Non – Conventional machining
Module 7

Introduction

- Non traditional machining processes, are employed where traditional machining processes are not feasible, satisfactory or economical due to special reasons as outlined.

- The complexity of the job profile, hard materials, need for smooth **surface finish, closer dimensional tolerance and higher accuracy has led to the unconventional machining processes more important**

Characteristics of unconventional process

1. Very hard and brittle material can be machined
2. Flexible or slender work piece be machined, due to absence of physical contact of tool and work (less cutting force)
3. Complex part geometries that can be produced
4. Provide very good quality of surface finish and dimensional accuracy
5. Stress free components are possible
6. Less tool wear due the absence of tool contact

Disadvantages of non-conventional machining

1) High cost
2) complex set-up
3) skilled operator required

Classification of non-conventional machining processes

Erosion

Ion Displacement

Ion displacement

Corrosive reaction

Fusion + vaporization

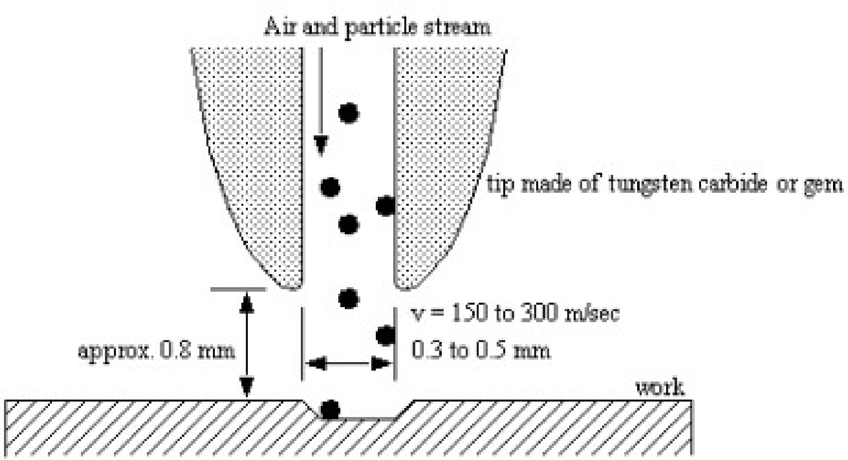
Energy Typ		Energy source
Mechanical	sive jet machining ii. Ul	Mechanical or Fluid motion
Electrochemical	i. Elect	Electric current
Mechanical & Electrochemical	i. El	Electric current & mechanical motion
Chemical		Corrosive agent
Thermal	ric discharge m/c'ing lectron beam m/c'ing. iii. Laser beam machining iv. Ion beam machining v. Plasma arc machining	Electric spark High speed electron Powerful radiation Ionized substance Ionized substance

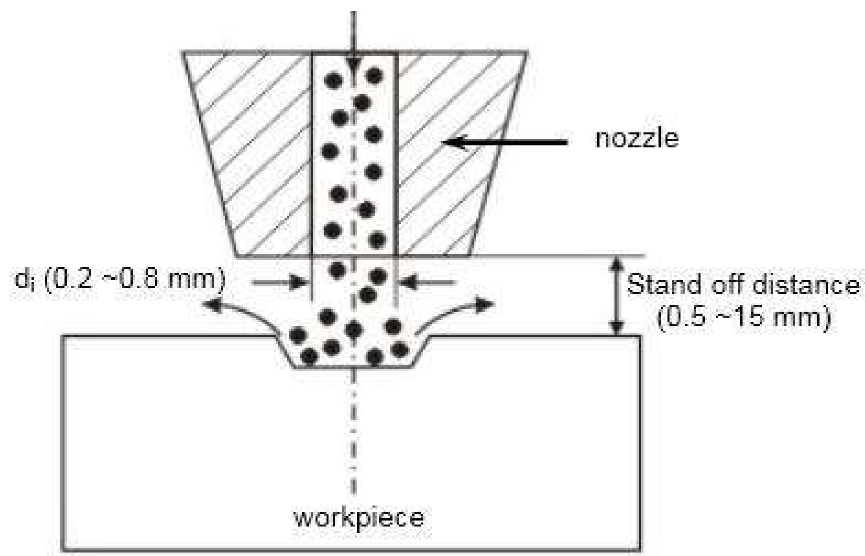
Physical Parameters of the Non-conventional Processes

Parameters	*USM*	*AJM*	*ECM*	*CHM*	*EDM*	*EBM*	*LBM*	*PAM*
Potential (V)	220	220	10	—	45	150000	4500	100
Current (Amp)	12 (A.C.)	1.0	10000 (D.C.)	—	50 (Pulsed D.C.)	0.001 (Pulsed D.C.)	2 (Average 200 Peak)	500 (D.C.)
Power (W)	2400	220	100000	—	2700	150	—	50000
Gap (m.m.)	0.25	0.75	0.20	—	0.025	100	150	7.5
Medium	Abrasive in water	Abrasive in gas	Electrolyte	Liquid chemical	Liquid dielectric	Vaccum	Air	Argon or hydrogen

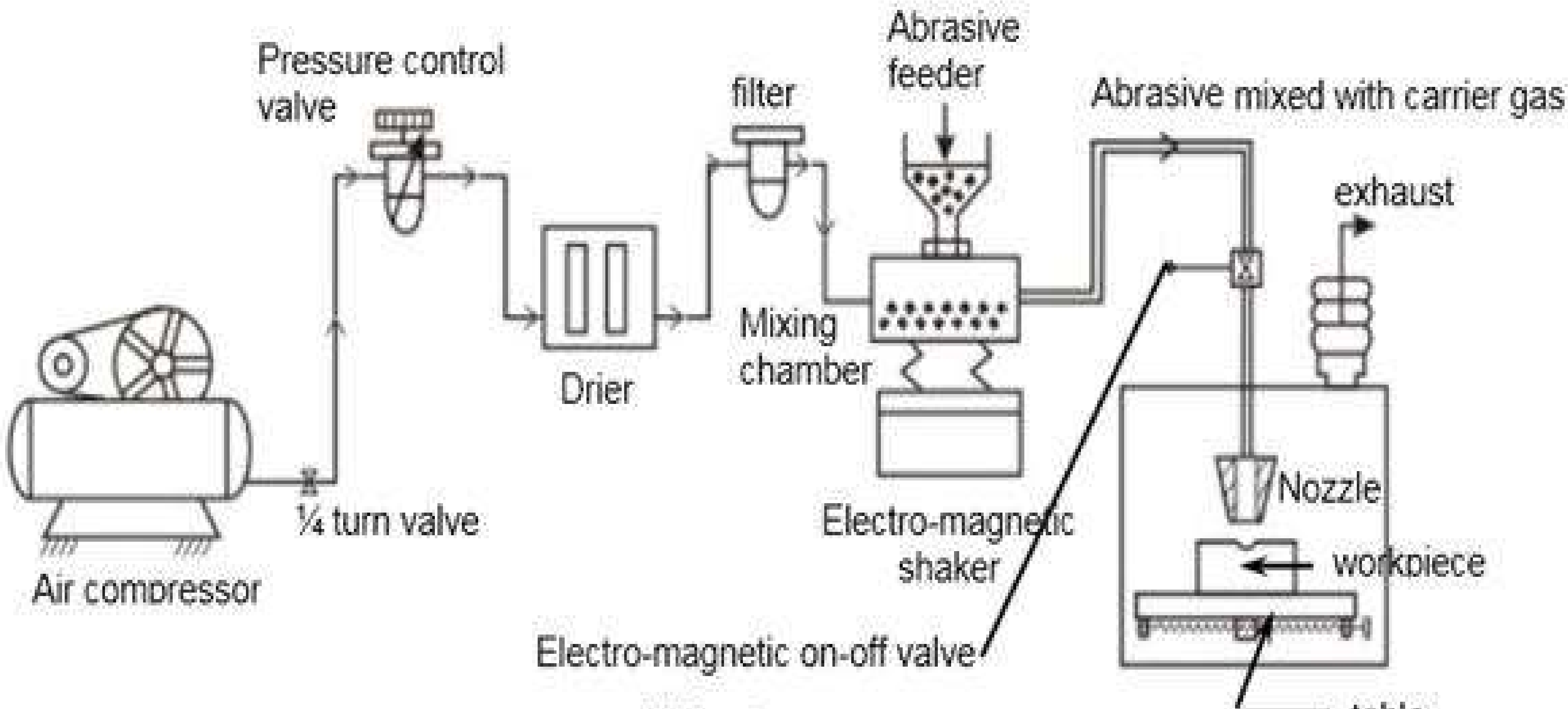
Abrasive Jet machining (AJM)

- In abrasive jet machining, a focused stream of abrasive particles, carried by high pressure air or gas is made to impinge on the work surface through a nozzle and work material is removed by erosion by high velocity abrasive particles.





Set Up of AJM



AJM set-up

https://www.youtube.com/watch?v=P6HXn7HdawY

https://www.youtube.com/watch?v=8Hn_UMNqFmQ

Working

- Dry air or gas is filtered, compressed and regulated (pressure and flow rate) while passed into the mixing chamber
- In the mixing chamber, abrasive powder is fed and is thoroughly mixed with air.
- The nozzle increases the velocity of the mixture at the expense of its pressure.
- Nozzles direct abrasive jet in a controlled manner onto work material
- The velocity of the abrasive stream ejected through the nozzle is generally of the order of 330m/sec.

Process Parameters

Factors that affect the process are:

- MRR
- Geometry of cut
- Roughness of surface produced
- Rate of nozzle wear

The following parameters affect these factors:

- Abrasive: composition; strength; size; mass flow rate
- Gas composition: pressure and velocity
- Nozzle: geometry; material; distance to work; inclination to work

Abrasive : Material – Al_2O_3 / SiC

–Shape – irregular / spherical

–Size – 10 ~ 50 μm

–Mass flow rate – 2 ~ 20 gm/min

Gas Composition : Composition – Air, CO_2, N_2

- Density – Air ~ 1.3 kg/m3
- Velocity – 500 ~ 700 m/s
- Pressure – 2 ~ 10 bar

Abrasive Jet : Velocity – 100 ~ 300 m/s

Mixing ratio – mass flow ratio of abrasive to gas

Stand-off distance – 0.5 ~ 5 mm

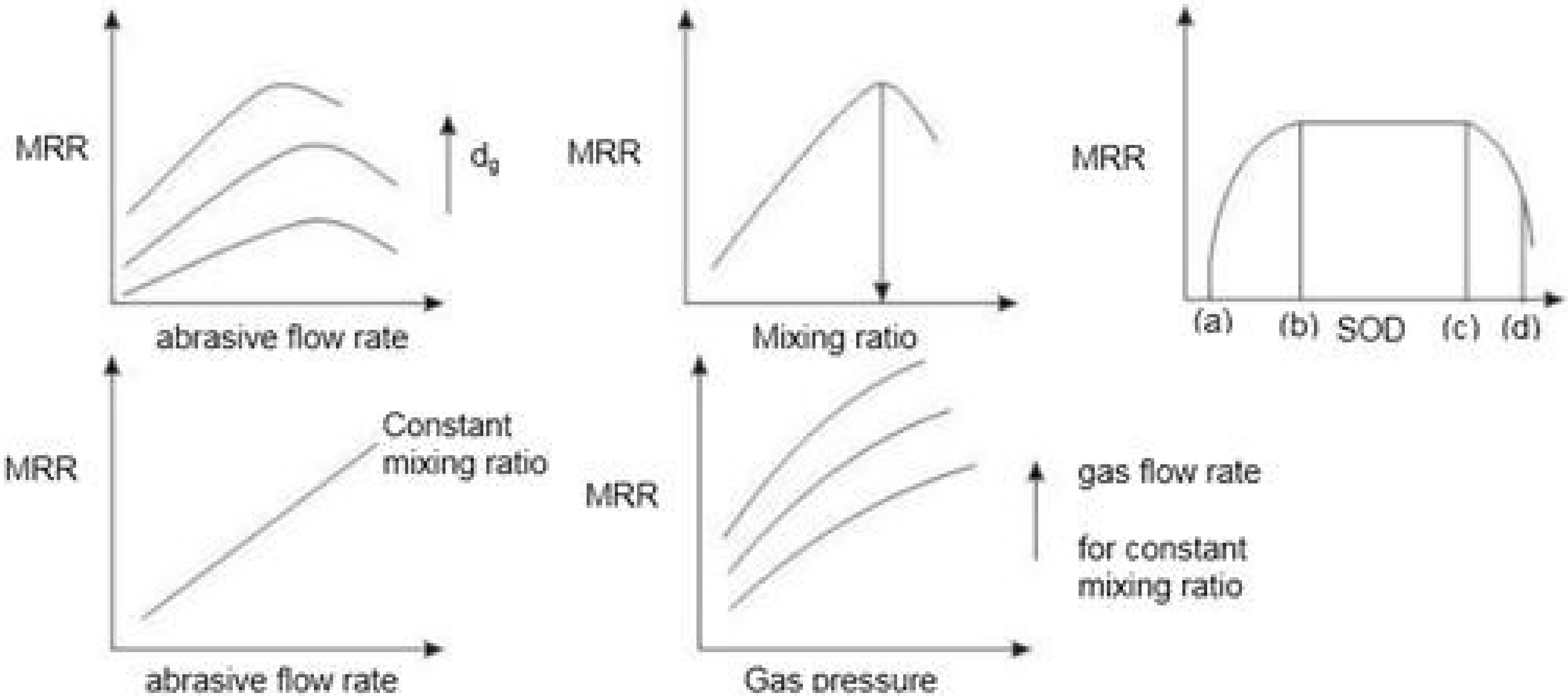
Impingement Angle – 60^0 ~ 90^0

Nozzle : Material – WC

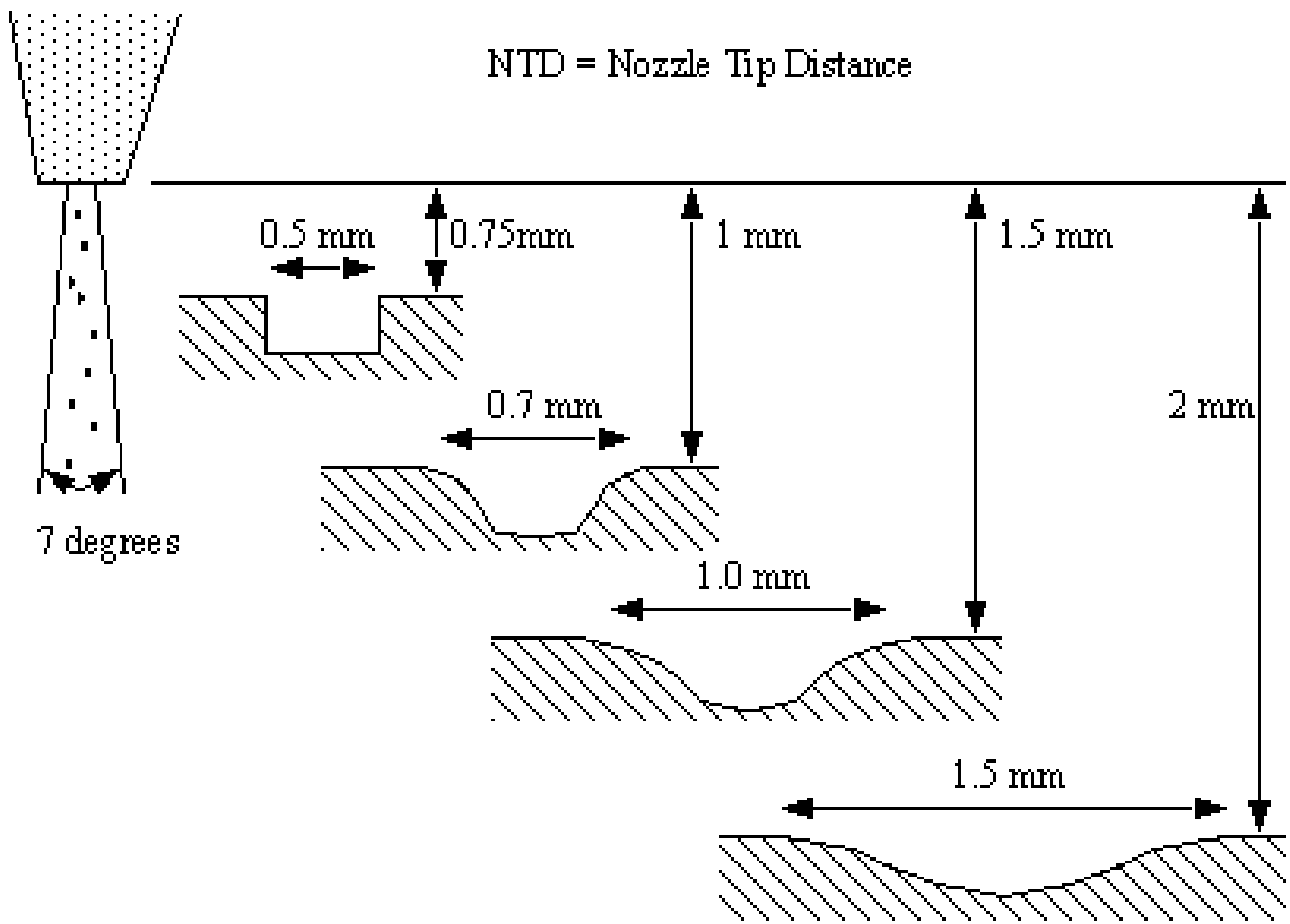
Diameter – (Internal) 0.2 ~ 0.8 mm

Life – 10 ~ 300 hours

Effect of process parameters on MRR



Relationship between head & nozzle tip distance



Stand off distance

- Stand off distance is defined as the distance between the face of the nozzle and the work surface of the work

- A large SOD results in flaring of jet which leads to poor accuracy

- MRR increase with nozzle tip distance or Stand off distance up to certain distance and then decreases.

- Decrease in SOD improves accuracy, decreases kerfwidth, and reduces taper in machined groove.

Process capabilities

1. Surface of the workpiece is cleaned automatically.
2. Smooth surface finish can be obtained.
3. Equipment cost is low.
4. Hard materials and materials of high strength can be easily machined.
5. Narrow slot can be produced

Limitations

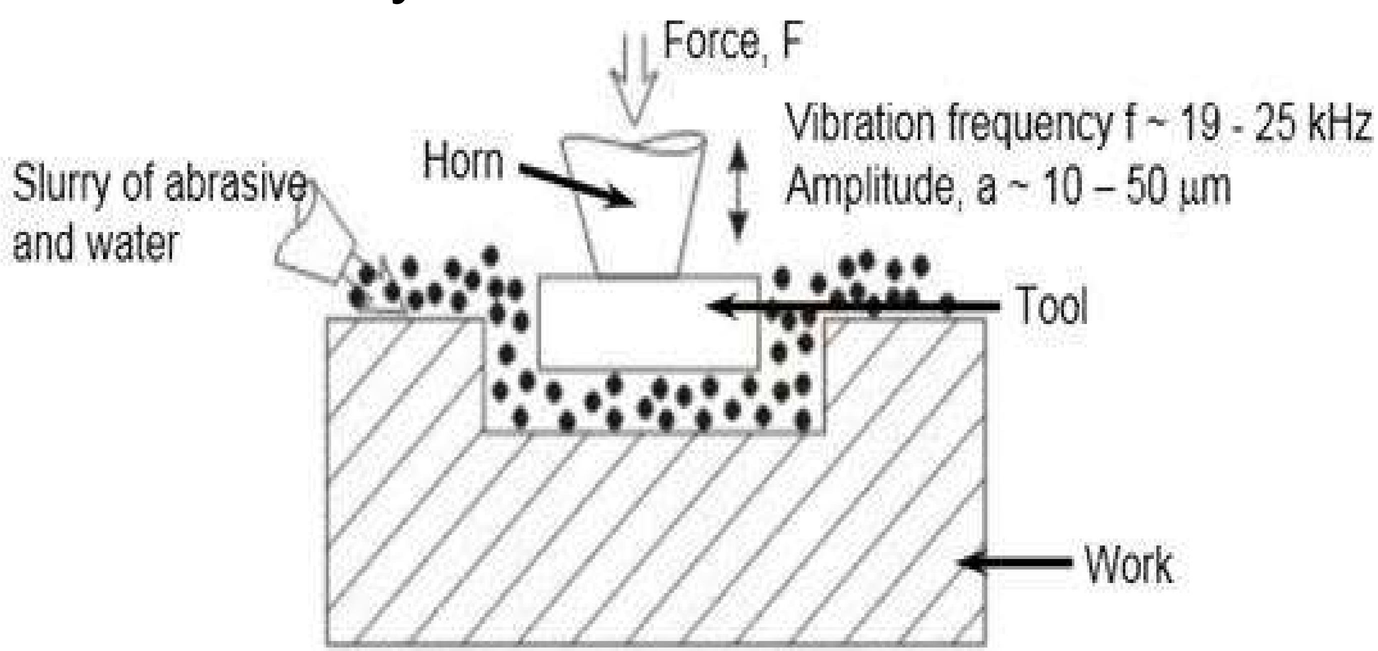
- Metal removal rate is low
- In certain circumstances, abrasive particles might settle over the workpiece.
- Nozzle life is less. Nozzle should be maintained periodically.
- Abrasive Jet Machining cannot be used to machine soft materials

Applications

1. Used for cutting thin fragile components like germanium, silicon etc.
2. Most suitable for machining brittle and heat sensitive materials like glass, ceramics germanium , silicon and gallium.
3. De-flashing small castings, engraving registration numbers on toughened glass used for car windows
4. AJM is useful in manufacture of electronic devices , drilling of glass wafers, making of nylon and Teflon parts permanent marking on rubber stencils, cutting titanium foils

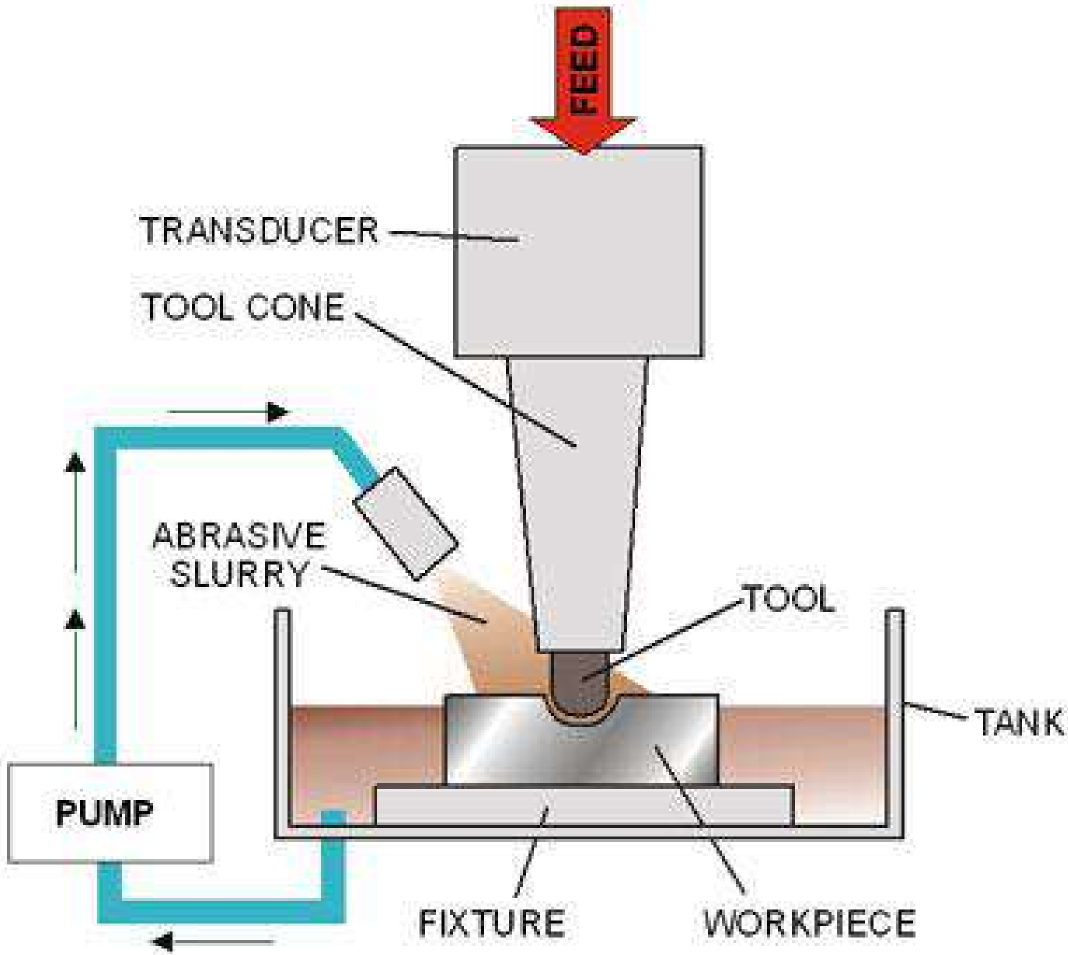
Ultrasonic machining (USM)

- The tip of the tool vibrates at low amplitude and at high frequency in an abrasive slurry.
- This vibration transmits a high velocity to fine abrasive grains between tool and the surface of the work piece.
- Material removed by erosion with these abrasive particles.



Set up for USM

https://www.youtube.com/watch?v=jh8852sfhpw



Working

- A tool of desired shape vibrates at an ultrasonic frequency (19 ~ 25 kHz) with an amplitude of around 15 – 50 μm over the workpiece.

- 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 water based slurry

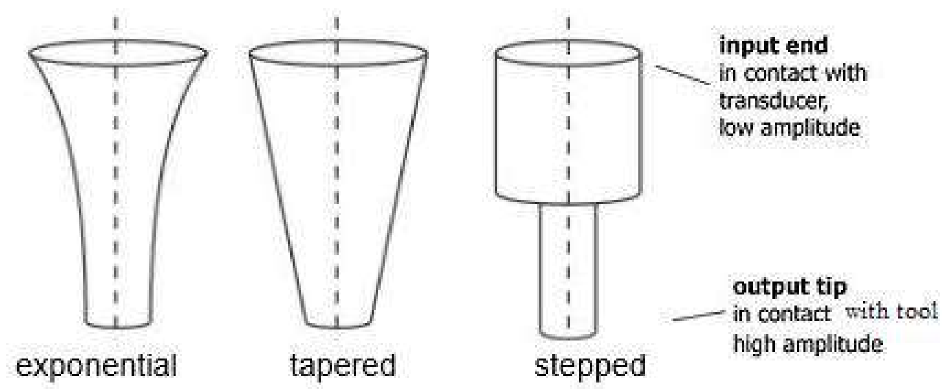
- As the tool vibrates over the workpiece, the abrasive particles act as the indenters and indent both the work material and the tool.

- The abrasive particles as they indent the work piece, material get removed

Typical elements of USM

- **Transducer** :- The ultrasonic vibrations are produced by the transducer. Essentially transducer converts electrical energy to mechanical vibration.

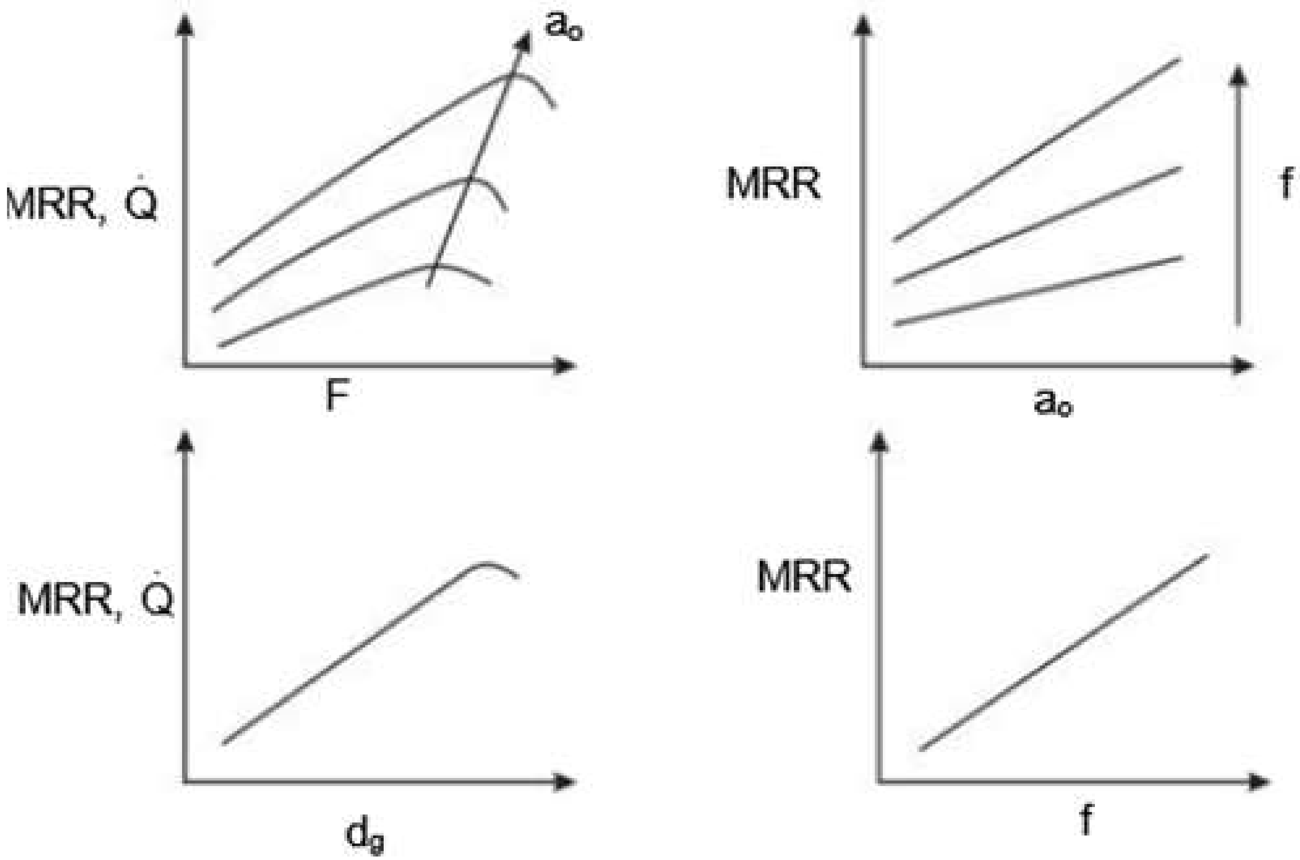
- **Tool holder or Horn or concentrator** *:-* The tool holder holds and connects the tool to the transducer. The concentrator is usually a cylindrically shaped metal rod which amplifies and concentrates the vibration to the tool from the transducer.



Different Horns used in USM

Process Parameters and their Effects

- Amplitude of vibration (a_o) – 15 – 50 μm
- Frequency of vibration (f) – 19 – 25 kHz
- Feed pressure (p)
- Abrasive size – 15 μm – 150 μm
- Abrasive material – Al_2O_3-SiC -B_4C -Boronsilicarbide -Diamond
- Volume concentration of abrasive in water slurry – C



MRR, Q̇
F
a₀
MRR
a₀
f
MRR, Q̇
d_g
MRR
f

Advantages of USM

1. Extremely hard and brittle materials can be machined, their machining is very difficult by conventional methods

2. Very good dimensional accuracy and surface finish can be obtained

3. Operational cost is low

4. The process is environmental friendly as it is noiseless and no chemical and heating is used

Disadvantages of USM

1. Its metal removal rate (MRR) is very low and it cannot be used for large machining cavities

2. Its initial setup cost and cost of tool is very high, frequency tool replacement is required as tool wear takes place in this operation

3. Not recommended for soft and ductile material due to their ductility

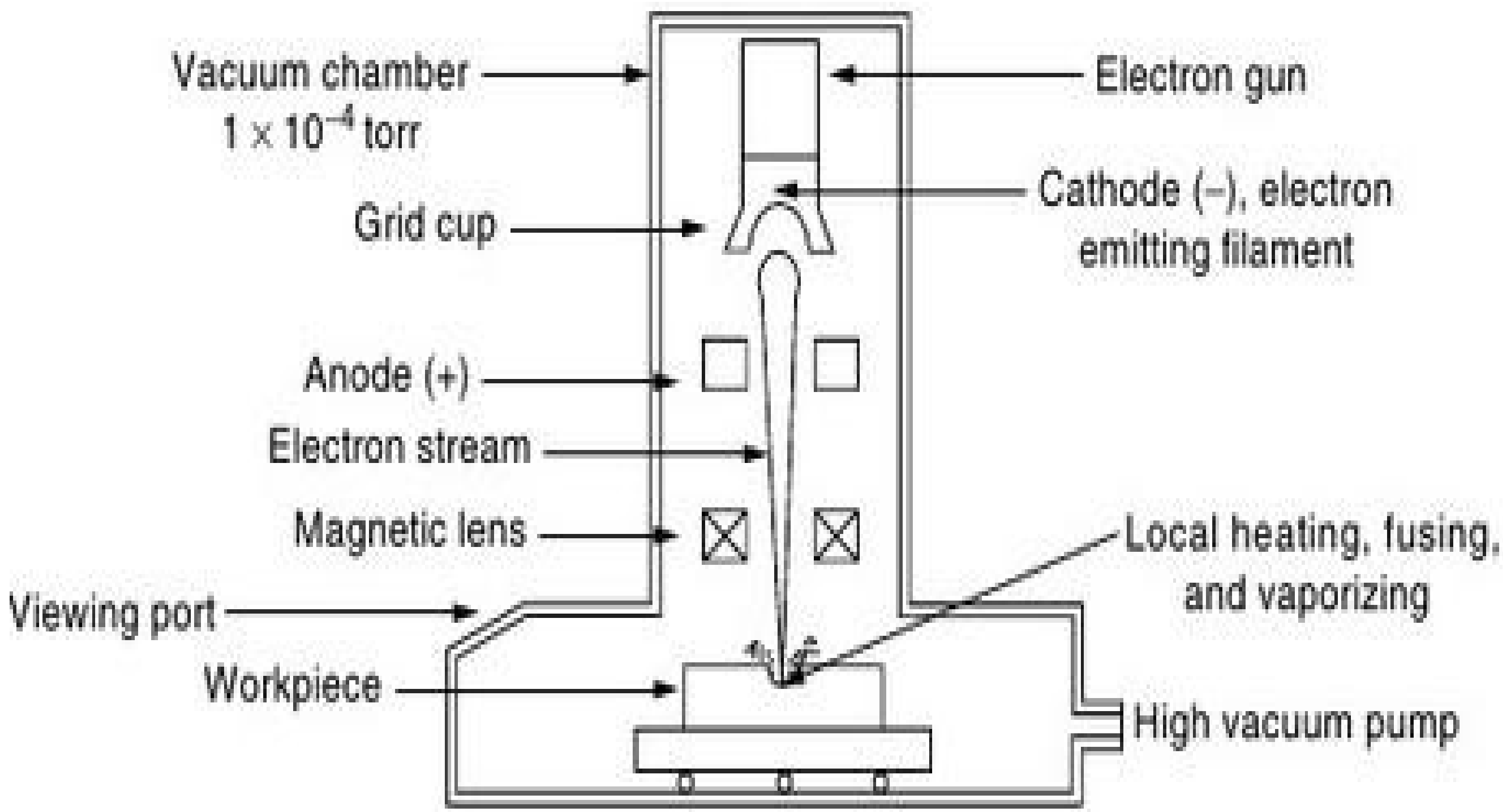
4. Power consumption is quite high

Applications

- Used for machining hard and brittle metallic alloys, semiconductors, glass, ceramics, carbides etc.

- Used for machining round, square, irregular shaped holes and surface impressions

Electron Beam Machining (EBM)



Electron Beam Machining (EBM)

- EBM is a metal removal process by a high velocity focused stream of electrons

- As the electrons strike the workpiece with high velocity, their kinetic energy is transformed into thermal energy which melts and vaporizes the material.

- The production of free electrons (negatively charged particles) are obtained by electron gun

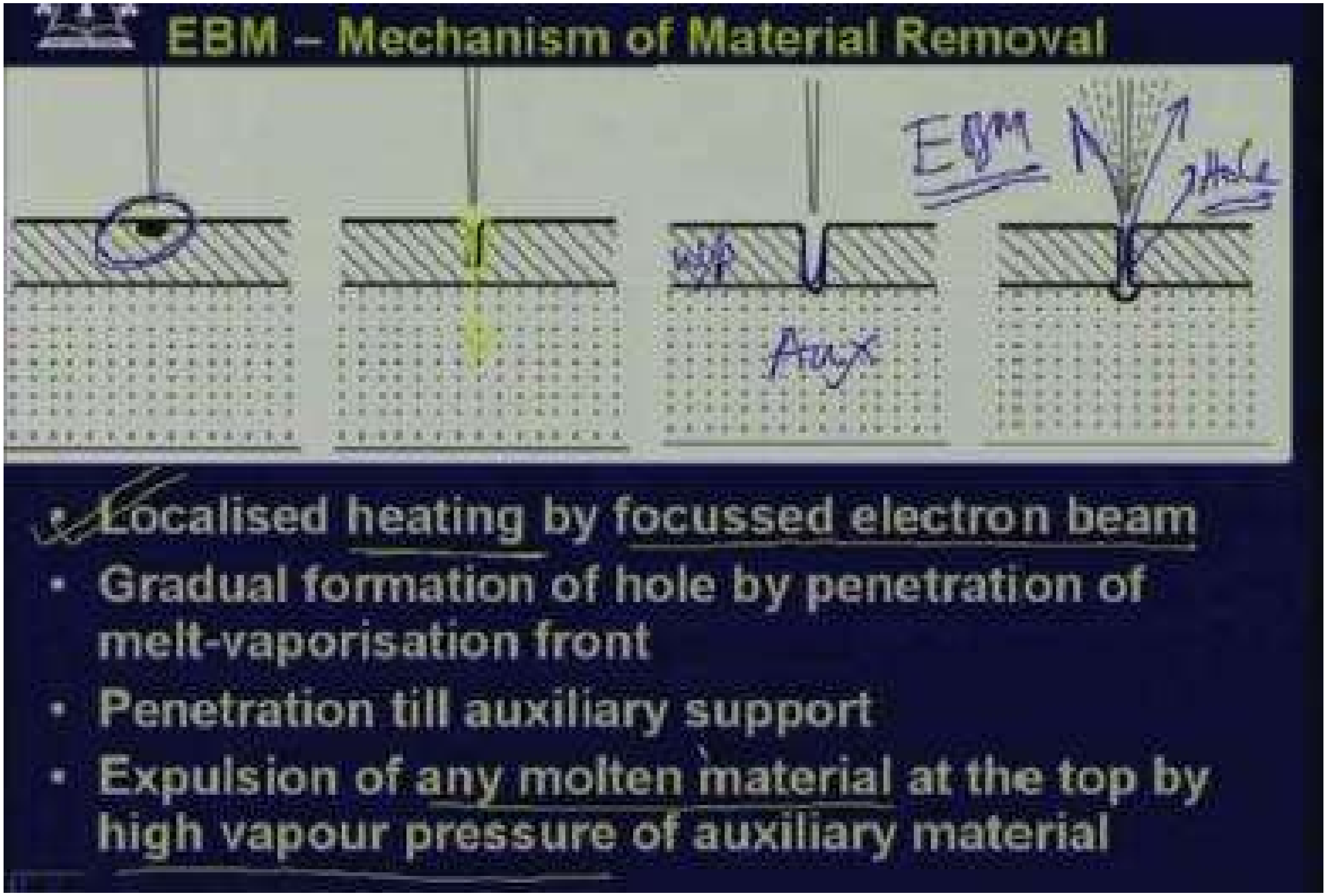
- Due to pattern of electrostatic field produced by grid cup, electrons are focused and made to flow in the form of a converging beam through anode

- The electrons are accelerated while passing through the anode by applying high voltage at anode.

- A magnetic deflection coil is used to make electron beam circular and to focus electron beam at a point (localized heating).

- The process is carried out in a vacuum chamber to prevent electrons from colliding with molecules of the atmospheric air and to prevent tungsten filament from getting oxidizing with air

Material removal mechanism



Advantages of EBM

1. There is no mechanical contact between too land work piece, hence no tool wear.

2. Very small holes can be machined in every type of material with high accuracy

3. Drilling holes with high depth/diameter ratios, greater than 100:1

4. A wide range of materials like steel, stainless steel, Ti and Ni super-alloys, aluminium as well as plastics, ceramics can be machined successfully using electron beam.

Disadvantages of EBM

1. Cost of equipment is high.
2. Rate of material removal is low.
3. It can be used for small cuts only.
4. Vacuum requirements limits the size of work piece.

Application of EBM

1. Drilling of holes in pressure differential devices used in nuclear reactors, air craft engine
2. Machining of wire drawing dies having small cross sectional area

Laser Beam Machining (LBM)

- LASER is an acronym for

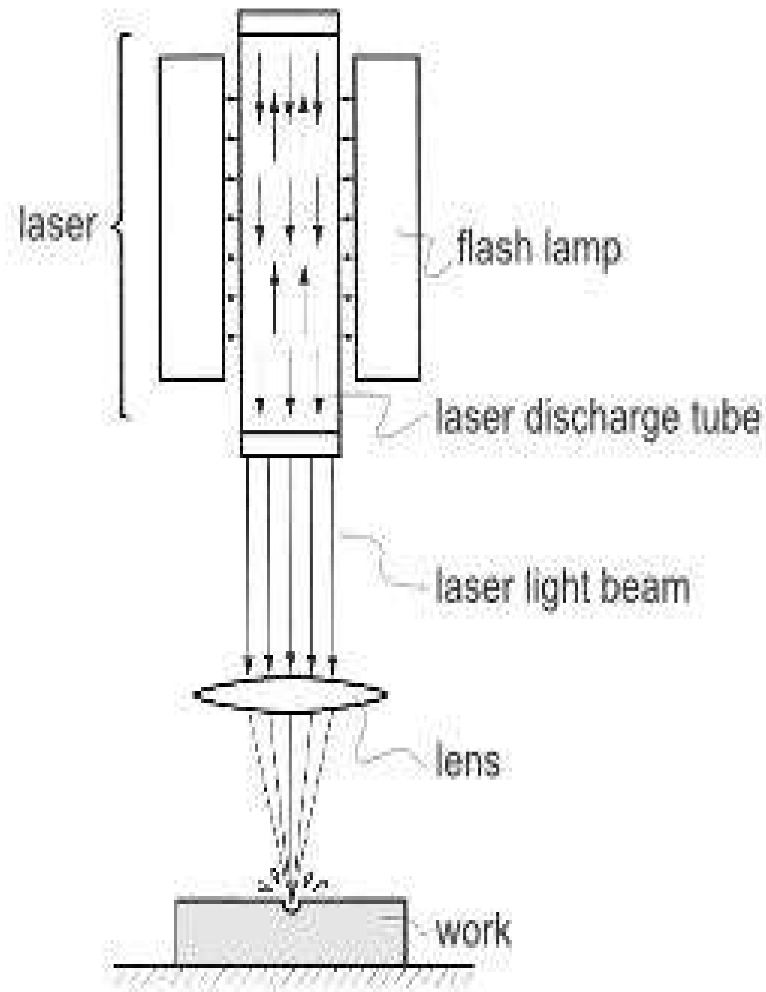
  Light **A**mplification by **S**timulated **E**mission of **R**adiation (electromagnetic radiation)
- **Properties of laser**

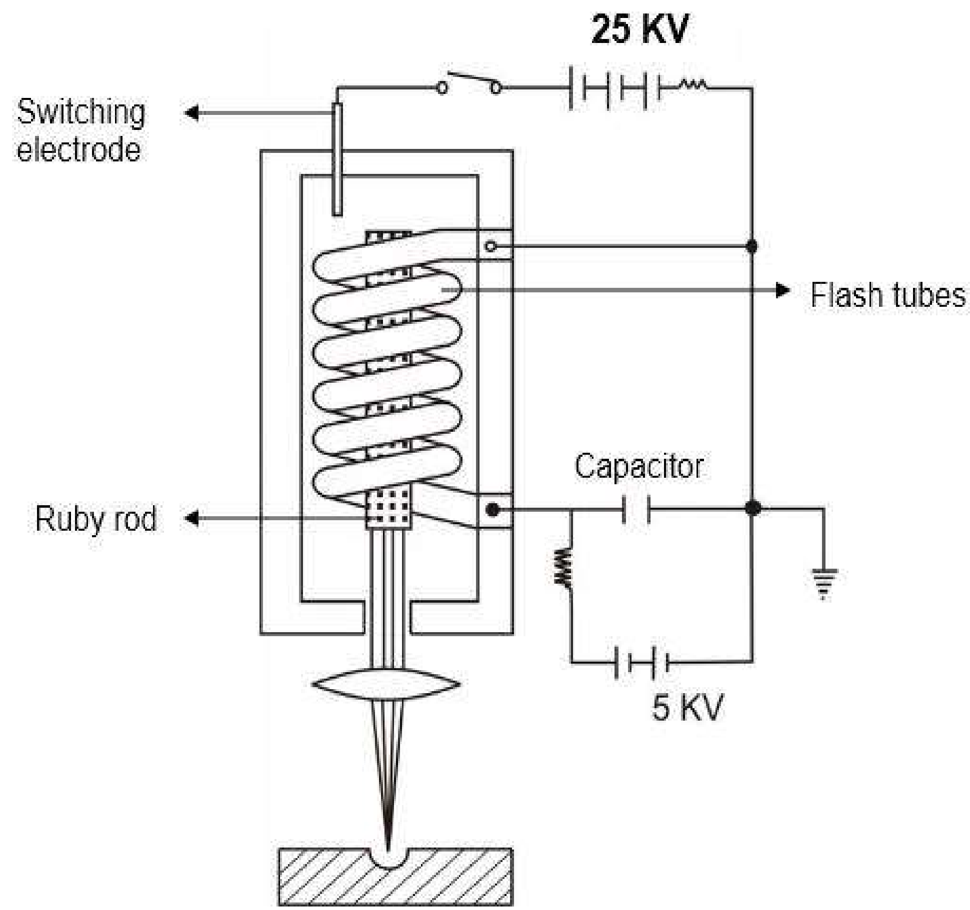
- Laser light is different from normal light
- It is a **monochromatic** Light
- Light released is **coherent** (constructive)
- Light is very much **directional** and a very strong and concentrated beam

- Laser beam machining (LBM) uses the light energy from a laser to remove material by vaporization and ablation

- Laser beam melts the material by focusing a coherent beam of monochromatic light on the work-piece

- The LBM process does not involve mass material removal, but does provide rapid material removal with an easily controlled, non-contact, non wearing tool.


laser
flash lamp
laser discharge tube
laser light beam
lens
work


25 KV
Switching electrode
Flash tubes
Capacitor
Ruby rod
5 KV

Tool Feed Mechanism

- Focusing laser beam (cutting tool) at a pre-decided point in the workpiece serves as the tool. The movement of the converging lens to shift the focusing is the tool feed mechanism in LBM process

- Mirrors direct the beam from the source down to the lens

- The lens then focuses the beam into the desired geometry

Other aspects of LBM

- Efficiency of LBM is 0.3 % to 0.5 %
- Typical output energy of a laser is 20J with the a pulse duration of 1 millisecond
- Peak power touches a value around 20,000W
- Divergence of the beam is 2×10^{-3} rad and this with a lens of focal length of 25 mm gives a spot diameter of 50 μm

Advantages of LBM

1. Materials which cannot be machined by conventional methods are machined by LBM (ceramics, glass to softer materials like plastics, rubber wood).

2. There is no tool so no tool wear.

3. Application of heat is very much focused so rest of the workpiece is least affected by the heat.

4. Drills very find and precise holes and cavities

Disadvantages of LBM

1. High capital investment is involved. Operating cost is also high.

2. Recommended for some specific operations only as production rate is very slow.

3. Cannot be used comfortably for high heat conductivity materials light reflecting materials.

4. Skilled operators are required.

Applications of LBM

- LBM is used to perform different machining operations like drilling, slitting, slotting, scribing operations. It is used for drilling holes of small diameter of the order of 0.025 mm. It is used for very thin stocks.

- Making complex profiles in thin and hard materials like integrated circuits and printed circuit boards (PCBS).

- Machining of mechanical components of watches.

- Smaller machining of very hard material parts.

Plasma arc machining (PAM)

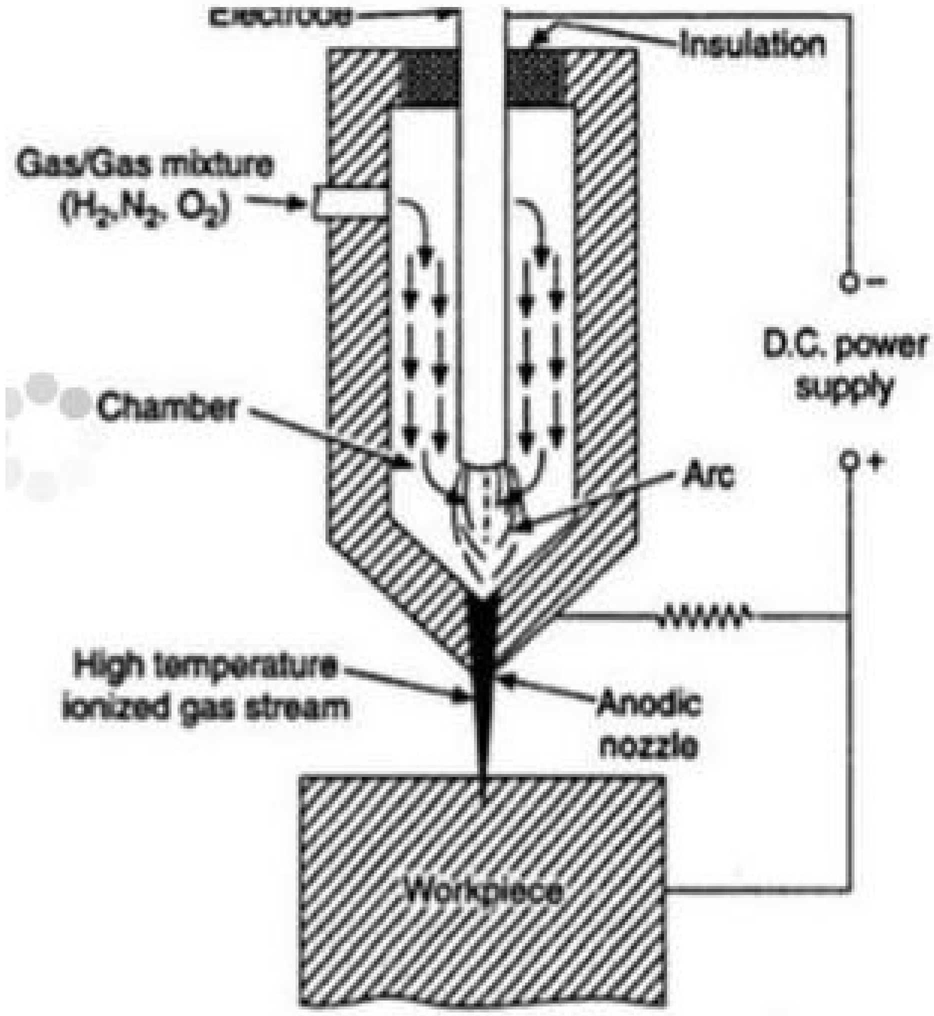


Fig. 12.8. Plasma Arc Machining (PAM).

PLASMA?

- Plasma is generated by subjecting a flowing gas to the electron bombardment of an arc

- The arc is set up between the electrode and the anodic nozzle; gas is forced to flow through this arc

APPLICATIONS

- Profile cutting of stainless steel, monel and super alloy plates

- A plasma is a high temperature ionized gas

- PAM is done with a high speed jet of a high temperature plasma

- This jet heats up the workpiece causing a quick melting

- PAM can be used on all materials which conduct electricity, including those which are resistant to oxy-fuel gas cutting

Mechanics of PAM

- In this process gases are heated and charged to plasma state
- Plasma state is the superheated and electrically ionized gases at approximately 5000 C.
- high velocity jet flow of hot ionized gas melts the metal and then removes the molten material to form a kerf.

Plasma Gun

- The plasma gun consists of a tungsten electrode fitted in the chamber.
- The electrode is given negative polarity and nozzle of the gun is given positive polarity.
- Supply of gases is maintained into the gun.
- A strong arc is established between the two terminals anode and cathode.
- Gases are used to create plasma like, nitrogen, argon, hydrogen or mixture of these gases.

- There is a collision between molecules of gas and electrons of the established arc.
- As a result of this collision gas molecules get ionized and heat is evolved.
- This hot and ionized gas called plasma is directed to the workpiece with high velocity.
- The established arc is controlled by the supply rate of gases.

Power Supply and Terminals

- Power supply (DC) is used to develop two terminals in the plasma gun.

- A tungsten electrode is inserted to the gun and made cathode and nozzle of the gun is made anode.

- Heavy potential difference is applied across the electrodes to develop plasma state of gases.

Cooling Mechanism

- As hot gases continuously comes out of nozzle so there are chances of its overheating
- A water jacket is used to surround the nozzle to avoid its overheating.
- The metals usually cut with this process are the aluminium and stainless steels.

Advantages of PAM Process

- It gives faster production rate.
- Very hard and brittle metals can be machined.
- Small cavities can be machined with good dimensional accuracy

Disadvantages of PAM Process

- Its initial cost is very high.

- The process requires over safety precautions which further enhance the initial cost

- Some of the workpiece materials are very much prone to metallurgical changes on excessive heating so this fact imposes limitations to this process.

- It is uneconomical for bigger cavities to be machined.

Applications of PAM

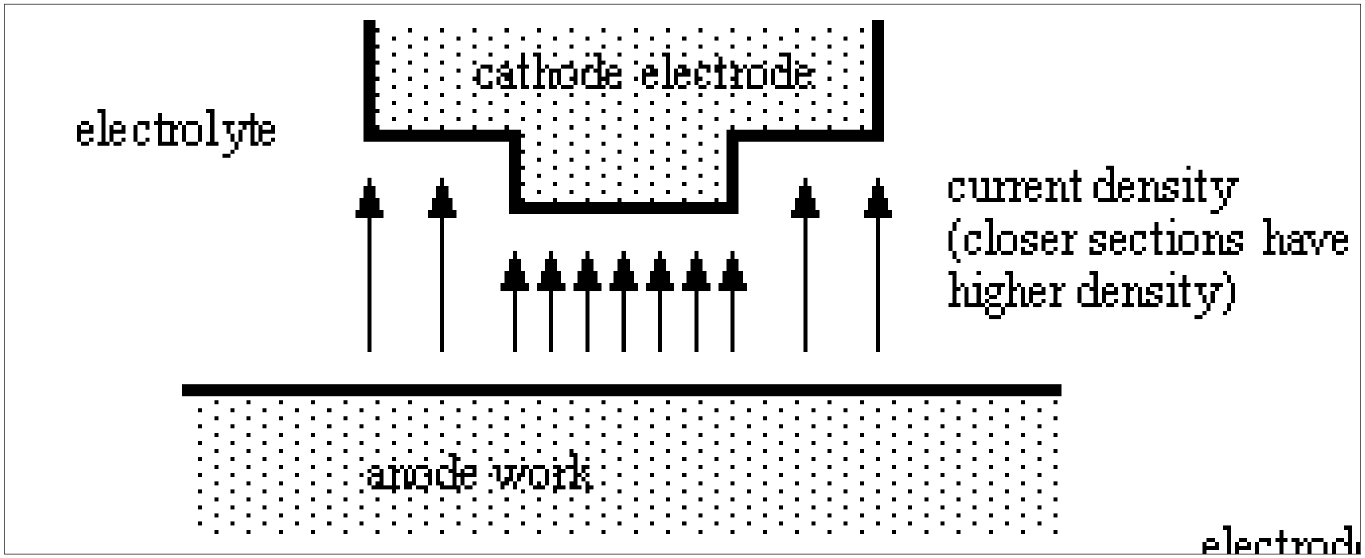
- The main application of this process is profile cutting as controlling movement of spray focus point is easy in case of PAM process. This is also recommended for smaller machining of difficult to machining materials

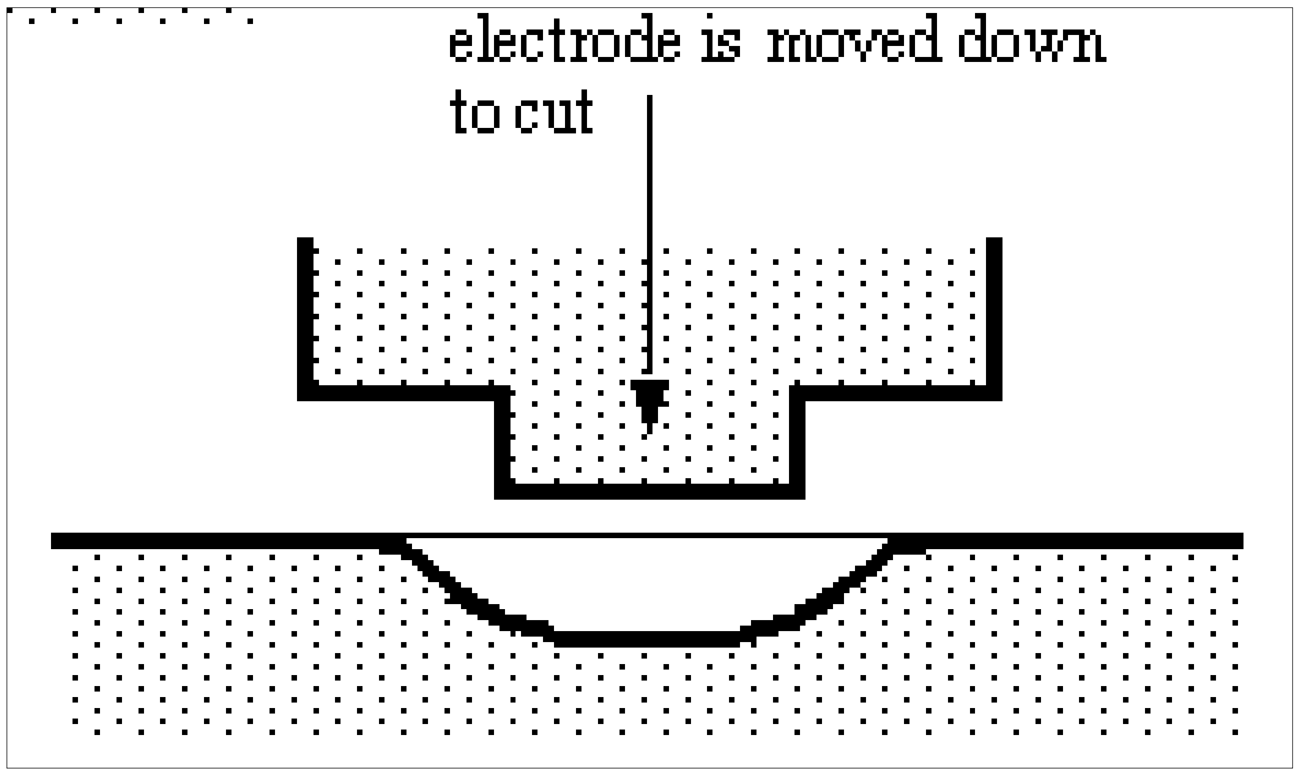
Electrochemical machining (ECM)

- ECM is one of the most potential unconventional machining process
- The basic principle of this machining process has been known for a long time
- Principle is the reverse of electroplating
- Flow of current through an electrolyte is always accompanied by movement of matter

What exactly happens?

- A cathode (tool) and anode (workpiece) are placed in an electrolyte
- A potential voltage is applied.
- On the anode (positive) side the metal molecules ionize (lose electrons) break free of the workpiece
- The shape of the tool is reproduced on the workpiece
- .
- In ECM, electrolyte is so chosen that there is no deposition on tool and shape of tool remains unchanged. The machined surface takes the replica of tool shape


cathode electrode
electrolyte
current density
(closer sections have
higher density)
anode work
electrod


electrode is moved down
to cut

Electrolyte

- Normally water soluble NaCl and NaNO3 are used as electrolyte.
- Electrolyte facilitates are carrier of dissolved workpiece material.

Functions of the electrolytes

1. Create conditions for anodic dissolution of workpiece material

2. Remove the debris of the electrochemical reactions from the gap

3. Carry away the heat generated by the machining process

Process parameters and performance factors

- Supply voltage = 8 to 20V,
- Current (I) = 50 to 5000 A.
- Electrode gap is typically 0.1 to 0.2 mm.
- Tool material - Cu, Brass, Steel
- Tool feed rate,
- Electrolyte composition and temperature etc
- MRR is about 1600mm3/min per 1000 A
- Surface finishes 0.1 to 0.5 microns using ECM
- Specific power consumption 7W/mm3/min

process capabilities

1. Machining of hard and brittle material is possible with good surface finish
2. Good for complicated shapes.
3. There is almost negligible tool wear so cost of tool making is one time
4. No direct contact between tool and work and absence of force or heat, so no scope of mechanical and thermal residual stresses in the work-piece.
5. Very good surface finish can be obtained.
6. MRR is not dependent on material hardness

Limitations of ECM

1. Electricity non-conducting materials can not be machined.

2. Tool and workpiece material should be chemically stable with the electrolyte

3. Accurate feed rate of tool is required to be maintained.

4. High cost and difficult in dimensional control

Applications of ECM Process

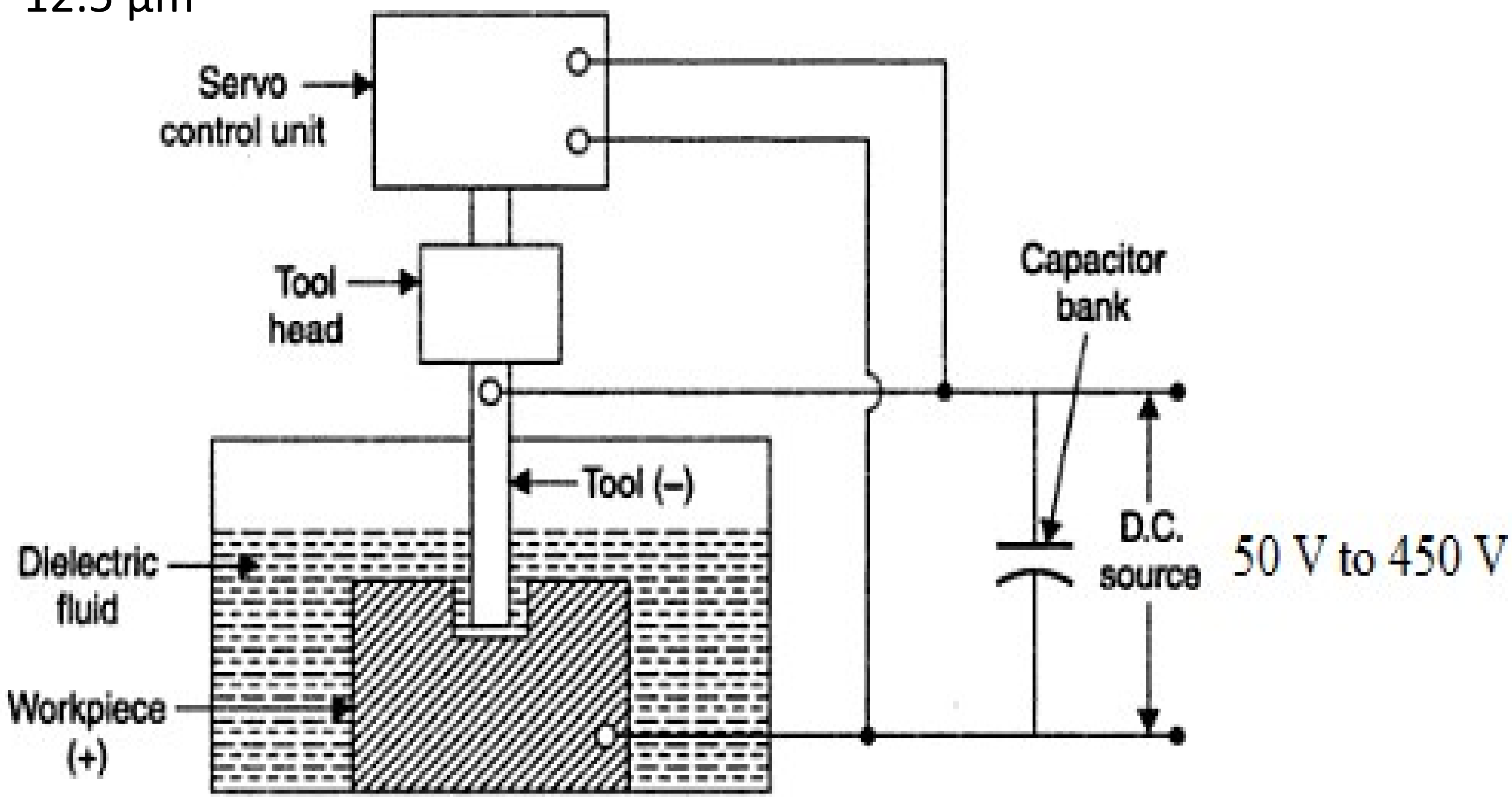
1. Used to machine dies, turbine and compressor blades

2. ECM is used for deburring of parts like gears

3. ECM has been used in a wide variety of industrial applications ranging from cavity sinking to deburring.

Electric discharge machining (EDM)

- Voltage 50 to 450 V (DC)
- *Electrode gap = 0.01 to 0.5 mm*
- MRR: 2 to 400 mm3/min.
- Ra varies from 0.05 – 12.5 µm



Electric Discharge Machining (EDM).

- Known as spark erosion machining or spark machining
- Material of workpiece removed due to erosion caused by electric spark.
- The metal electrode (tool) and the part (work) are placed very close to each other, separated by a non-conducting liquid (called a dielectric) – a commonly used dielectric is kerosene.
- A voltage difference is then applied to the part and tool, generating a spark; the heat from the spark melts a tiny bit of metal from the part

Tool/ electrodes in EDM

- The geometry which is to be machined into the workpiece decides the shape and size of the tool

- The electrode is conductor, usually copper, graphite, tungsten and brass etc. Tool is given negative polarity

1. High electrical conductivity
2. High thermal conductivity –the local temperature rise would be less
3. High melting point – high melting point leads to less tool wear
4. Easy manufacturability
5. Cost – cheap
6. Less wear rate

Properties of dielectric fluid

1. Low viscosity to ensure efficient flushing
2. High flash point
3. Non-toxic
4. Non-corrosive
5. High latent heat
6. Suitable dielectric strength

Process capability of EDM

1. Can machine hard material economically with close tolerance.
2. High degree of dimensional accuracy, so recommended for tool and die making.
3. Complicated geometries can be produced which are very difficult otherwise.
4. Highly delicate sections and weak materials can be processed without any risk of their distortion, because tool never applies direct contact on the workpiece
5. Fine holes can be drilled easily and accurately.
6. A good surface finish can be obtained.

Limitations

1. Electrically non-conducting materials cannot be processed by EDM.
2. EDM process is not capable to produce sharp corners.
3. The slow rate of material removal.
4. Specific power consumption is very high.
5. Excessive Tool wear affects dimensional accuracy
6. Cannot be used on large sized workpieces, size is constrained by the size of set up.

Application

- EDM is widely used for die making as complex cavities are to be made, cutting very small and accurate dimension holes, e.g. in injection nozzles for motor engines etc

- It is also used for making holes with straight and curved axes which cannot be produced by conventional machining operations.

Similarities between EDM and ECM

- The tool and workpiece are separated by a very small gap, i.e. no contact in between
- The tool and material must be conductors of electricity.
- A fluid is used as a medium between the tool and the work
- The tool is fed continuously towards the workpiece to maintain a constant gap
- Needs high capital investment and power

Thanks