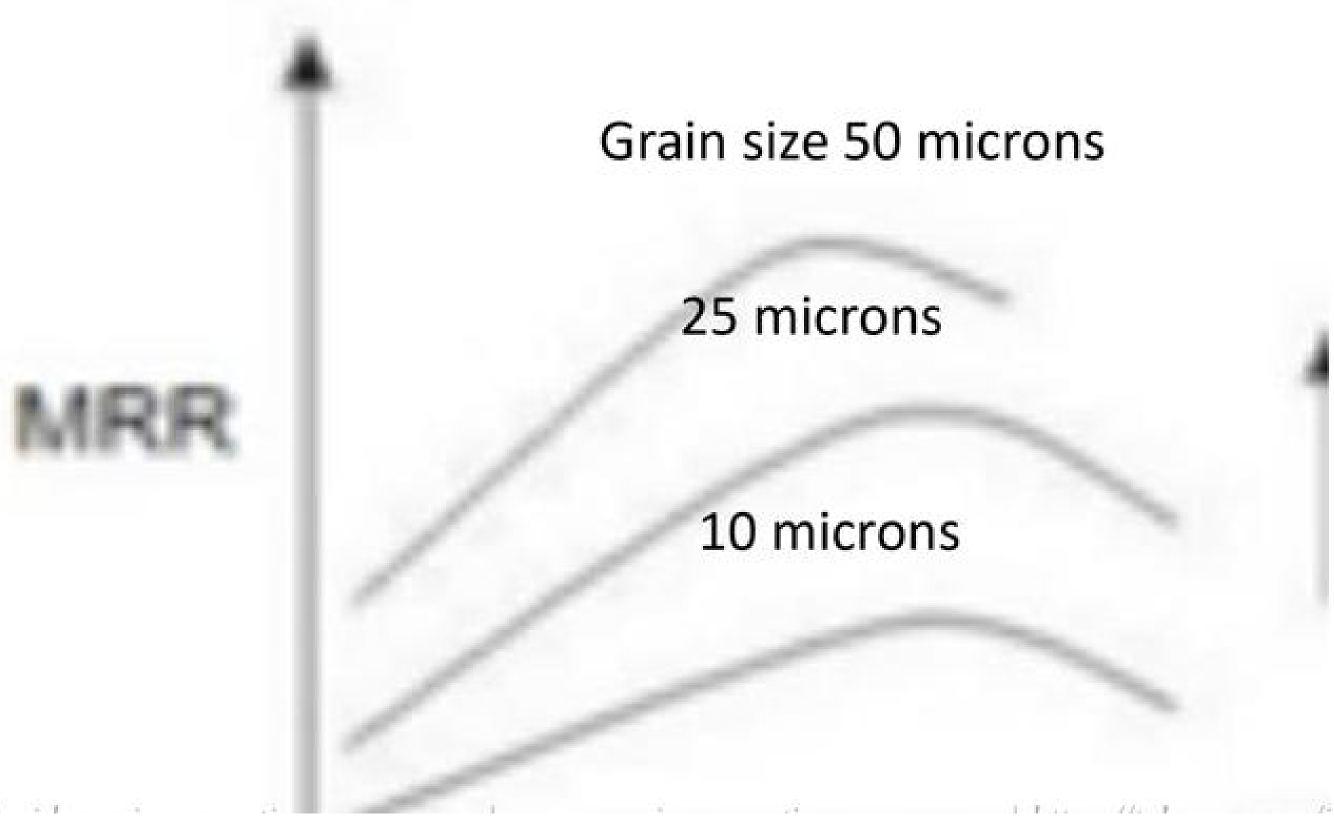
At particular pressure, the material removal rate increases with the abrasive flow rate. But , after reaching an optimum value , the material removal rate decreases with further increase in abrasive flow rate. This is due to the fact that the mass flow rate of gas or air decreases with the increase of abrasive flow rate.



2. ABRASIVE GRAIN SIZE:-

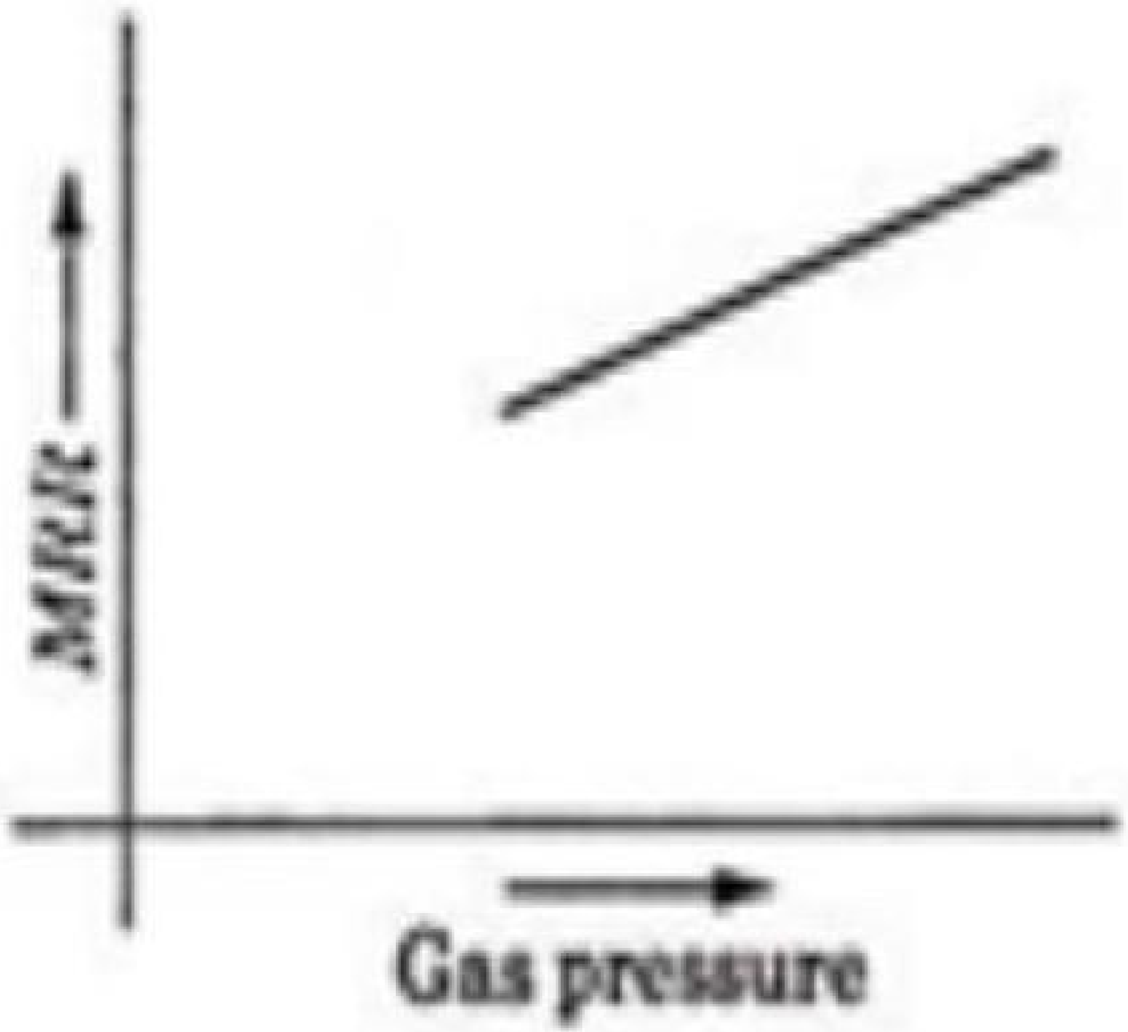
The various abrasive particles used in AJM process are aluminum oxide (Al203) , silicon carbide (sic), glass powder, dolomite and specially prepared sodium bicarbonate. Aluminium oxide is a general purpose abrasive and is used in sizes of 10, 25 and 50 microns. Silicon carbide is used for faster cutting on extremely hard materials. It is used in sizes of 25 and 50 microns. Dolomite of 200 grit size is found suitable for light cleaning and etching. Glass powder of 0.30 to 0.60 mm are used for light polishing and deburring.

in general, larger sizes are used for rapid removal rate while smaller sizes are used for good surface finish and precision.



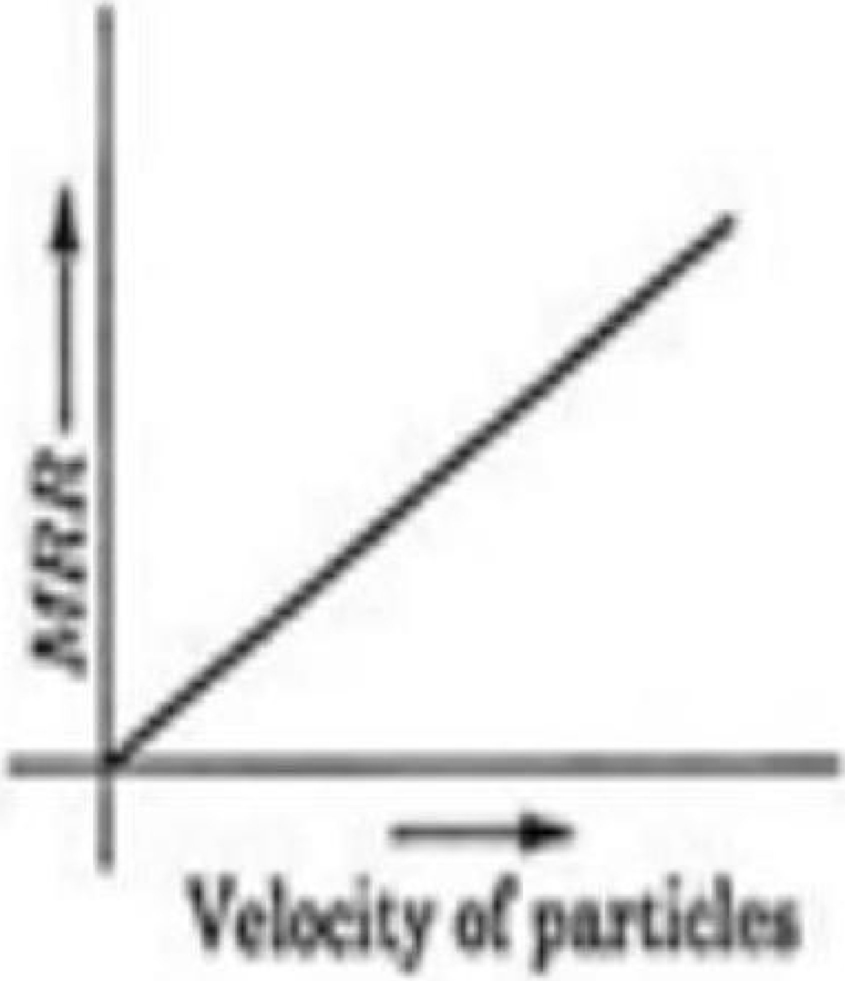
3. GAS PRESSURE:-

The metal removal rate increases with increase in gas or air pressure as shown in fig



4. VELOCITY OF ABRASIVE PARTICLES:-

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

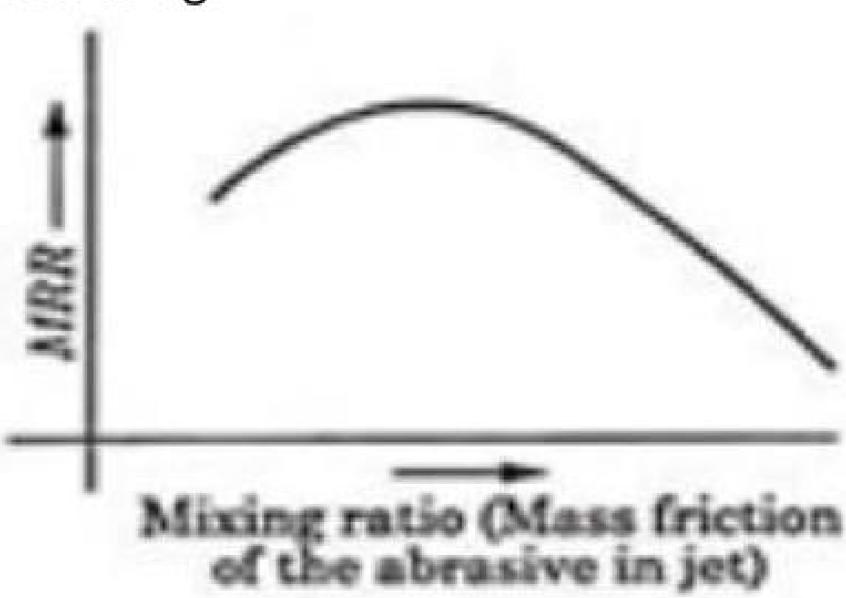


5. MIXING RATIO:-

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

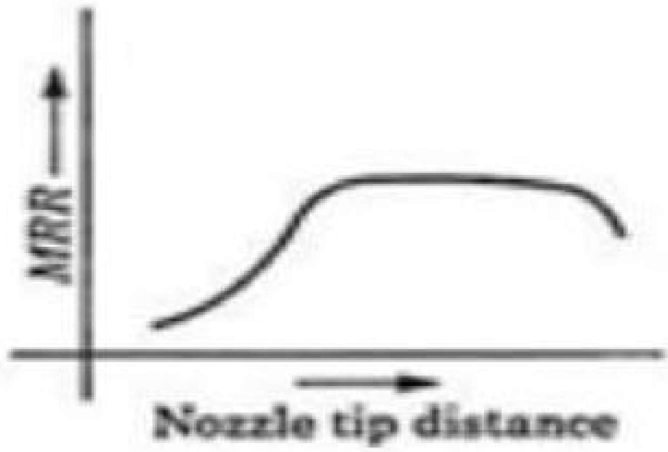
mixing ratio= mass flow rate of abrasive/mass flow rate of gas

metal removal rate first increases with the increase of mixing ratio up to certain limit after that it decreases gradually as shown in fig.



6. NOZZLE TIP CLEARNCE OR STAND OFF DISTANCE:-

The distance between the nozzle tip and the work piece has great influence on the diameter of cut , its shape, size and also on the rate of material removal.
The material removal rate first increases with the increase of tip clearance from work piece up to a certain limit after that it remains unchanged for a certain tip clearance and then decreases gradually as shown in fig



ADVANTAGES

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- It has the capability of cutting holes of intricate shape in hard materials.
- Thin sections of hard & brittle materials like germanium, mica, silicon, glass and ceramics can be machined.
- Process is free from chatter and vibration as there is no contact between the tool and work piece.
- Abrasive jet machining process creates localized forces and generates lesser heat than the conventional machining processes.
- The power consumption in abrasive jet machining process is considerably low.

DISADVANTAGES

- The accuracy of cutting is hampered by tapering of hole due to unavoidable flaring of abrasive jet.
- Abrasive powders cannot be reused as the sharp edges are worn and smaller particles can clog the nozzle.
- The mixing chamber and the nozzle are the two critical components and they need to be changed very frequently because of the wear.
- Material removal rate in abrasive jet machining process is rather low(around 15 mm^3/min for glass).

APPLICATIONS

- AJM is useful in manufacture of electronic devices. Micro-machining of brittle objects.
- Making of nylon and Teflon parts, permanent marking on rubber stencils, cutting titanium foils.
- Cutting of optical fibers without altering its wavelength is one of the most important applications of this process.
- Deburring of some critical zones in the machined parts.
- Cutting, drilling and frosting of precision optical lenses.
- Cutting and etching of inaccessible areas and internal surfaces can be done.
- Reproducing designs on a glass surface with the help of rubber or copper masks.

- Characteristics of AJM:

Work material → hard and brittle materials like glass,ceramics,mica.
Abrasive → Al2O3,Silicon carbide, Glass powder
Dolomite
Size of abrasive → around 25μm
Flow rate → 2-20g/min
Medium → N2 (or) CO2 (or) air
Velocity → 125-300m/s
Pressure → 2 to 8 kg/cm2
Nozzle material → tungsten carbide or synthetic sapphire
Life of nozzle → tungsten carbide (12 to 20 hours)
sapphire (300hours)
Gap → 0.25-0.75mm
Tolerance → ±0.05mm
Machining operation → drilling,cutting,cleaning etc

INTRODUCTION:-

water jet machining process is an extension of abrasive jet machining process. In this process , high pressure and high velocity stream of water is used to cut the relatively soft and non-metallic materials like paper boards,wood,plastics, rubber, fiber glass , leather, etc.

PRINCIPLE:-

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

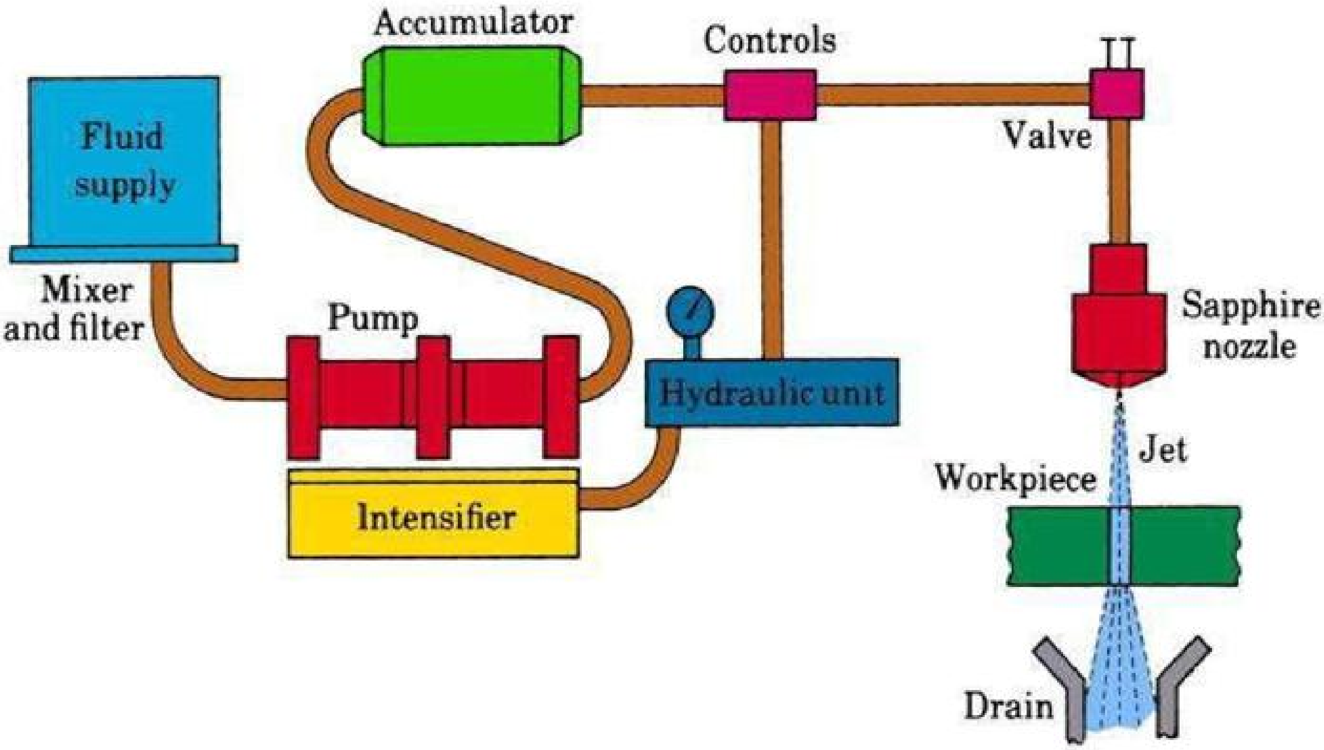


Fig : schematic diagram of WJM

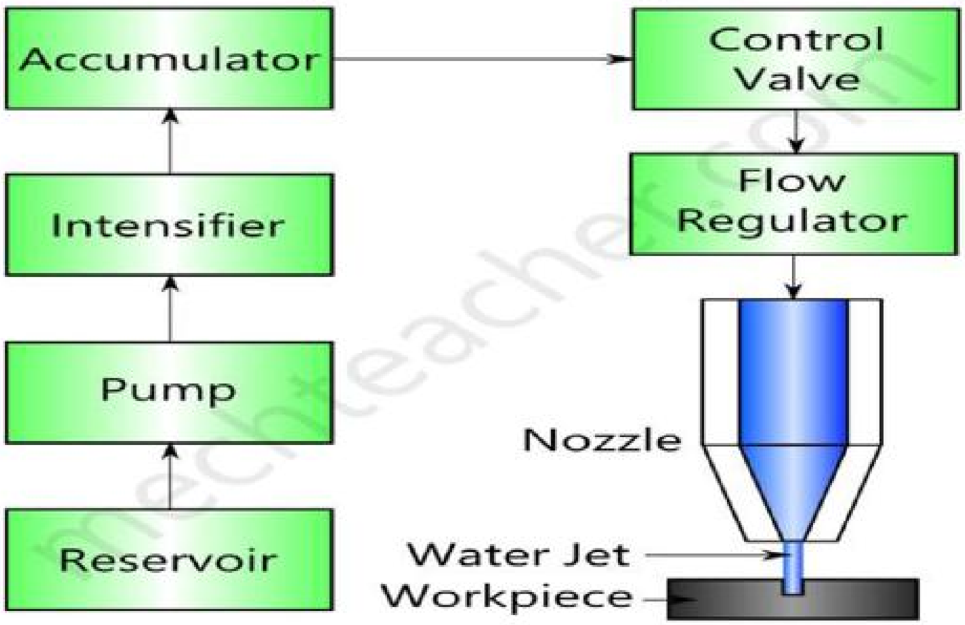


Fig : schematic diagram of WJM

Construction of Water Jet Machining (WJM):

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

1. **Reservoir:** It is used for storing water that is to be used in the machining operation.
2. **Pump:** It pumps the water from the reservoir.

3. **Intensifier:** It is connected to the pump. It pressurizes the water acquired from the pump to a desired level. in the range of 1500 to 4000 N/mm2.
4. **Accumulator:** It is used for temporarily storing the pressurized water. It is connected to the flow regulator through a control valve.
5. **Control Valve:** It controls the direction and pressure of pressurized water that is to be supplied to the nozzle.
6. **Flow regulator:** It is used to regulate the flow of water.
7. **Nozzle:** It renders the pressurized water as a water jet at high velocity. The exit diameter of the nozzle is in the range of 0.05 to 0.35 mm and the exit velocity of the water jet from the nozzle varies up to 920 m/s.

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 Map.
- 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 work piece, stresses are induced. These stresses are used to remove material from the work piece.

- 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.

PROCESS PARAMETERS:-

The following process parameters are needed to utilize the WJM process successfully.

1. Material removal rate
2. Geometry and surface finish of work material.
3. Wear rate of the nozzle.

MATERIAL REMOVAL RATE:-

in water jet machining process, material removal rate is directly proportional to the reactive force(F) of the jet.

MRRα F

MRR αmix

Where m=mass flow rate, and

v=jet velocity.

Mass flow rate depends on nozzle diameter (d) and fluid pressure (p). Jet velocity depends on fluid pressure.

MRR αd αP

Stand-off distance is the distance between the nozzle tip and the surface of the material being machined.

When MRR increases , the SOD also increases up to a certain limit after that it remains unchanged for a certain tip distances and then falls gradually.

2. GEAOMETRY AND SURFACE FINISH OF WORK MATERIAL:-

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

- Nozzle design,
- Jet velocity,
- Cutting speed,
- Depth of cut, and

- Properties of the material to be machined.

3. WEAR RATE OF THE NOZZLE:-

Nozzle wear rate depends up on the following factors.

- Hardness of the nozzle material,
- Pressure of the jet,
- Velocity of the jet,
- Nozzle design.

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

Disadvantages of Water Jet Machining:

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

Applications of Water Jet Machining:

- 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.

CHARCTERISTICS OF WJM

WORK MATERIAL	SOFT AND NON METALLIC MATERIALS LIKE PAPER BOARDS, WOOD,PLASTICS,RUBBER, etc.
TOOL	WATER OR WATER WITH ADDITIVES
ADDITIVES	GLYCERIN,POLYETHYLENE OXIDE
PRESSURE OF WATER	100 TO 1000 MPA
MASS FLOW RATE	8 LIT/MIN
POWER	45KW
METAL REMOVAL RATE	0.6 MM3/S
FEED RATE	1-4 mm/s
NOZZLE MATERIAL	TUNSTEN CARBIDE,SYNTHETIC SAPPHIRE
STAND OFF DISTANCE	2 TO 50 mm

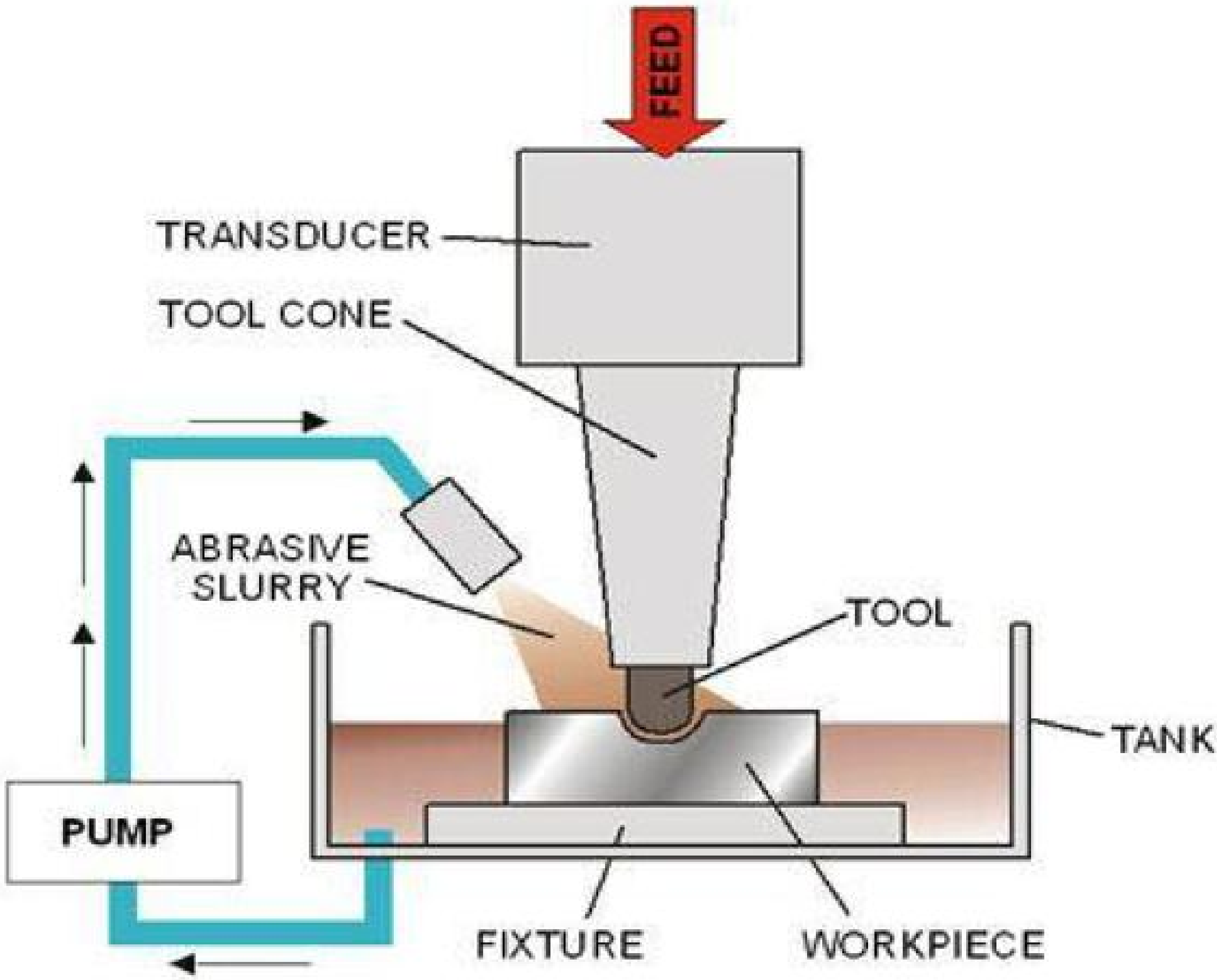
7.Ultrasonic machining

INTRODUCTION:-

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

PRINCIPLE OF USM:-

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



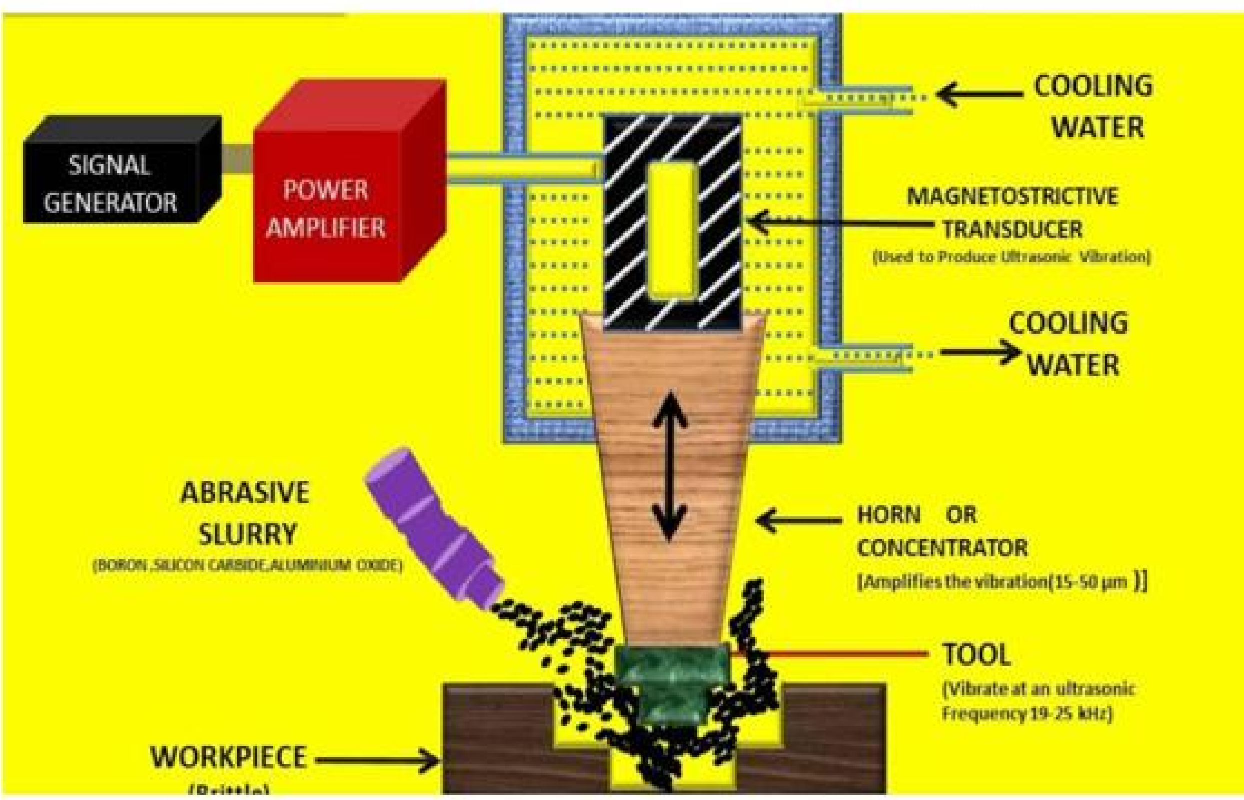


Fig : arrangement of ultrasonic machining process

- It consists of abrasive slurry, work piece, fixture, table, cutting tool, circulating pump, reservoir, ultrasonic oscillator, leads, excitation coil, feed mechanism, ultrasonic transducer, transducer cone, connecting body and tool holder.

- The ultrasonic oscillator and amplifier also known as generator is used to convert the applied electrical energy at low frequency to high frequency.
- The transducer is made up of magnetosrictive material and it consists of a stack of nickel laminations that are wound with a coil.
- The function of the transducer is to convert the electrical energy in to mechanical energy.
- Generally tough and ductile tool material is used in this process. Low carbon steels and stainless steels are commonly used as tool materials.
- The tool is brazed, soldered or fastened mechanically to the transducer through a tool holder. Generally tool holder is of cylindrical or conical shape.
- The materials used for tool holders are titanium alloys, monel, aluminum, stainless steel, etc.
- An abrasive slurry, usually a mixture of abrasive grains and water of definite proportion (20-30 percent), is made to flow under pressure through the gap between tool and work piece . The gap between the tool and work piece is of the order 0.02 to 0.1 mm.
- The most commonly used abrasives are boron carbides (b4c), silicon carbide(sic), aluminum oxide (al2o3), and diamond. Boron carbide is most commonly used abrasive slurry , since it has the fastest cutting abrasive property.

WORKING:-

- Electric power is given to ultrasonic oscillator and this oscillator converts the electrical energy at low frequency to high frequency(20khz).
- High frequency power (20khz) from oscillator is supplied to the transducer.

- The function of the transducer is to convert the electrical energy in to mechanical vibrations. The transducer is made up of magnetostrictive material, which is excited by flowing high frequency electric current and this results in the generation of mechanical vibrations. The vibrations are generated in the transducer of the order of 20khz to 30khz and hence ultrasonic waves are produced.
- These vibrations are then transmitted to the cutting tool through transducer cone, connecting body and tool holder. This makes the tool to vibrate in a longitudinal direction .
- Abrasive slurry is pumped from the reservoir and it is made to flow under pressure through the gap between tool and work piece.
- In an abrasive slurry, when the cutting tool vibrates at high frequency, it leads in the removal of metal from the work piece.
- The impact force arises out from the vibration of tool end and the flow of slurry through the work piece tool gap causes thousands of microscopic grains to remove the work piece material by abrasion.
- A refrigerated cooling system is used to cool the abrasive slurry to a temperature of 5 to 6 degree centigrade.
- The ultrasonic machining process is a copying process in which the shape of the cutting tool is same as that of the cavity produced.

PROCESS PARAMETERS:-

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

1. Metal removal rate.
2. Tool material.
3. Tool wear rate.
4. Abrasive materials and abrasive slurry.
5. Surface finish.

6. Work material.

1. **METAL REMOVAL RATE:-**

- The material removal rate per unit time is inversely proportional to the cutting area of the tool. Boron carbide is the hardest material and has the highest metal removal rate.
- Wear ratio is defined as the ratio of volume of material removed from the work to volume of material eroded from tool.
  wear ratio=volume of material removed from the work/volume of material eroded from the tool.
- Material removal in USM is a very complex process and it depends on certain factors. They are:

1. Grain size of abrasive.
2. Abrasive materials.
3. Concentration of slurry.
4. Amplitude of vibration.
5. Frequency of ultra sonic waves.

<u>1. GRAIN SIZE OF ABRASIVE:-</u>

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

For rough work operation grit size of 200-400 are used and for finishing operation ,grit size of 800-1000 are used.

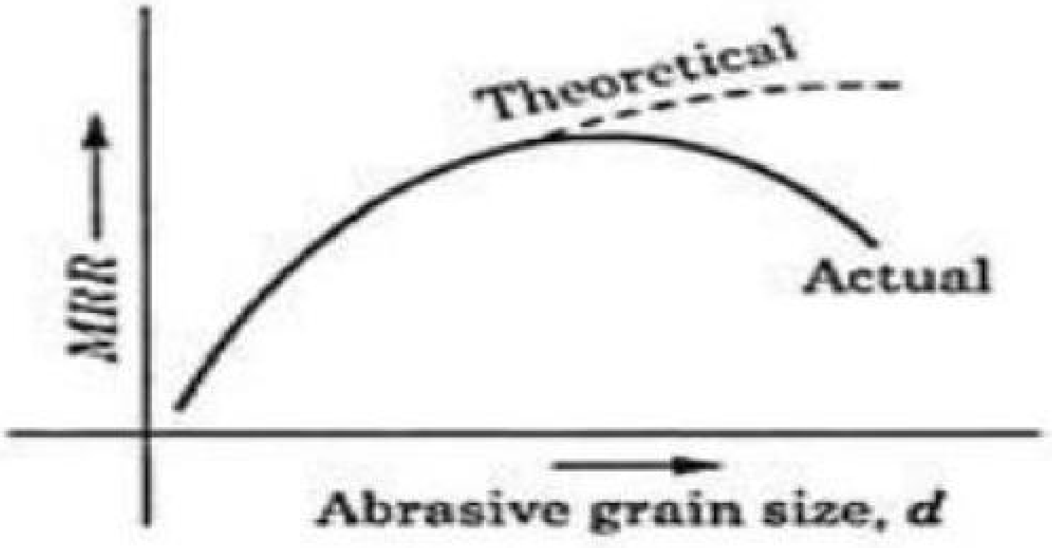


Fig. 10.48

2. ABRASIVE MATERIALS:-

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

the proper selection of abrasive particles depends on the type of material to be machined, hardness of the material, metal removal rate desired and the surface finish required.

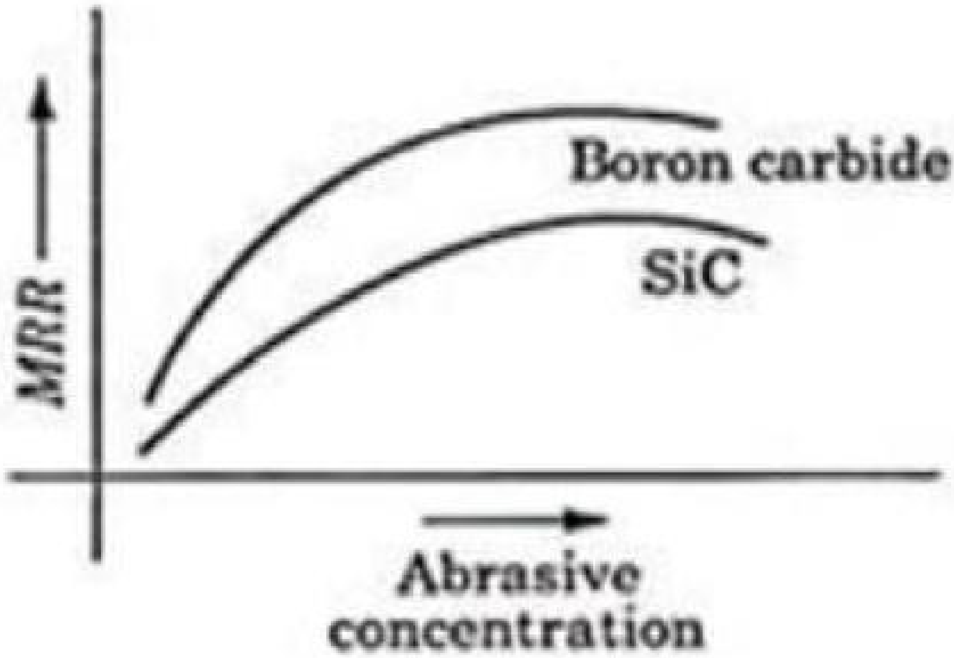
The most commonly used abrasives are boron carbide and silicon carbide which are used for machining tungsten carbide, die steel, etc.

Aluminum oxide is the softest abrasive and it is used for machining glass and ceramics.

3. CONCENTRATION OF SLURRY:-

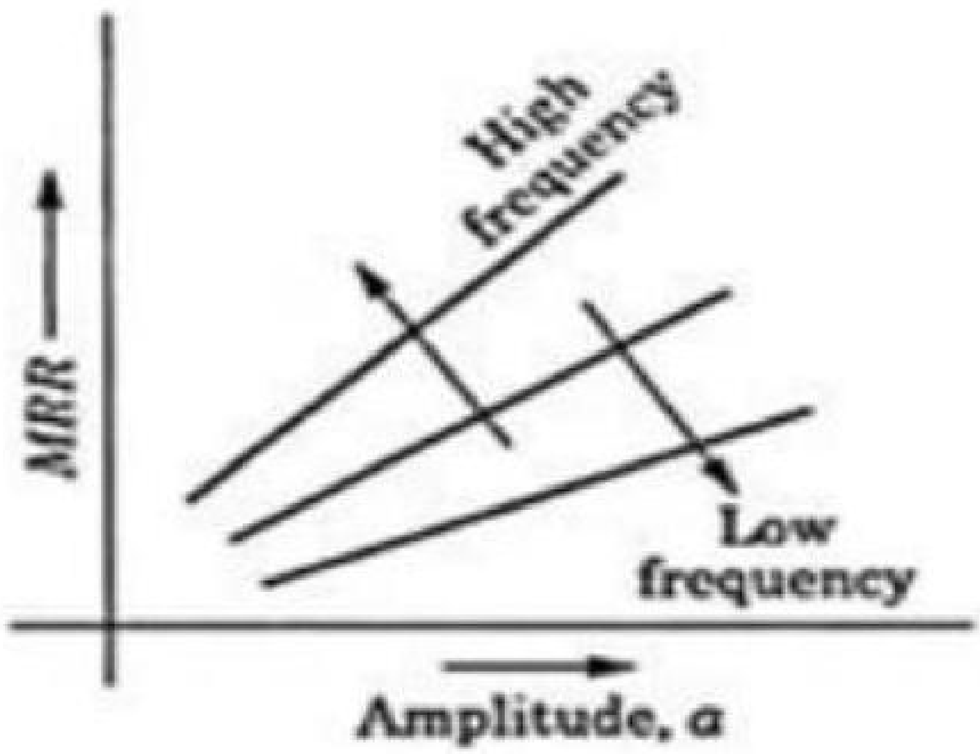
an abrasive slurry, usually a mixture of abrasive grains and water of definite proportion(20-30 percent), is made to flow under pressure through the gap between tool and work piece.

the fig shows how the material removal rate in ultrasonic machining process varies with slurry concentration.



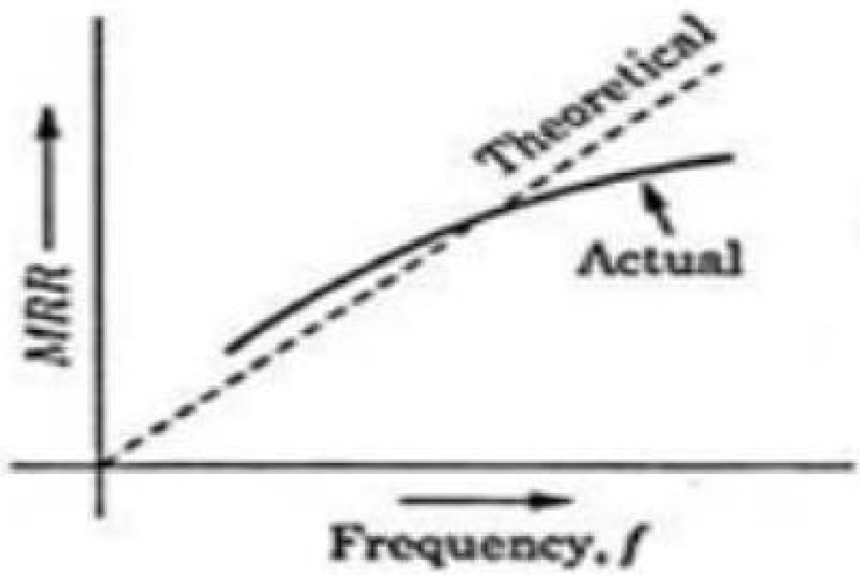
4. AMPLITUDE OF VIBRATION:-

metal removal rate in ultrasonic machining process increases with increasing amplitude of vibration which is shown in fig



5. FREQUENCY:-

ultrasonic wave frequency is directly proportional to the metal removal rate which is shown in fig



2. <u>TOOL MATERIAL:-</u>

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

hollow tool can be made with wall thickness greater than 0.5 to 0.8 mm.

the USM process is a copying process in which the shape of the cutting tool is same as that of the cavity produced.

3. <u>TOOL WEAR RATE:-</u>

- Wear ratio is defined as the ratio of volume of material removed from the work to volume of material eroded from tool.
  wear ratio=volume of material removed from the work/volume of material eroded from the tool.
- The wear ratio is approximated to 1.5 : 1 for tungsten carbide (WC) work piece, 100:1 for glass , 50:1 for quartz , 75:1 for ceramics and 1:1 for hardened tool steel.

4. <u>ABRASIVE MATERIALS AND ABRASIVE SLURRY:-</u>

- the cutting power of different abrasives are shown in the table.

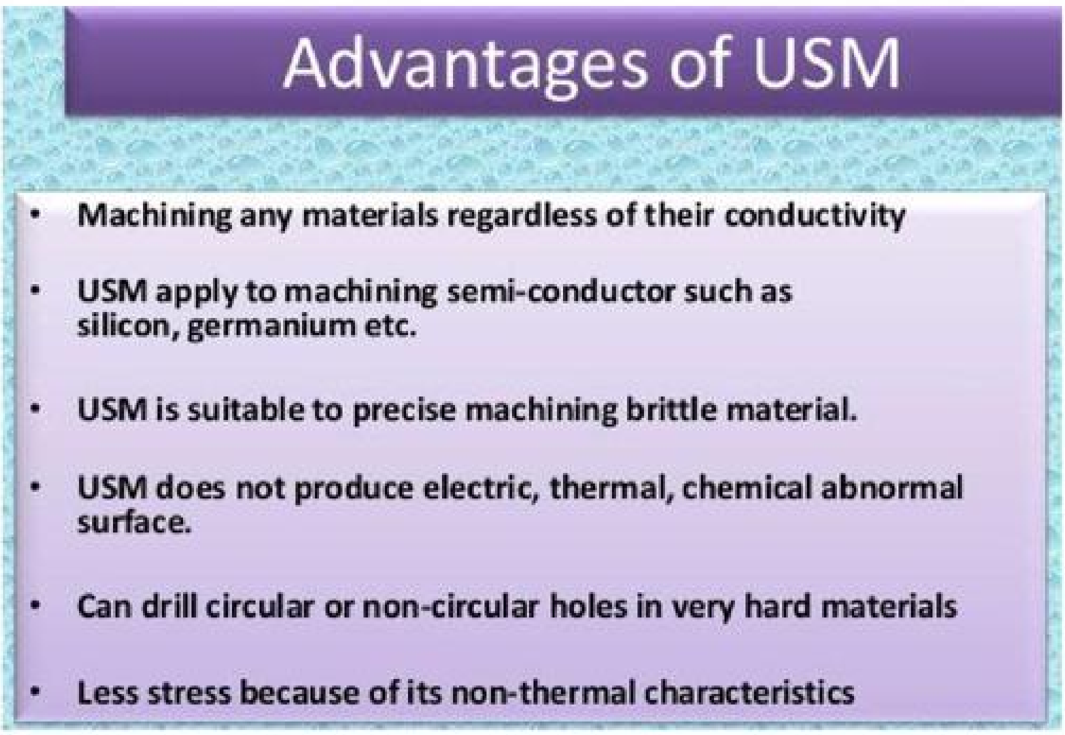
SNO	ABRASIVE	HARDNESS	RELATIVE CUTTING POWER
1	BORON CARBIDE(B4C)	2800	0.50-0.60
2	SILICON CARBIDE(SIC)	2450-2500	0.25-0.458
3	ALLUMINIUM OXIDE(AL2O3)	2000-2100	0.14-0 .16
4	DIAMOND	6500-7000	1

5. SURFACE FINISH:-

The maximum speed of penetration in soft and brittle materials such as soft ceramics are of the order of 200 mm/min. Penetration rate is lower for hard and tough materials. Accuracy of this process is plus or minus 0.006 mm and surface finish up to 0.02 to 0.8 micron value can be achieved.

6. WORK MATERIALS:-

Hard and brittle metals, non metals like glass , ceramics, etc, and semiconductors are used as work material in USM process.



Disadvantages of USM

- USM has low material removal rate. (3-15mm3/min)
- Tool wears fast in USM.
- Machining area and depth is restraint in USM.

Applications

It is mainly used for

(1) drilling

(2) grinding,

(3) Profiling

(4) coining

(5) piercing of dies

(6) welding operations on all materials which can be treated suitably by abrasives.

(7) Used for machining hard and brittle metallic alloys, semiconductors, glass, ceramics, carbides etc.

(8) Used for machining round, square, irregular shaped holes and surface impressions.

CHARCTERISTICS OF USM:-

METAL REMOVAL MECHANISM	SLURRY OF SMALL ABRASIVE PARTICLES IS FORCED AGAINST THE WORKPIECE BY MEANS OF A VIBRATING TOOL AND IT CAUSES THE REMOVAL OF METAL FROM THE WORKPIECE.
ABRASIVE	BORON CARBIDE(B4C),SILICON CARBIODE (SIC),ALLUMINUM OXIDE (AL2O3) AND DIAMOND
ABRASIVE SLURRY	ABRASIVE GRAINS + WATER(20-30 PERCENT)
VIBRATION FREQUENCY	20 TO 30 KHZ
AMPLITUDE	25 TO 100 MICRONS
WEAR RATIO	1.5:1 FOR TUNGSTEN CARBIDE , 100:1 FOR GLASS , 50:1 FOR QUARTZ, 75:1 FOR CERAMICS AND 1:1 FOR TOOL STEEL.
WORK MATERIAL	TUNGSTEN CARBIDE,GERMANIUM,GLASS,CERAMICS, QUARTZ, TOOL STEEL ETC
TOOL MATERIAL	LOW CARBON STEELS, STAINLESS STEELS.
SURFACE FINISH	0.2 TO 0.7 MICRONS.

INTRODUCTION:-

In electron beam machining process , 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., 1.6X108 m/s. this process is best suited for micro cutting of materials.

PRINCIPLE:-

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

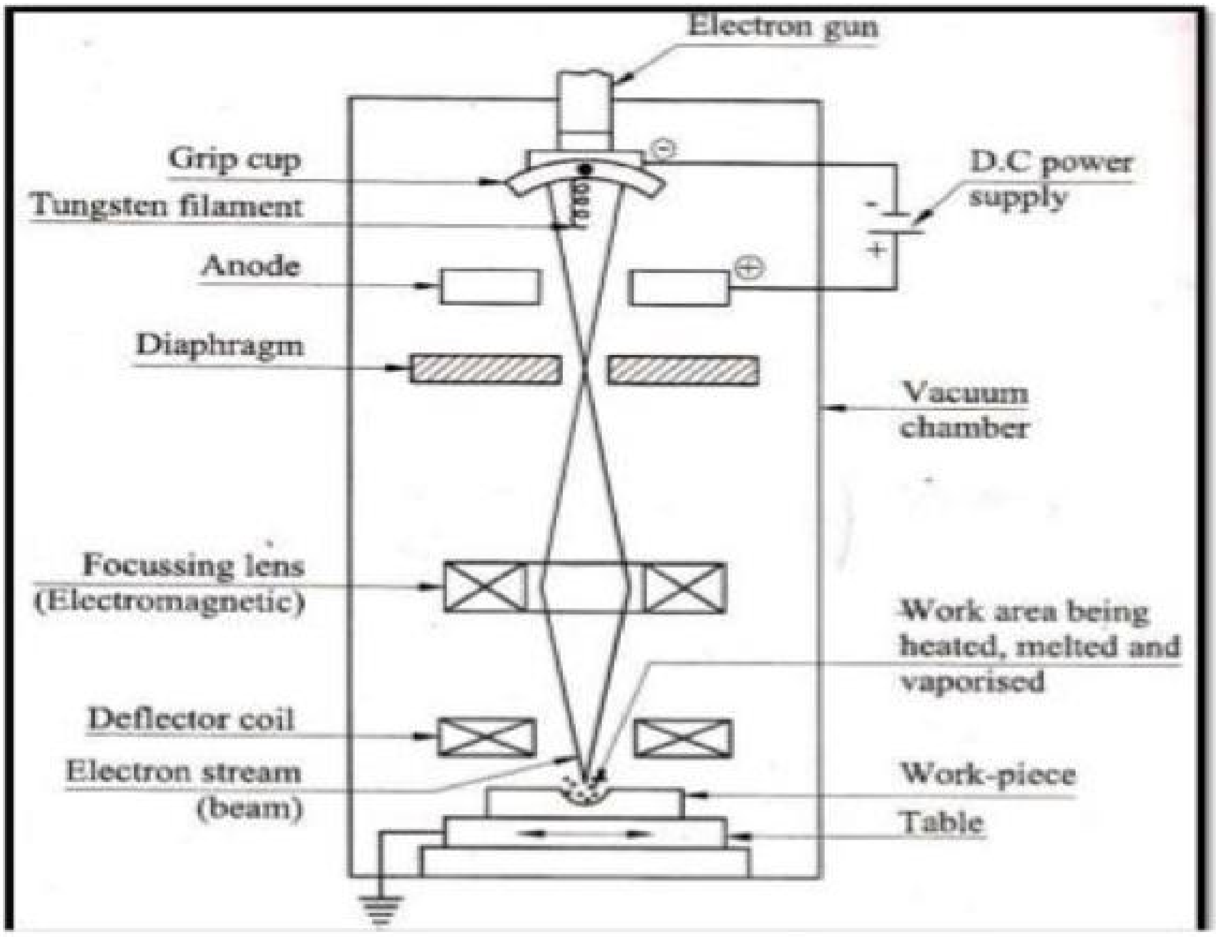


fig. arrangement of electron beam machining

CONSTRUCTION:-

- The schematic arrangement of electron beam machining (EBM) is shown in fig.
- It consist of electron gun , diaphragm , focusing lens , deflector coil , work table, etc.
- In order to avoid collision of accelerated electrons with air molecules, vacuum is required. So the entire EBM setup is enclosed in a vacuum chamber, which carries vacuum of the order 10-5 to 10-6 mm of mercury. This chamber carries a door, through which the work piece is placed over the table. The door is then closed and sealed.
- The electron gun is responsible for the emission of electrons, which consists of the following three main parts.

1. **Tungsten filament**- which is connected to the negative terminal of the DC power supply and acts as cathode.
2. **Grid cup** – which is negatively based with respect to the filament.

3. **Anode**- which is connected to positive terminal of the DC power supply.

- The focusing lens is used to focus the electrons at a point and reduces the electron beam up to the cross sectional area of 0.01 to 0.02 mm diameter.

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

WORKING:-

- When the high voltage DC source is given to the electron gun , tungsten filament wire gets heated and the temperature raises up to 2500oc.
- Due to this high temperature, electrons are emitted from tungsten filament. These electrons are directed by grid cup to travel towards downwards and they are attracted by anode.
- The electrons passing through the anode are accelerated to achieve high velocity as half the velocity of light (i.e 1.6 x 108 m/s) by applying 50 to 200 kv at the anode.
- The high velocity of these electrons are maintained till they strike the work piece . It becomes possible because the electrons travel through the vacuum.

- This high velocity electron beam , after leaving the anode , passes through the tungsten diaphragm and then through the electromagnetic focusing lens.
- Focusing lens are used to focus the electron beam on the desired spot of the work piece.
- When the electron beam impacts on the work piece surface , the kinetic energy of high velocity electrons is immediately converted in to the heat energy . This high intensity heat melts and vaporises the work material at the spot of beam impact.

- Since the power density is very high (about 6500 billion W/mm2), it takes a few micro seconds to melt and vaporise the material on impact.
- This process is carried out in repeated pulses of short duration. The pulse frequency may range from 1 to 16,000 Hz and duration may range from 4 to 65,000 micro seconds
- By alternately focusing and turning off the electron beam , the cutting process can be continued as long as it is needed.
- A suitable viewing device is always incorporated with the machine. So , it becomes easy for the operator to observe the progress of machining operation.

EBM process parameter:

- Voltage: 1,50,000 V
- Vacuum requirement: 133 x 10-6 N/m2
- MRR: 1.6 mm^3/min
- Surface Finish: 0.4-2.5 μm (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.