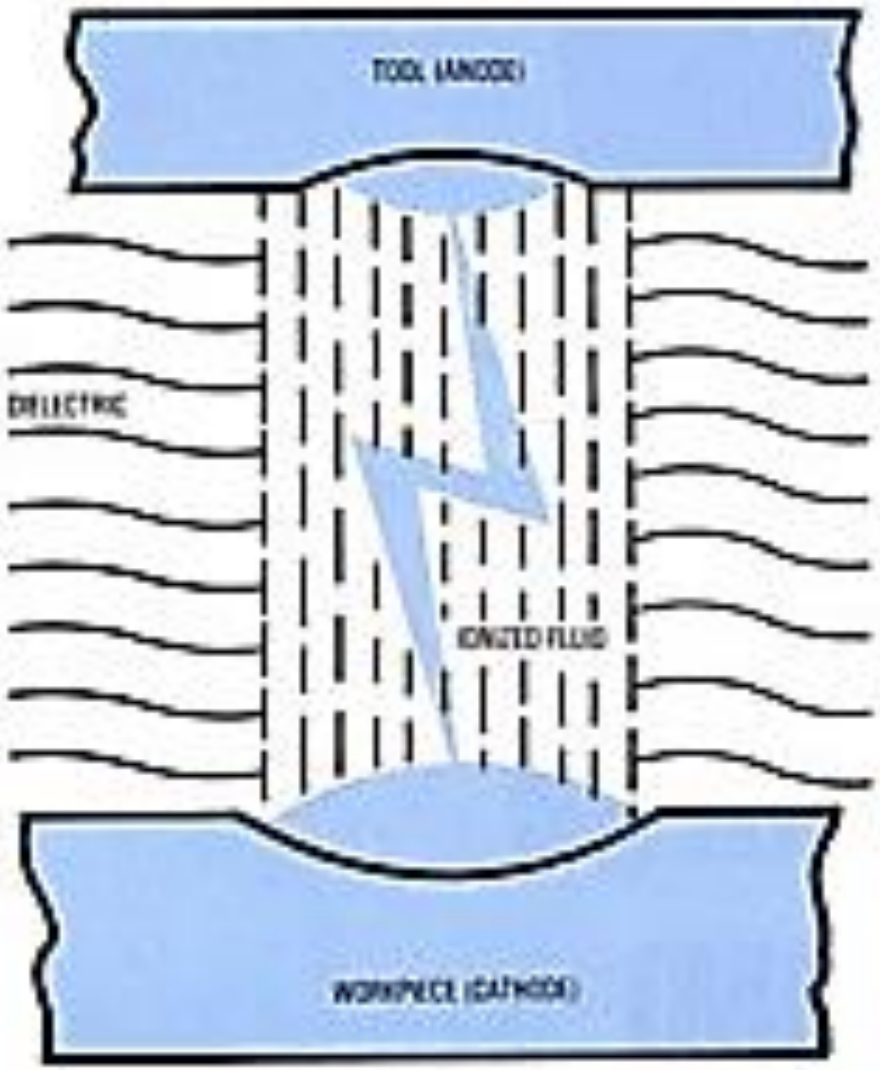
MODULE 3

- ELECTRIC DISCHARGE MACHINING
- ULTRASONIC MACHINING
- ELECTRO CHEMICAL MACHINING

ELECTRIC DISCHARGE MACHINING (EDM)

- Its a manufacturing process whereby a desired shape is obtained using electrical discharges (sparks).



EDM spark erosion is the same as having an electrical short that burns a small hole in a piece of metal it contacts.

Electro Discharge Machining (EDM) is an electro-thermal non-traditional machining process, where electrical energy is used to generate electrical spark and material removal mainly occurs due to thermal energy of the spark.

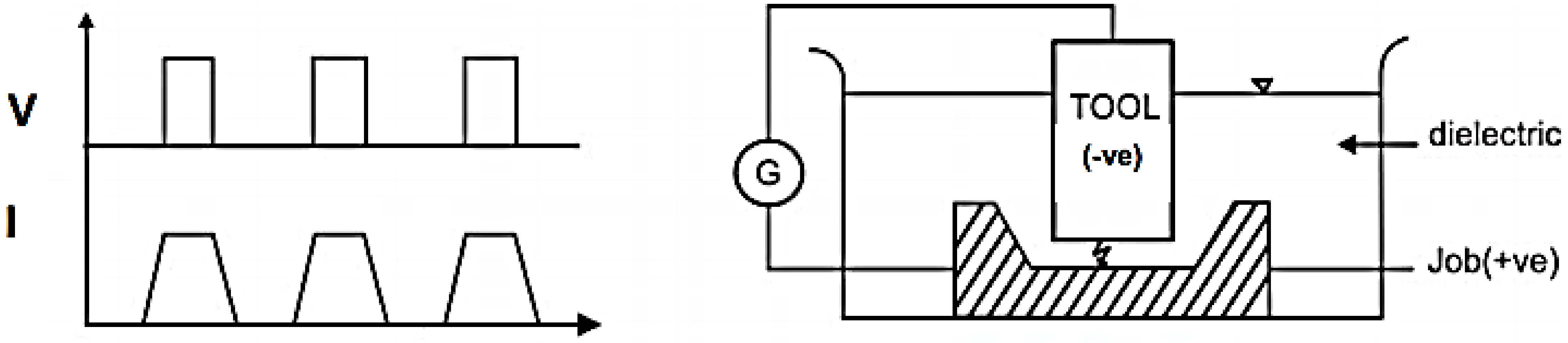
- EDM is mainly used to machine difficult-to-machine materials and high strength temperature resistant alloys.
- EDM can be used to machine difficult geometries in small batches or even on job-shop basis.
- Work material to be machined by EDM has to be electrically conductive.

The EDM process can be used in two different ways:

1. A preshaped or formed electrode (tool),usually made from graphite or copper, is shaped to the form of the cavity it is to reproduce. The formed electrode is fed vertically down and the reverse shape of the electrode is eroded (burned) into the solid workpiece.

2. A continuous-travelling vertical-wire electrode, the diameter of a small needle or less, is controlled by the computer to follow a programmed path to erode or cut a narrow slot through the workpiece to produce the required shape.

EDM - Process



Schematic representation of the basic working principle of EDM process

In EDM,

- ✓ A potential difference is applied between the tool and workpiece.
- ✓ Both the tool and the work material are to be conductors of electricity. The tool and the work material are immersed in a dielectric medium.
- ✓ A gap is maintained between the tool and the workpiece.
- ✓ Depending upon the applied potential difference and the gap between the tool and workpiece, an electric field would be established.

- ✓ Generally the tool is connected to the negative terminal of the generator and the workpiece is connected to positive terminal.
- ✓ As the electric field is established between the tool and the job, the free electrons on the tool are subjected to electrostatic forces.
- ✓ If the work function or the bonding energy of the electrons is less, electrons would be emitted from the tool (assuming it to be connected to the negative terminal).
- ✓ Such emission of electrons are called or termed as cold emission.

- ✓ "Cold emitted" electrons are then accelerated towards the job through the dielectric medium.

- ✓ As they gain velocity and energy, and start moving towards the job, there would be collisions between the electrons and dielectric molecules.

- ✓ Such collision may result in ionisation of the dielectric molecule depending upon the work function or ionisation energy of the dielectric molecule and the energy of the electron.

- ✓ Thus, as the electrons get accelerated, more positive ions and electrons would get generated due to collisions.

- ✓ This cyclic process would increase the concentration of electrons and ions in the dielectric medium between the tool and the job at the spark gap.

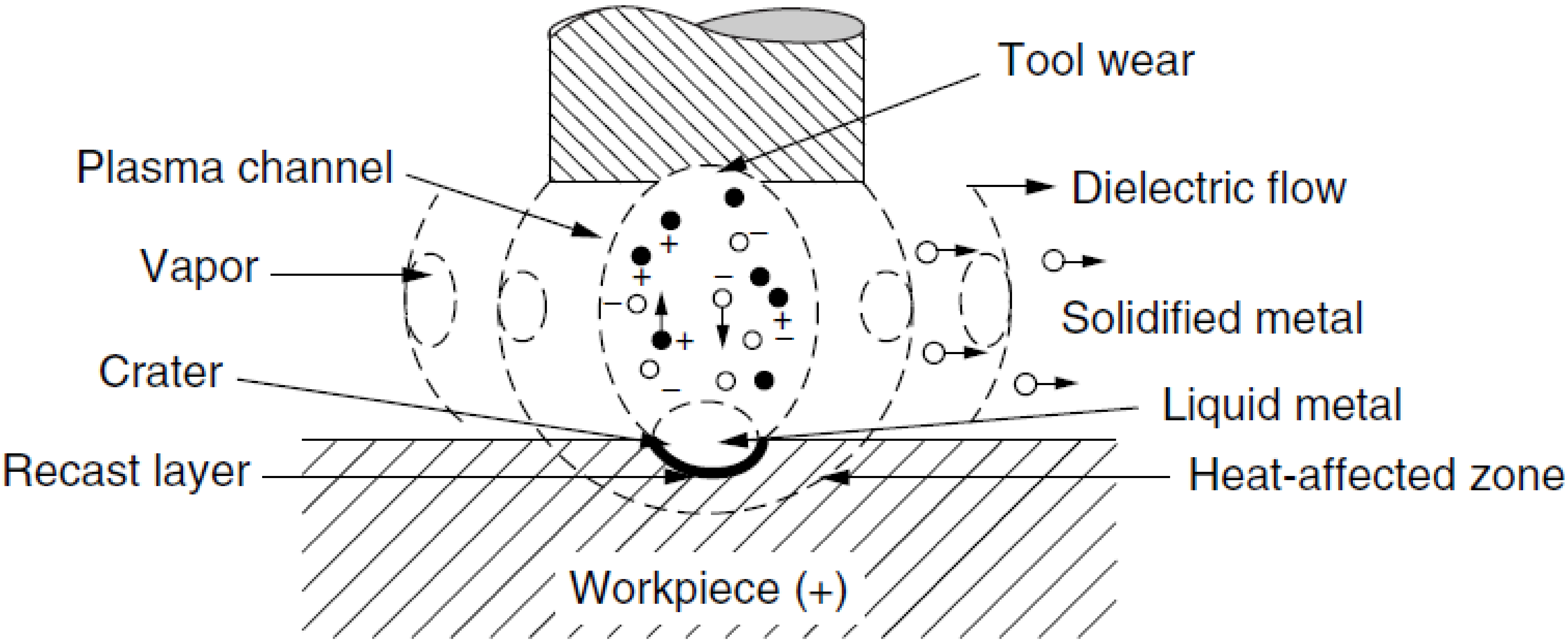
- ✓ Concentration would be so high that the matter existing in that channel could be characterised as "plasma".

- ✓ Electrical resistance of such plasma channel would be very less.

- ✓ Thus all of a sudden, a large number of electrons will flow from the tool to the job and ions from the job to the tool.

- ✓ This is called avalanche motion of electrons.

EDM – Working Principle



EDM spark description.

- ✓ Such movement of electrons and ions can be visually seen as a spark.
- ✓ Thus the electrical energy is dissipated as the thermal energy of the spark.
- ✓ High speed electrons then impinge on the job and ions on the tool.
- ✓ Kinetic energy of the electrons and ions on impact with the surface of the job and tool respectively would be converted into thermal energy or heat flux.
- ✓ Such intense localised heat flux leads to extreme instantaneous confined rise in temperature which would be in excess of 10,000°C.

- ✓ Such localised extreme rise in temperature leads to material removal.

- ✓ Material removal occurs due to instant vapourisation of the material as well as due to melting.

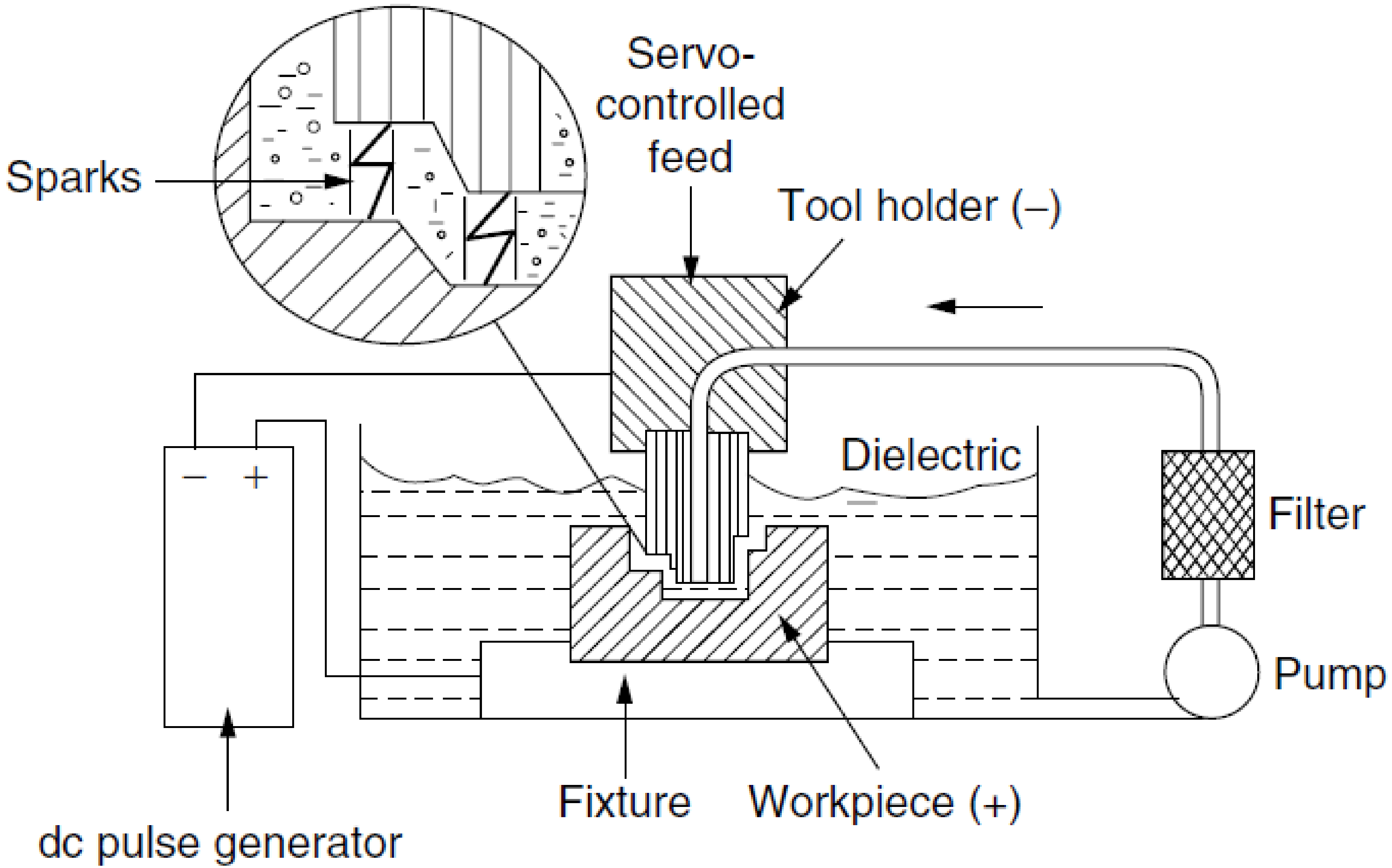
- ✓ The molten metal is not removed completely but only partially.

- ✓ As the potential difference is withdrawn, the plasma channel is no longer sustained.

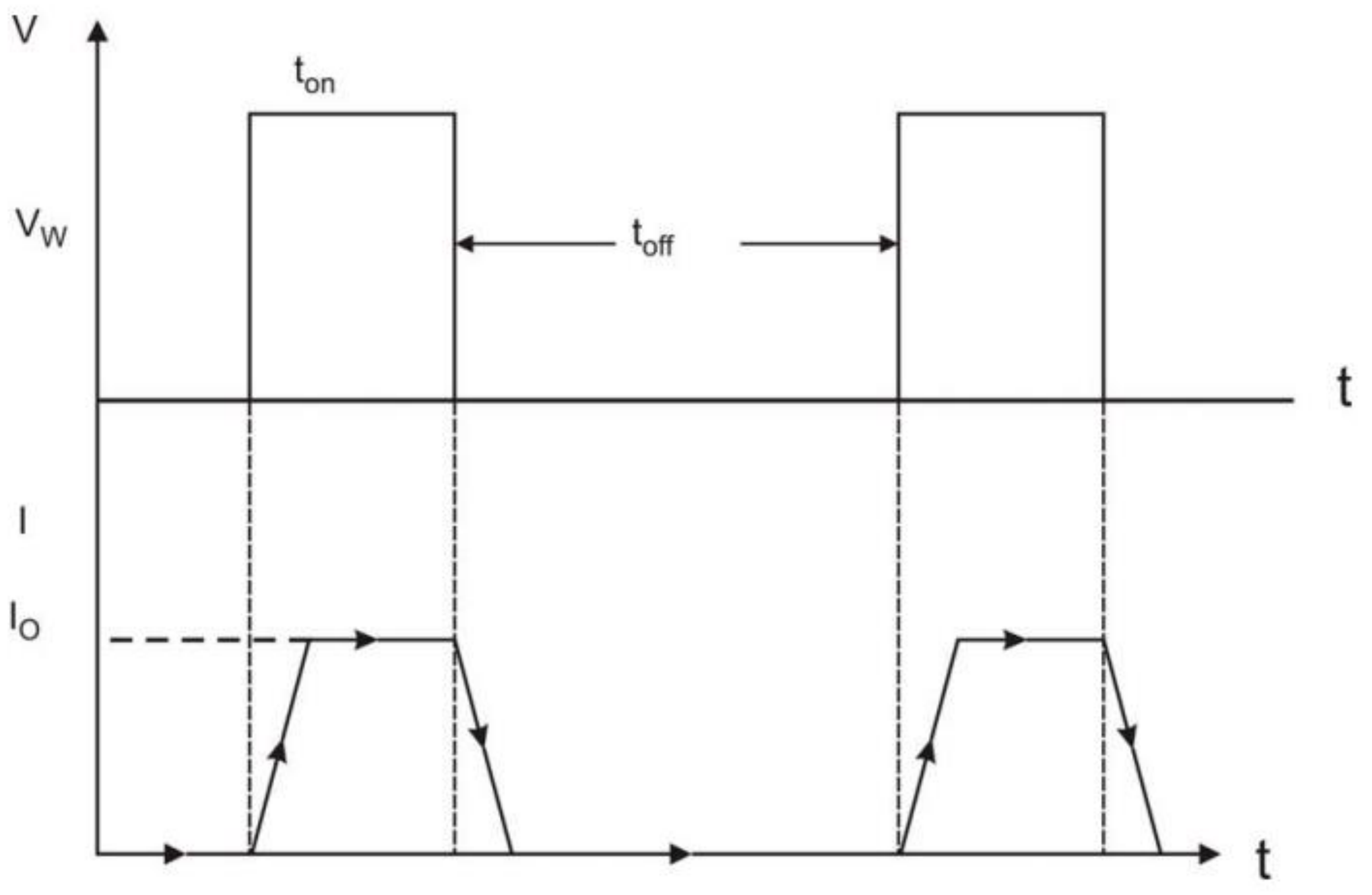
- ✓ As the plasma channel collapse, it generates pressure or shock waves, which evacuates the molten material forming a crater of removed material around the site of the spark.

Material removal in EDM mainly occurs due to formation of shock waves as the plasma channel collapse owing to discontinuation of applied potential difference.

EDM Schematic



Process Parameters



The waveform is characterised by the

- The open circuit voltage - Vo
- The working voltage - Vw
- The maximum current - Io
- The pulse on time – the duration for which the voltage pulse is applied - t_{on}
- The pulse off time - t_{off}
- The gap between the workpiece and the tool – spark gap - δ
- The polarity – straight polarity – tool (-ve)
- The dielectric medium
- External flushing through the spark gap.

Characteristics of EDM

(a) The process can be used to machine any work material if it is electrically conductive

(b) Material removal depends on mainly thermal properties of the work material rather than its strength, hardness etc

(c) In EDM there is a physical tool and geometry of the tool is the positive impression of the hole or geometric feature machined

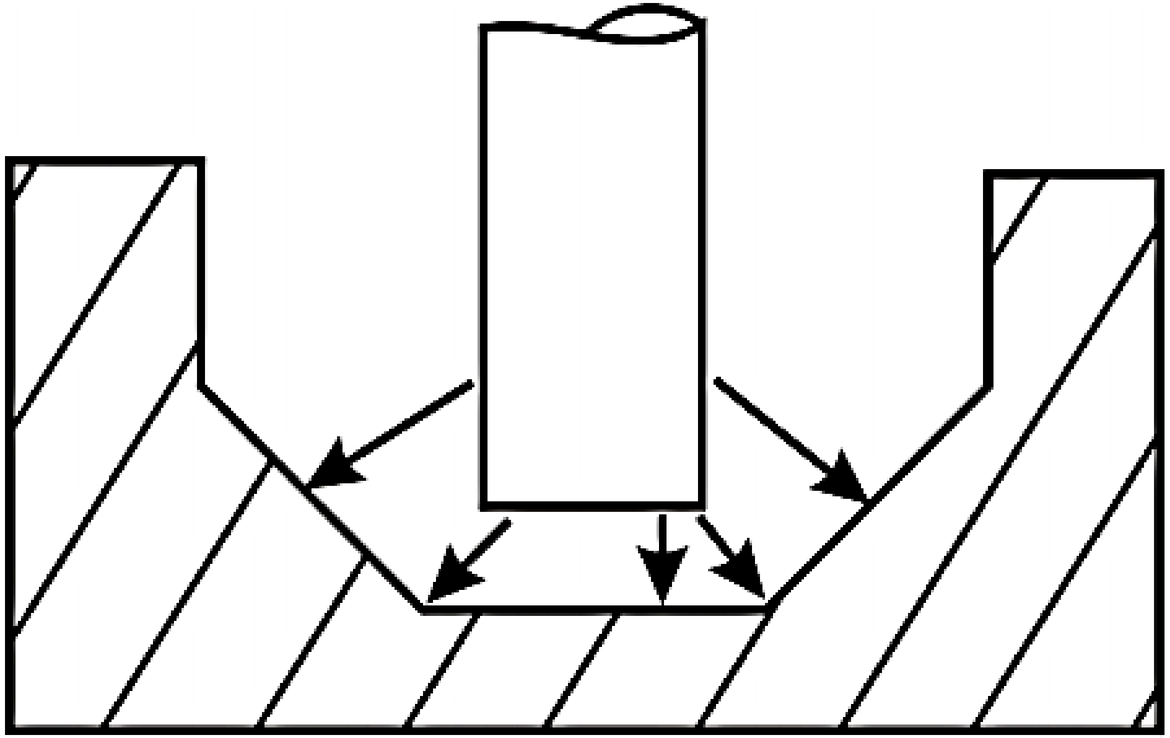
(d) The tool has to be electrically conductive as well. The tool wear once again depends on the thermal properties of the tool material

(e) Though the local temperature rise is rather high, still due to very small pulse on time, there is not enough time for the heat to diffuse and thus almost no increase in bulk temperature takes place.

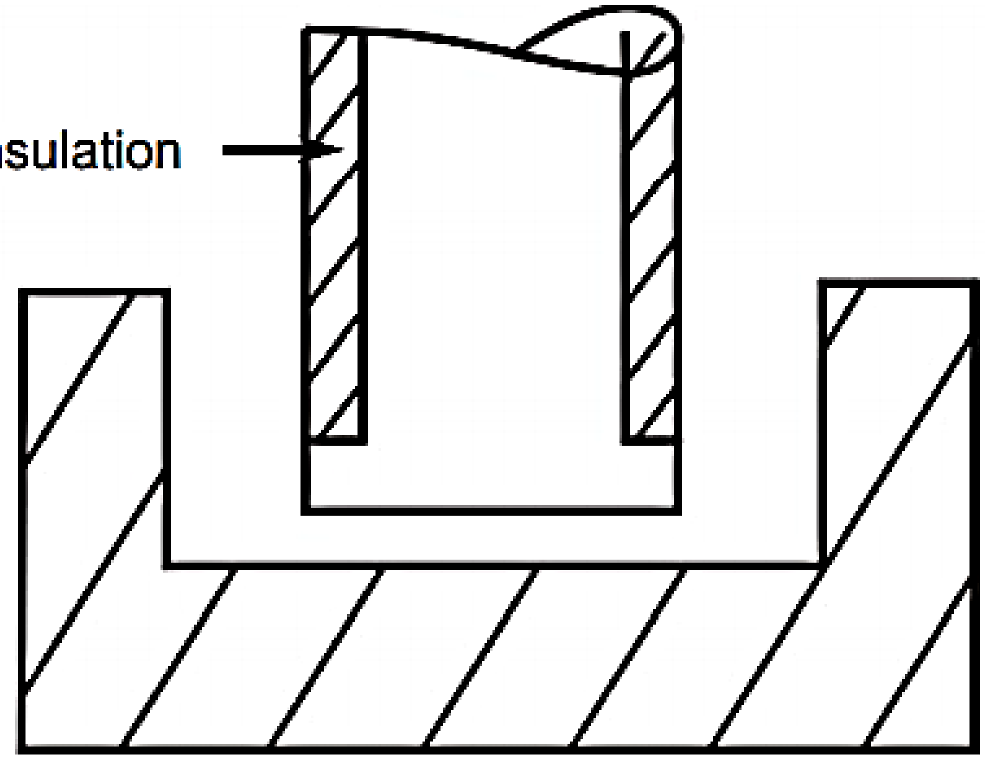
Thus the heat affected zone is limited to 2 – 4 μm of the spark crater

(f) However rapid heating and cooling and local high temperature leads to surface hardening which may be desirable in some applications

(g) Though there is a possibility of taper cut and overcut in EDM, they can be controlled and compensated.



tapercut and overcut



tapercut prevention

Schematic depiction of taper cut and over cut and control of taper cut

Dielectric – low viscosity hydrocarbon oil

- Dielectric fluid should provide an oxygen free machining environment.
- It should have enough strong dielectric resistance so that it does not breakdown electrically too easily but at the same time ionise when electrons collide with its molecule.
- During sparking it should be thermally resistant as well.

Dielectric

Generally kerosene and deionised water is used as dielectric fluid in EDM.

Tap water cannot be used as it ionises too early and thus breakdown due to presence of salts as impurities occur.

Dielectric medium is generally flushed around the spark zone. It is also applied through the tool to achieve efficient removal of molten material.

Functions of Dielectric fluid: Essential functions of a dielectric fluid used in EDM process are:

1. Remain electrically non-conductive until the required breakdown voltage is attained, i.e., it should possess high dielectric strength.
2. When once the breakdown voltage is reached it should breakdown electrically instantly.
3. Deionize the spark gap, i.e., quench the spark rapidly after the discharge has occurred.
4. Carry away the metal particles removed from the arc gap.
5. Act as a good cooling medium.

Desirable Properties of dielectric fluid: In order to act as a good dielectric medium and meet the various functions the fluid is required to possess the following properties:

1. High electric strength for proper insulation.
2. High flash and fire point to prevent fire hazards.
3. Low viscosity and good wetting properties
4. Chemically neutral to prevent corrosion.
5. Non-toxic in nature.
6. Low decomposition rate for long life.
7. Low cost
8. Good quenching properties.

Sl. No.	*Dielectric fluid*	*Material removal Rate cm^3/amp min $\times 10^4$*	*Wear ratio-work material /tool material*
1.	Kerosene	40.0	2.8
2.	Distilled water	54.5	2.7
3.	Tetraethylene glycol	103.0	6.8

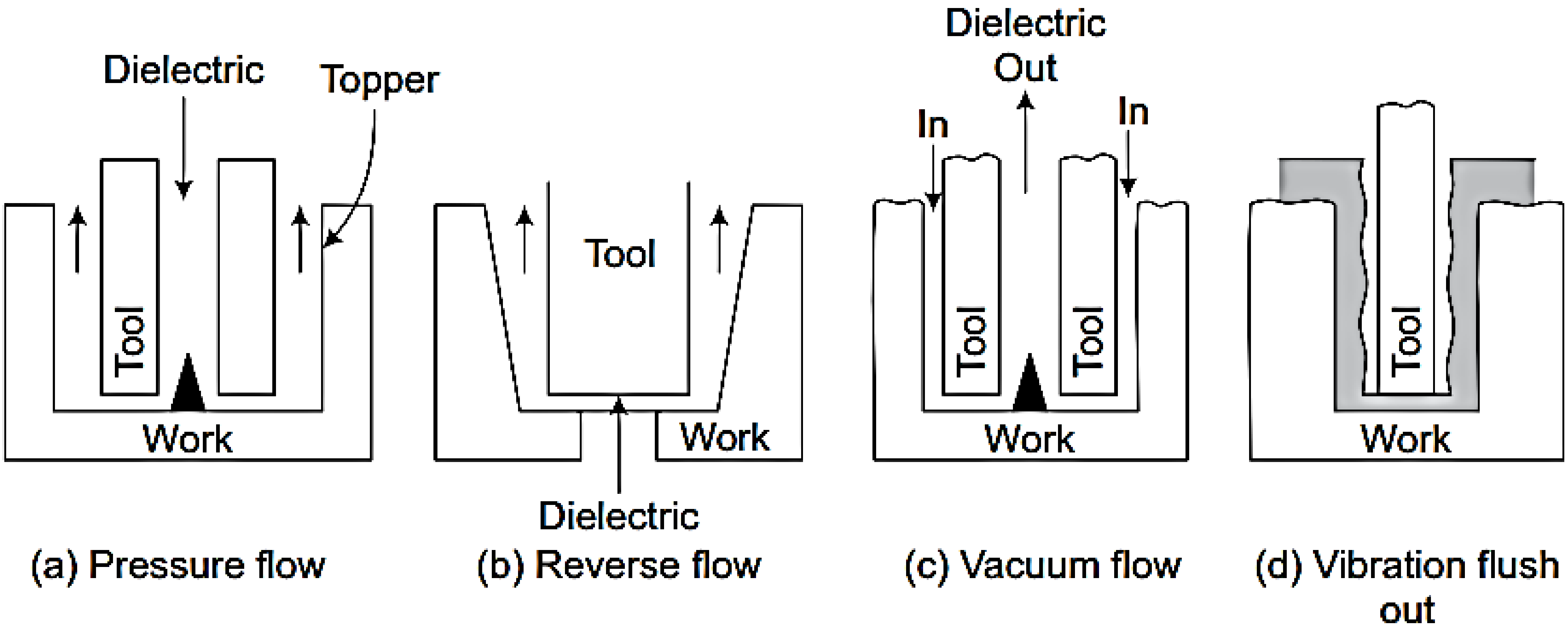
Performance of different dielectric fluids in machining steel using brass tool.

FLUSHING OF DIELECTRIC

Flushing refers to proper circulation of dielectric fluid at the gap between the work and electrode tool in EDM

The different methods of circulation of dielectric fluid for flushing in EDM are:

1. Pressure dielectric flow
2. Reverse dielectric flow
3. Vacuum dielectric flow
4. Vibration flush cut



TYPES OF FLUSHING

EDM Tool Material

The main factors that determine the suitability of a material for application as electrode tool material in EDM are:

1. Higher metal removal rate
2. Lower tool wear
3. Higher degree of electrical efficiency

TOOL MATERIAL USED IN EDM AND THEIR CHARACTERISTICS

Material	*Material Removal Rate*	*Wear ratio*	*Fabrication*	*Cost*	*Application*
Graphite	High	Low	Easy	High	All metals
Copper	High in roughing	Low	Easy	High	All metals
Brass	High in finishing	High	Easy	Low	All metals
Tungsten	Low	Low	Difficult	High	For small holes
Tungsten-Copper alloys	Low	Low	Difficult	High	Accurate work
Cast Iron	Low	Low	Easy	Low	Restricted
Steel	Low	High	Easy	Low	Finishing
Zinc Alloys	High in roughing	High	Easy	Low	All metals

EDM Equipment

EDM machine has the following major modules

- Dielectric reservoir, pump and circulation system
- Power generator and control unit
- Working tank with work holding device
- X-y table accommodating the working table
- Tool holder
- Servo system to feed the tool

EDM - APPLICATIONS

1. Dies, fixtures, gauges
2. Cutting tools
3. Press tools, extrusion dies
4. Die moulds for plastics
5. Diecasting dies, mould inserts
6. Remachining, repairing of worn dies for hot and cold forging
7. Making forging dies like connecting rod forging dies, etc.
8. Sintering dies
9. Calibrating tools
10. Shaping carbide tools, templates.

Wire Cut Electric Discharge Machining (WEDM)

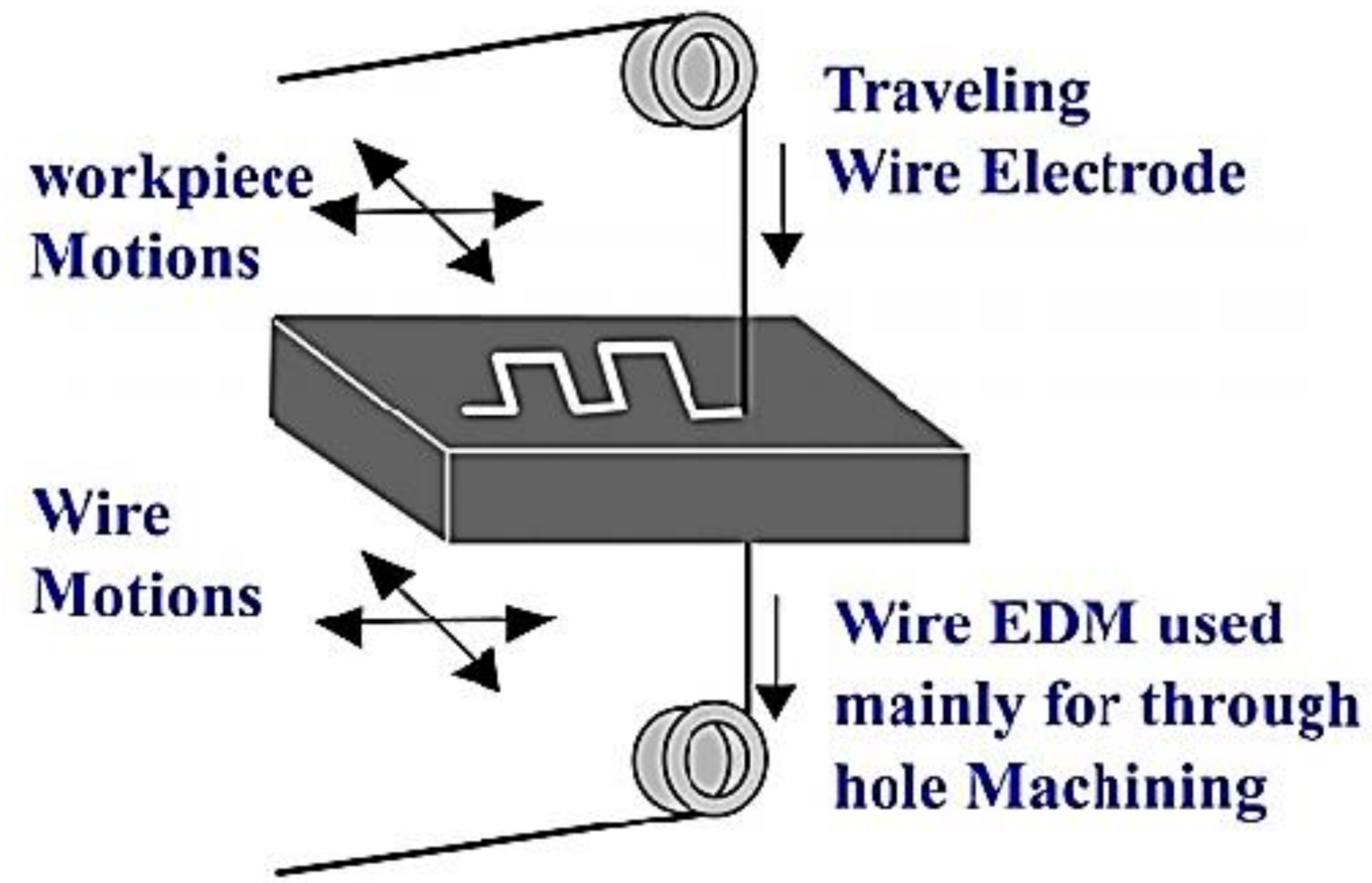
- A thin metallic wire is fed on-to the workpiece, which is submerged in a tank of dielectric fluid such as deionized water.

- This process can also cut plates as thick as 300mm and is used for making punches, tools and dies from hard metals that are difficult to machine with other methods.

- The wire, which is constantly fed from a spool, is held between upper and lower diamond guides.

- Guides are usually CNC-controlled and move in the x–y plane.
- On most machines, the upper guide can move independently in the z–u–v axis, giving it a flexibility to cut tapered and transitioning shapes
- Wires made of brass are generally preferred, (also uses copper or tungsten or brass coated and multi coated wires).
- Water helps in flushing away the debris from the cutting zone.
- Flushing also helps to determine the feed rates to be given for different thickness of the materials

Wire-cut EDM Process - SCHEMATIC



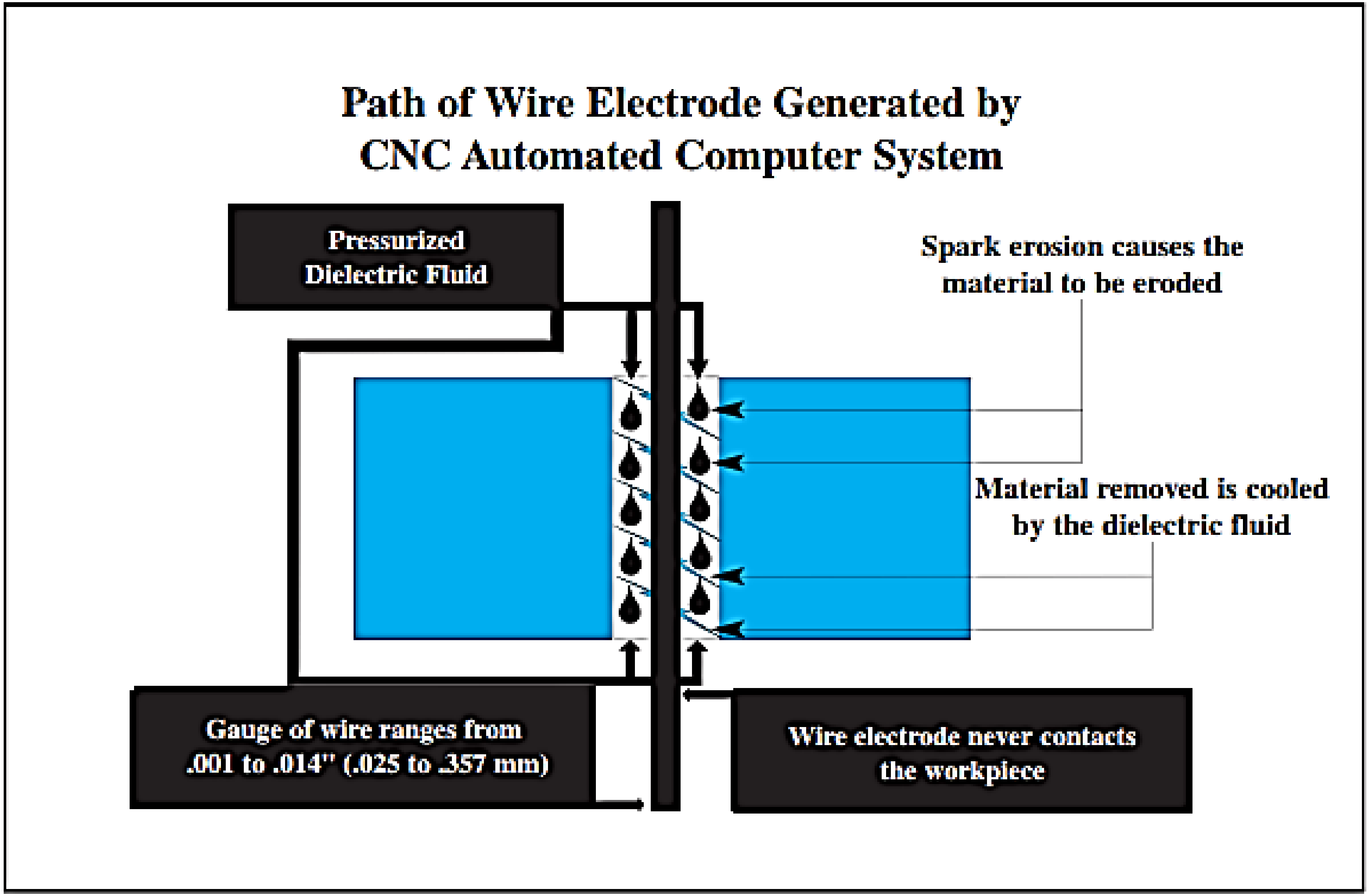
PROCESS OF MATERIAL REMOVAL IN WIRE CUT EDM

- In the WEDM process, the motion of wire is slow.
- Wire is fed in the programmed path and material is cut/ removed from the workpiece accordingly.
- Material removal takes place by a series of discrete discharges between the wire electrode and workpiece in the presence of a di-electric fluid.

- Di-electric fluid gets ionized in between the tool-electrode gap thereby creating a path for each discharge.

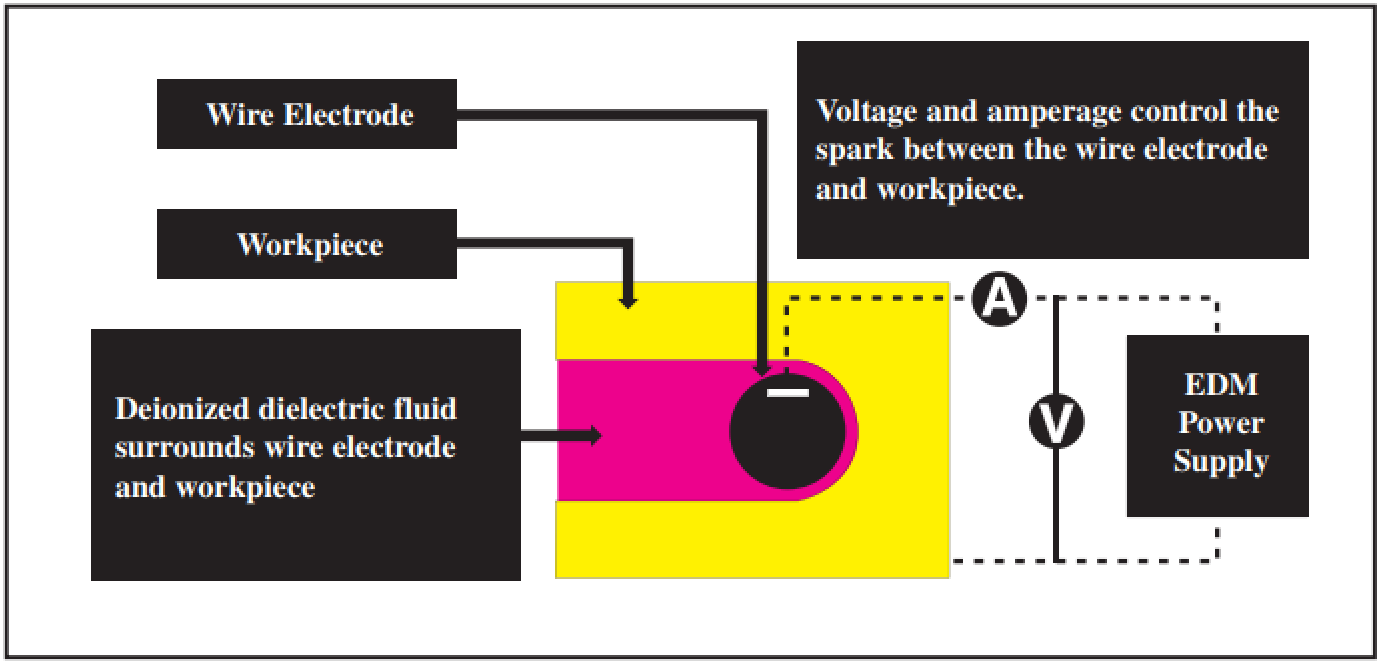
- Area wherein discharge takes place gets heated to very high temperatures such that the surface gets melted and removed.

- Cut particles (debris) get flushed away by the continuously flowing dielectric fluid.



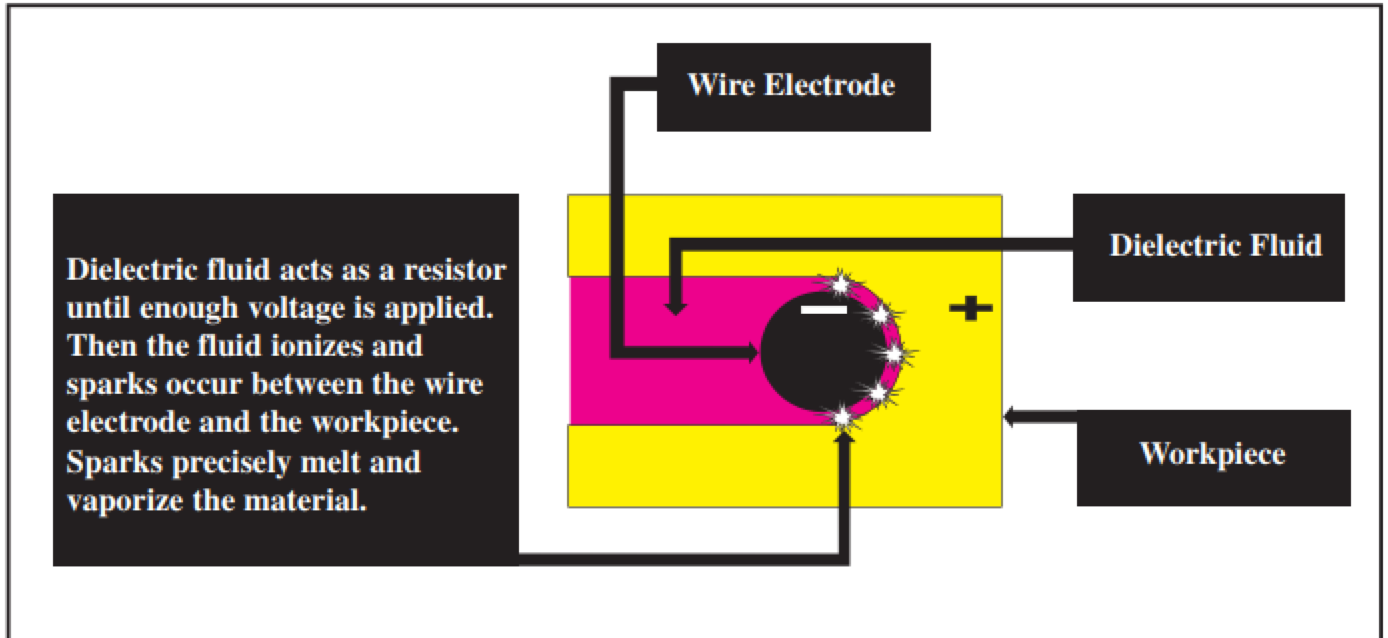
How Wire EDM Works
Precisely controlled sparks erode the metal using deionized water.
Pressurized water removes the eroded material.

A. Power Supply Generates Volts and Amps

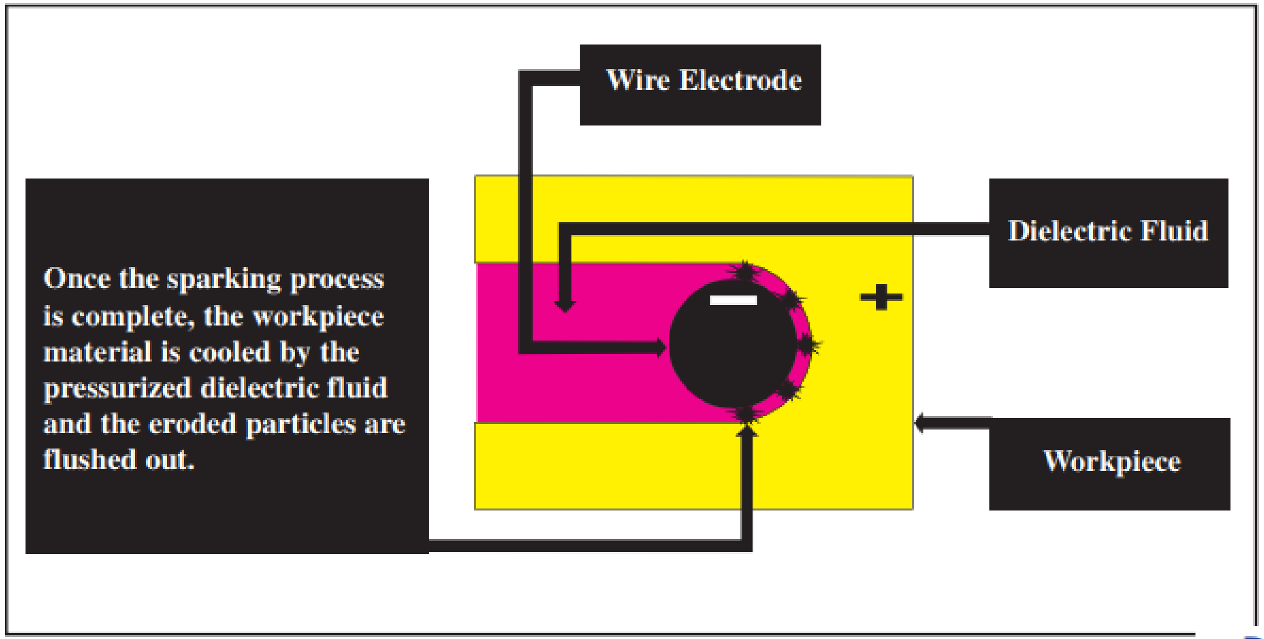


STEP BY STEP PROCEDURE

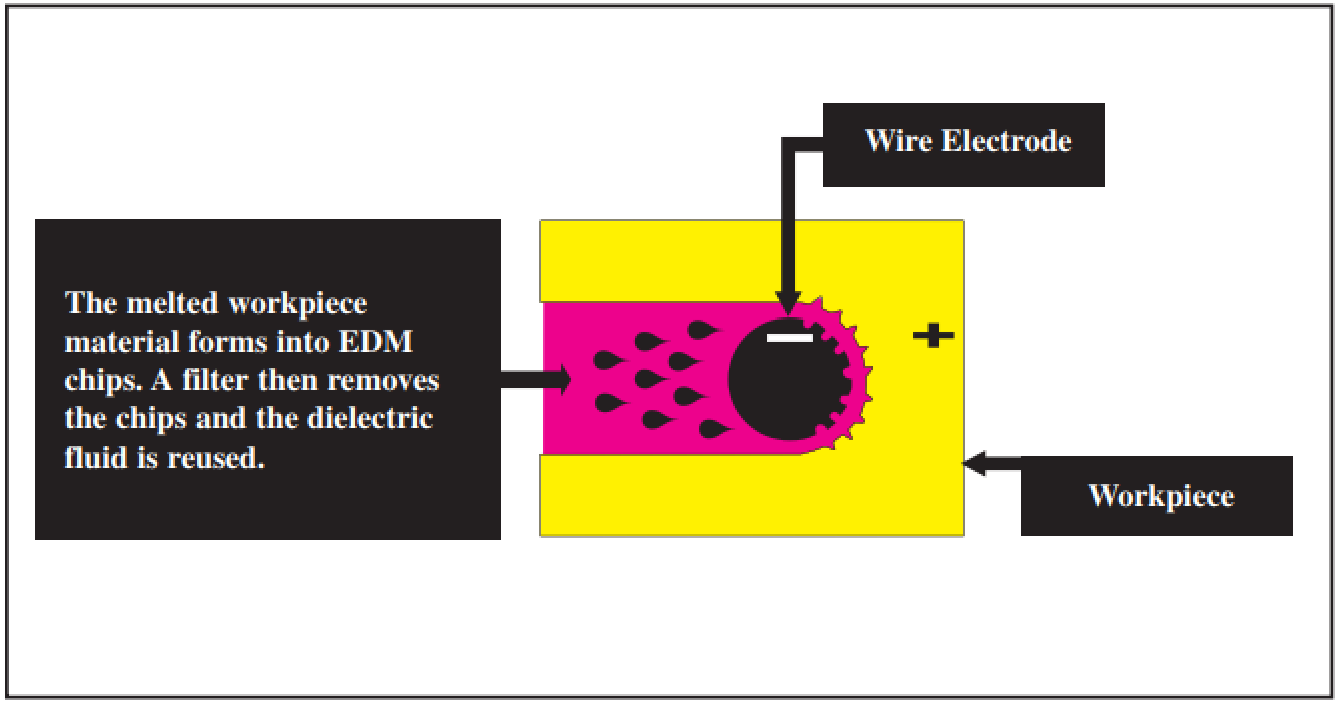
B. During On Time Controlled Spark Erodes Material



C. Off Time Allows Fluid to Remove Eroded Particles



D. Filter Removes Chips While the Cycle is Repeated



WEDM - APPLICATIONS

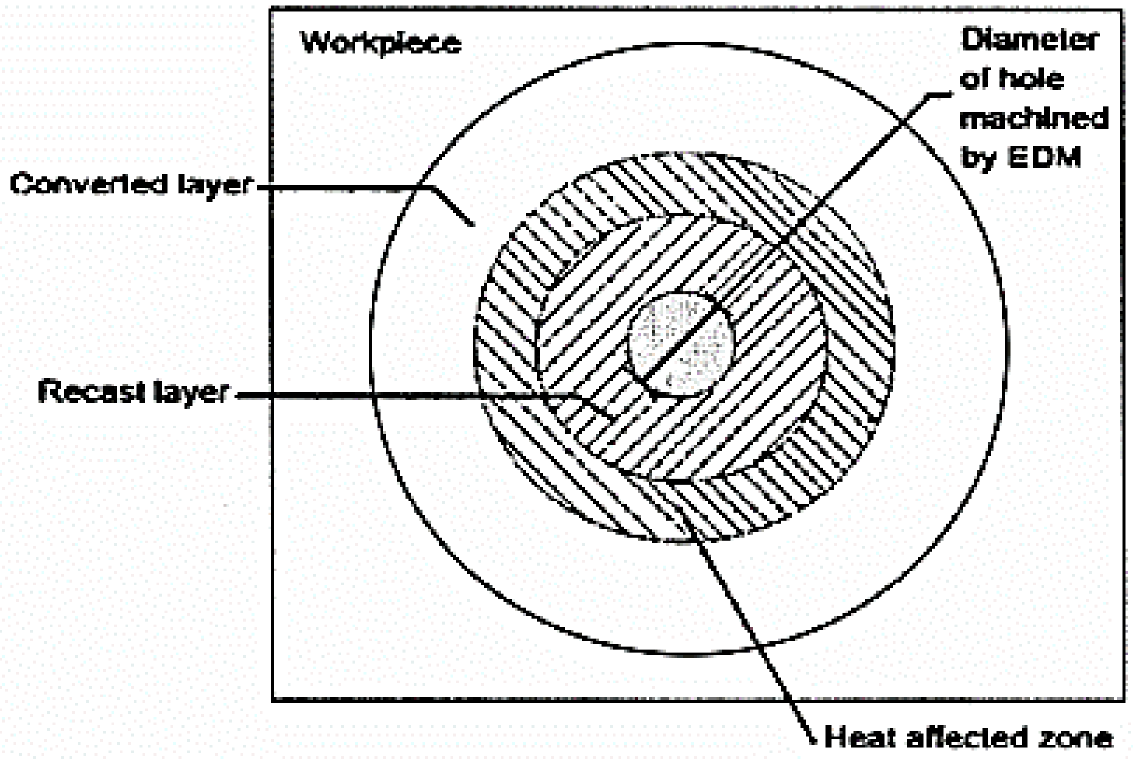
Wire EDM is used for cutting aluminium, brass, copper, carbides, graphite, steels and titanium

- ✓ Aerospace, Medical, Electronics and Semiconductor applications
- ✓ Tool & Die making industries.
- ✓ For cutting the hard Extrusion Dies
- ✓ In making Fixtures, Gauges & Cams
- ✓ Cutting of Gears, Strippers, Punches and Dies
- ✓ Manufacturing hard Electrodes.
- ✓ Manufacturing micro-tooling for Micro-EDM, Micro-USM and such other micromachining applications

Wire EDMing Internal Keyways

MICROSCOPIC STUDY OF EDMed COMPONENTS REVEALS THE PRESENCE OF 3 KINDS OF LAYERS

- ✓ RECAST Layer
- ✓ HEAT AFFECTED ZONE (HAZ)
- ✓ CONVERTED Layer



RECAST LAYER

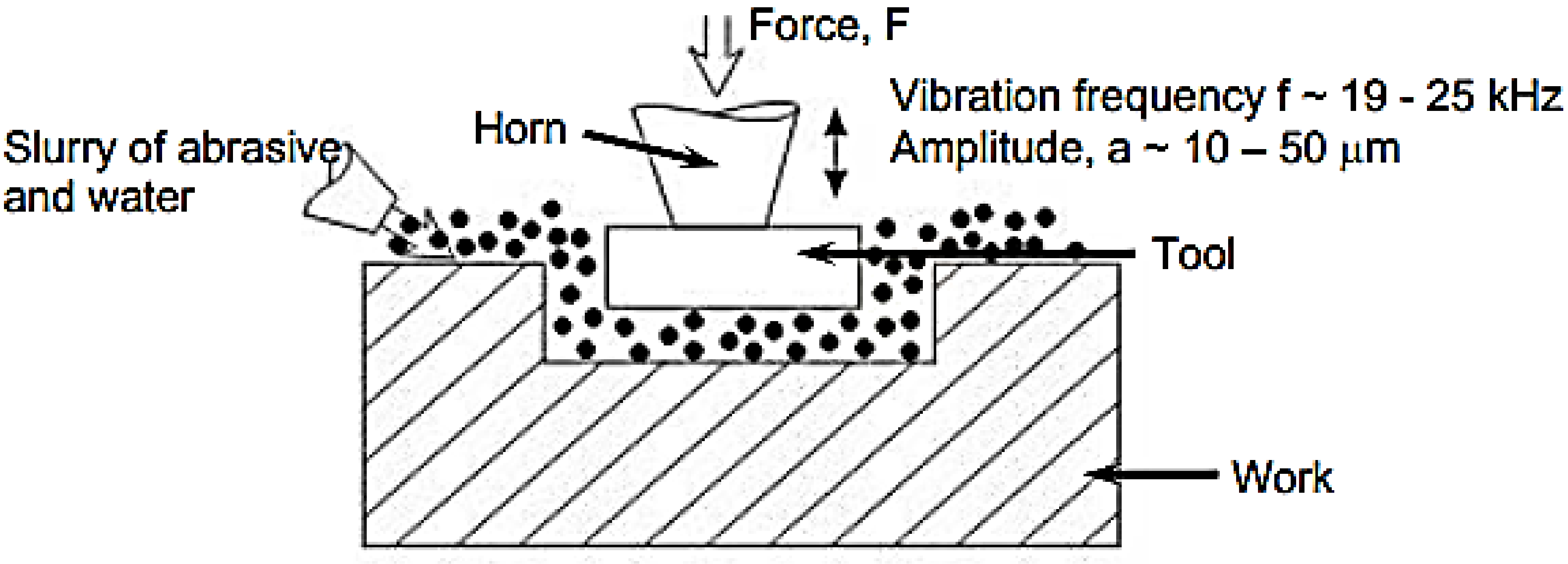
If molten material from the workpiece is not flushed out quickly, it will resolidify and harden due to the cooling effect of the dielectric and gets adhered to the machined surface. This thin layer of about 2.5-50 μm is formed and is called re-cast layer.

HAZ

- Beneath the recast layer, a HAZ is formed due to rapid heating and quenching cycles during EDM.
- Layer is approximately 25 μm thick.
- Heating-cooling cycle and diffused material during machining are the responsible reasons for the presence of this zone.
- Thermal residual stresses, grain boundary weaknesses, and grain boundary cracks are some of the characteristics of this zone.

Conversion zone (or converted layer) is identified below the HAZ and is characterized by a change in grain structure from the original structure

ULTRASONIC MACHINING (USM)


Force, F
Vibration frequency f ~ 19 - 25 kHz
Amplitude, a ~ 10 – 50 μm
Horn
Slurry of abrasive and water
Tool
Work

USM PROCESS

ULTRASONIC MACHINING

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

- ✓ Generally the tool is pressed downward with a feed force, F.

- ✓ Between the tool and workpiece, the machining zone is flooded with hard abrasive particles generally in the form of a water based slurry.

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

Abrasive particles, as they indent, the work material, would remove the same, particularly if the work material is brittle, due to crack initiation, propagation and brittle fracture of the material.

Hence, USM is mainly used for machining brittle materials {which are poor conductors of electricity and thus cannot be processed by Electrochemical and Electro-discharge machining (ECM and ED)}.

Mechanisms of Material Removal in USM

- Material removal primarily occurs due to the indentation of the hard abrasive grits on the brittle work material. As the tool vibrates, it leads to indentation of the abrasive grits.

- During indentation, due to Hertzian contact stresses, cracks would develop just below the contact site, then as indentation progresses the cracks would propagate due to increase in stress and ultimately lead to brittle fracture of the work material under each individual interaction site between the abrasive grits and the workpiece.

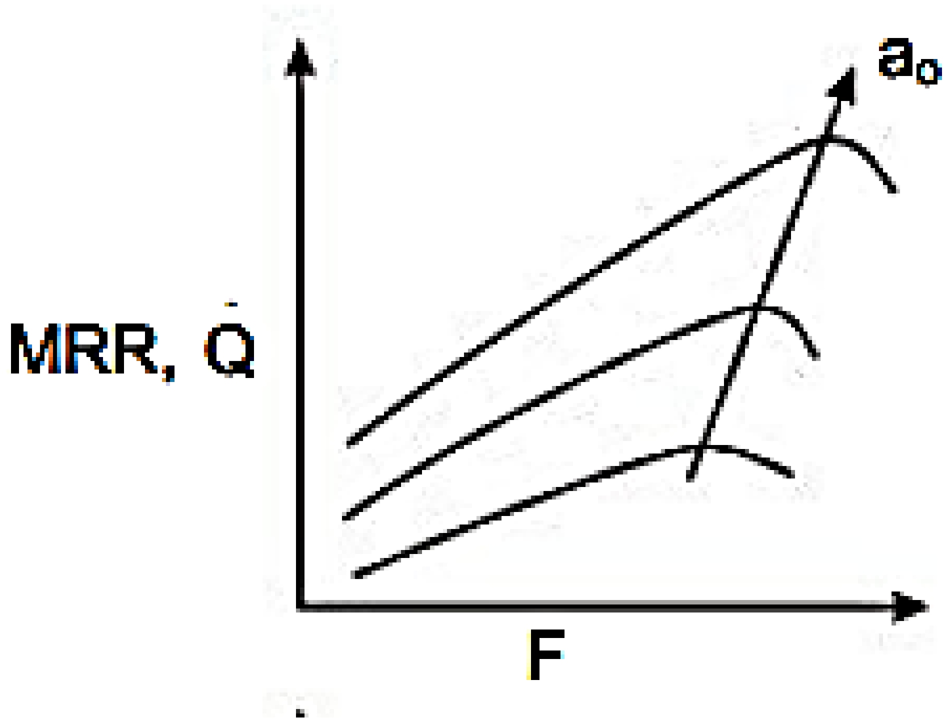
- ✓ Tool material should be such that indentation by the abrasive grits does not lead to brittle failure.
- ✓ Thus the tools are made of tough, strong and ductile materials like steel, stainless steel and other ductile metallic alloys.

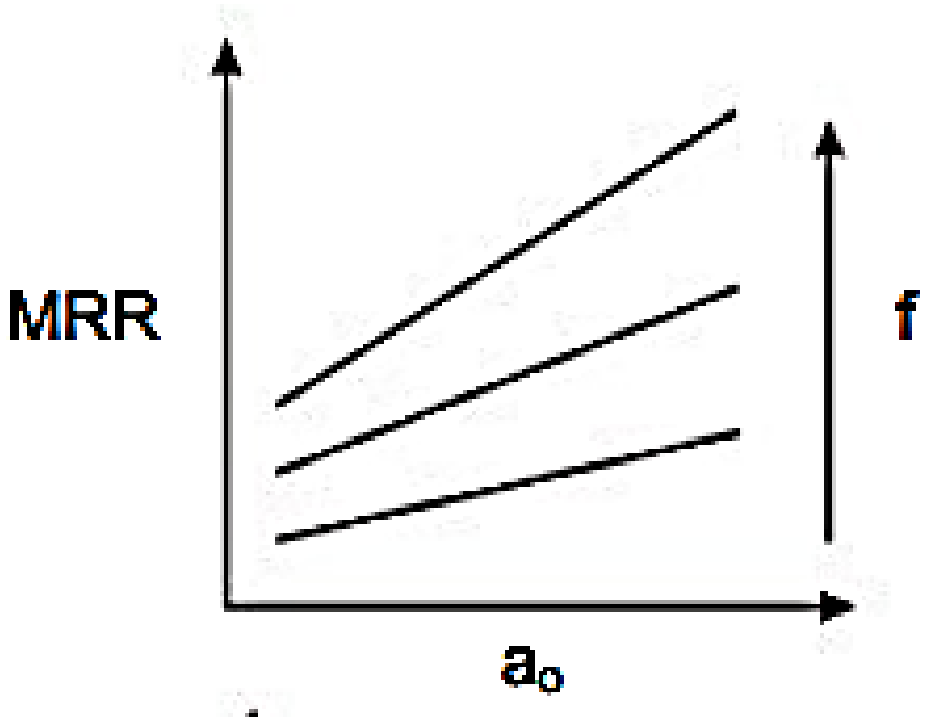
- ✓ Other than this brittle failure of the work material due to indentation some material removal may occur due to free flowing impact of the abrasives against the work material and related solid-solid impact erosion, but it is estimated to be rather insignificant.

Process Parameters and their Effects

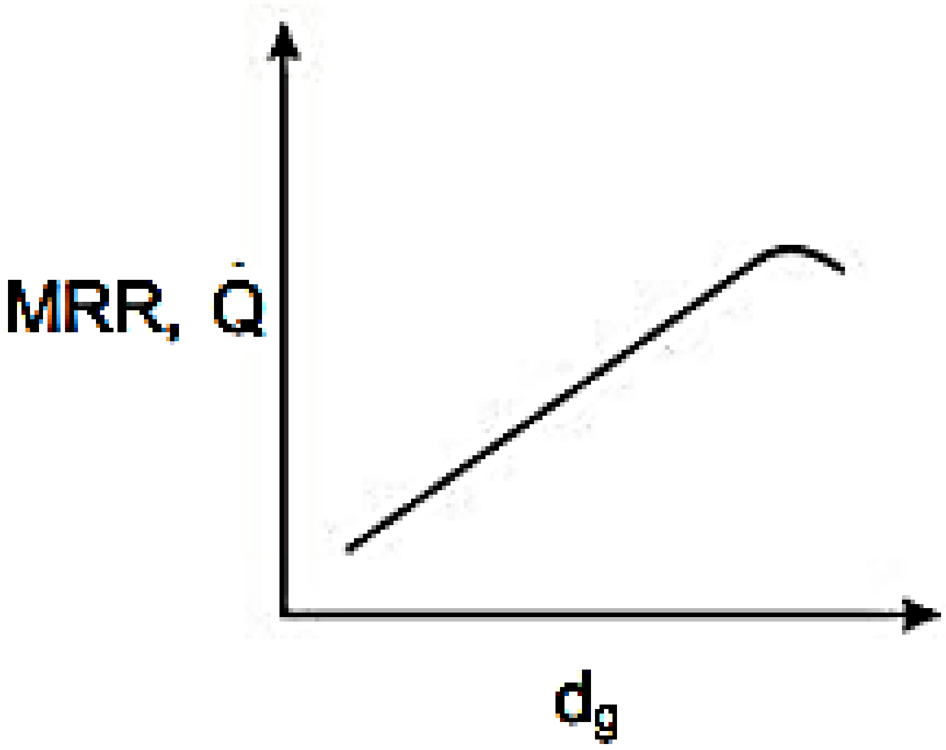
- ✓ Amplitude of vibration (ao) – 15 – 50 μm
- ✓ Frequency of vibration (f) – 19 – 25 kHz
- ✓ Feed force (F) – related to tool dimensions
- ✓ Feed pressure (p)
- ✓ Abrasive size – 15 μm – 150 μm
- ✓ Abrasive material – Al_2O_3 - SiC - B_4C - Boronsilicarbide - Diamond
- ✓ Flow strength of work material
- ✓ Flow strength of the tool material
- ✓ Contact area of the tool – A
- ✓ Volume concentration of abrasive in water slurry – C

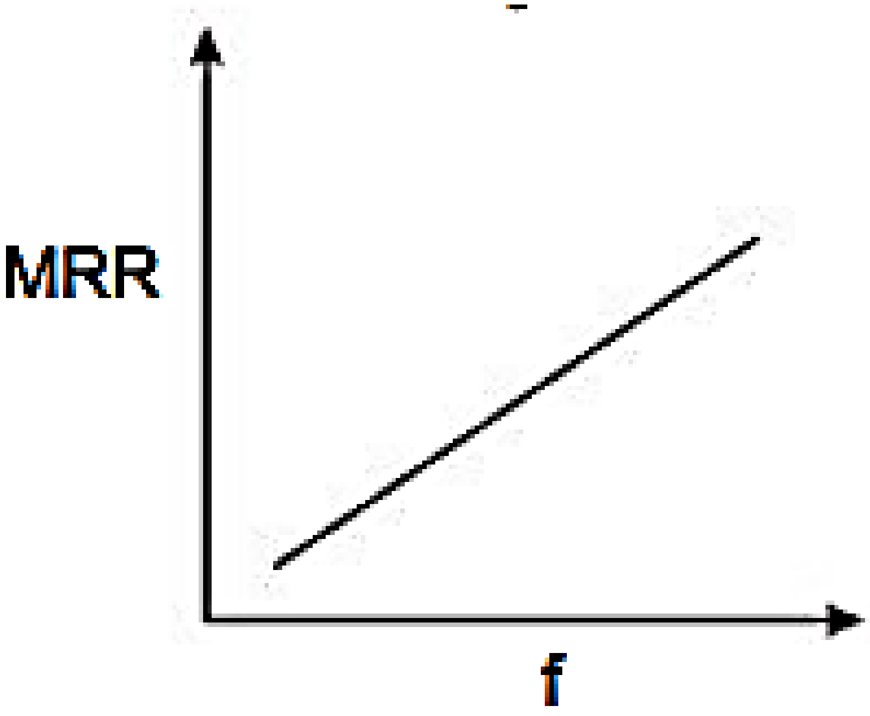
Effect of machining parameters on MRR



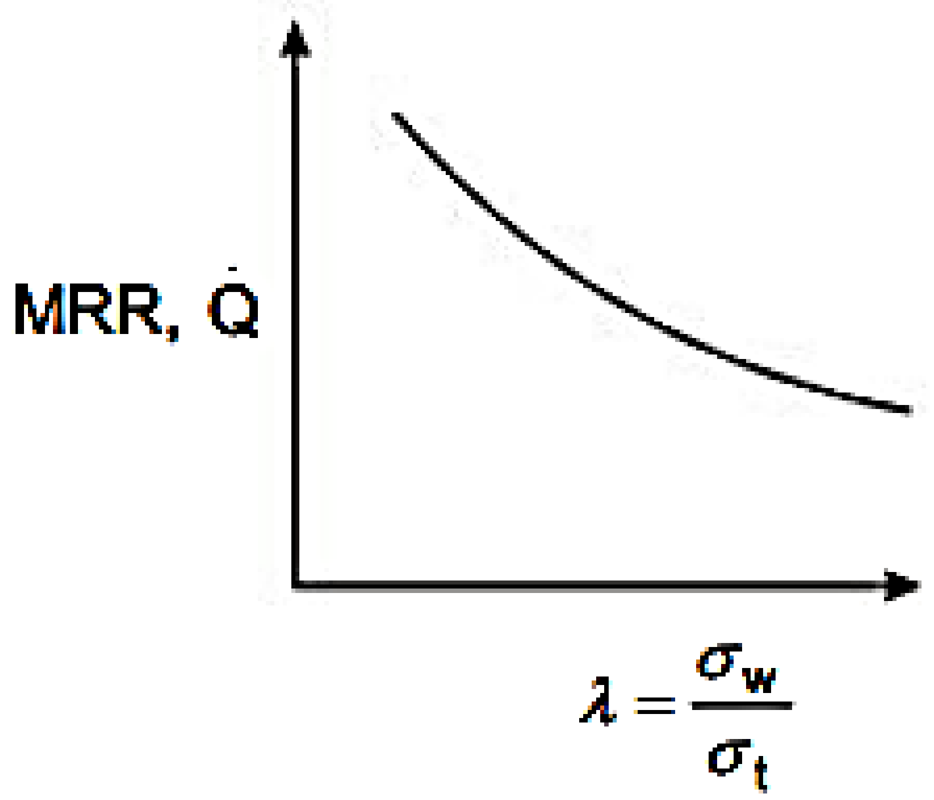


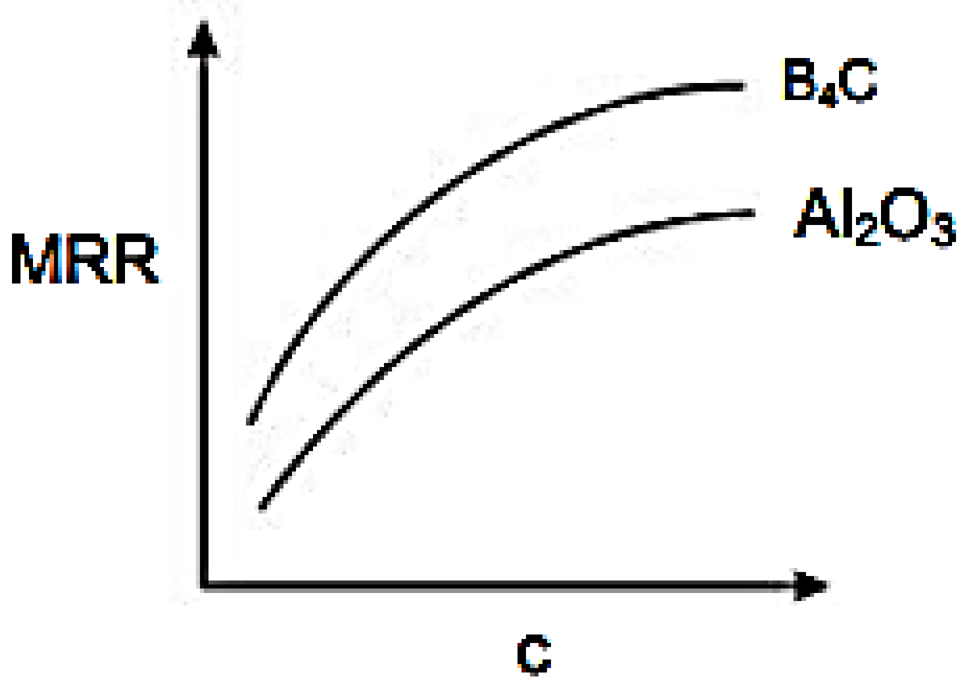
Effect of machining parameters on MRR





Effect of machining parameters on MRR





USM Machine

- The basic mechanical structure of an USM is very similar to a drill press.

- However, it has additional features to carry out USM of brittle work material.

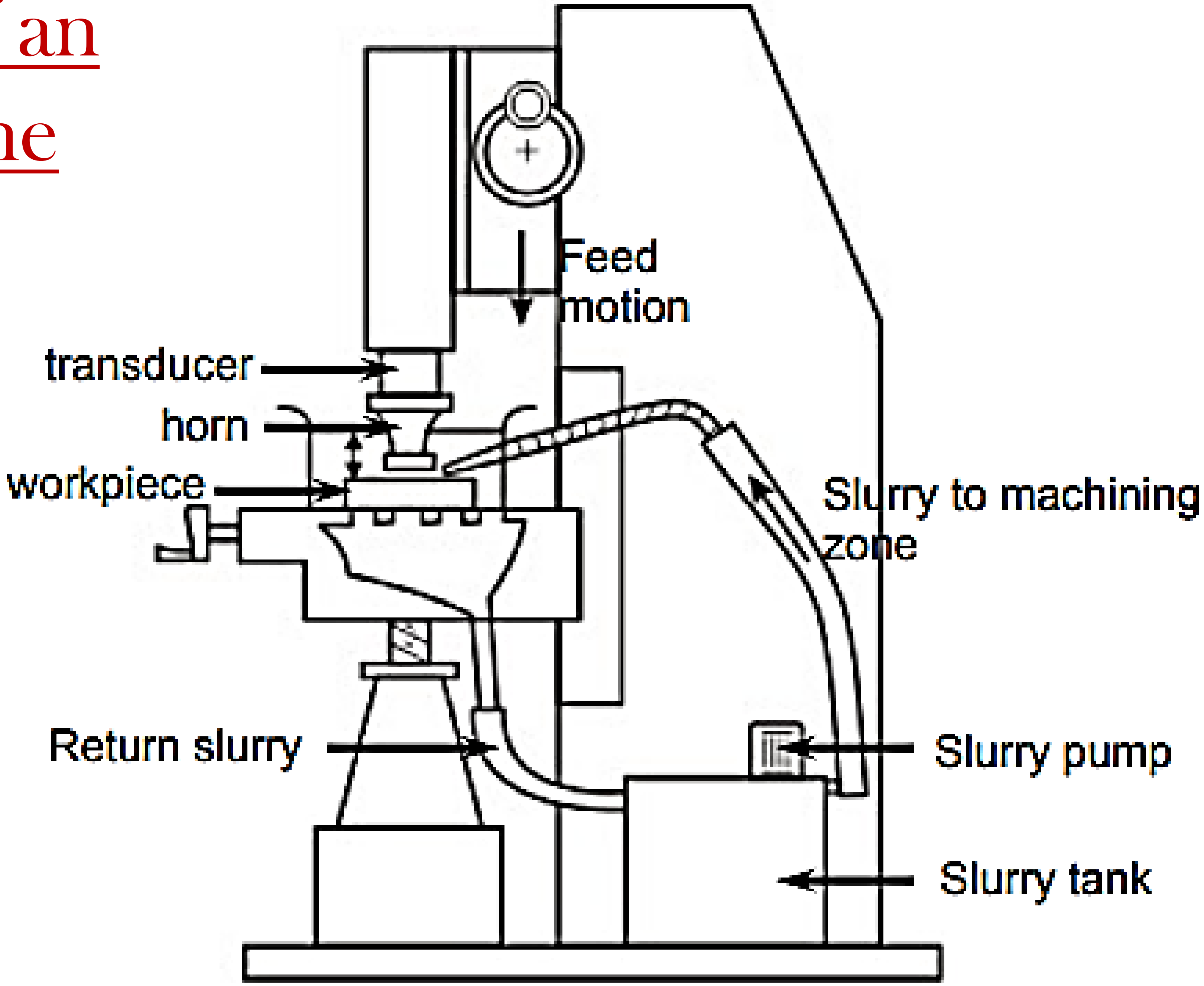
- Workpiece is mounted on a vice, which can be located at the desired position under the tool using a 2 axis table.

- Table can further be lowered or raised to accommodate work of different thickness.

The typical elements of an USM are

- Slurry delivery and return system
- Feed mechanism to provide a downward feed force on the tool during machining
- Transducer, which generates the ultrasonic vibration
- Horn or concentrator, which mechanically amplifies the vibration to the required amplitude of 15 – 50 μm and accommodates the tool at its tip

Schematic view of an Ultrasonic Machine

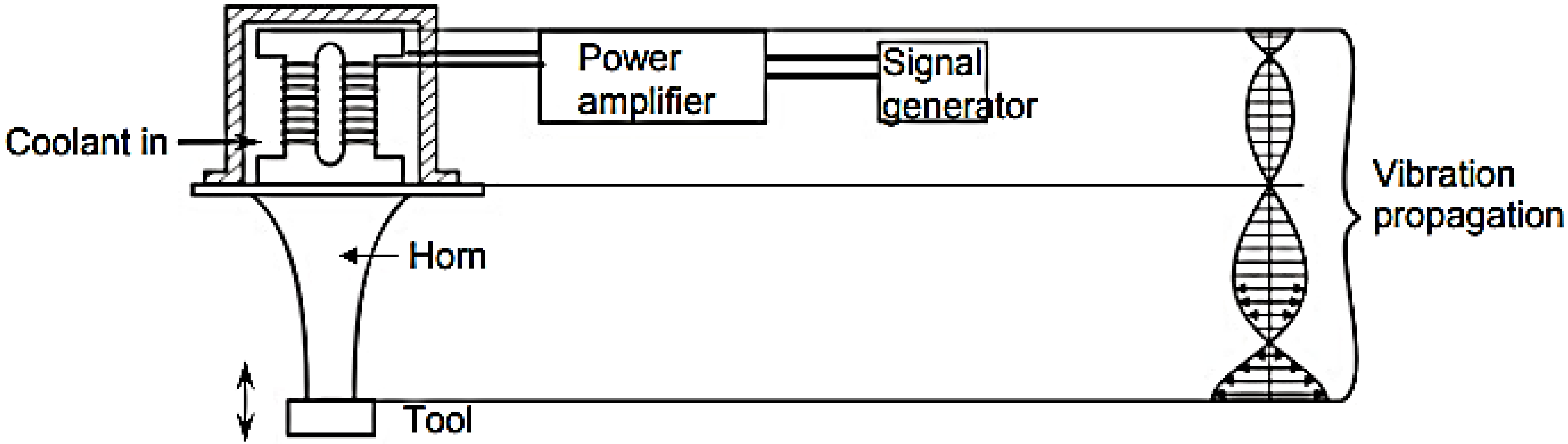


- The ultrasonic vibrations are produced by the transducer.
- The transducer is driven by suitable signal generator followed by power amplifier.
- The transducer for **USM** works on the following principle

  Piezoelectric effect

  Magnetostrictive effect

  Electrostrictive effect

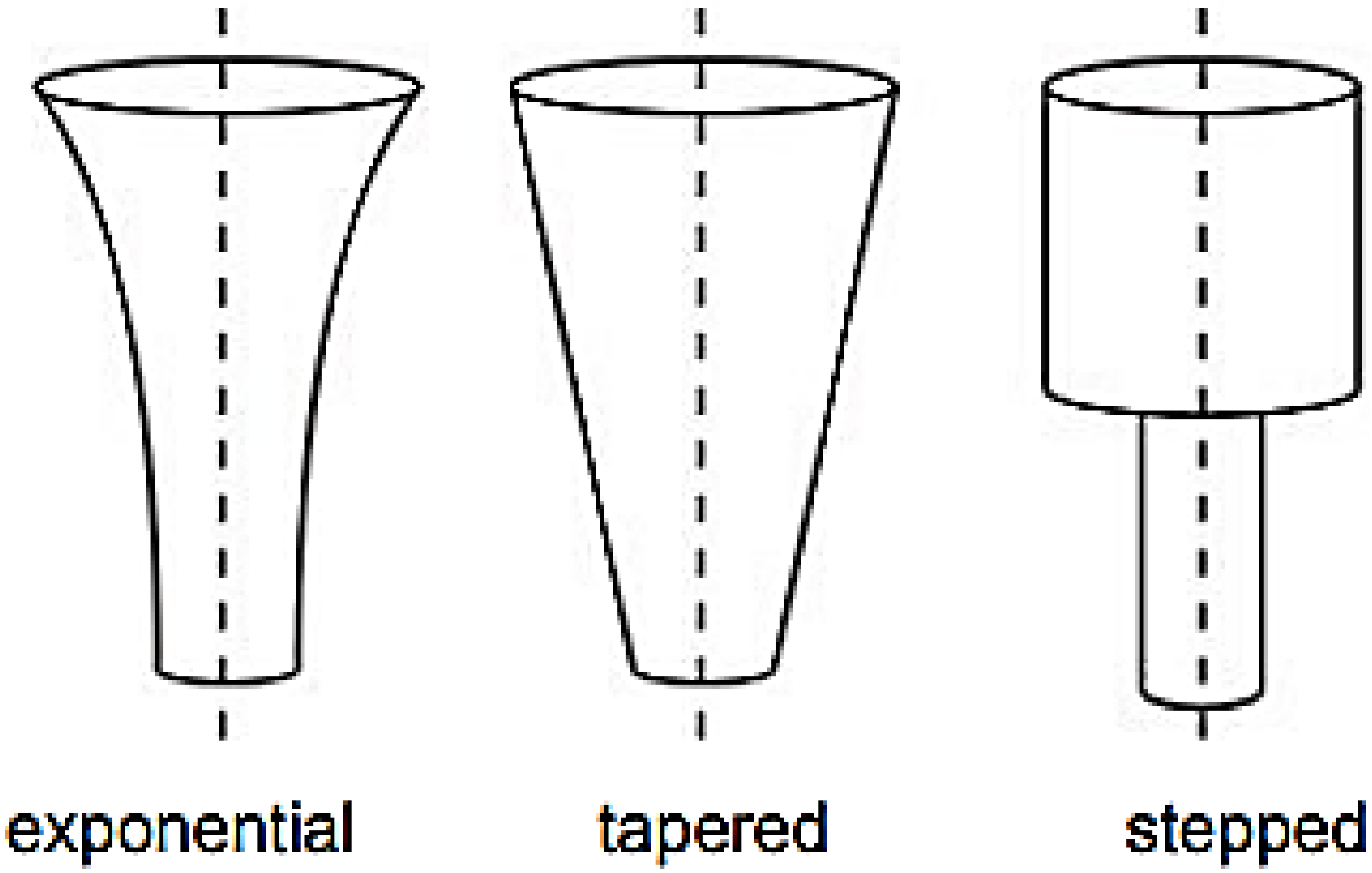


Working of horn as mechanical amplifier of amplitude of vibration

The horn or concentrator is a wave-guide, which amplifies and concentrates the vibration to the tool from the transducer.

The horn or concentrator can be of different shape like

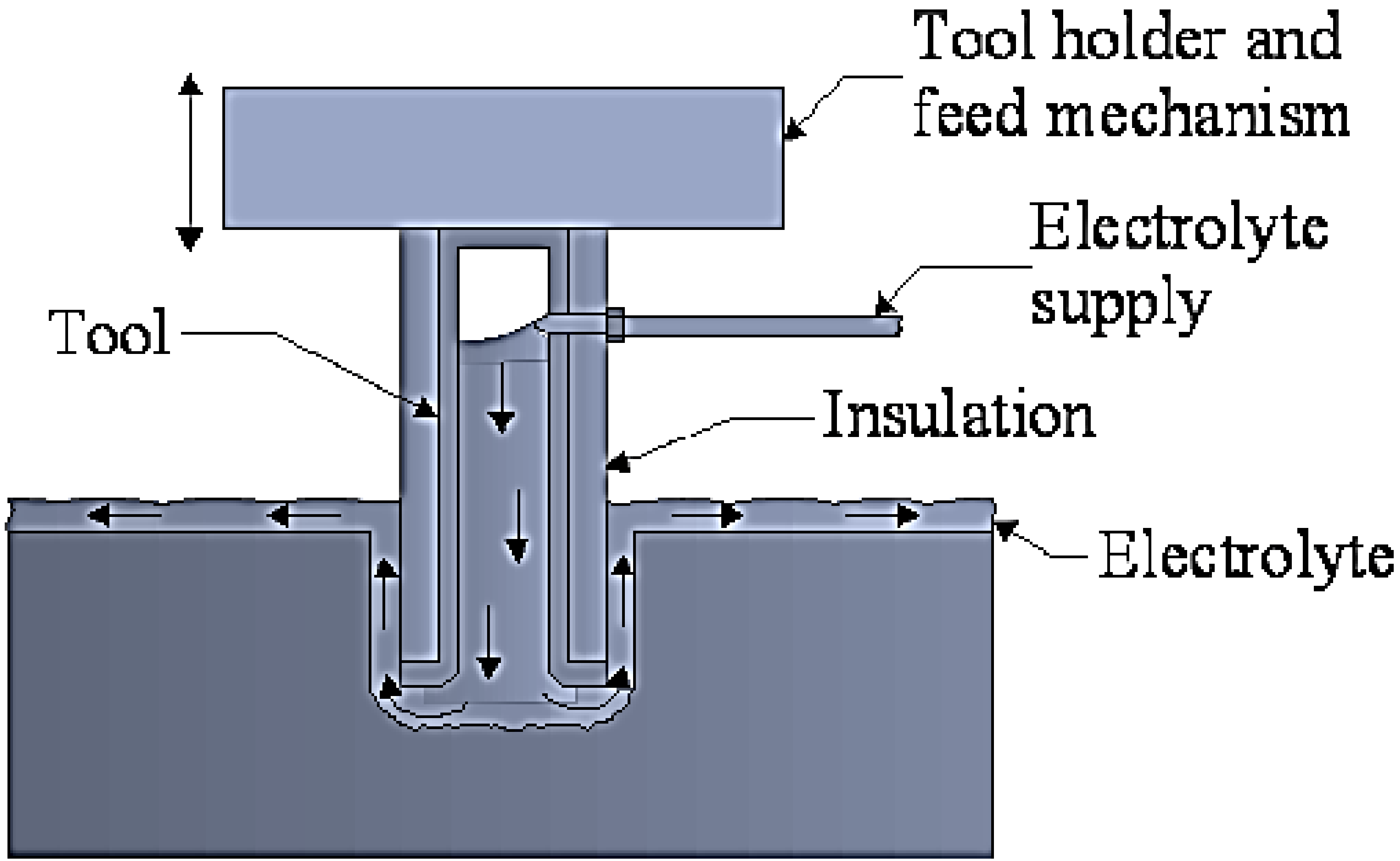
- Tapered or conical
- Exponential
- Stepped



Applications of USM

- Used for machining hard and brittle metallic alloys, semiconductors, glass, ceramics, carbides etc.
- Used for machining round, square, irregular shaped holes and surface impressions.
- Machining, wire drawing, punching or small blanking dies.

ELECTROCHEMICAL MACHINING



- In the actual process of ECM, the cathode is tool shaped(mirror image of work-piece) and anode is the work-piece.
- A gap(0.05 to 0.7 mm) is provided between the tool and work-piece and electrolyte flows through the gap at a velocity of 30 to 60 m/s and it completes the electrical circuit.
- Electrolyte is pumped at high pressure of 20 kgf/cm^2(1.96 MPa) through the gap.
- Electrolyte must be circulated at a rate sufficiently high to conduct current between them and to carry heat.
- Metal is removed from the work-piece by dissolution

- The electric current is of the order of 50 to 40,000 A at 5 to 35 V D.C for current density of 20 to 300 A/cm^2.
- Power of 3 KWh is needed to remove 16 cm^3 of metal which is almost 30 times the energy required in the conventional process(when the material is readily machinable).

Electrochemical machining (ECM) is a metal-removal process based on the principle of reverse electroplating (*means it removes metal instead of adding it*)

- ✓ In this process, particles travel from the anodic material (workpiece) toward the cathodic material (machining tool).
- ✓ A current of electrolyte fluid carries away the deplated material before it has a chance to reach the machining tool.
- ✓ The cavity produced is the female mating image of the tool shape.

- ✓ Similar to EDM, the workpiece hardness is not a factor, making ECM suitable for machining difficult-to –machine materials.

- ✓ Difficult shapes can be made by this process on materials regardless of their hardness.

- ✓ The ECM tool is positioned very close to the workpiece and a low voltage, high amperage DC current is passed between the workpiece and electrode.

Principle

Faraday's law of electrolysis :

Weight of the substance produced during electrolysis process is directly proportional to

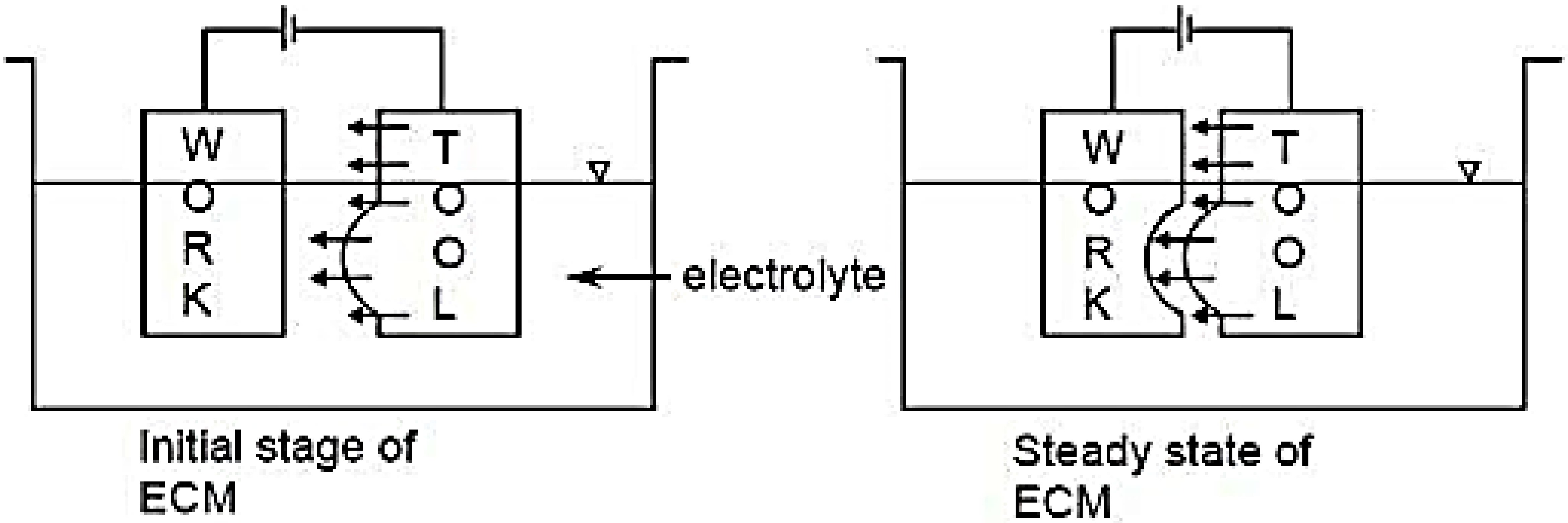
1.the current which passes

2.the length of time of process

3.The equivalent weight of the material

- Two dissimilar metals are in contact with an electrolyte and anode loses metal to cathode

- Anode : Workpiece
- Cathode : Tool
- Electrolyte : An electrically conductive fluid

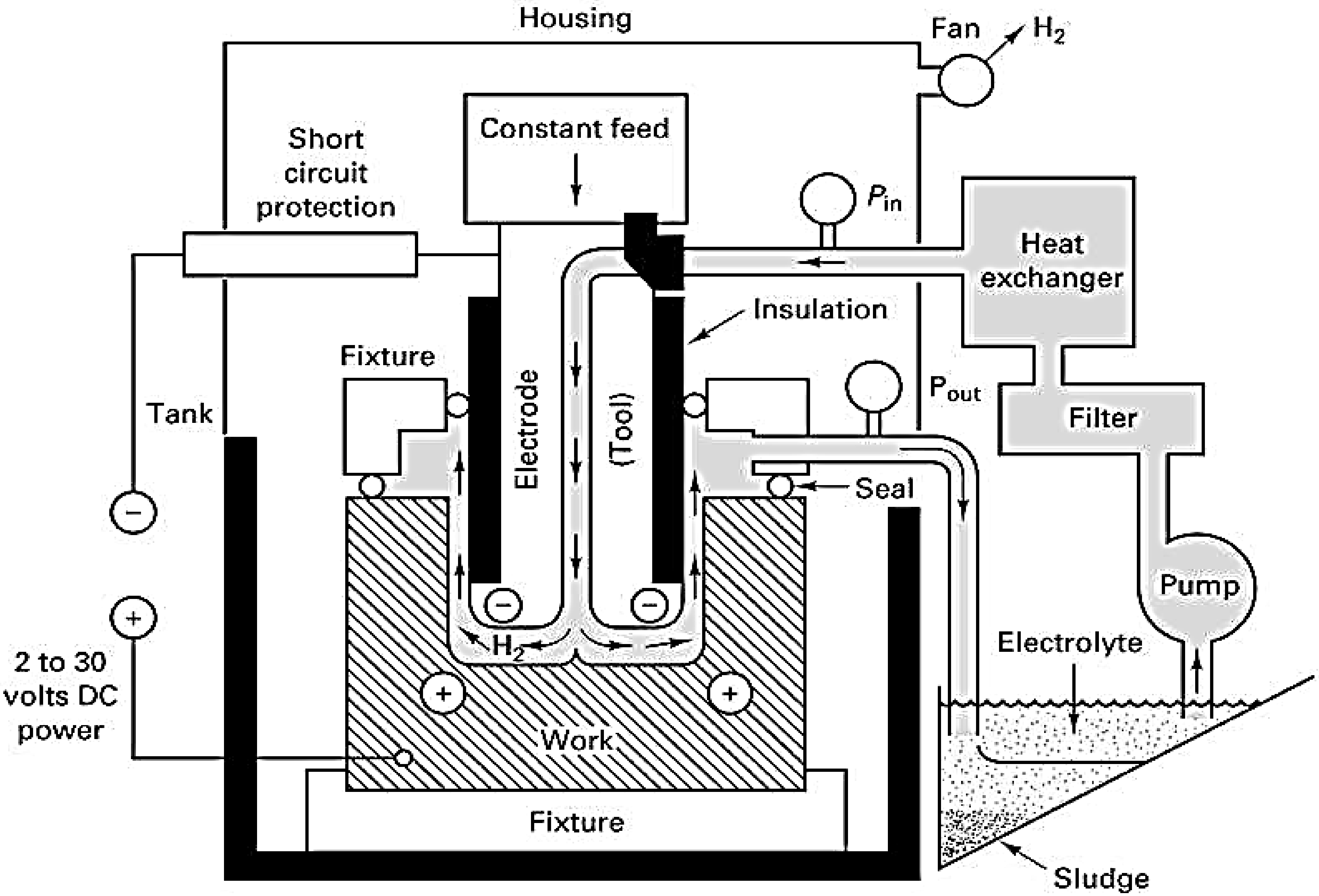


Schematic principle of ECM

PROCESS PARAMETERS

Power Supply	
Type	direct current
Voltage	2 to 35 V
Current	50 to 40,000 A
Current density	0.1 A/mm^2 to 5 A/mm^2
Electrolyte	
Material	NaCl and $NaNO_3$
Temperature	20°C – 50°C
Flow rate	20 lpm per 100 A current
Pressure	0.5 to 20 bar
Dilution	100 g/l to 500 g/l
Working gap	0.1 mm to 2 mm
Overcut	0.2 mm to 3 mm
Feed rate	0.5 mm/min to 15 mm/min
Electrode material	Copper, brass, bronze
Surface roughness, R_a	0.2 to 1.5 μm

ECM PROCESS



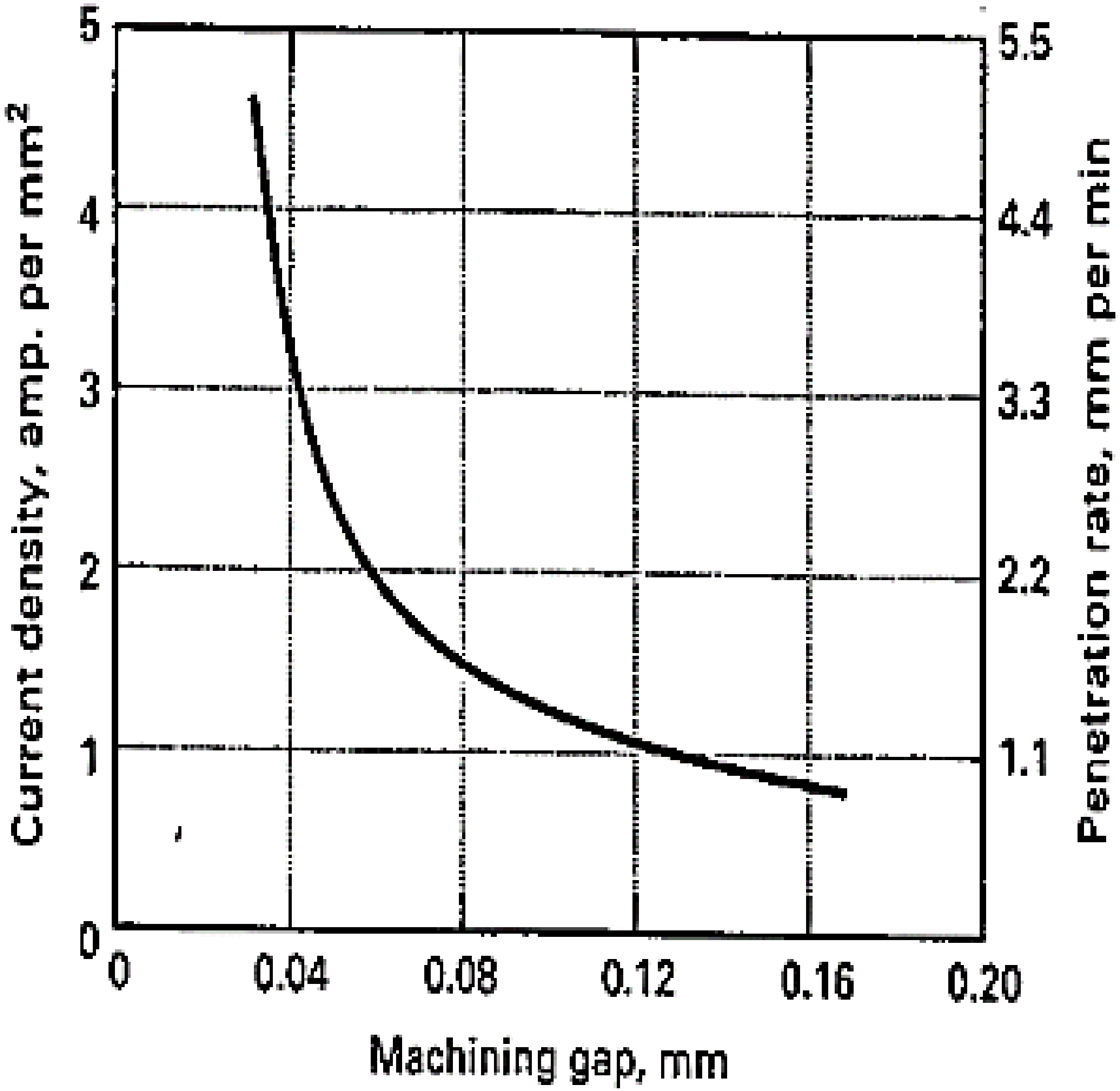
Housing
Fan
H_2
Constant feed
Short circuit protection
P_{in}
Heat exchanger
Insulation
Fixture
Electrode
(Tool)
Tank
P_{out}
Filter
Seal
Pump
Electrolyte
H_2
2 to 30 volts DC power
Work
Fixture
Sludge

Main sub sytem

- Power Supply
- Electrolyte
- Tool
- The Control system
- The machine

Power Supply

- Available in sizes upto 10,000 amp (some circuits are available upto 40,000amp)
- Range of voltage – 2 to 30 volts d.c.
- A constant voltage has to be maintained and high density is required



Relationship of current density, penetration rate, and machining gap in electrochemical machining.

Electrolyte

- Essential for electrolytic process
- It cools the cutting zone which becomes hot due to the flow of high current
- Neutral salts are used as electrolyte in place of highly corrosive acids and alkalies
- Electrolyte solution is pumped between the tool/workpiece gap at about 2.5 N/mm^2 and 30 m/s

Tool

Requirements of Tool For ECM :

- ✓ Good thermal conductivity
- ✓ Strong enough to withstand high pressures
- ✓ It should be easily machined

- Material for tool : Copper,brass or stainless steel

- Outer insulation material : Vinyl, Teflon, epoxy, enables or high temperature varnish

The control system

- Control Parameters include
  - Voltage
  - Inlet and outlet pressure of electrolyte
  - Temperature of electrolyte

- The current is dependent on above parameters and feed rate

Parts made by ECM

Advantages of ECM

- The components are not subject to either thermal or mechanical stress.
- No tool wear during ECM process.
- Fragile parts can be machined easily as there is no stress involved.
- ECM deburring can debur difficult to access areas of parts.
- High surface finish (up to 25 µm in) can be achieved by ECM process.
- Complex geometrical shapes in high-strength materials particularly in the aerospace industry for the mass production of turbine blades, jet-engine parts and nozzles can be machined repeatedly and accurately.
- Deep holes can be made by this process.

Limitations of ECM

- ECM is not suitable to produce sharp square corners or flat bottoms because of the tendency for the electrolyte to erode away sharp profiles.

- ECM can be applied to most metals but, due to the high equipment costs, is usually used primarily for highly specialised applications.

Material removal rate, MRR, in electrochemical machining:

$$MRR = C\,.I.\,h\ (cm^3/min)$$

C: specific (material) removal rate (e.g., 0.2052 cm^3/amp-min for nickel);

I: current (amp);

h: current efficiency (90–100%).

- ✓ The rates at which metal can electrochemically remove are in proportion to the current passed through the electrolyte and the elapsed time for that operation.

- ✓ Many factors other than current influence the rate of machining.

These involve <u>electrolyte type, rate of electrolyte flow, and some other process conditions</u>.