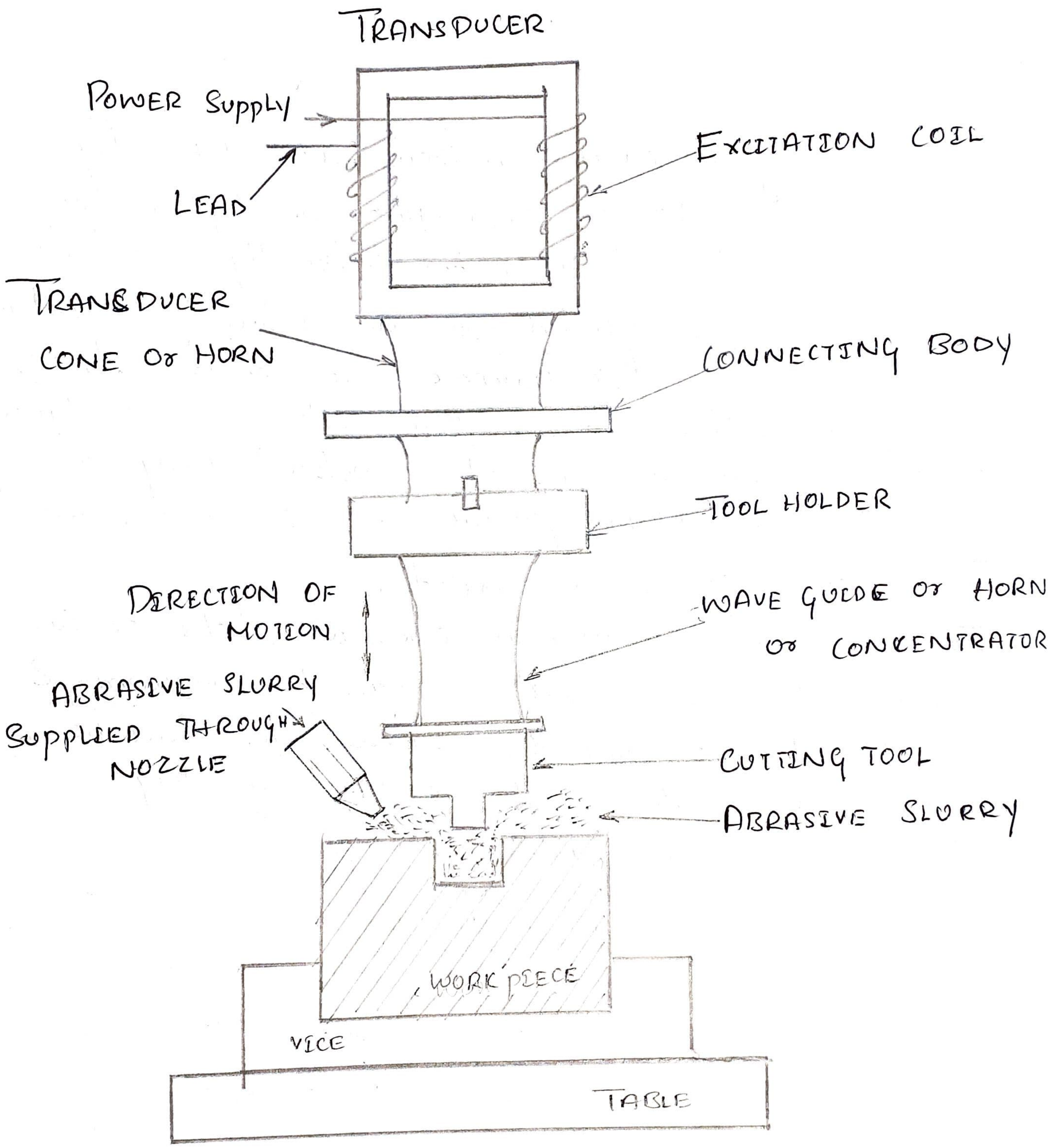
MODULE - 2

ULTRASONIC MACHINING

⇒ USM EQUIPMENT



The Equipment consists of the following parts:

→ power supply
→ Transducer
→ Tool holder & horn
→ Tool, and
→ Abrasives.

a) **POWER SUPPLY**: The power supply used for ultrasonic machining is high-power sine-wave generator that converts the low-frequency electrical power (60 Hz) to high-frequency electric power (approx 20KHz). The electrical signal is then supplied to the transducer.

b) **TRANSDUCER**: A transducer is a device that converts high-frequency electrical signal to a high-frequency mechanical motion (vibrations) to the tool and this particular vibration of the tool enables machining using abrasives. There are 2 types of transducers working on 2 different principles: piezoelectric & magnetostrictive.

c) **TOOL HOLDER**: The high frequency mechanical motion obtained from the transducer is transmitted to the tool via a tool holder. The horn amplifies and focuses the mechanical energy (vibrations) produced by the transducer and imparts this energy to the w/p in such a way that energy utilization is optimum.

d) **TOOL**: The tool is constructed from ductile materials like stainless steel, brass, or mild steel and has the same shape as that of the cavity to be machined in the workpiece.

e) **ABRASIVES**: Abrasives are usually suspended in liquid (water), and supplied to the cutting zone during the operation. Boron carbide, silicon carbide and aluminium oxide are the most commonly used abrasives. The type of abrasive selected depends on the hardness of the workpiece material.

⟹ **NEED FOR USM**

Brittle materials such as glass, ceramics, carbides, precious stones, hardened steels etc., are difficult to mach by conventional methods. USM is non-thermal; non creates no changes in the microstructure, chemica or physical properties of the workpiece and offers virtually stress free machined surfaces. These features enable hard and brittle materials to be economically and efficiently machined, which otherwise would have been difficult to shape by conventional methods.

→ PRINCIPLE OF USM

Ultrasonic machining is based on the principle that, when a tool vibrating at a very high frequency is brought closer to the workpiece with abrasive particles between them, the vibrating energy of the tool can propel the abrasive particles to strike the workpiece with a great velocity. The impact of the abrasive particles fractures the hard work surface resulting in the removal of material from the workpiece.

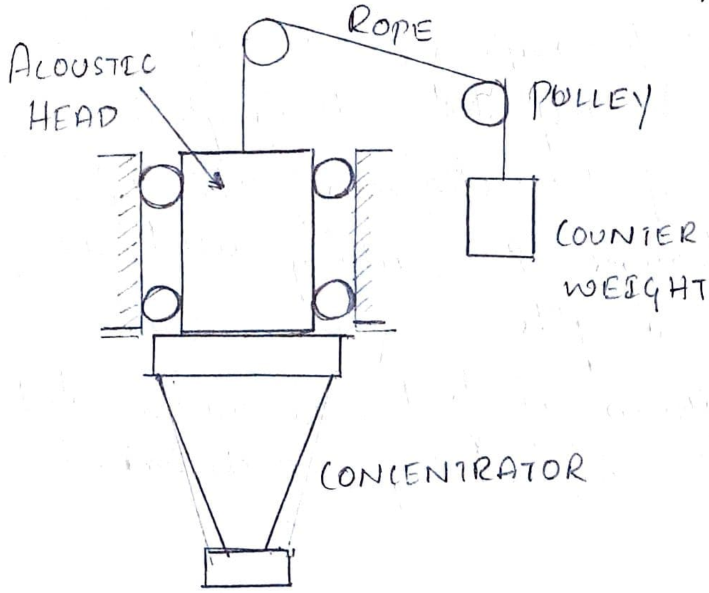
→ USM OPERATION

USM process begins with the conversion of low-frequency electrical power to a high-frequency electrical signal, which is then fed to a transducer. The transducer converts the high-frequency electrical signal to a high-frequency mechanical motion (vibrations), which in turn is amplified by means of wave guide (horn) and then transmitted to the tool tip. The tool, which is having the same shape as the cavity to be machined, vibrates or oscillates at a very high frequency in the abrasive slurry pumped between the tool-work interface.

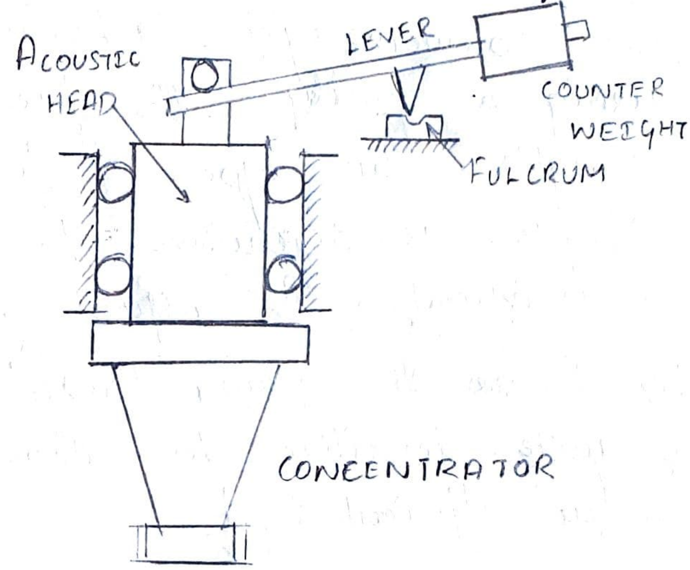
The vibration of the tool transmits a high velocity to the abrasive particles, and as a result, the abrasive particles strike the workpiece with a great force. This impact fractures the hard and brittle
→ surface resulting in the removal of material in the
→ small wear particles.

→ TOOL FEED MECHANISM IN USM

The various feed mechanism available in USM are illustrated in the simplest form in the below figure

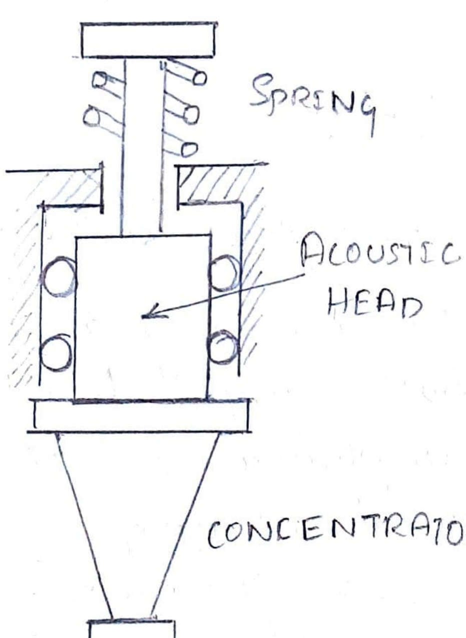


COUNTER WEIGHT WITH ROPE & PULLEY

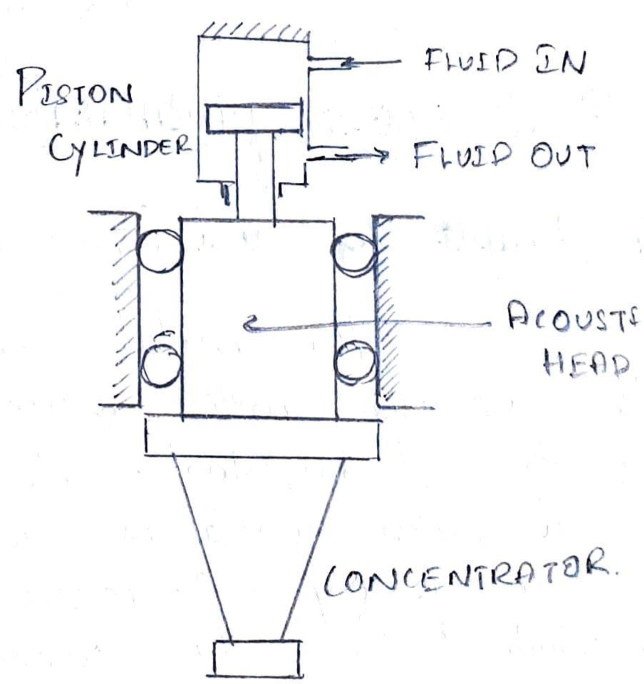


COUNTER WEIGHT WITH LEVER & FULCRUM.

a) COUNTER - WEIGHT SYSTEM



b) SPRING-LOADED SYSTEM



c) HYDRAULIC (pneumatic) SYSTEM.

a) Counter type mechanism; the feed force being the difference between the weight of the acoustic head (ultrasonic transducer and tool holder) and that of the counterweight attached through a lever system a using a pulley. The force is adjusted through the weights. This type of feeding mechanism although simple, is insensitive to changes in cutting and hence inconvenient to adjust the weights.

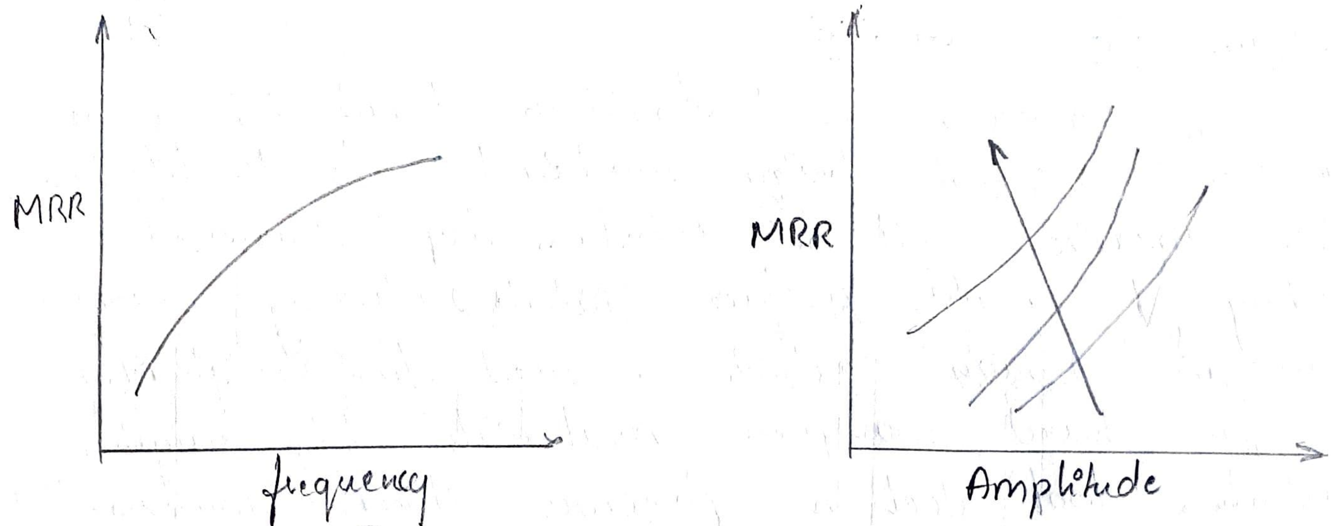
b) Shows the spring loaded system of feed mechanism, which is quite sensitive to changes in cutting conditions, but is less efficient;

c) Shows the pneumatic (or hydraulic) type of feeding mechanism which is the commonly used in USM. This system makes use of a piston-cylinder arrangement with a suitable liquid or air as the working substance through which the required force is applied to the tool to perform the machining operation.

→ PROCESS PARAMETERS IN USM.

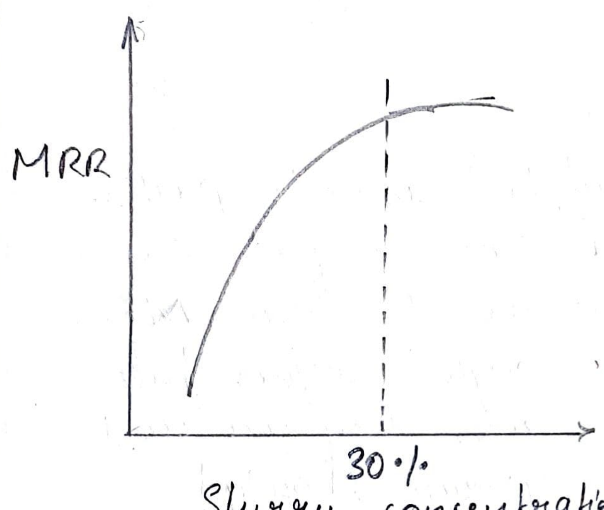
a) Amplitude and frequency of vibrations of the tool.

The metal removal rate (MRR) or cutting rate increases with increase in both amplitude and vibration of the tool. At large amplitudes, the KE rises, this in turn enhances the mechanical chipping action and consequently increases MRR. But increasing the amplitude tends to increases the surface roughness. The frequency and amplitude of vibrations ranges from 15 - 30 kHz and 25 - 100 μm respectively.



Relation between MRR & amplitude / frequency.

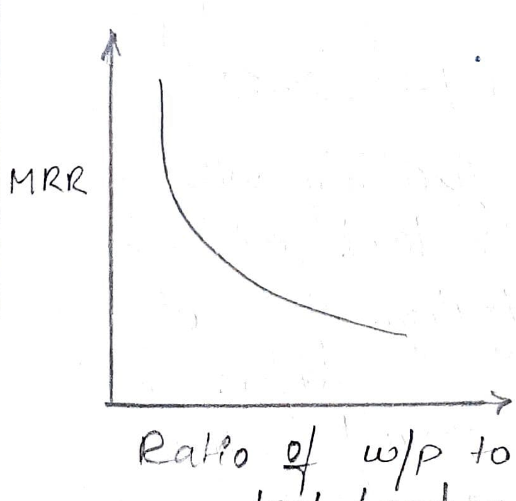
b) Slurry (Abrasive - water mixture)



Relation between MRR and slurry concentration

→ MRR increases with increase in slurry concentration. The machining rate reaches to a optimum value with 30% slurry concentration. The metal removal rate drops with further increasing viscosity of the slurry.

c) TOOL & WORK MATERIAL

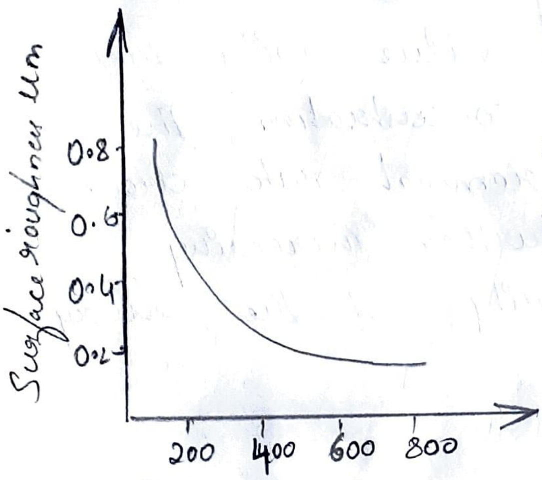


Since the tool has to withstand the vibrations, it should not fail or wear out quickly. The harder the tool material, the faster its wear rate will be, thereby leading to unfavourable metal removal rate and surface finish on the workpiece. Tough malleable materials such as alloy steel and stainless steel give satisfactory results.

d) TYPE OF ABRASIVE

The abrasive used should be harder than the workpiece material being machined, else the life time of the abrasive will be substantially shortened resulting in poor surface finish during subsequent machining. Boron carbide is used for high MRR & also for hard workpiece materials like tungsten carbide, tool steel & precious stone. However, It is costlier. Aluminium oxide wears out fast & loses its cutting power. Silicon carbide is best suited & finds maximum application in USM.

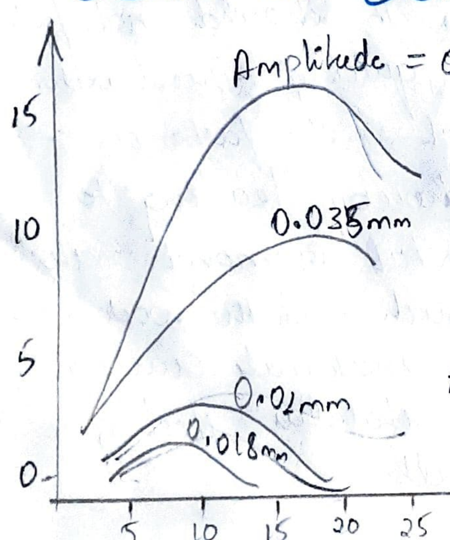
e) ABRASIVE SIZE



Effect of abrasive size on MRR & surface finish

The size of the abrasive particle varies between 240-800 grit. Coarse grades are suitable for high MRR, but result in rough surface finish as shown. Hence, they are used for roughing operations only. Finer grades, say 750-800 grit are used for fine surface finish, but the MRR decreases.

f) EFFECT OF APPLIED STATIC LOAD (feed force)



In practice, initially with increase in static load on the tool, the depth of penetration of the abrasive particle on the work surface is more, leading to increased MRR. However, there is a limit to the applied static load, and beyond this limit, the depth of penetration is found to decrease leading low MRR

→ Process Capabilities (Characteristics) of USM

a) Metal Removal Rate (MRR)

Sl.No	Work Material	MRR (mm^3/min)
1	Glass	425
2	Ceramic	185
3	Mica (glass bonded)	390
4	Tungsten carbide	40
5	Tool steel (hardened)	30

MRR for different materials

It is clear from the table that, brittle non-metallic materials can be cut at higher rate than ductile materials (steels).

b) Surface Finish

The larger the grit size (fine sizes of abrasives), the finer will be the surface finish produced. surface finish may range from 0.2 - 0.6 μm. However, finer abrasives result in slower metal removal rate.

c) Accuracy

The process accuracy is measured through the overcut (oversize) produced during drilling of holes. The overcut is considered to be about two to four times greater than the mean grain size when machining glass and tungsten carbide. It is about 3 (three) times greater than the mean grain size of boron carbide. In general, an accuracy of ± 25 μm is possible with USM process.

d) Drilling hole capacity

Hole depths upto 51 mm have been easily achieved, while 152 mm deep hole has also been drilled using special flushing technique. Aspect ratio of 40:1 has been achieved.

e) The corner radius obtained is limited to 0.025 mm.

ADVANTAGES, LIMITATIONS & APPLICATIONS OF USM PROCESS

→ ADVANTAGES

a) Ability to machine non-conductive materials like glass, ceramics, etc.

b) USM is a non-thermal; non-chemical; creates no change in the microstructure, chemical or physical properties of the workpiece material

c) No burrs and no distortion of workpiece

d) Suitable for hard and brittle workpiece material

→ LIMITATIONS

a) Low metal removal rates.

b) Depth of holes and cavities produced are small. usually the depth of hole is limited to 2.5 times the diameter of the tool. There is a tendency for holes to break out at the bottom owing to high static load and amplitude of vibration of the tool.

c) Abrasive slurry has to be periodically replaced for efficient machining.

d) Tool wear is more.

e) Not suitable for soft workpiece materials.

f) process becomes costlier for complex shapes and very hard materials.

→ APPLICATIONS

a) Drilling and machining cavities or holes in conductive and non-conductive materials like glass, ceramics etc.

b) Threading of various glass and ceramic materials. Also used in engraving process on similar materials.

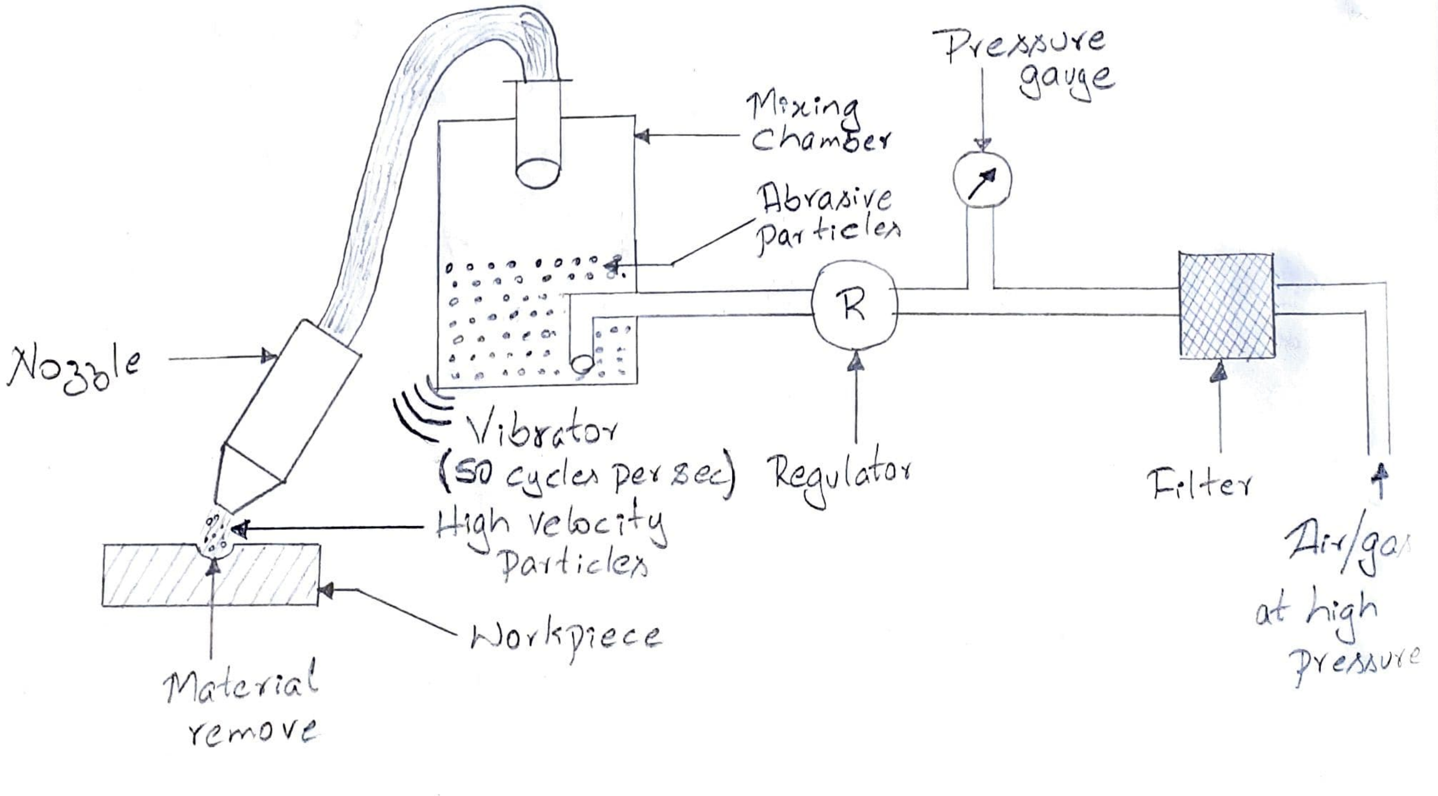
c) Lapping, broaching and deburring operations
d) cutting of semiconductor materials for electronic applications
e) Hard materials and precious stones such as synthetic ruby for the preparation of jewels for watch and timer movements are successfully machined by this method.
f) Manufacture of hard alloy wire drawing, punching and blanking dies, also making small complicated steel dies and punches.

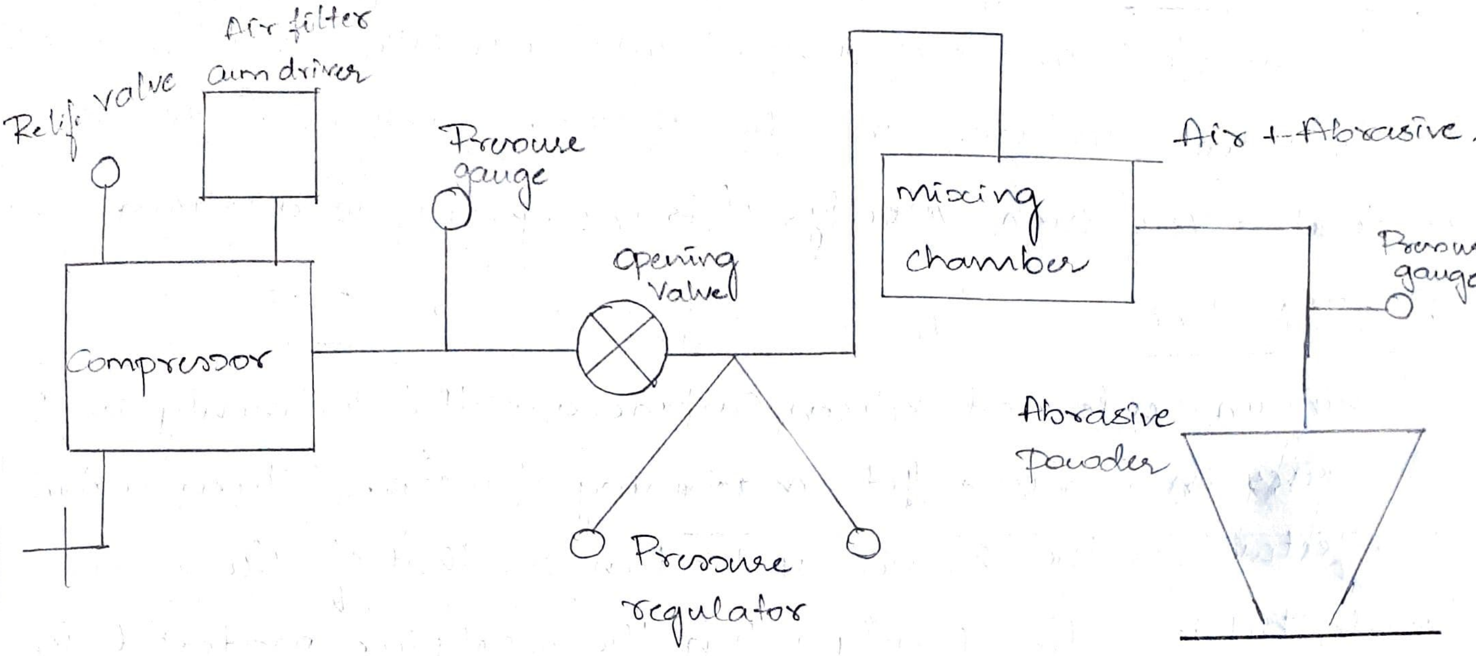
ABRASIVE JET MACHINING

INTRODUCTION :-

Abrasive jet machining is a process of material removal through the action of focused stream of fluid (gaseous, ie: high pressure gas or air] with the abrasive particles made to impinge on the work piece through a nozzle, and the material is removed by the action of Erosion of the high velocity abrasive particles.

the process is used mainly to cut intecrete shapes in brittle materials which are sensitive to heat. the cutting action is called by the carrier gas/air ~~stres~~. serves as coolant.





A Schematic layout of abrasive jet machining is as shown in fig. the filtered gas or air is supplied under pressure to the mixing chamber Containing abrasive powder (particles). the abrasive particles then Vibrating at 50 Cycles per Second. the abrasive energes as a. passes through the Connecting base and finally the abrasive gas mixture through a nozzle at high Velocity. the quantity of abrasive powder in the gas mixture is Controlled by the amplitude and frequency of Vibration of the mixing chamber. A dust removal equipment is necessary to protect the erosion environment.

the equipment consist of the following main parts:-

a) Nozzle
b) Abrasive.
c) Carrier Gas
d) Metering System.

a). NOZZLE

The nozzle is made of a hard material like tungsten Carbide (or) Synthetic Sapphire. Since the abrasive particles leave the nozzle at a very high Velocity, it is Subjected to abrasion wear.

b) ABRASIVE

Aluminium oxide and Silicon Carbide are the commonly used abrasives in abrasive jet machining process. Silicon Carbide is effective for the Same application as that of aluminium oxide, but is preffered only when the workpiece material is Very hard. the size of the abrasive particle ranges from 10-50 μm, with Smaller Sizes used for polishing and Cleaning, while the large one's used for Cutting and peening Operations. However, the abrasive Should be fine enough to Remain Suspended in the carrier gas and Should have excellent flow characteristics.

Apart from machining, there are Certain abrasives like, Sodium bicarbonate, dolomite, glass beads, etc. Used for clea-ning, deburring and polishing Operations.

c) CARRIER GAS

Air, nitrogen or Carbon dioxide is generally used as a Carrier gas. Air, when used must be filtered to remove moisture, oil and other Contaminants before entering the nozzle. the pressure required is in the range of 2-8 kg/cm^2. Higher pressure leads to nozzle wear, while lower pressure leads to low metal removal rate, Hence, gas pressure must be adjusted accordingly.

d) METERING SYSTEM

the metering System includes mixing chamber, regulator, Valves and other devices. the System must inject a uniform adjustable flow of abrasive particles into the gas steam.

AJM OPERATION :-

In Operation, the filtered gas is Supplied under pressure into the mixing chamber Containing fine abrasive particles. the Vibrating action of the mixing chamber entrains the the abrasive particles into the jet Steam. the abrasive and the gas mixture is then ~~plased~~ passed into the nozzle through the Connecting base. the Steam of mixture emerging from the nozzle at a high Velocity is directed into the worksurface to be machined. the impact of the particles on the worksurface produce Sufficient force to Cut a Small hole (or) Slot, deburring, trimming (or) removing oxides and other Surface films from the worksurface. the metal removal from the worksurface usually Occurs Surfaces due to erosion (or) chipping Caused by the abrasive particles impacting the worksurface at high Speed.

the nozzle is usually mounted on a fixture. Either the workpiece or the nozzle is moved by Cones, pantographs or other Suitable mechanisms to control the Size and Shape of operation cut. A dust hood or Vaccum dust Collector is used to draw the dust particles and keep the operation and operators Clear.

Variables or Parameters of AJM.

i) Carrier Gas
ii) Type of Abrasive
iii) Size of abrasive grain
iv) Velocity of Abrasive Jet
v) Mean no of particles / unit Volume of gas
vi) work material
vii) Stand off
viii) Nozzle Design.

i) Carrier Gas :-

Carrier gas to be used in AJM must not flare excessively when discharged from the nozzle to atmosphere. the gas Should be non-toxic, cheap, easily available and Capable of being dried and cleaned without difficulty. the gases that can be used are Air, Carbondioxide and Nitrogen.

Type of Abrasive :-

The choice of Abrasive depends on the type of mfg operation. Eg:- roughing, finishing etc, work material and cost.

the abrasives Should have Sharp and irregular Shape and be fine enough to remain Suspended in the Carrier gas and Should.

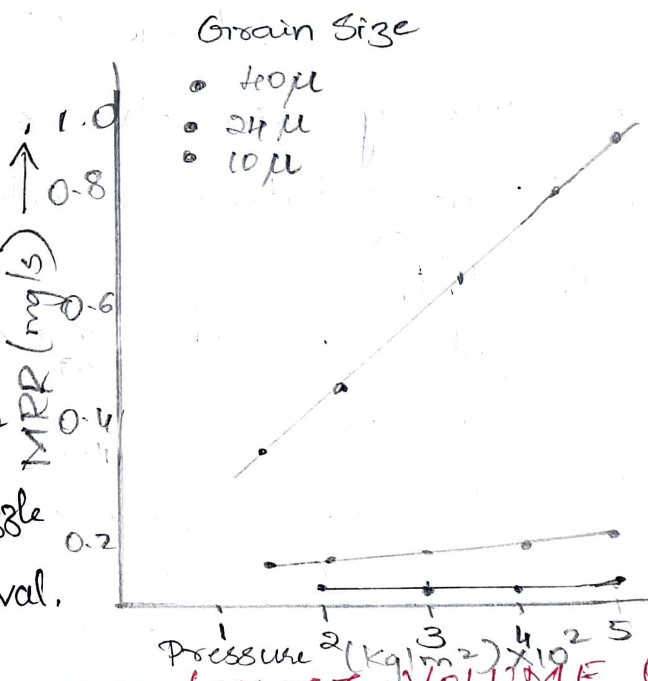
Excellent flow characteristics. the abrasives used are Aluminium oxide, Silicon Carbide whereas Sodium bicarbonate, glass beads are used for cleaning, etching and polishing.

GRAIN SIZE :-

the rate of metal removal depends on the size of the grains finer are less irregular in shape and hence, posses lesser cutting ability, Moreover, finer grains stick together and choke the nozzle. the most favourable grain size are ranged from 10 to 50μ. Coarse grains are recommented for cutting whereas finer grains are useful in polishing, deburring etc.

JET VELOCITY :-

It is the function of nozzle pressure, nozzle design, abrasive grain size and mean no of particles / unit volume of carrier gas. Fig shows the effect of nozzle pressure on rate of metal removal.



MEAN NO OF ABRASIVE GRAINS / UNIT VOLUME OF CARRIER GAS :-

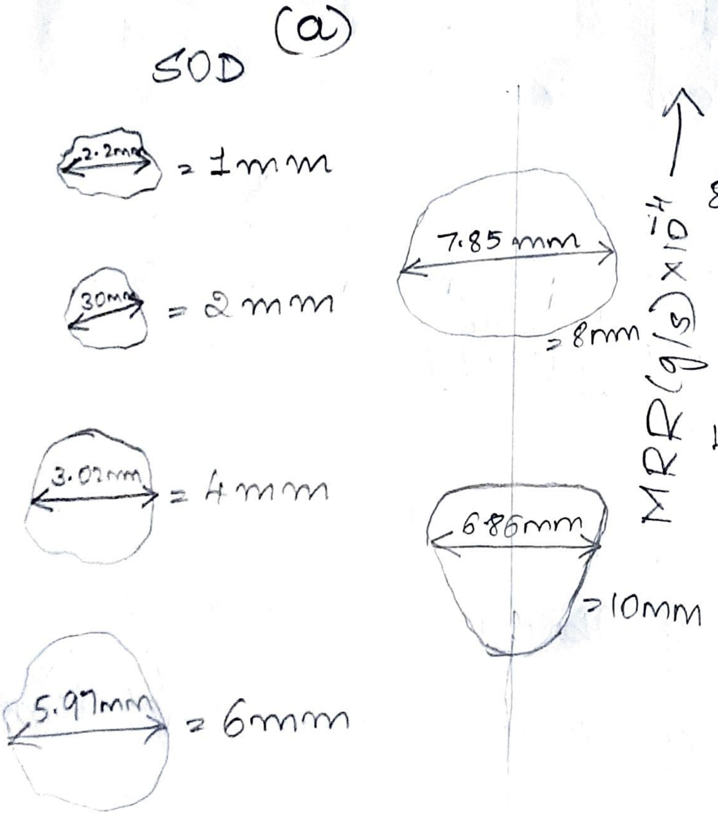
It is defined as,

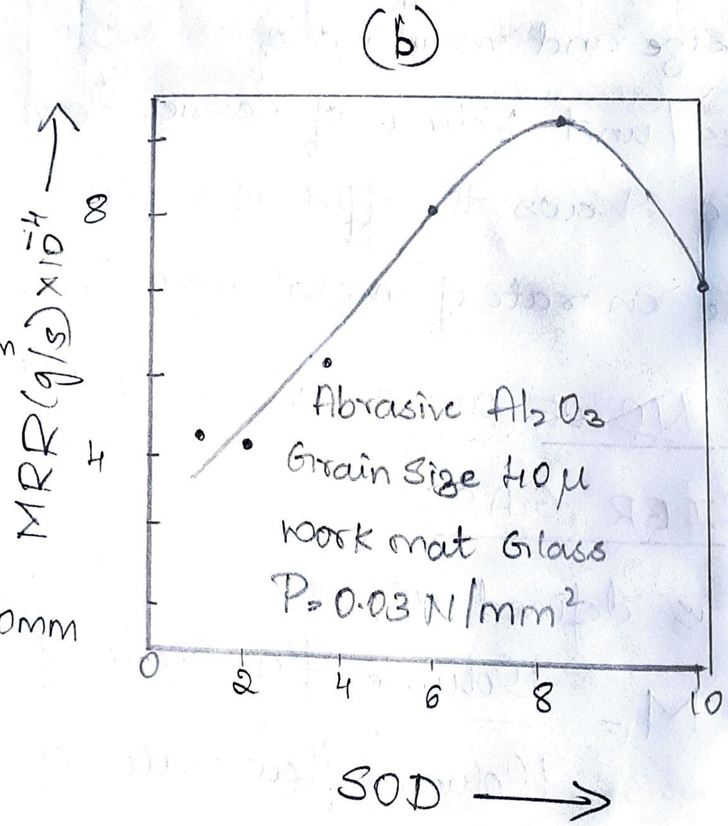
$$M = \frac{\text{Volume flow rate of Abrasive per unit time}}{\text{Volume flow rate of Carrier gas per unit time}}$$

Large value of M should result in high MRR but large abrasive flow rate has been found to adversly influence jet velocity and the nozzle. these for given conditions, optimum mixing ratio is used for maximum MRR.

Work Material :- AJM is recommended for processing brittle materials like glass, ceramics, refractions etc.

Stand off Distance (SOD) :- It is defined as the distance between the face of nozzle and working surface. A large SOD results in flaring of jet and poor accuracy. Fig shows effect of SOD on accuracy. Fig (b) shows relationship between SOD and MRR (metal removal rate).





NOZZLE DESIGN :-

Nozzle has to withstand the erosive action of the abrasive particles and hence, must be made of materials that can provide high resistance to wear. The common material for the nozzle are Sapphire and tungsten Carbide.

PROCESS CHARACTERISTICS OF AJM :-

i) Material removal Rate [MRR]

It is due to the chipping of the work Surface brought about by the impacting abrasive particles.

A typical metal Removal Rate for AJM is 16 mm^3/min in cutting glass. A minimum width of about 0.1mm Can be cut using a Rectangular nozzle with an orifice of 0.075×1.5 mm placed at a distance of 0.08 mm from the worksurface.

ii) Nozzle wear :-

The life of the nozzle is limited by excessive wear, this effect the accuracy of working and the metal removal rate.

iii) Accuracy :-

With Close Control of the Various parameters a dimensional tolerance of ±0.05 mm Can be obtained on normal production work, an accuracy of ±0.1mm is easily held.

iv) Surface Finish:-

Surface finish is obtained with fine (grain) abrasive particles, generally 0.5 to 1.2μ of Surface finish is obtained.

APPLICATIONS OF ABRASIVE JET MACHINING:-

i) Removing flash and parting lines from injection moulded part.

ii) Deburring and polishing plastic, Nylon and teffling component.

iii) Cleaning metallic mould cavities.

iv) Cutting thin Sectioned fragieimed components made of glass, refractors (or) Ceramics, mica etc.

v) Producing high quality Surface.

vi) Removing glass and paints from painting and leather objects

vii) Reproducing designs on a glass Surface through the help of marks made of Rubber, Copper etc.

viii) Froasting interior Surfaces of glass tubes.

IX) Hetching markings on glass Cylinders.

ADVANTAGES OF AJM:-

1). This process has the ability to machine brittle materials with thin Sections.

2). It is used in areas which are inaccessible by Ordinary methods.

3). Absense of tool work contact and metal removal at ma-
-croscopic scale leads to very little (or) no heat generation.

4). the process is characterized by low capital investment and low power consumption.

DISADVANTAGE OF AJM :-

1). the applications of AJM is restricted to brittle materials because of low rates of metal removal.

2). Sometimes parts modified machined by this process have to undergo an additional operation of cleaning as there is a possibility of abrasive grain sticking to the surface.

3) the machining accuracy is poor.

4) the nozzle wear rate is high

5) the process tends to pollutes the environment.