16MEE09 UNCONVENTIONAL MACHINING PROCESSES

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SYLLABUS

COURSE OBJECTIVES

- To study the advanced machining processes.
- To understand the traditional machining processes.
- To understand the unconventional machining processes
- To know the principles and working of various nontraditional processes based on mechanical and thermal energy.
- To know the principles and working of various nontraditional processes based on electrical and electrochemical energy

SYLLABUS

COURSE OUTCOMES

- Able to understand unconventional machining processes.
- Able to understand difference between conventional and unconventional machining processes.
- Able to select the suitable machining process to machine the hard advanced materials.
- Be familiar with electrical energy involved in non traditional machining processes.
- Be familiar with electrochemical energy involved in non traditional machining processes.

SYLLABUS

UNIT I: INTRODUCTION 9

- Unconventional Machining Process
  - Introduction
- Need – Classification
- Comparison of conventional and unconventional machining process
- Energies employed in the processes
- Brief overview of various techniques.

SYLLABUS

UNIT II: MECHANICAL ENERGY BASED PROCESSES 9

- Working Principles – equipment used – Process parameters – Material removal rate- Variation in techniques used – Applications.
  - Abrasive Jet Machining
  - Water Jet Machining
  - Ultrasonic Machining..

SYLLABUS

UNIT III: ELECTRICAL ENERGY BASED PROCESSES 9

- Electric Discharge Machining- working Principles-equipments-Process Parameters-Material removal rate - electrode / Tool – Power Circuits-Tool Wear – Dielectric – Flushing – Wire cut EDM
- Applications
- Recent developments in Electro discharge machining

SYLLABUS

UNIT IV: CHEMICAL & ELECTRO-CHEMICAL ENERGY BASED PROCESSES 9

- Process principles of Chemical machining and Electro-Chemical machining
- Etchants-maskants-techniques-Process Parameters – Material removal rate - Applications-equipments-Electrical circuit-Process Parameters
- Electro chemical grinding, Electro chemical honing and Electro chemical deburring Applications.

SYLLABUS

UNIT V: THERMAL ENERGY BASED PROCESSES 9

- Principles – Equipment
  - Laser Beam machining
  - Plasma Arc Machining
- Electron Beam Machining.
  - Principles – Equipment - Types-Beam control techniques- Material removal rate
- Applications.

TEXTBOOKS

Sl.No	Author(s)	Title of the Book	Publisher	Year of Publication
1.	P. K. Mishra	Non Conventional Machining	Narosa Publishing House, New Delhi	2007
2	P. C. Pandey and H.S.Shan	Modern Machining Processes	Tata McGraw Hill Publishing Company PvtLtd.,New Delhi	2008

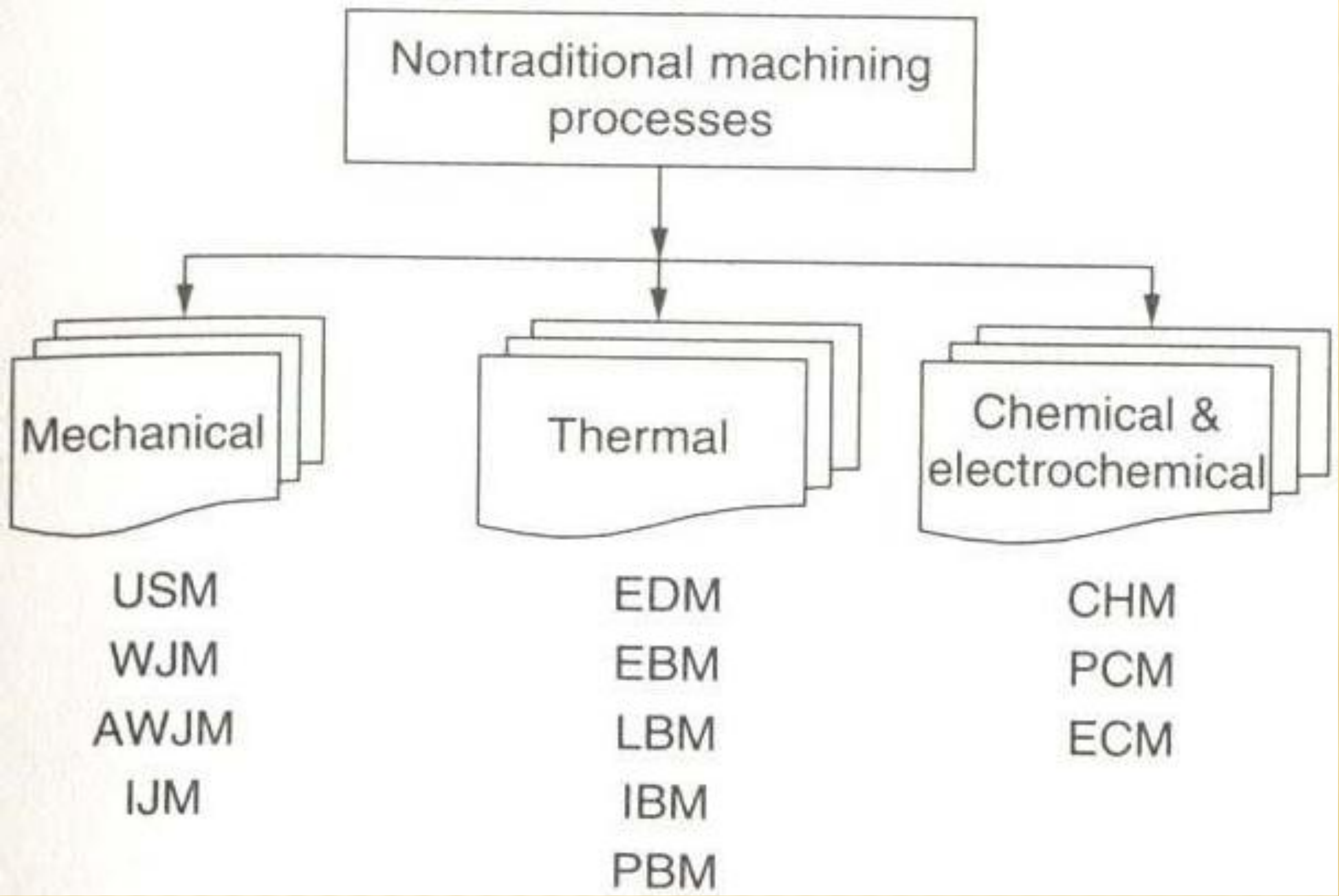
REFERENCE BOOKS

Sl.No	Author(s)	Title of the Book	Publisher	Year of Publication
1.	G. F. Benedict	Nontraditional Manufacturing Processes	Marcel Dekker Inc., New York	1987
2	Ronald.A.Kohser	Material and Processes in Manufacturing	Prentice Hall of India Pvt. Ltd., New Delhi	2007
3	Paul De Garmo, J.T.Black and Ronald.A.Kohser	Material and Processes in Manufacturing	Prentice Hall of India Pvt. Ltd., New Delhi	2007
4	Vijaya Kumar Jain	Advanced Machining Processes	Allied Publishers Pvt. Ltd., New Delhi	2005
5	McGeough	Advanced Methods of Machining	Chapman and Hall, London	1998

VIDEO LECTURES / URL'S

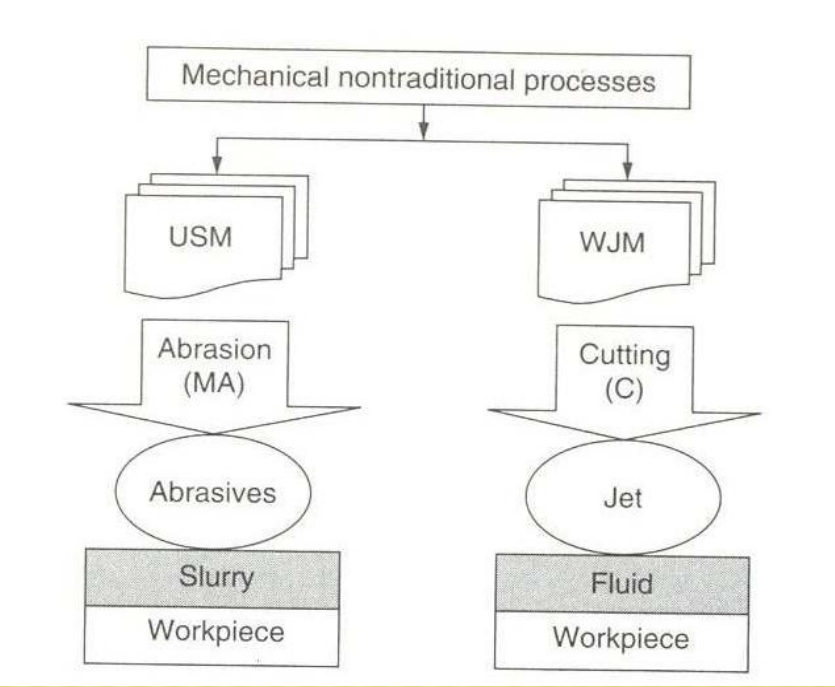
- www./mechteacher.com/unconventional-machining-processes-introduction-and-classification
- www.nptel.iitm.ac.in/video.php?subjectId=112105126
- www.ustudy.in/mech/mmp/u2
- www.web.mit.edu/2.813/www/readings/Gutowski-CIRP.pdf
- www.en.aau.dk/education/master/energy-engineering/specialisations/thermal-energy-and-process-engineering

CLASSIFICATION OF NON-TRADITIONAL MACHINING

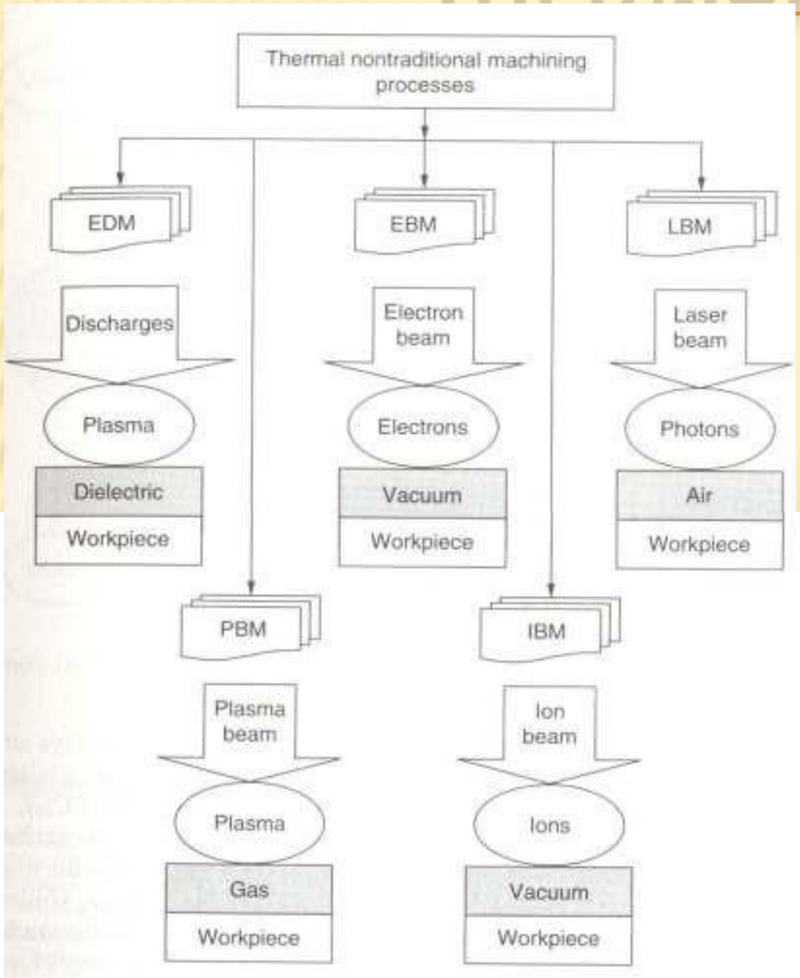


MECHANICAL MACHINING

- Ultrasonic Machining (USM) and Waterjet Machining (WJM) are typical examples of single action, mechanical non traditional machining processes.
- The machining medium is solid grains suspended in an abrasive slurry in the former, while a fluid is employed in the WJM process.
- The introduction of abrasives to the fluid jet enhances the machining efficiency and is known as abrasive water jet machining. Similar case happens when ice particles are introduced as in Ice Jet Machining.

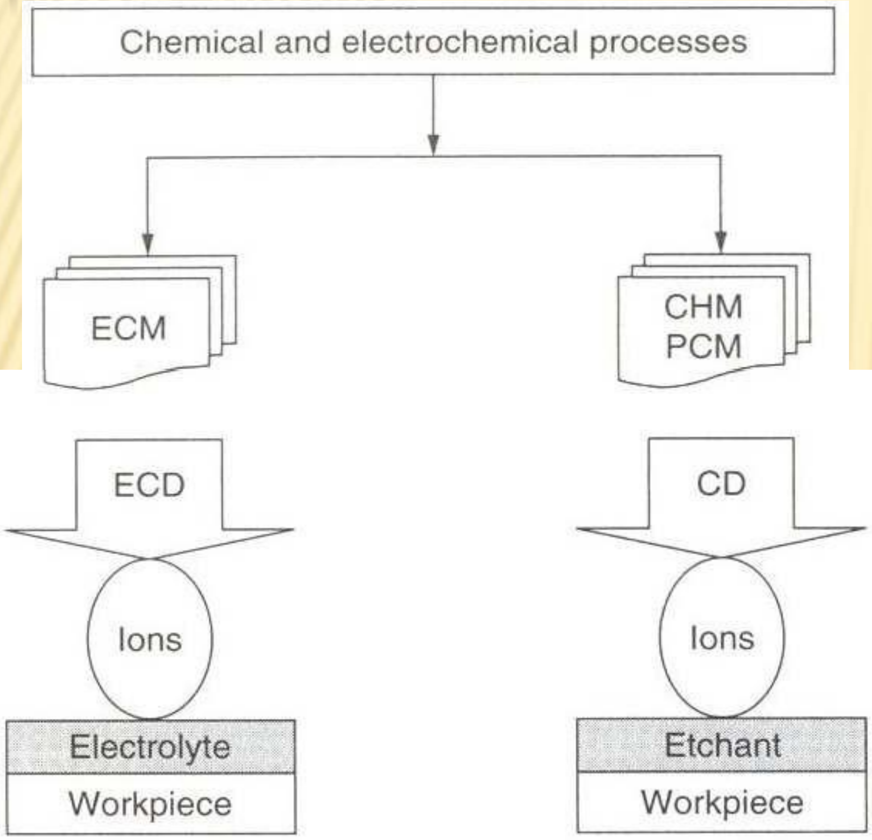


THERMAL MACHINING



- Thermal machining removes materials by melting or vaporizing the work piece material.
- Many secondary phenomena occur during machining such as microcracking, formation of heat affected zones, striations etc.
- The source of heat could be plasma as during EDM and PBM or photons as during LBM, electrons in EBM, ions in IBM etc.

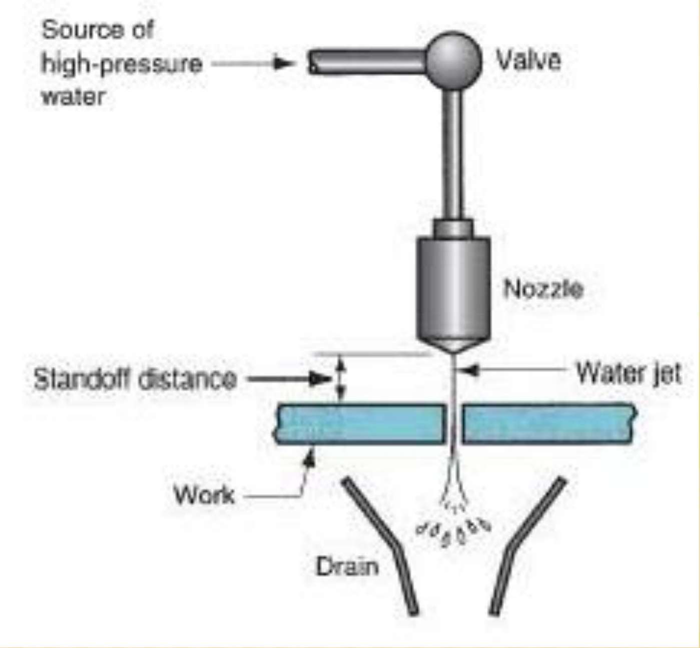
CHEMICAL AND ELECTROCHEMICAL MACHINING



- Chemical milling and photochemical machining or photochemical blanking all use a chemical dissolution action to remove the machining allowance through ions in an etchant.
- Electrochemical machining uses the electrochemical dissolution phase to remove the machining allowance using ion transfer in an electrolytic cell.

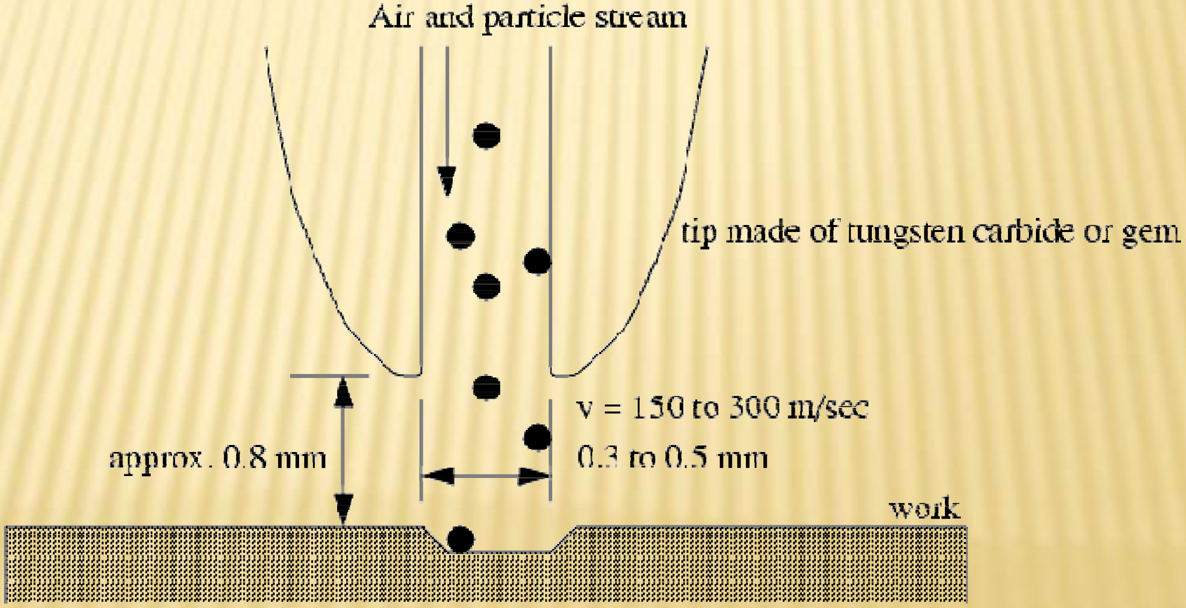
WATER JET CUTTING (WJC)

- Also known as hydrodynamic machining.
- Uses a fine, high-pressure, high-velocity of water directed at the work surface to cause cutting of the work.



ABRASIVE JET MACHINING (AJM)

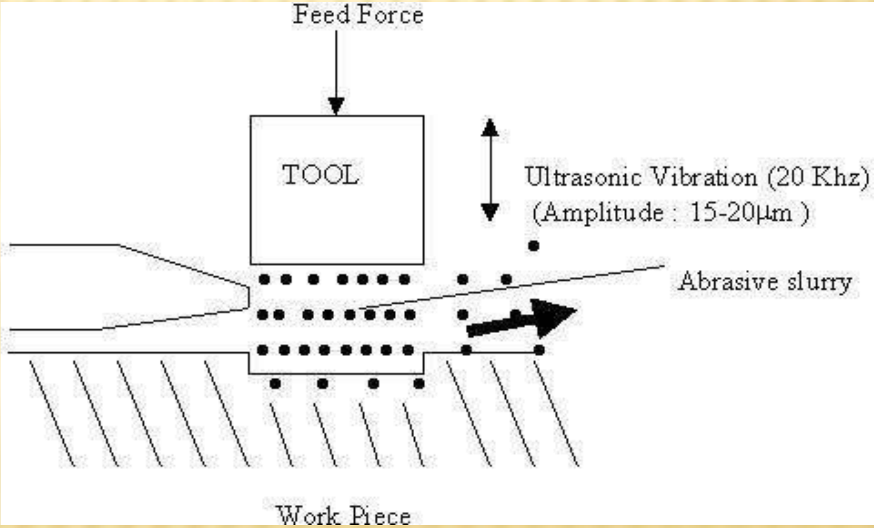
- In AJM, the material removal takes place due to impingement of the fine abrasive particles.
- The abrasive particles are typically of 0.025mm diameter and the air discharges at a pressure of several atmosphere.



ABRASIVE JET MACHINING (AJM)

ULTRASONIC MACHINING (USM)

- The basic USM process involves a tool (made of a ductile and tough material) vibrating with a low amplitude and very high frequency and a continuous flow of an abrasive slurry in the small gap between the tool and the work piece.
- The tool is gradually fed with a uniform force.
- The impact of the hard abrasive grains fractures the hard and brittle work surface, resulting in the removal of the work material in the form of small wear particles.
- The tool material being tough and ductile wears out at a much slower rate.



SUMMARY

Mechanics of material removal	Brittle fracture caused by impact of abreasive grains due to tool vibrating at high frequency
Medium	Slurry
Abrasives	B_4C, SiC, Al_2O_3, diamond 100-800 grit size
Vibration Frequency Amplitude	 15-30 kHz 25-100 µm
Tool Material MRR/Tool wear rate	 Soft steel 1.5 for WC workpiece, 100 for glass workpiece
Gap	25-40 µm
Critical parameters	Frequency, amplitude, tool material, grit size, abrasive material, feed force, slurry concentration, slurry viscosity
Materials application	Metals and alloys (particularly hard and brittle), semiconductors, nonmetals, e.g., glass and ceramics
Shape application	Round and irregular holes, impressions
Limitations	Very low MRR, tool wear, depth of holes and cavities small

ELECTRICAL DISCHARGE MACHINING

ELECTRICAL DISCHARGE MACHINING

- It is also known as Spark over-initiated discharge machining, Spark erosion machining or simply Spark machining.
- It is probably the most versatile of all the electrical machining methods. **Mechanics of material removal** - melting and evaporation aided by cavitations.
- This process may be used for machining any material, irrespective of its hardness, which is an electrical conductor.

ELECTRICAL DISCHARGE MACHINING

- ✓ The rate of metal removal and the resulting surface finish can be controlled by proper variation in the energy and the duration of spark discharge.

- ✓ A liquid dielectric, like paraffin or some light oil, like transformer oil or kerosene oil, is always used in the process.

ELECTRICAL DISCHARGE MACHINING (EDM)

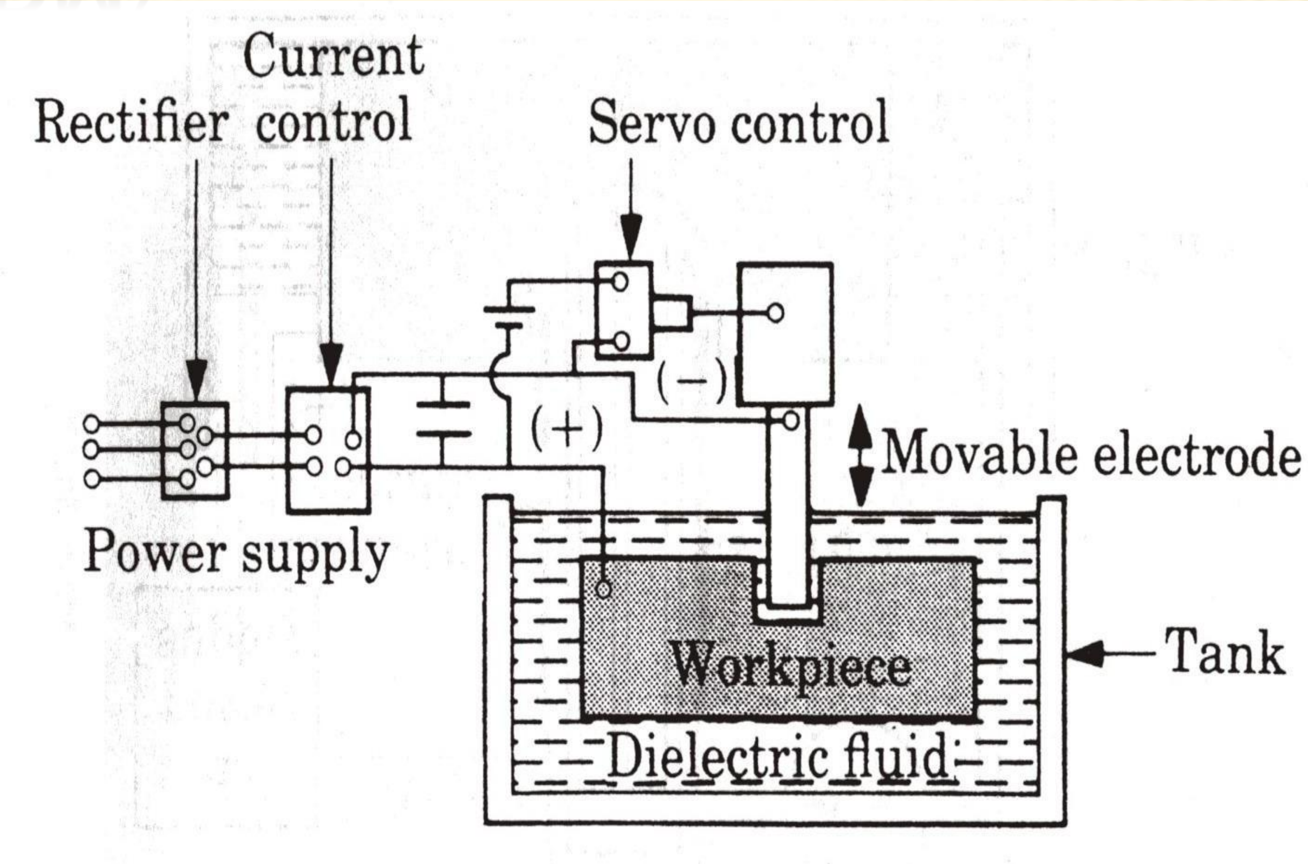


Figure 1: Schematic Diagram of EDM

EDM (CONTD.)

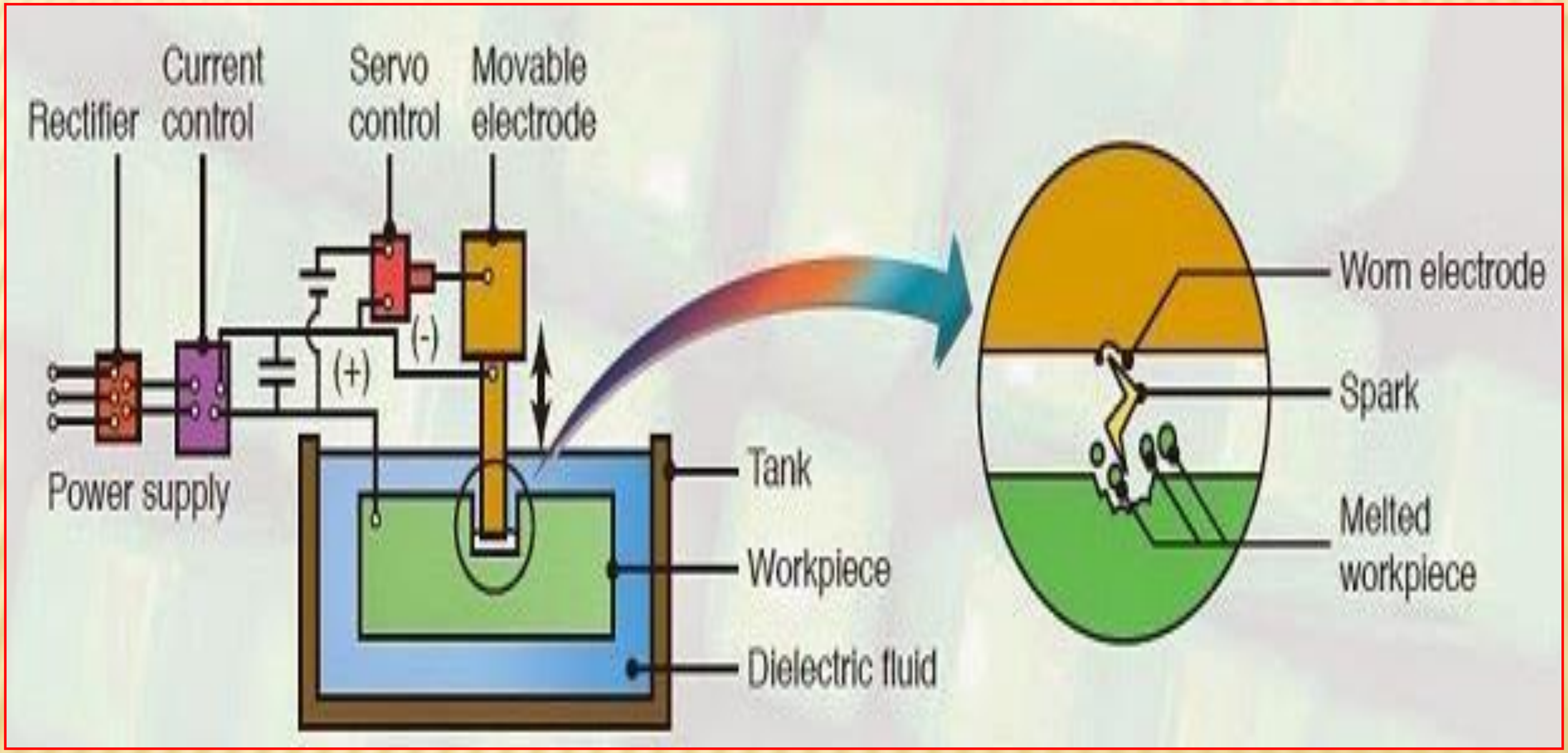


Figure 2: Schematic Diagram of EDM

ELECTRON BEAM MACHINING

ELECTRON BEAM MACHINING (PRINCIPLE)

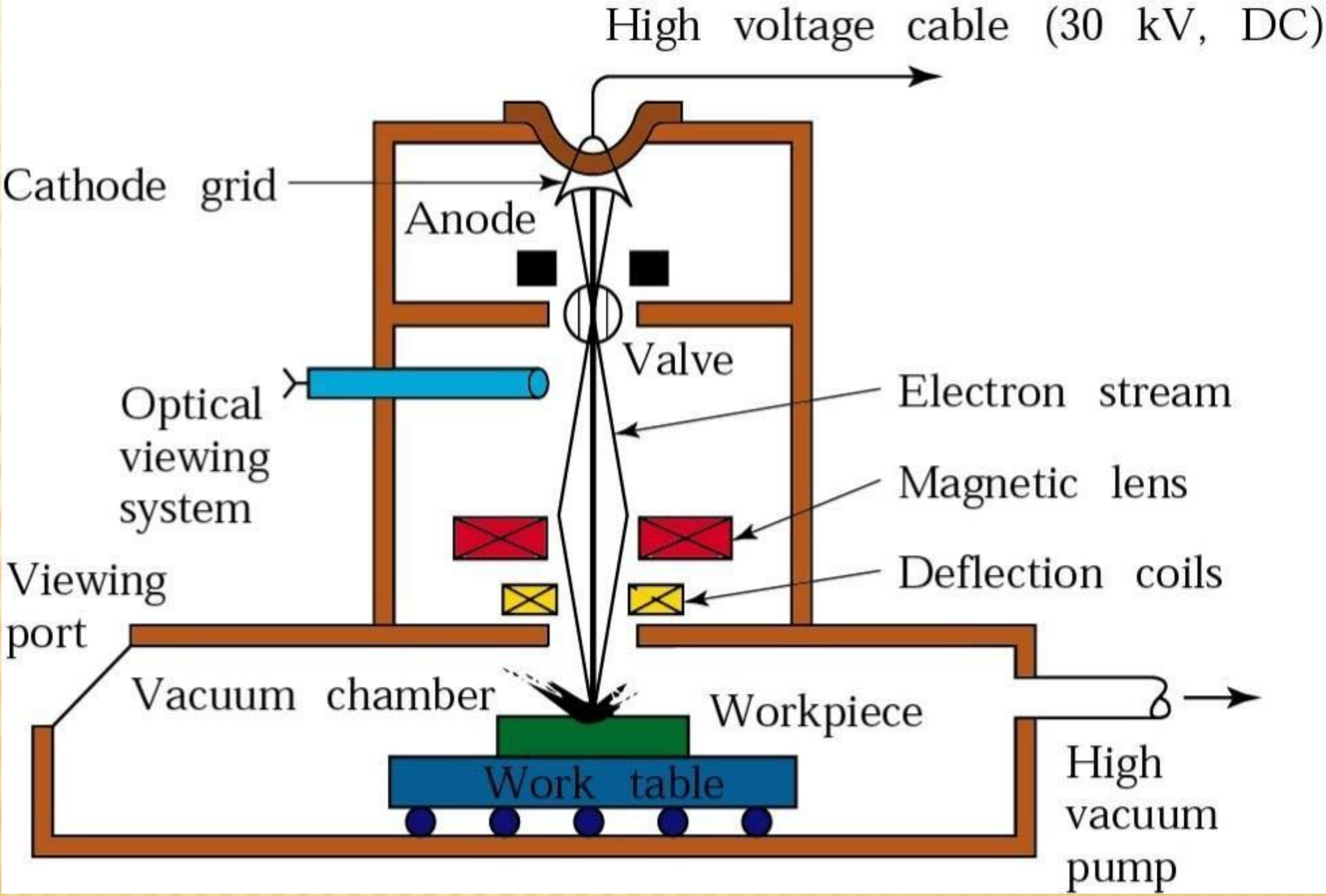
- Electron Beam Machining (EBM) is a **thermal process**. Here a steam of high speed electrons impinges on the work surface so that the **kinetic energy** of electrons is transferred to work producing **intense heating**.

- Depending upon the intensity of heating the workpiece can **melt and vaporize**.

- The process of heating by electron beam is used for **annealing, welding or metal removal**.

ELECTRON BEAM MACHINING

- It is a process of machining materials with the use of a high velocity beam of electrons.
- The workpiece is held in a vacuum chamber and the electron beam focused on to it magnetically.
- As the electrons strike the workpiece, their kinetic energy is converted into heat.
- This concentrated heat raises the temperature of workpiece materials and vaporizes a small amount of it, resulting in removal of metal from the workpiece.
- The reason for using a vacuum chamber is that, if otherwise, the beam electrons will collide with gas molecules and will scatter.


High voltage cable (30 kV, DC)
Cathode grid
Anode
Valve
Optical
viewing
system
Electron stream
Magnetic lens
Deflection coils
Viewing
port
Vacuum chamber
Workpiece
Work table
High
vacuum
pump

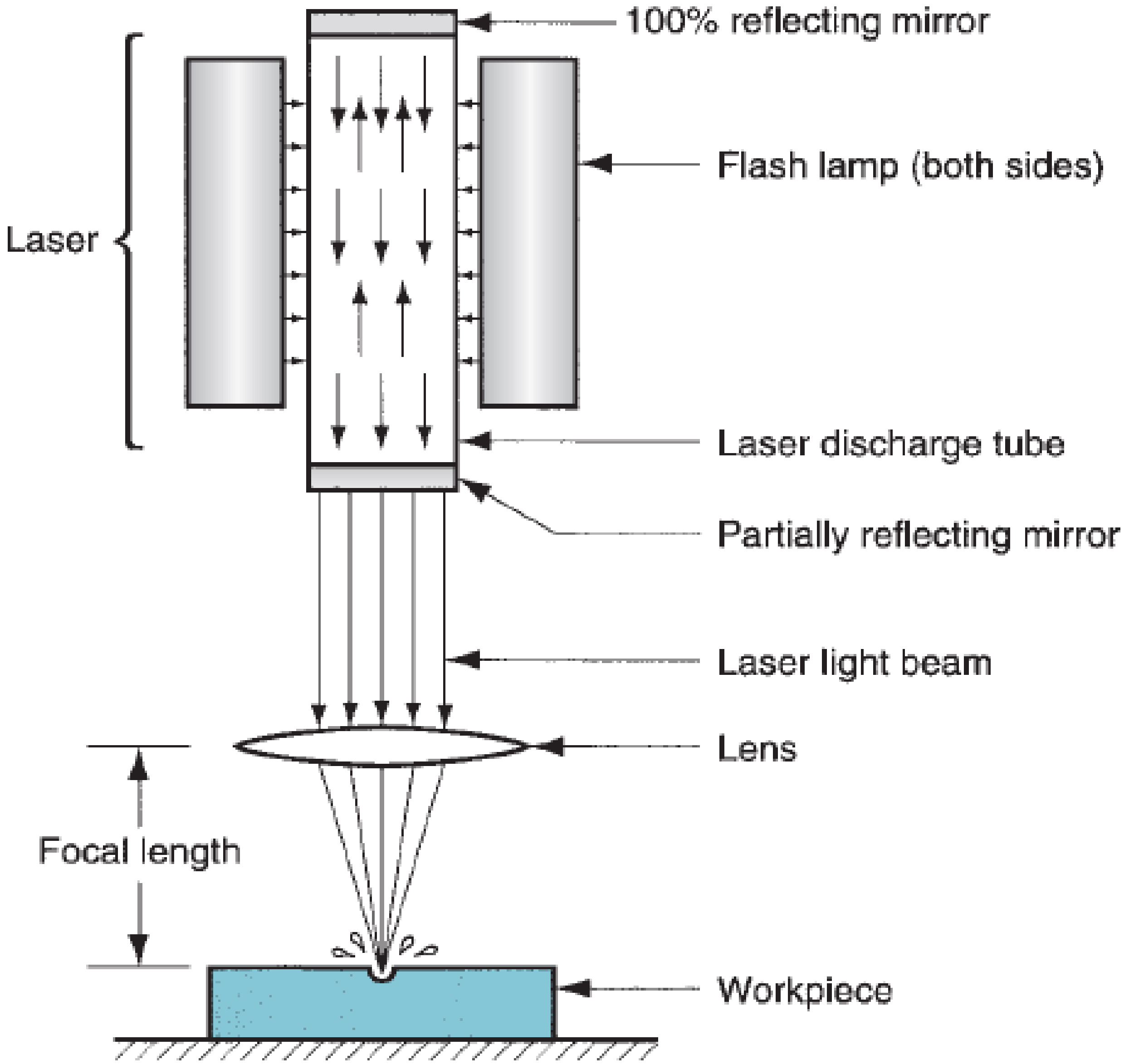
LASER BEAM MACHINING

LASER BEAM MACHINING (PRINCIPLE)

- Laser beam machining (LBM) **uses the light energy from a laser** device for the **material removal by vaporization**.
- Laser is the term used for the phenomenon of **'amplification of light'** by stimulated emission of radiation'.
- A laser is an optical transducer that converts electrical energy into a highly coherent light beam.
- The energy of the **coherent light beam** is concentrated not only optically but also with time.

LASER BEAM MACHINING

- The setup consists of a stimulating light source (like flash lamp) and a laser rod.
- The light radiated from the flash lamp is focused on to the laser rod (Laser tube), from where it is reflected and accelerated in the path.
- This light is emitted in the form of a slightly divergent beam. A lens is incorporated suitably in the path of this beam of light which converges and focuses the light beam on to the workpiece to be machined.
- This concentration of the laser beam on the workpiece melts the work material and vaporizes it.
- It is very costly method and can be employed only when it is not feasible to machine a workpiece through other methods.


100% reflecting mirror
Flash lamp (both sides)
Laser
Laser discharge tube
Partially reflecting mirror
Laser light beam
Lens
Focal length
Workpiece

ULTRASONIC MACHINING

ULTRASONIC MACHINING

- A high frequency electric current is sent by the ultrasonic oscillator to the ultrasonic transducer.
- The function of the transducer is to convert this electrical energy into mechanical vibrations.
- The vibrations so generated are of the order of **20 kHz to 30 kHz**, although the available amplitude usually varies from **15 – 50 μm .**
- The transducer is made of a magneto strictive material, which is excited by the following high frequency electric current and this results in the generation of mechanical vibrations.
- These vibrations are then transmitted to the cutting fool via the intermediate connecting parts, such as transducer cone or horn, connecting body and tool holder.

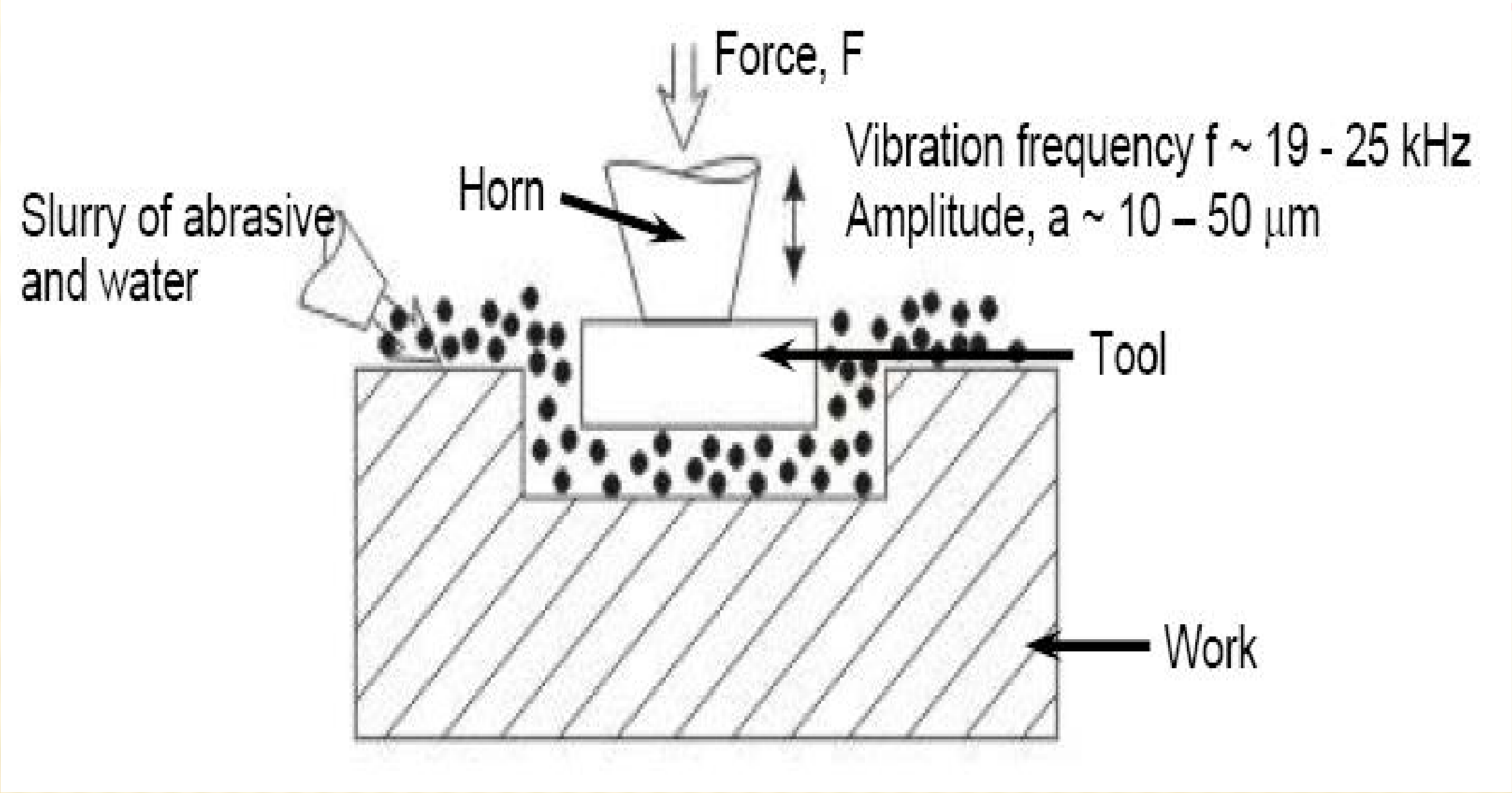
ULTRASONIC MACHINING

- Slurry of small abrasive particles is forced against the work by means of a vibrating tool, removing the workpiece material in the form of extremely small chips.
- The grains used are of silicon carbide, aluminum oxide, boron carbide or diamond dust.
- This processes is suitable only for hard and brittle materials like carbides, glass, ceramics, silicon, precious stones, germanium, titanium, tungsten, tool steels, die steels, ferrite quartz, etc.
- The vibrating frequency used for the tool is of the order of over 20,000 oscillations second.
- Such a high frequency, which is more than the upper limit of audible frequency for human ear' makes the process inaudible (silent).

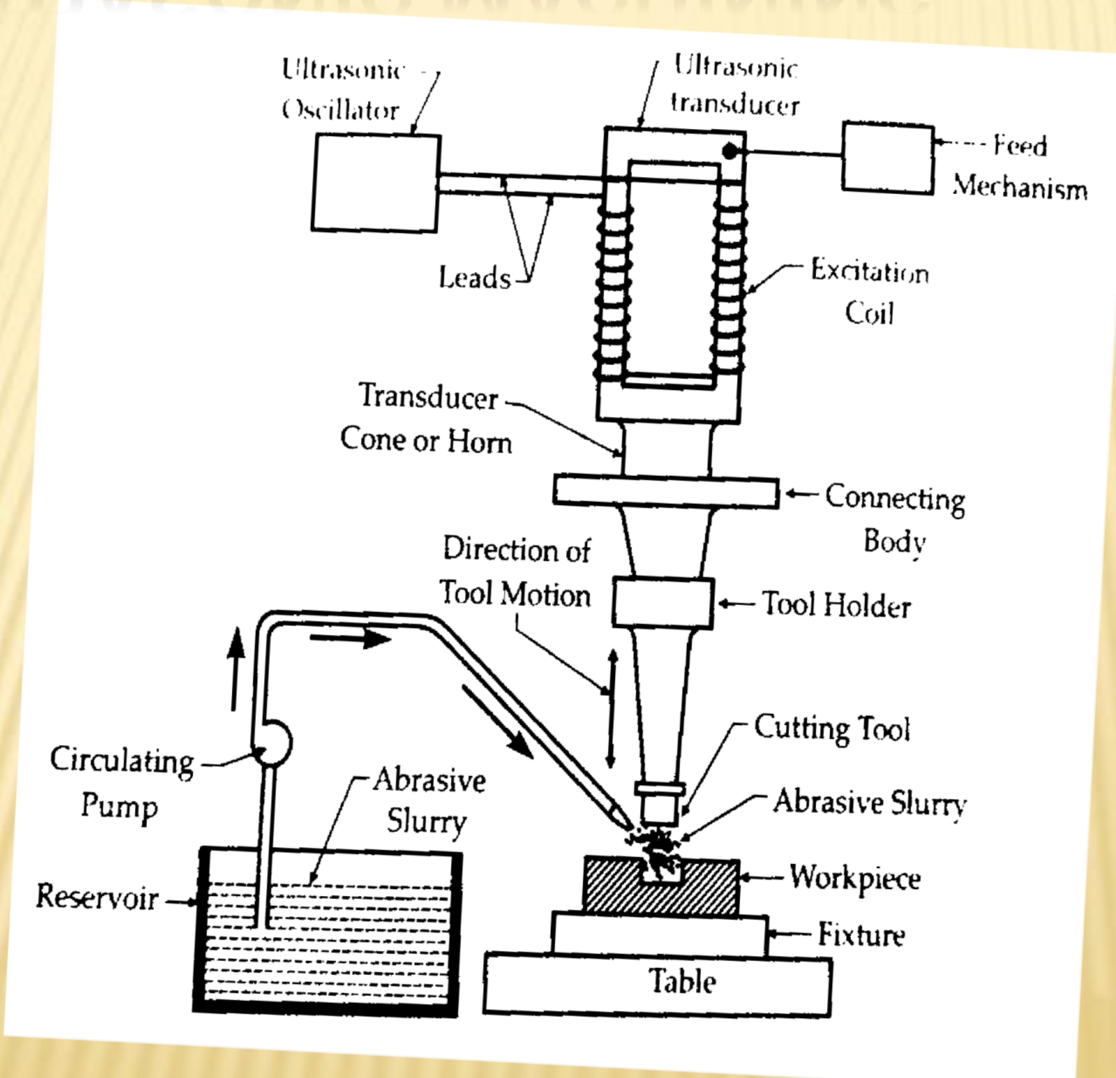
ULTRASONIC MACHINING

- This makes the tool vibrate in a longitudinal direction, as, shown.
- The intermediate parts together form what is known as the focusing unit and the cutting tool is fastened at its end.
- The shape of the cutting tool is the same as that of the cavity to be produced by it.
- The slurry, formed by the suspension of abrasive grains in a carrier fluid, is fed into the machining area by means of a circulating pump.
- However, in order to keep its temperature low a suitable cooling system may be incorporated.

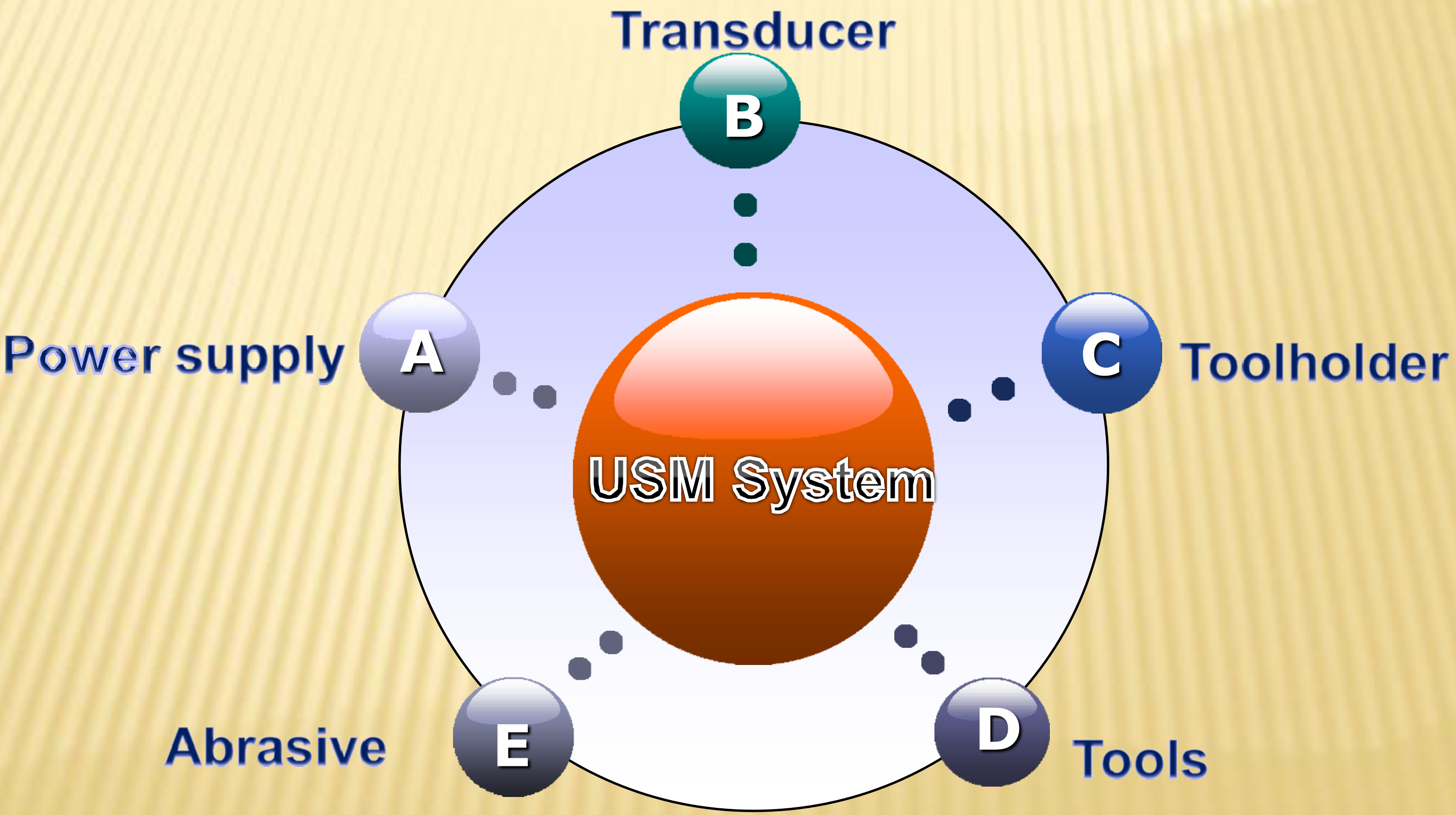
ULTRASONIC MACHINING

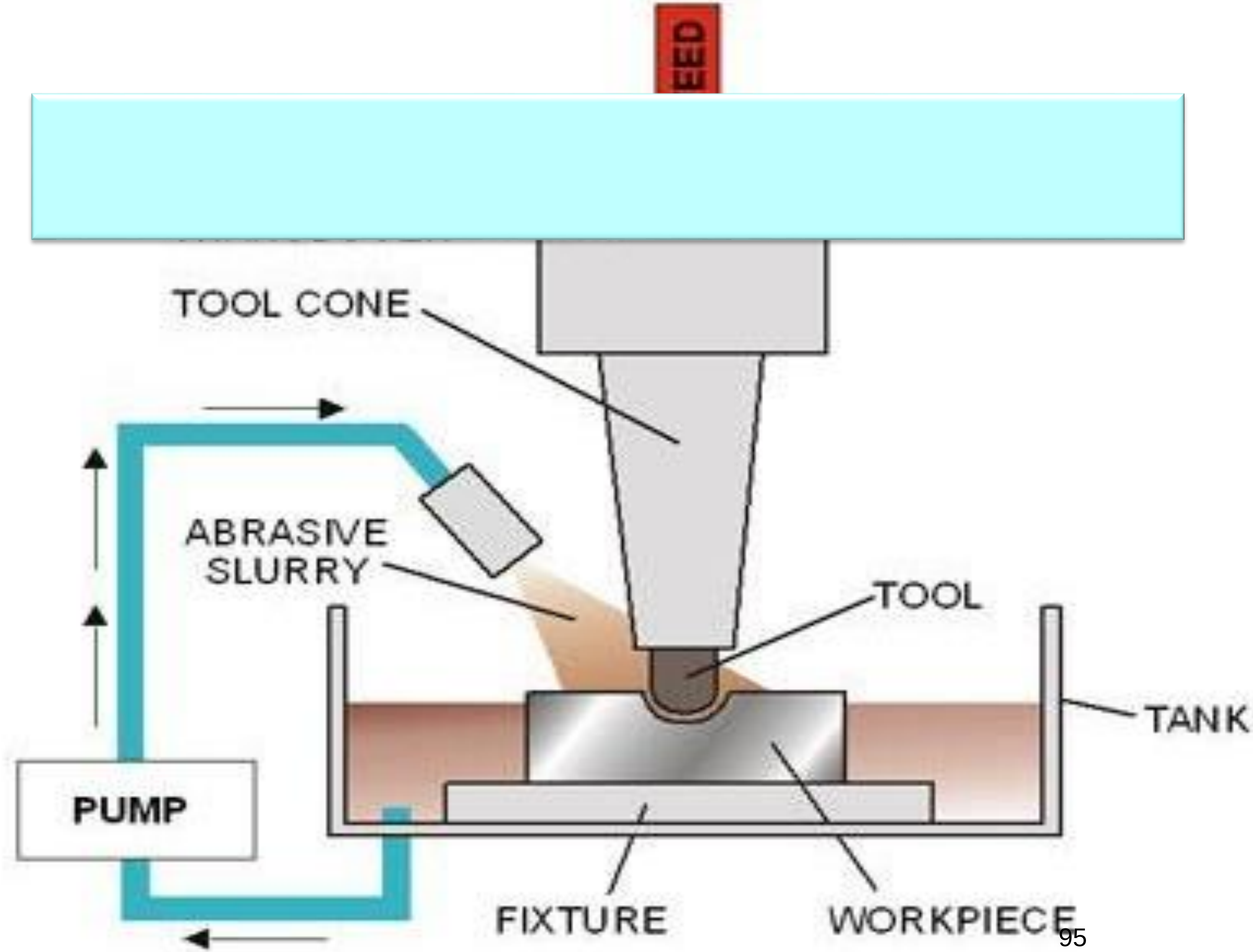


ULTRASONIC MACHINING



SUBSYSTEMS OF USM




TOOL CONE
ABRASIVE
SLURRY
TOOL
TANK
PUMP
FIXTURE
WORKPIECE

PLASMA ARC MACHINING

WHAT IS PLASMA?

- When gases are heated to temperatures above **5500°C**, they are ionized and exist in the form of a mixture of free **electrons, positively charged ions** and **neutral atoms**. This mixture is termed as plasma.

- The temperature of **central part of plasma** goes as high as between **11000°C to 28000°C**, where the gas is completely ionized.

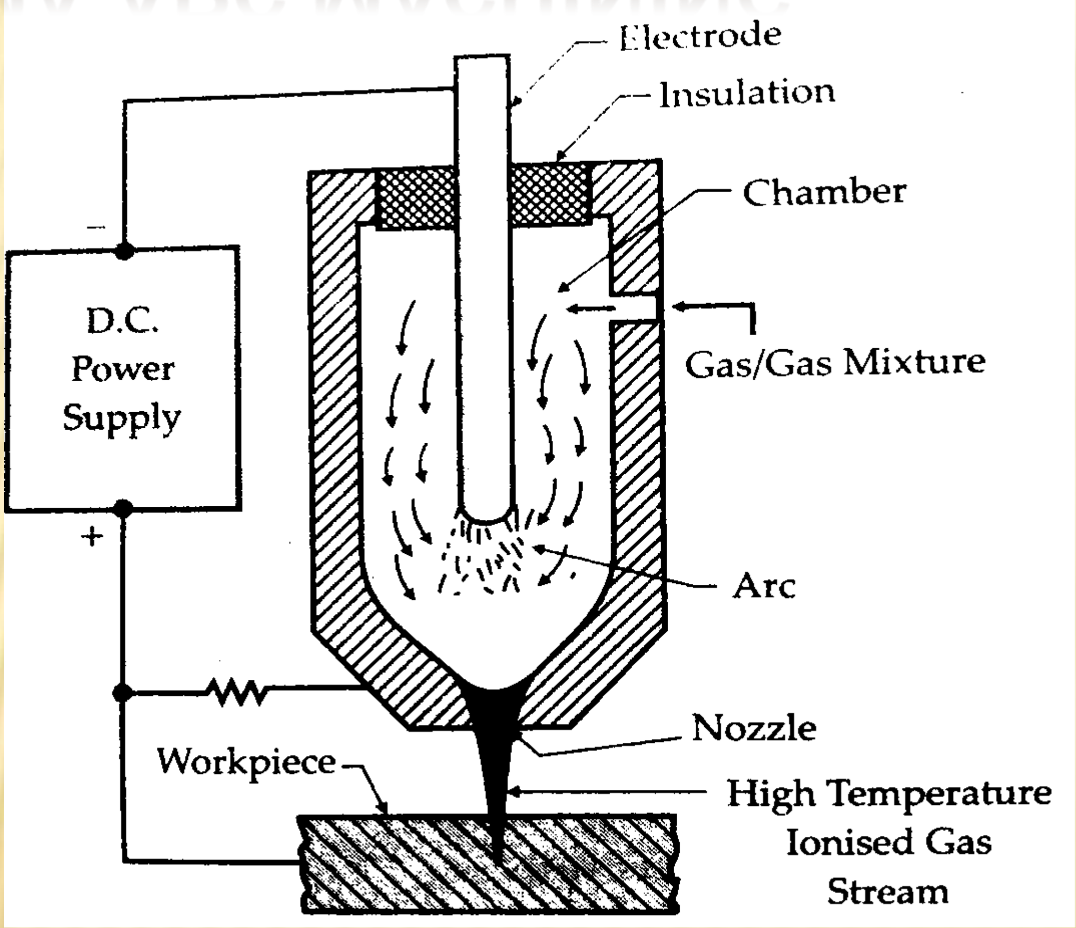
PLASMA ARC MACHINING

- In Plasma arc machining or Plasma arc cutting, **a high velocity jet** of this high temperature ionized gas is directed on to the workpiece surface by means of a well-designed torch.

- This jet **melts the metal** of the workpiece and displaces the molten metal away from its path. **The heating of workpiece material is not due to any chemical reaction but on account of the continuous attack of electrons which transfer the heat energy of high temperature ionized gas to the work material**.

- This process can, therefore, be safely used for machining of any metal, including those which can be subjected **to chemical reaction**.

PLASMA ARC MACHINING

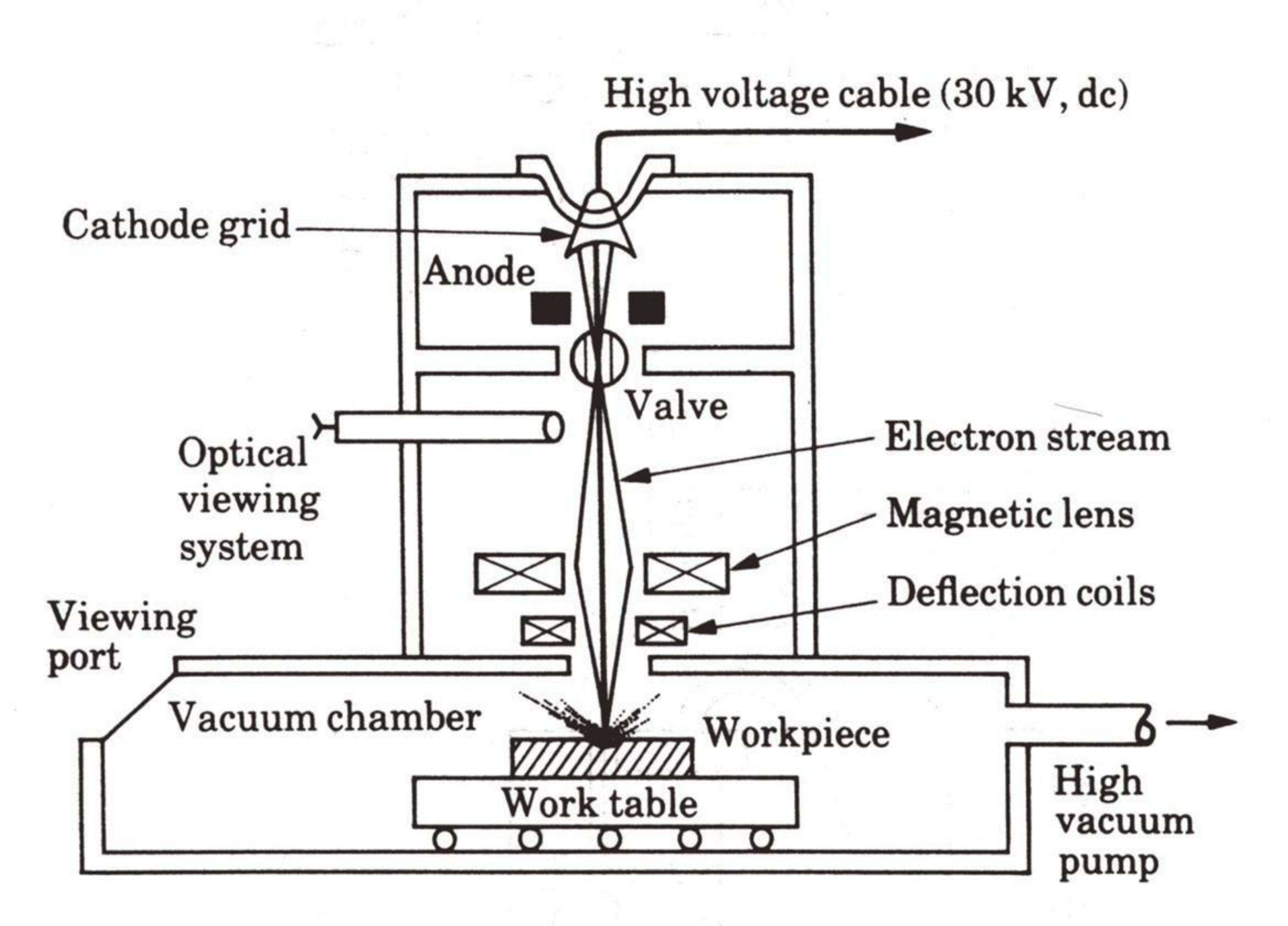


ELECTRO CHEMICAL MACHINING

ELECTRO-CHEMICAL MACHINING (ECM)

ECM is an extension of electroplating with some modifications, but in a reverse direction.

Thus ECM can be describe as a controlled **anodic dissolution at atomic level of the work piece** that is electrically conductive by a shaped tool due to flow of **high current at relatively low potential difference through an electrolyte** which is quite often water based neutral salt solution.



High voltage cable (30 kV, dc)
Cathode grid
Anode
Valve
Optical
viewing
system
Electron stream
Magnetic lens
Deflection coils
Viewing
port
Vacuum chamber
Workpiece
Work table
High
vacuum
pump

ELECTRO-CHEMICAL MACHINING (ECM)

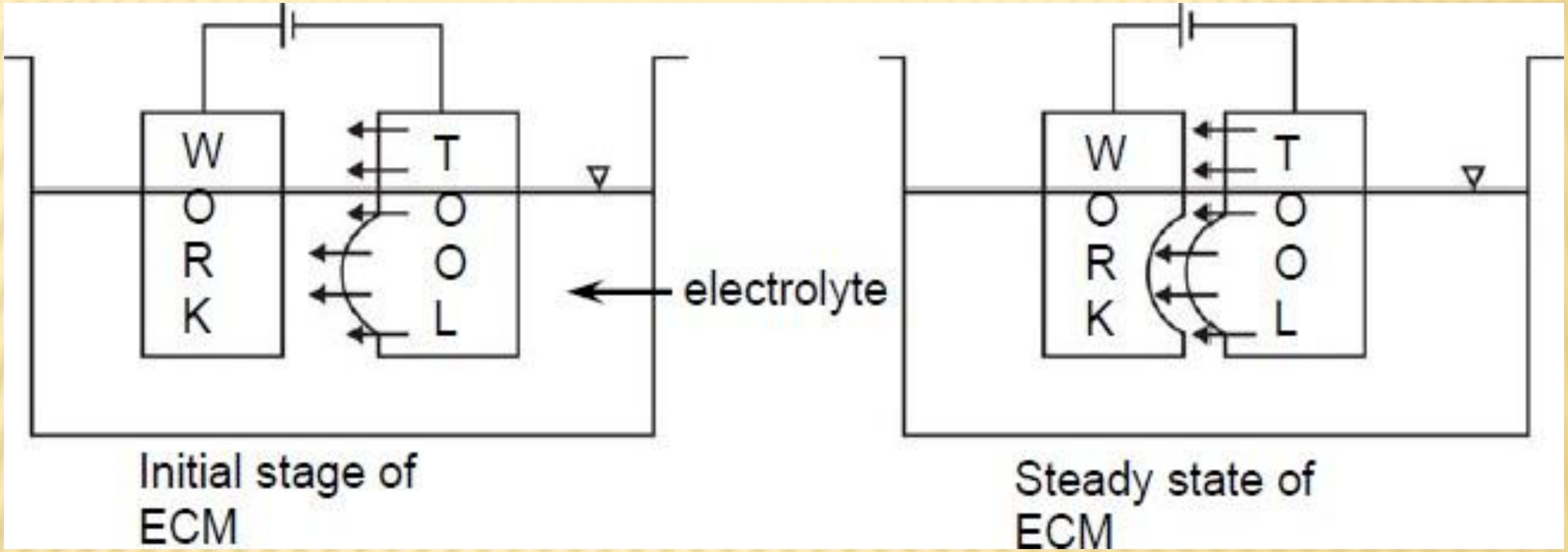
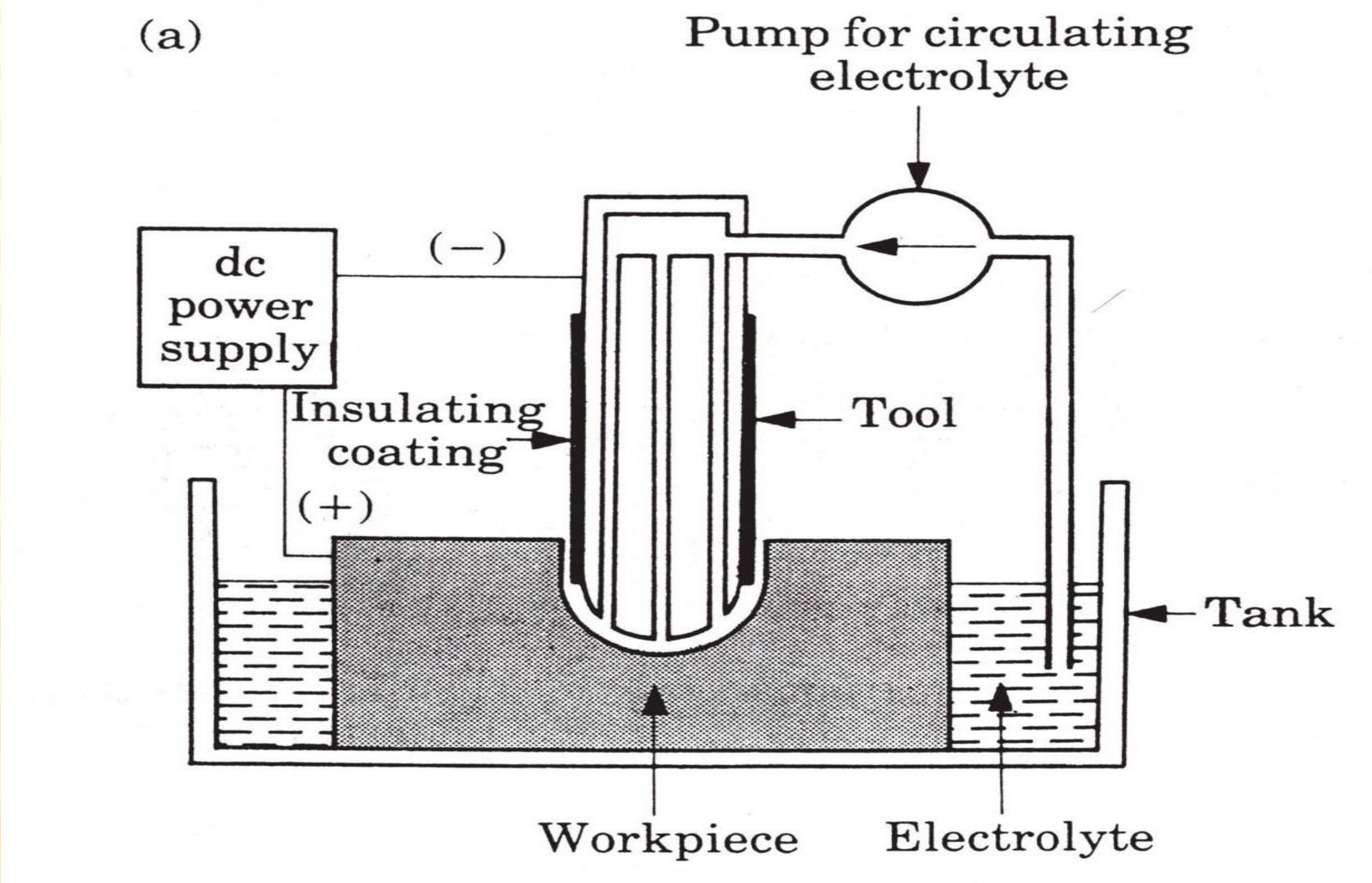


Figure: Schematic basic Principle of Electro chemical Machining (ECM)

ELECTROCHEMICAL MACHINING



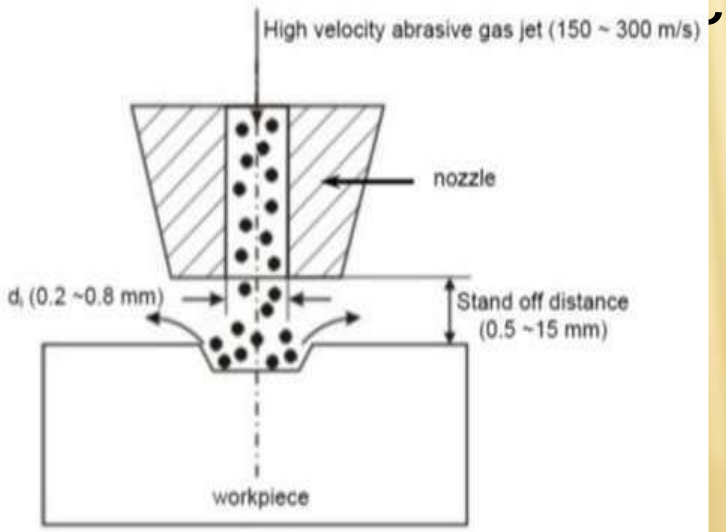
MECHANICAL ENERGY BASED PROCESSES

- Abrasive Jet Machining – Water Jet Machining – Ultrasonic Machining..
- Working Principles – equipment used – Process parameters – Material removal rate- Variation in techniques used – Applications.

PRINCIPLE OF ABRASIVE JET MACHINING

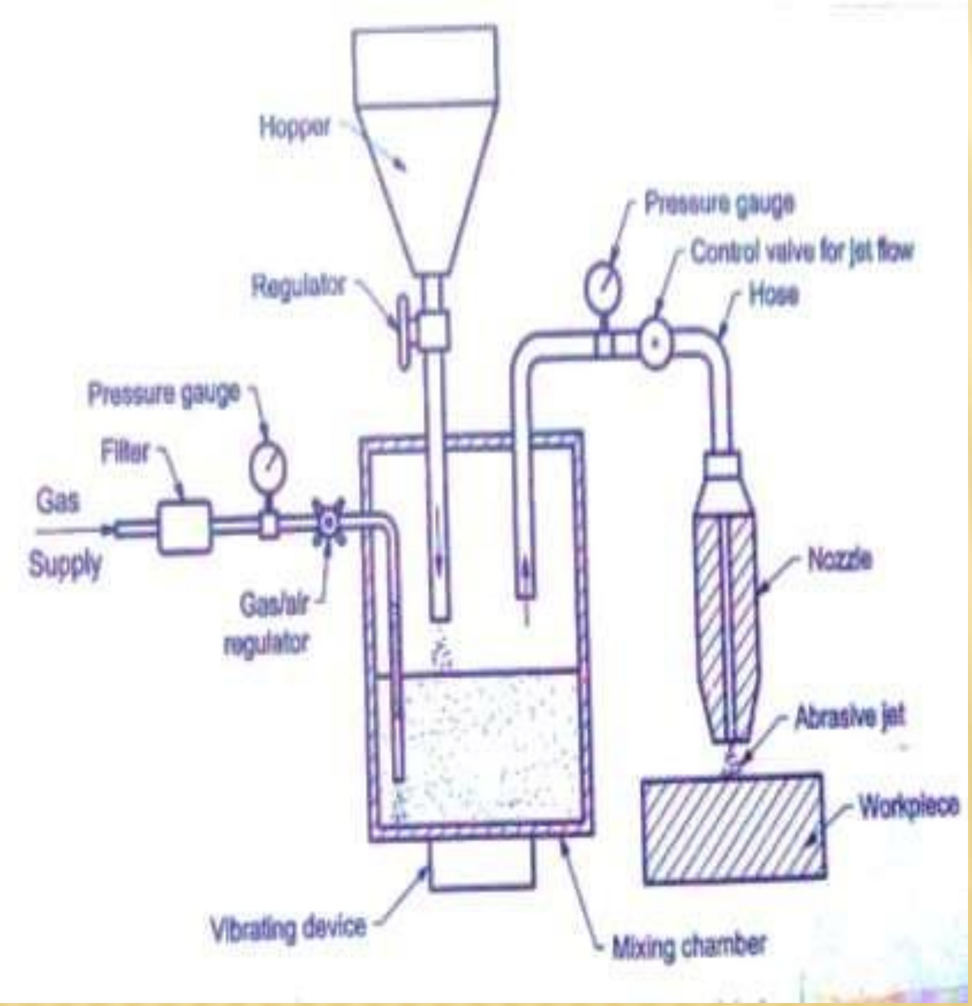
- Principle of AJM :

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



AJM

CONSTRUCTION OF AJM



- It consists of a mixing chamber, nozzle, pressure gauge, hopper, filter, compressor, vibrating device, regulator
- The gases used in this process are Nitrogen, carbon dioxide Or compressed air
- The abrasive particles used in this process are aluminum oxide, silicon carbide, glass powder, dolomite and specially prepared sodium bicarbonate.
- Aluminium oxide is a general purpose abrasive and it is used in the sizes of 10,20,25 micron.
- Silicon carbide is used for fast cutting on extremely hard materials. The size used to 20,25 microns.
- Dolomite of 200 grit size is suitable for light cleaning and etching.
- Glass powder of diameter 0.30 to 0.60mm 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 etc to reduce the wear rate.
- Nozzles made of tungsten carbide have an average life of 12 to 20 hours. Synthetic sapphire nozzle have an average life of 300 hours.
- Nozzle tip clearance from work is kept at a distance of 0.25 to 0.75mm.
- The abrasive powder feed rate is controlled by the amplitude of the vibration of the mixing chamber. A pressure regulator controls the gas or airflow and pressure.
- To control the size and shape of cut, either the workpiece is moved or the nozzle is moved by a well designed cam mechanism

WORKING OF AJM

- Dry air or gas enters the compressor through the filter where the pressure of the gas is increased
- The pressure of the gas is from $2 Kg/cm^2$ to $8 Kg/cm^2$
- Compressed air or high pressure gas is supplied to the mixing chamber through the pipe line. The pipe line carries a regulator to control the air or gas flow and its pressure.
- The fine abrasive particles are fed through the hopper and fed into the mixing chamber. A regulator is provided to control the flow of abrasive particles.
- The mixture of abrasive particles and gas flows through the nozzle at a considerable speed. The mixture flows at a speed of 300m/s.
- 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.

WORKING OF AJM

- Used for machining hard, brittle and non metallic materials of thin sections.
- Examples : Germanium, glass, ceramics and mica.
- This process is capable of drilling, cutting, deburring, etching and cleaning the surfaces.
- AJM differs from sand blasting process. In AJM metal removal with the use of small abrasive particles is done where in sand blasting only surface cleaning is done.

ADVANTAGES OF AJM

- Process is suitable for cutting all materials. Even diamond can be machined using diamond as an abrasive.
- There is no heat generation during this process. Thermal damage of the work piece is avoided.
- Very thin and brittle materials can be cut without any risk of breaking.
- There is no contact between the workpiece and the tool
- Low initial investment
- Good surface finish
- It can be used to cut intricate holes shapes in hard andbrittle materials

DISADVANTAGES OF AJM

- Material removal rate is slow
- Soft material cannot be machined
- Machining accuracy is poor.
- Nozzle wear rate is high
- The abrasive powder used in this process cannot be reused because of decreasing cutting capacity and clogging of the nozzle due to contamination.
- There is always a danger of abrasive particles getting embedded in the workpiece. So cleaning is essential after the operation.
- It requires some kind of dust collection system.

APPLICATIONS OF AJM

- Machining of hard and brittle materials like quartz, ceramics, glass, sapphire
- Fine drilling
- Machining of semi conductors
- Machining of intricate profiles on hard and brittle materials
- Cleaning and polishing of plastics, nylon and components.
- Surface etching and surface preparation
- Frosting of the interior surface of the glass tubes.

CHARACTERISTICS OF AJM

S.No.	Characteristics	Details
1	**Work Material**	**Hard and brittle materials like glass, quartz, ceramics, mica**
2	**Abrasive**	**Aluminum oxide, Silicon Carbide, Glass powder, Dolomite**
3	**Size of Abrasive**	**Around 25µm**
4	**Flow Rate**	**2-20 g/min**
5	**Medium**	**Nitrogen, Carbon dioxide or Air**
6	**Velocity**	**125-300 m/s**
7	**Pressure**	**2 to 10 Kg/cm^2**
8	**Nozzle Material**	**Tungsten Carbide, Synthetic Sapphire**
9	**Life of Nozzle**	**Tungsten Carbide – 12- 20 hours Synthetic Sapphire – 300 hours**
10	**Nozzle tip clearance**	**0.25 to 15 mm**
11	**Tolerance**	**± 0.05 mm**
12	**Machining Operation**	**Drilling, cutting, deburring, cleaning**

MATERIAL REMOVAL RATE(MRR)

- The metal removal rate depends upon the following parameters

  (a) Mass flow rate

  (b) Abrasive grain size

  (c) Gas pressure

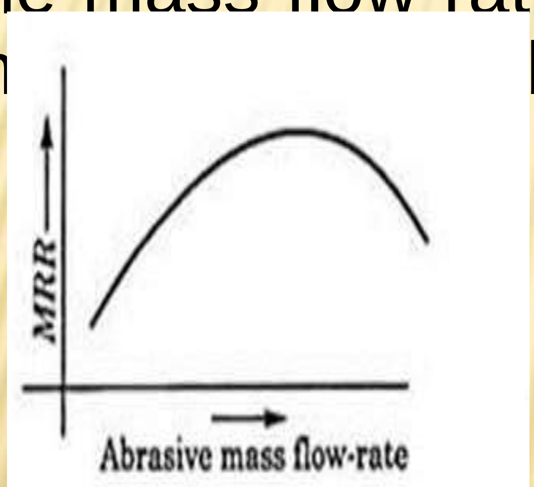
  (d) Velocity of abrasive particles

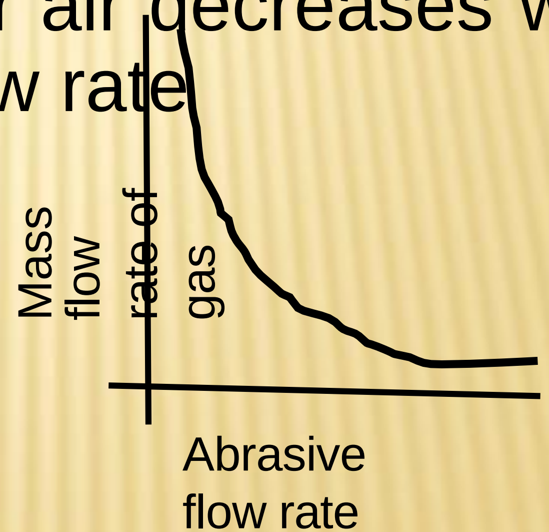
  (e) Mixing ratio

  (f) Nozzle tip Clearance

MATERIAL REMOVAL RATE(MRR)

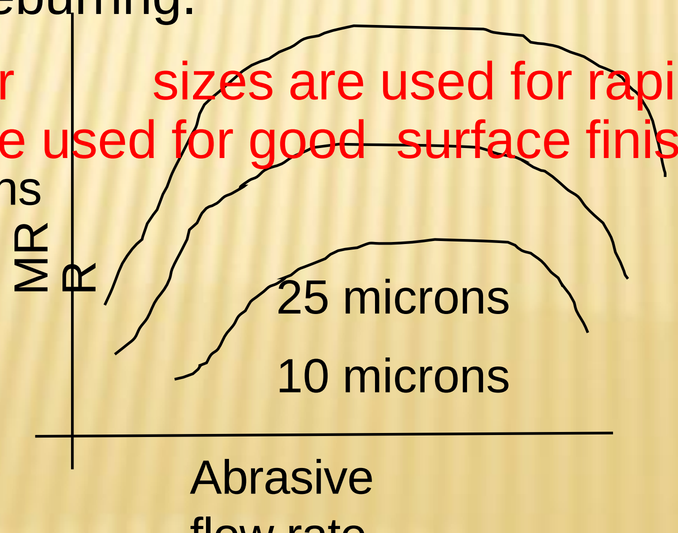
- (a) Mass flow rate : At a particular pressure the material removal rate increases with the abrasive flow rate. But after reaching an optimum value the MRR decreases with further increase in abrasive flow rate. This is because the mass flow rate of gas or air decreases with th brasive flow rate





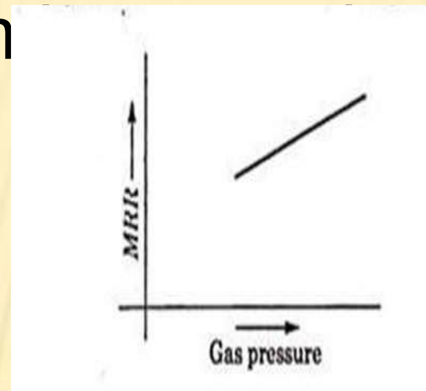
• (b) Abrasive Grain Size :

- ✓ The various abrasive particles used in AJM process are Aluminum oxide, Silicon Carbide, Glass powder, Dolomite and specially prepared sodium bicarbonate.
- ✓ Aluminum oxide is a general purpose abrasive and it is used in the sizes of 10,20,25 micron.
- ✓ Silicon carbide is used for fast cutting on extremely hard materials. The size used to 20,25 microns.
- ✓ Dolomite of 200 grit size is suitable for light cleaning and etching.
- ✓ Glass powder of diameter 0.30 to 0.60mm 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

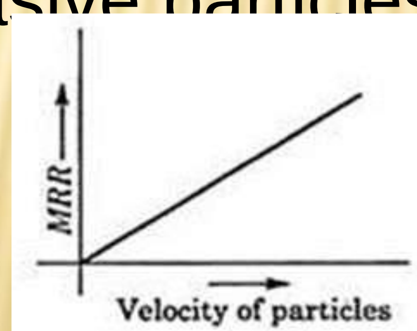


MATERIAL REMOVAL RATE(MRR)

- (c) Gas pressure : The metal removal rate increases with gas or air pressure.



- (d) Velocity of abrasive particles : The metal removal rate increases with the increase in velocity of abrasive particles

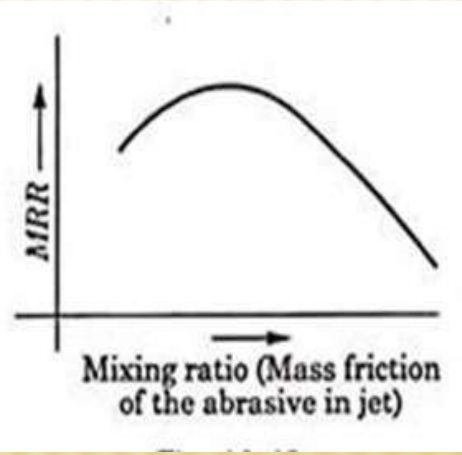


MATERIAL REMOVAL RATE(MRR)

- (e) Mixing Ratio : Mixing ratio is defined as the ratio of mass flow rate of abrasive to the mass flow rate of the gas

$$\text{Mixing ratio} = \frac{\text{Mass flow rate of abrasive}}{\text{Mass flow rate of gas}}$$

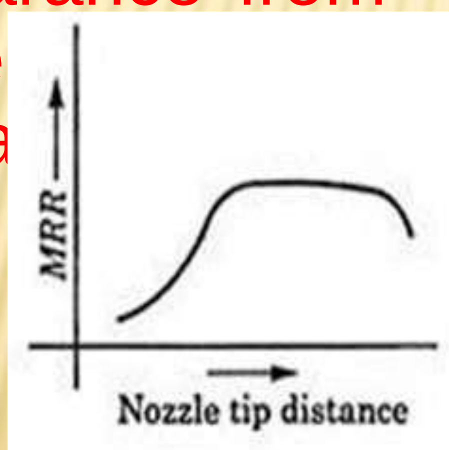
✓Metal removal rate first increases with the increase of mixing ratio upto certain limit after that it decreases gradually as shown in the fig

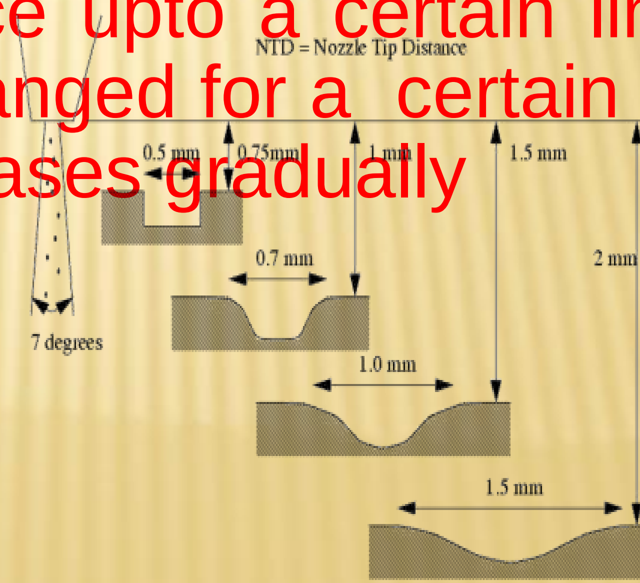


MATERIAL REMOVAL RATE(MRR)

- (f) Nozzle tip clearance or Stand off distance : The distance between the nozzle tip and the workpiece has great influence on the diameter of cut, its shape and size and also on the rate of MRR

✓The MRR first increases with the increase of tip clearance from workpiece upto a certain limit afte ... ns unchanged for a certain tip clea ... en decreases gradually





WATER JET MACHINING

INTRODUCTION

- Key element in WJM is a jet of water.
- Water jet travels at velocities as high as 900 m/s

  (approximately Mach 3).
- When the water stream strikes a work piece surface, the erosive force

of water removes the material rapidly.

- The water, in this case, acts like a saw and cuts a narrow

  groove in the work piece material.
- True cold cutting process – no HAZ (Heat Affected Zones),

  mechanical stresses or operator and environmental hazards

PRINCIPLE

- The water jet machining involves directing a high pressure (150-1000 MPa) high velocity (540-1400 m/s) water jet (faster than the speed of sound) to the surface to be machined. The fluid flow rate is typically from 0.5 to 2.5 l/min
- The kinetic energy of water jet after striking the work surface is reduced to zero.
- The bulk of kinetic energy of jet is converted into pressure energy.
- If the local pressure caused by the water jet exceeds the strength of the surface being machined, the material from the surface gets eroded and a cavity is thus formed.
- Water is the most common fluid used, but additives such as alcohols, oil products and glycerol are added when they can be dissolved in water to improve the fluid

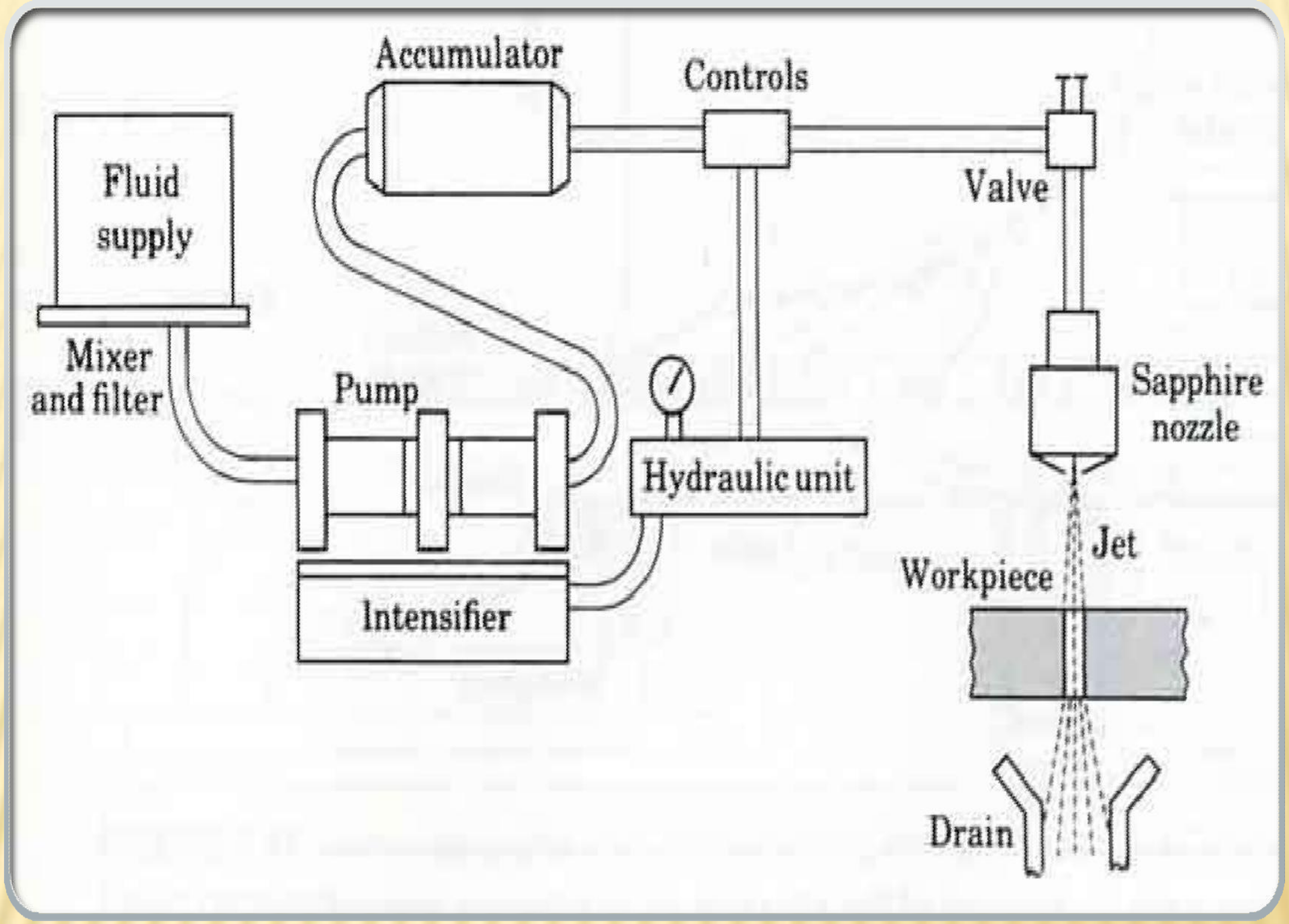
PROCESSES

EQUIPMENT

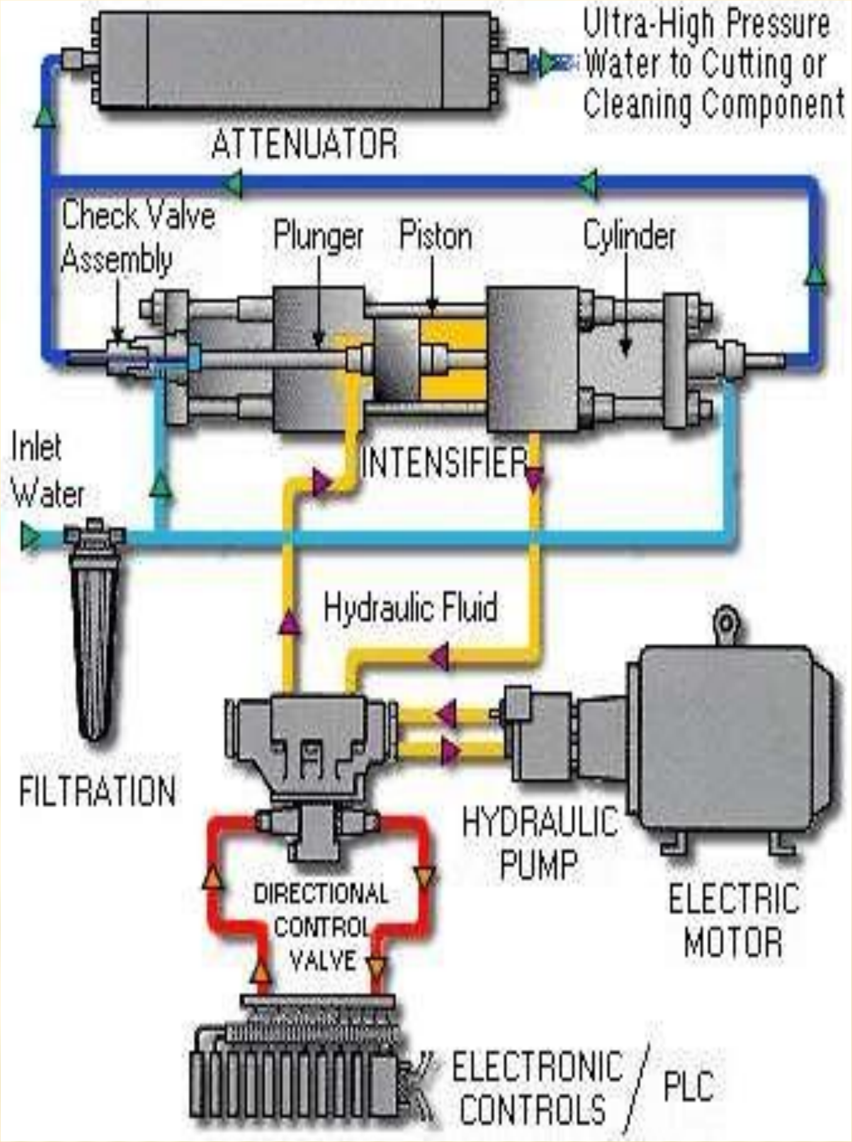
Typical work materials involve soft metals, paper, cloth, wood, leather, rubber, plastics, and frozen food. If the work material is brittle it will fracture, if it is ductile, it will cut well .

Water jet Machining consists of:

- Hydraulic Pump
- Intensifier
- Accumulator
- High Pressure Tubing
- Jet Cutting Nozzle
- Catcher



SCHEMATIC LAYOUT OF WJM



WATER PUMPING

HYDRAULIC PUMP

- Powered from a 30 kilowatt (kW) electric motor
- Supplies oil at pressures as high as 117 bars.
- Compressed oil drives a reciprocating plunger pump termed an

intensifier.

- The hydraulic pump offers complete flexibility for water jet cutting and cleaning applications.
- It also supports single or multiple cutting stations for increased machining productivity.

INTENSIFIER

- Accepts the water at low pressure(typically 4 bar) and expels it, through an accumulator,

at higher pressures of 3800 bar.

- The intensifier converts the energy from the low-pressure hydraulic fluid into ultrahigh- pressure water.
- The hydraulic system provides fluid power to a reciprocating piston in the intensifier

center section.

- A limit switch, located at each end of the piston travel, signals the electronic controls to shift the directional control valve and reverses the piston direction.
- The intensifier assembly, with a plunger on each side of the piston, generates pressure in both directions.
- As one side of the intensifier is in the inlet stroke, the opposite side is generating ultrahigh-pressure output.
- During the plunger inlet stroke, filtered water enters the high- pressure cylinder through the check value assembly

ACCUMULATOR

- Maintains the continuous flow of the high-pressure water and eliminates

pressure fluctuations.

- It relies on the compressibility of water (12 percent at 3800 bar) in order to maintain a uniform discharge pressure and water jet velocity, when the intensifier piston changes its direction.

HIGH PRESSURE TUBING

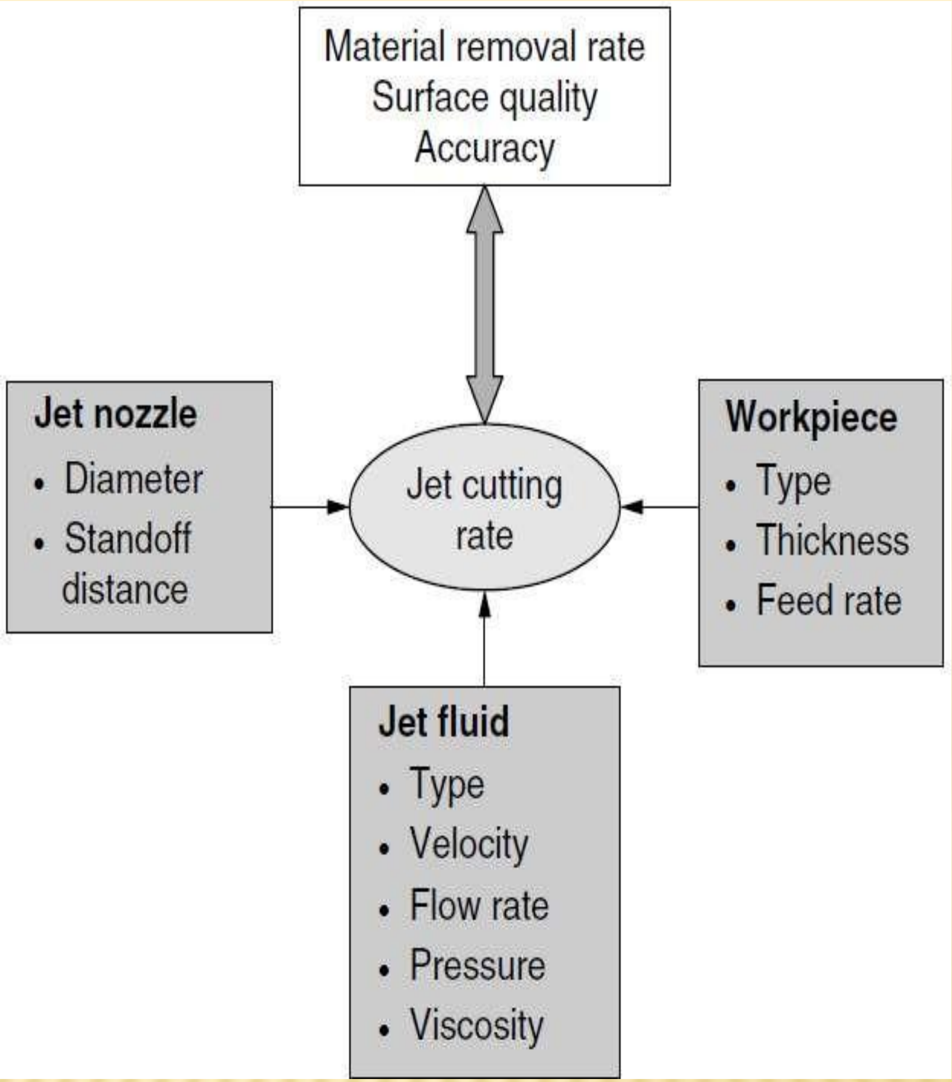
- Transports pressurized water to the cutting head.
- Typical tube diameters are 6 to 14 mm.
- The equipment allows for flexible movement of the cutting head.
- The cutting action is controlled either manually or through a remote- control valve specially designed for this purpose.

JET CUTTING NOZZLE

- Nozzle provides a coherent water jet stream for optimum cutting of low- density, soft material that is considered unmachinable by conventional methods.
- Nozzles are normally made from synthetic sapphire.
- About 200 h of operation are expected from a nozzle, which becomes damaged by particles of dirt and the accumulation of mineral deposits on the orifice due to erosive water hardness.
- A longer nozzle life can be obtained through multistage filtration, which removes undesired solids of size greater than 0.45 μm.
- The compact design of the water jet cutting head promotes integration with motion control systems ranging from two-axis (*XY) tables to sophisticated multiaxis* robotic installations.

CATCHER

- Acts as a reservoir for collecting the machining debris entrained in the water jet.
- Moreover, it reduces the noise levels [105 decibels (dB)] associated with the reduction in the velocity of the water jet from Mach 3 to subsonic levels.

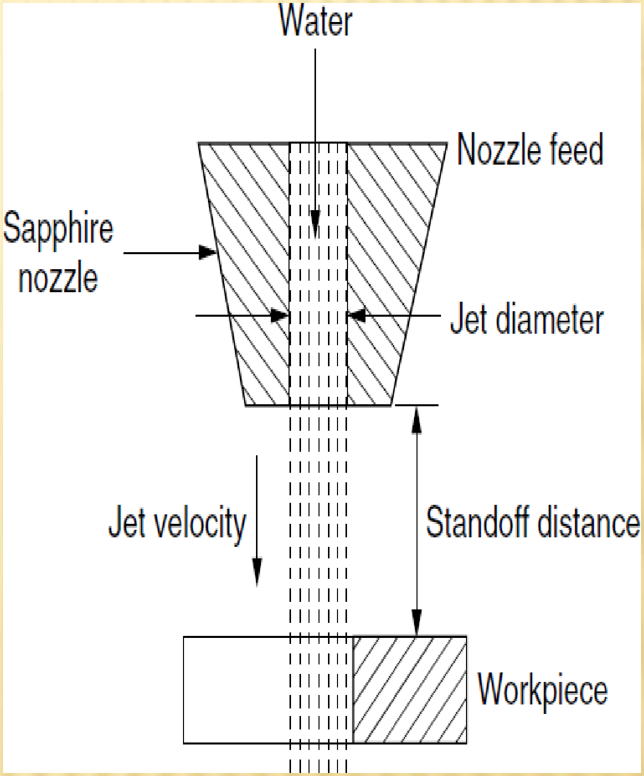


PARAMETERS AFFECTING THE PERFORMANCE OF WJM

PROCESS PARAMETERS

JET NOZZLE

- Standoff distance - Gap between the jet nozzle (0.1–0.3 mm diameter) and the workpiece (2.5 – 6 mm).
- However for materials used in printed circuit boards, it may be increased to 13 to 19 mm.
- But larger the standoff distance, smaller
would be the depth of cut.
- When cutting fiber-reinforced plastics, reports showed that the increase in machining rate and



JET FLUID

- Typical pressures used are 150 to 1000 MPa to provide 8 to 80 kW of power.
- For a given nozzle diameter, increase in pressure allows more power to be used in the machining process, which in turn increases the depth of the cut.
- Jet velocities range between 540 to 1400 m/s.
- The quality of cutting improves at higher pressures by widening the diameter of the jet and by lowering the traverse speed.
- Under such conditions, materials of greater thicknesses and densities can

be cut.

- Moreover, the larger the pump pressure, the greater will be

WORKPIECE

- Brittle materials will fracture, while ductile ones will cut well.
- Material thicknesses range from 0.8 to 25 mm or more.
- Table below shows the cutting rates for different material

Material	Thickness, mm	Feed rate, m/min
Leather	2.2	20
Vinyl chloride	3.0	0.5
Polyester	2.0	150
Kevlar	3.0	3
Graphite	2.3	5
Gypsum board	10	6
Corrugated board	7	200
Pulp sheet	2	120
Plywood	6	1

APPLICATIONS

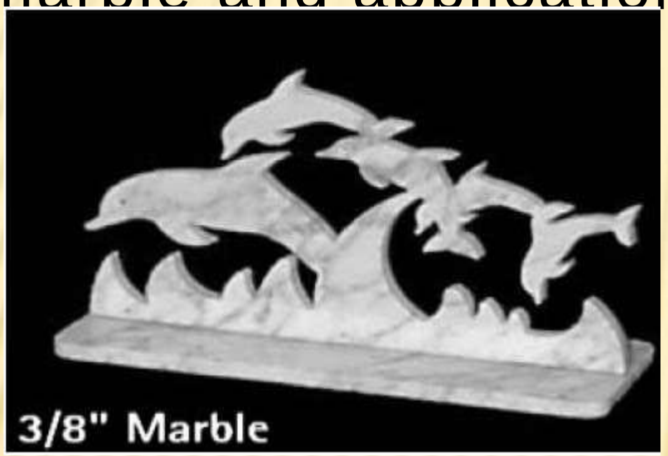
- WJM is used on metals, paper, cloth, leather, rubber, plastics, food, and ceramics.
- It is a versatile and cost-effective cutting process that can be used as an alternative to

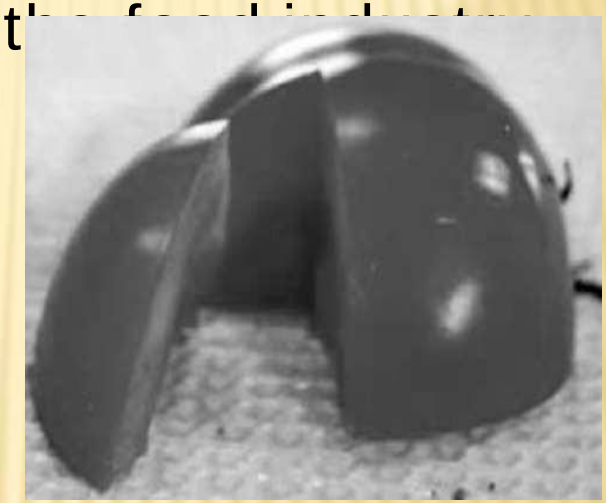
traditional machining methods.

- It completely eliminates heat-affected zones, toxic fumes, recast layers, work hardening and thermal stresses.
- It is the most flexible and effective cleaning solution available for a variety of industrial needs.
- In general the cut surface has a sandblast appearance.
- Moreover, harder materials exhibit a better edge finish.
- Typical surface finishes ranges from 1.6 μm root mean square (RMS) to very coarse depending on the application.
- Tolerances are in the range of ± 25 μm on thin material.

CUTTING

- WJMis limited to fibreglass and corrugated wood.
- Figure shows typical example of water jet cutting of water jet cutting
  marble and application in t





DRILLING

The process drills precision-angled and -shaped holes in a variety of materials for which other processes such as EDM or EBM are too expensive or too slow.

MACHINING OF FIBER-REINFORCED PLASTICS

- In this case the thermal material damage is negligible.
- The tool, being effectively pointed, accurately cuts any contours.
- The main drawback is the deflection of the water jet by the fiber embedded in the matrix, which protrudes after machining.
- The feed rate attainable depends on the surface quality required.
- Table below gives the limiting feed rates for water jet cutting of fiber-reinforced plastics.

Material	Thickness, mm	Feed rate, m/min
Glass fiber-reinforced	2.2	1.8–6.0
polymers (GFRP) (laminate)	3.0	1.4–5.0
	5.0	0.7–6.0
Aramid fiber-reinforced	1.0	10.0
polymers (AFRP) (weave)	2.0	2.4–4.0

CUTTING OF ROCKS

- Water jet cutting of a 51 mm deep slot in granite using two oscillating jets at 275 MPa during 14 passes at a 25.4 mm/s feed rate has been reported by McGeough (1988).
- Moreover an oscillating nozzle system operating at the same feed rate and pressure of 172 MPa, with the standoff distance adjusted every pass was used to cut a 178 mm deep slot in sandstone.

DEBURRING

- The method uses large pressures to remove large burrs (3 mm height) in 12 mm diameter drilled holes in a hollow molybdenum-chromium steel shaft at 15 s using 700 bar pressure and a flow rate of 27 L/min.
- In this method burrs are broken off by the impact of water.
- A higher pressure (4000 bar) and a lower flow rate (2.5 L/min) are used to remove burrs from nonmetallic materials.

CUTTING OF PCBS

- Using a small-diameter water jet, a printed circuit board (PCB) can be cut at a speed that exceeds 8 m/min, to the accuracy of ± 0.13 mm.
- Boards of various shapes for use in portable radios and cassette players can be cut using computer numerical control (CNC) technology.

SURFACE TREATMENT

- Removing deposits and residues without toxic chemicals, which eliminates costly cleanup and disposal problems.
- Surface cleaning of pipes and castings, decorative finishing, nuclear decontamination, food utensil cleaning, degreasing, polishing, preparation for precise inspection, and surface texturing.
- Economical surface preparation and coating removal.

WIRE STRIPPING

- Can remove the wire insulating material without damaging the metal or removing the tinning on the copper wire.
- Processing time can be decreased to about 20 % of the manual stripping method.



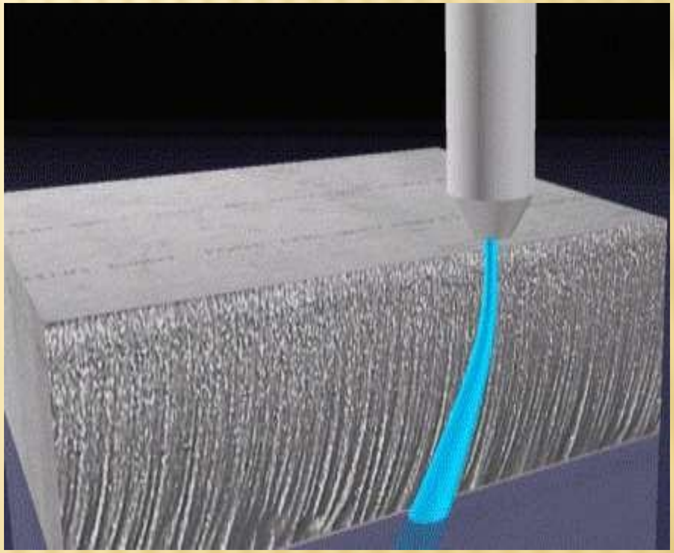
ADVANTAGES

- It has multidirectional cutting capacity.
- No heat is produced.
- Cuts can be started at any location without the need for predrilled holes.
- Wetting of the workpiece material is minimal.
- There is no deflection to the rest of the workpiece.
- The burr produced is minimal.
- The tool does not wear and, therefore, does not need sharpening.
- The process is environmentally safe.
- Hazardous airborne dust contamination and waste disposal problems that are common when using other cleaning methods are eliminated.
- There is multiple head processing.
- Simple fixturing eliminates costly and complicated tooling, which reduces turnaround time and lowers the cost.
- Grinding and polishing are eliminated, reducing secondary operation costs.

- The narrow kerf allows tight nesting when multiple parts are cut from a single blank.
- It is ideal for roughing out material for near net shape.
- It is ideal for laser reflective materials such as copper and aluminum.
- It allows for more accurate cutting of soft material.

- erythick parts can not be cut with water jet cutting and still hold dimensional accuracy. If the part is too thick, the jet may

dissipate some, and cause it to cut on a diagonal, or to have a wider cut at the bottom of the part than the top. It can also cause a rough wave pattern on the cut surface.



WATER JET LAG

- It is not suitable for mass production because of high maintenance requirements.

ELECTRICAL DISCHARGE MACHINING (EDM)

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INTRODUCTION

- Sometimes it is referred to as **spark machining**, **spark eroding**, **burning**, **die sinking** or **wire erosion**
- Its a manufacturing process whereby a desired shape is obtained using electrical discharges (sparks).
- Material is removed from the workpiece by a series of rapidly recurring current discharges between two electrodes, separated by a dielectric liquid and subject to an electric voltage.
- One of the electrodes – ‘tool-electrode’ or ‘tool’ or ‘electrode’. Other
- electrode - workpiece-electrode or ‘workpiece’.
- As distance between the two electrodes is reduced, the current intensity becomes greater than the strength of the dielectric (at least in some points) causing it to break.

HISTORY

- This allows current to flow between the two electrodes.
- This phenomenon is the same as the breakdown of a capacitor. As a result,
- material is removed from both the electrodes.
- Once the current flow stops, new liquid dielectric is usually conveyed into the electrode zone enabling the solid particles (debris) to be carried away.
- Adding new liquid dielectric in the electrode volume is commonly referred to as flushing.
- Also, after a current flow, a difference of potential between the two electrodes is restored to what it was before the breakdown, so that a new liquid dielectric breakdown can occur.

HISTORY

- In 1770, English Physicist Joseph Priestley studied the erosive effect of electrical discharges.
- Furthering Priestley's research, the EDM process was invented by two Russian scientists, Dr. B.R. Lazarenko and Dr. N.I. Lazarenko in 1943.
- In their efforts to exploit the destructive effects of an electrical discharge, they developed a controlled process for machining of metals.
- Their initial process used a spark machining process, named after the succession of sparks (electrical discharges) that took place between two electrical conductors immersed in a dielectric fluid.
- The discharge generator effect used by this machine, known as the Lazarenko Circuit, was used for many years in the construction of generators for electrical discharge.

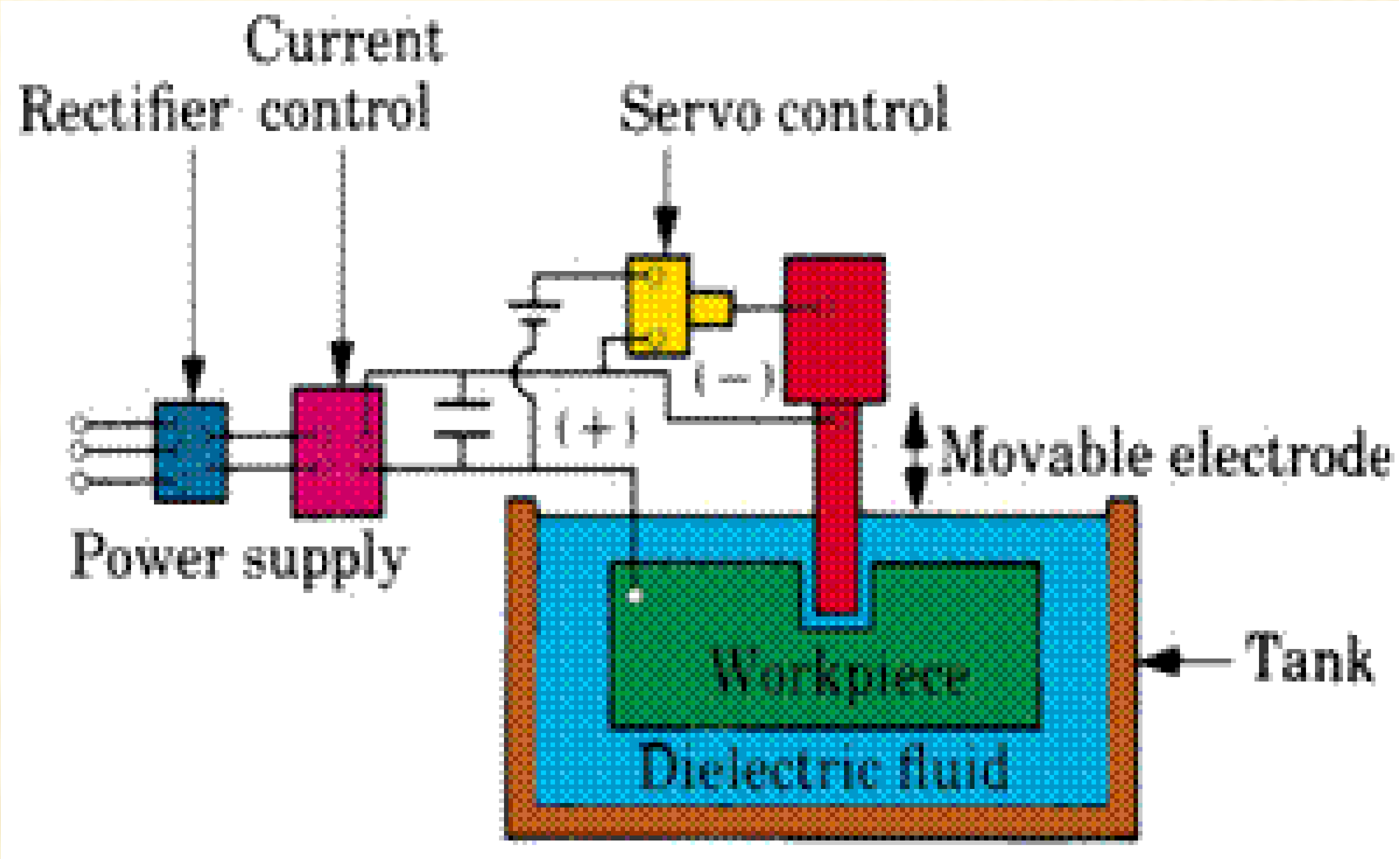
HISTORY

- New researchers entered the field and contributed many fundamental characteristics of the machining method we know today.
- In 1952, the manufacturer Charmilles created the first machine using the spark machining process and was presented for the first time at the European Machine Tool Exhibition in 1955.
- In 1969, Agie launched the world's first numerically controlled wire-cut EDM machine.
- Seibu developed the first CNC wire EDM machine in 1972 and the first system was manufactured in Japan.
- Recently, the machining speed has gone up by 20 times.
- This has decreased machining costs by at least 30 percent and improved the surface finish by a factor of 1.5

GENERAL ASPECTS OF EDM

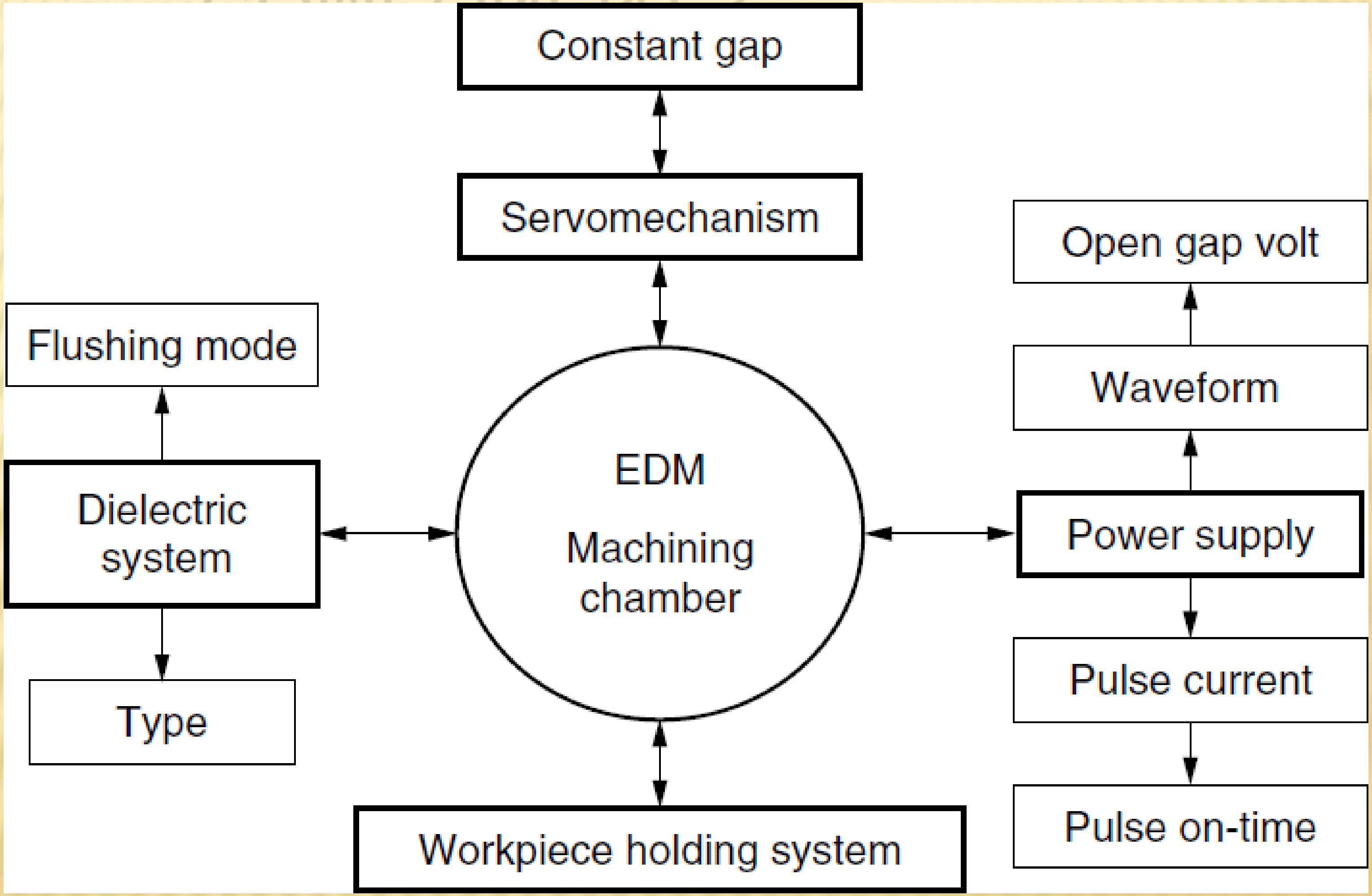
- EDM is a machining method primarily used for hard metals or those that would be very difficult to machine with traditional techniques.
- EDM typically works with materials that are electrically conductive, although methods for machining insulating ceramics with EDM have been proposed.
- EDM can cut intricate contours or cavities in hardened steel without the need for heat treatment to soften and re-harden them.
- This method can be used with any other metal or metal alloy such as titanium, hastelloy, kovar, and inconel.
- Also, applications of this process to shape polycrystalline diamond tools have been reported.

EDM - SYSTEM



Current
Rectifier control
Servo control
(−)
(+)
Movable electrode
Power supply
Workpiece
Tank
Dielectric fluid

EDM - COMPONENTS



EDM - COMPONENTS

- The main components in EDM:
  - Electric power supply
  - Dielectric medium
  - Work piece & tool
  - Servo control unit.
- The work piece and tool are electrically connected to a DC power supply.
- The current density in the discharge of the channel is of the order of 10000 A/cm^2 and power density is nearly 500 MW/cm^2.
- A gap, known as SPARK GAP in the range, from 0.005 mm to 0.05 mm is maintained between the work piece and the tool.
- Dielectric slurry is forced through this gap at a pressure of 2 kgf/cm^2 or lesser.

EDM – WORKING PRINCIPLE

- It is a process of metal removal based on the principle of material removal by an interrupted electric spark discharge between the electrode tool and the work piece.
- In EDM, a potential difference is applied between the tool and workpiece.
- Essential - Both tool and work material are to be conductors.
- The tool and work material are immersed in a dielectric medium. Generally
- kerosene or deionised water is used as the dielectric medium. A gap is
- maintained between the tool and the workpiece.
- Depending upon the applied potential difference (50 to 450 V) and the gap between the tool and workpiece, an electric field would be established.
- Generally the tool is connected to the negative terminal (cathode) of the generator and the workpiece is connected to positive terminal (anode).

EDM – WORKING PRINCIPLE

- 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 bonding energy of the electrons is less, electrons would be emitted from the tool.
- Such emission of electrons are called or termed as '**cold emission'**.
- The "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 ionization of the dielectric molecule.
- Ionization depends on the ionization energy of the dielectric molecule and the energy of the electron.

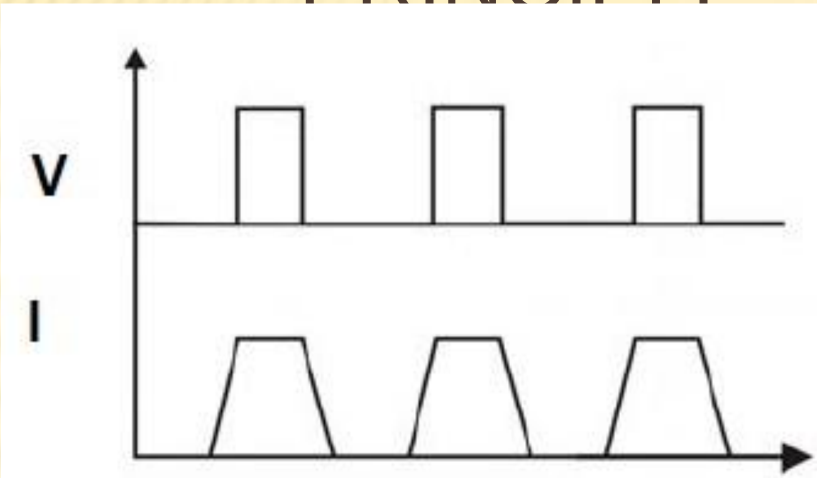
EDM – WORKING PRINCIPLE

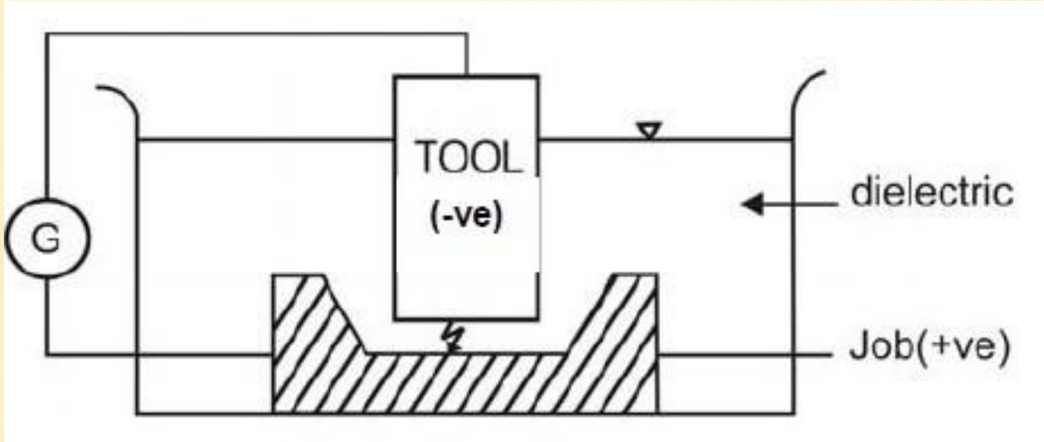
- As the electrons get accelerated, more positive ions and electrons would get generated due to collisions.
- This cyclic process would increase the concentration of electrons and ions in the dielectric medium between the tool and the job at the spark gap.
- The concentration would be so high that the matter existing in that channel could be characterised as "plasma".
- The electrical resistance of such plasma channel would be very less.
- Thus all of a sudden, a large number of electrons will flow from tool to job and ions from job to tool.
- This is called avalanche motion of electrons.
- 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.

EDM – WORKING PRINCIPLE

- The high speed electrons then impinge on the job and ions on the tool.
- The 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 localized heat flux leads to extreme instantaneous confined rise in temperature which would be in excess of 10,000^{o}C.
- Such localized extreme rise in temperature leads to material removal.
- Material removal occurs due to instant vaporization of the material as well as due to melting.
- The molten metal is not removed completely but only partially.

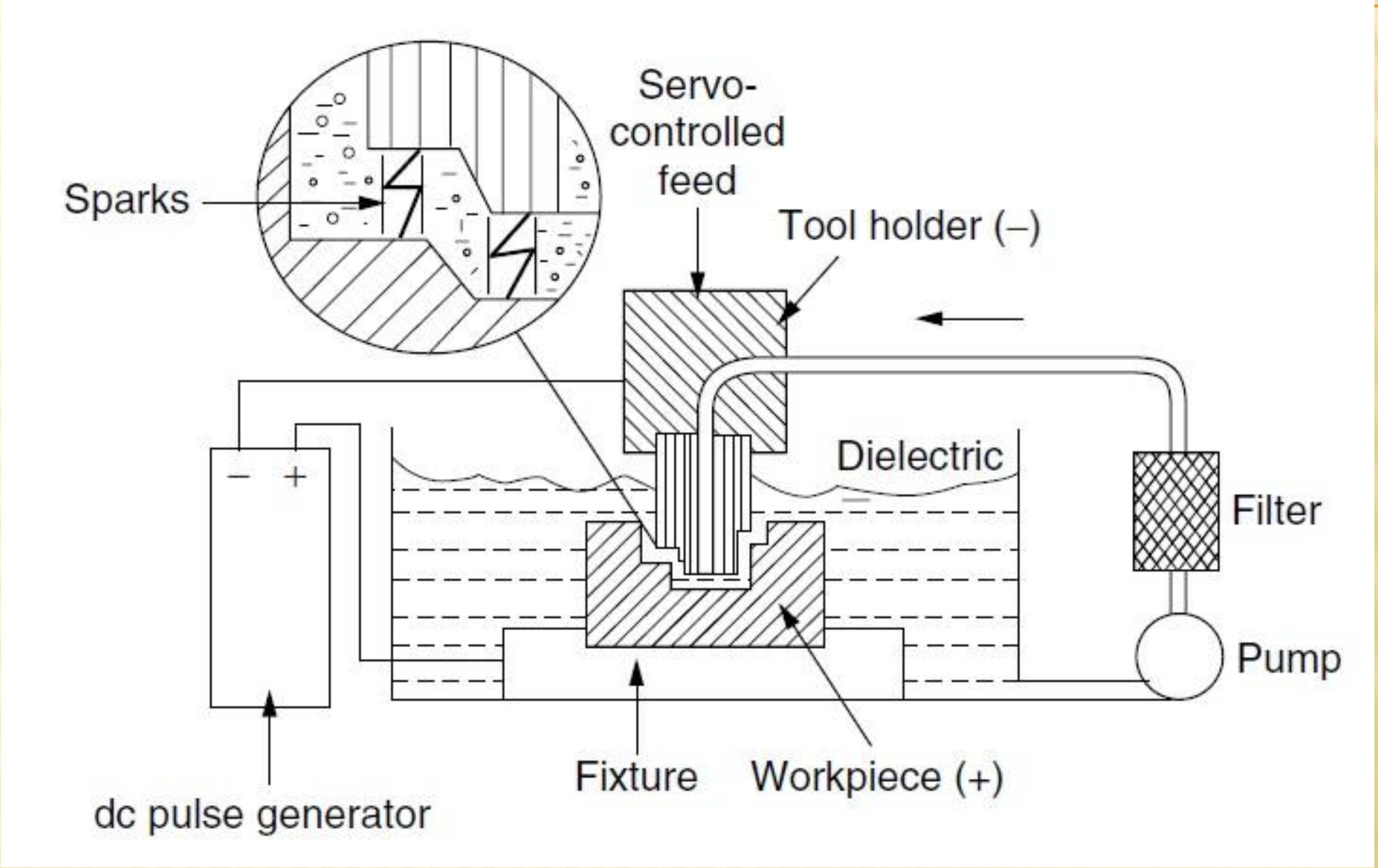
EDM – WORKING PRINCIPLE





- Upon withdrawal of potential difference, plasma channel collapses.
- This ultimately creates compression shock waves on both the electrode surface.
- Particularly at high spots on work piece surface, which are closest to the tool.
- This evacuates molten material and forms a crater around the site of the spark.
- The whole sequence of operation occurs within a few microseconds.

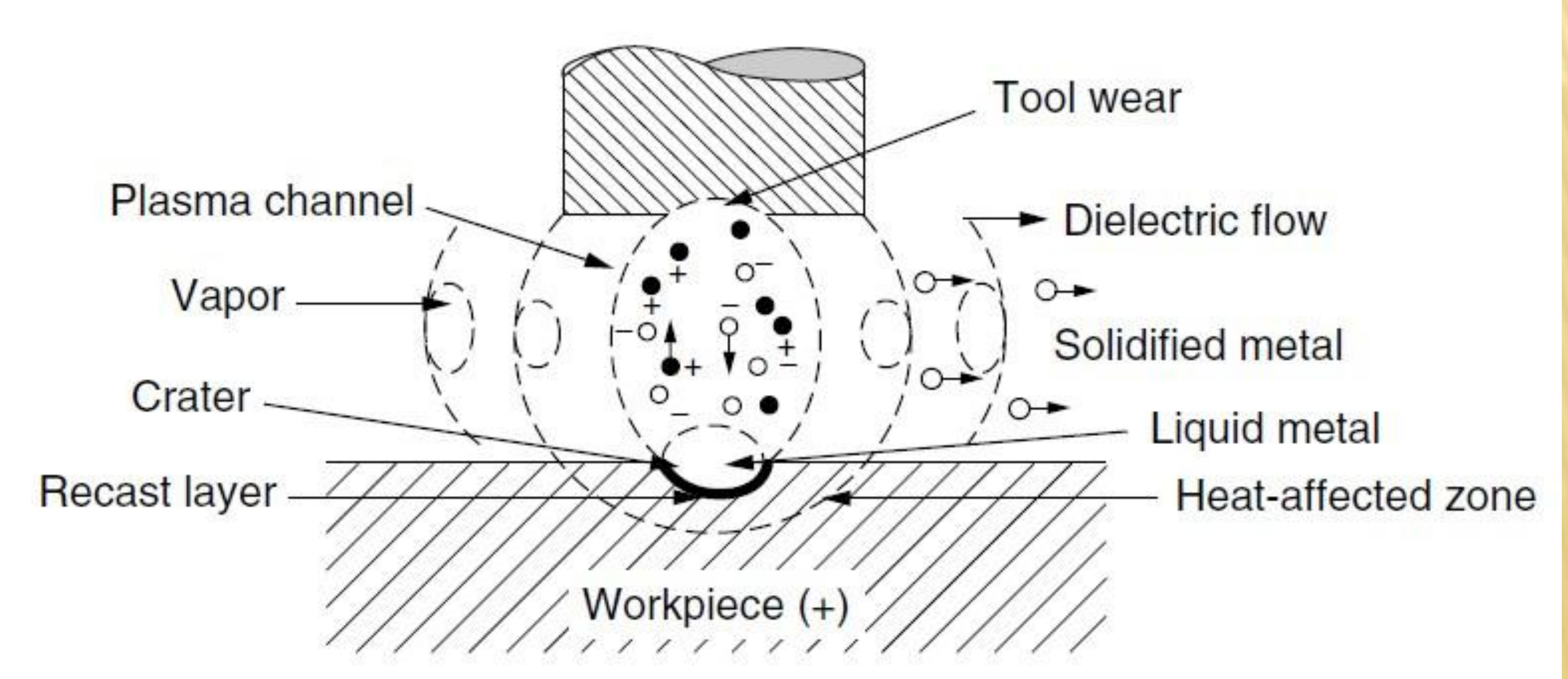
EDM – SCHEMATIC



EDM – WORKING PRINCIPLE

- Thus to summarise, the material removal in EDM mainly occurs due to formation of shock waves as the plasma channel collapse owing to discontinuation of applied potential difference
- Generally the workpiece is made positive and the tool negative.
- Hence, the electrons strike the job leading to crater formation due to high temperature and melting and material removal.
- Similarly, the positive ions impinge on the tool leading to tool wear.
- In EDM, the generator is used to apply voltage pulses between the tool and job.
- A constant voltage is not applied. Only sparking is desired rather than arcing.
- Arcing leads to localized material removal at a particular point whereas sparks get distributed all over the tool surface leading to uniform material removal.

EDM – WORKING PRINCIPLE



EDM spark description.

EDM – POWER & CONTROL CIRCUITS

- Two broad categories of generators (power supplies) are in use on EDM.
- Commercially available: RC circuits based and transistor controlled pulses.
- In the first category, the main parameters to choose from at setup time are the resistance(s) of the resistor(s) and the capacitance(s) of the capacitor(s).
- In an ideal condition, these quantities would affect the maximum current delivered in a discharge.
- Current delivery in a discharge is associated with the charge accumulated on the capacitors at a certain moment.
- Little control is expected over the time of discharge, which is likely to depend on the actual spark-gap conditions.
- Advantage: RC circuit generator can allow the use of short discharge time more easily than the pulse-controlled generator.

EDM – POWER & CONTROL CIRCUITS

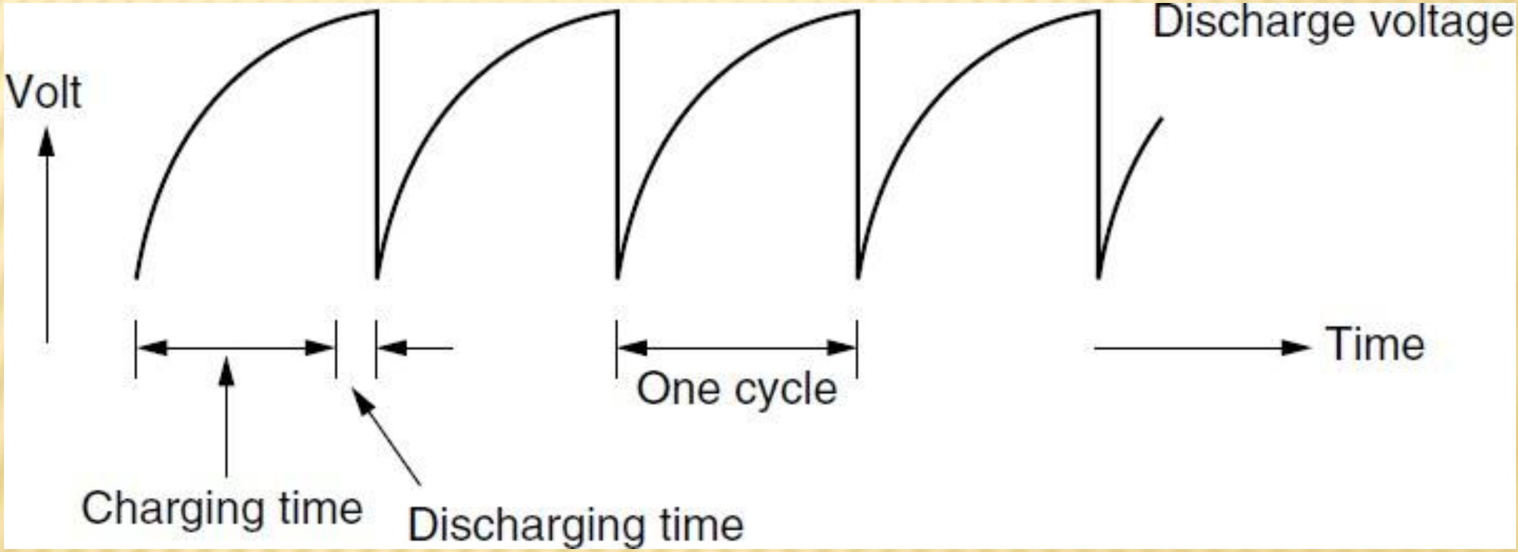
- Also, the open circuit voltage (i.e. voltage between electrodes when dielectric is not broken) can be identified as steady state voltage of the RC circuit.
- In generators based on transistor control, the user is usually able to deliver a train of voltage pulses to the electrodes.
- Each pulse can be controlled in shape, for instance, quasi-rectangular.
- In particular, the time between two consecutive pulses and the duration of each pulse can be set.
- The amplitude of each pulse constitutes the open circuit voltage.
- Thus, maximum duration of discharge is equal to duration of a voltage pulse.
- Maximum current during a discharge that the generator delivers can also be controlled.

EDM – POWER & CONTROL CIRCUITS

- Details of generators and control systems on EDMs are not always easily available to their user.
- This is a barrier to describing the technological parameters of EDM process.
- Moreover, the parameters affecting the phenomena occurring between tool and electrode are also related to the motion controller of the electrodes.
- A framework to define and measure the electrical parameters during an EDM operation directly on inter-electrode volume with an oscilloscope external to the machine has been recently proposed by Ferri *et al.*
- This would enable the user to estimate directly the electrical parameter that affect their operations without relying upon machine manufacturer's claims.
- When machining different materials in the same setup conditions, the actual electrical parameters are significantly different.

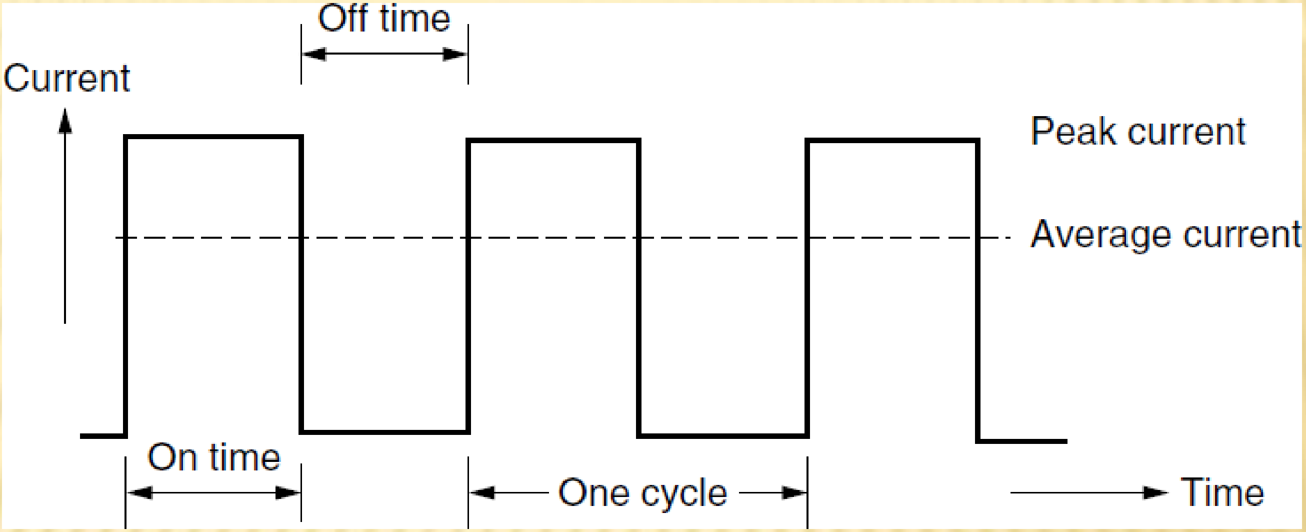
EDM – POWER & CONTROL CIRCUITS

- When using RC generators, the voltage pulses, shown in Fig. are responsible for material removal.
- A series of voltage pulses (Fig.) of magnitude about 20 to 120 V and frequency on the order of 5 kHz is applied between the two electrodes.



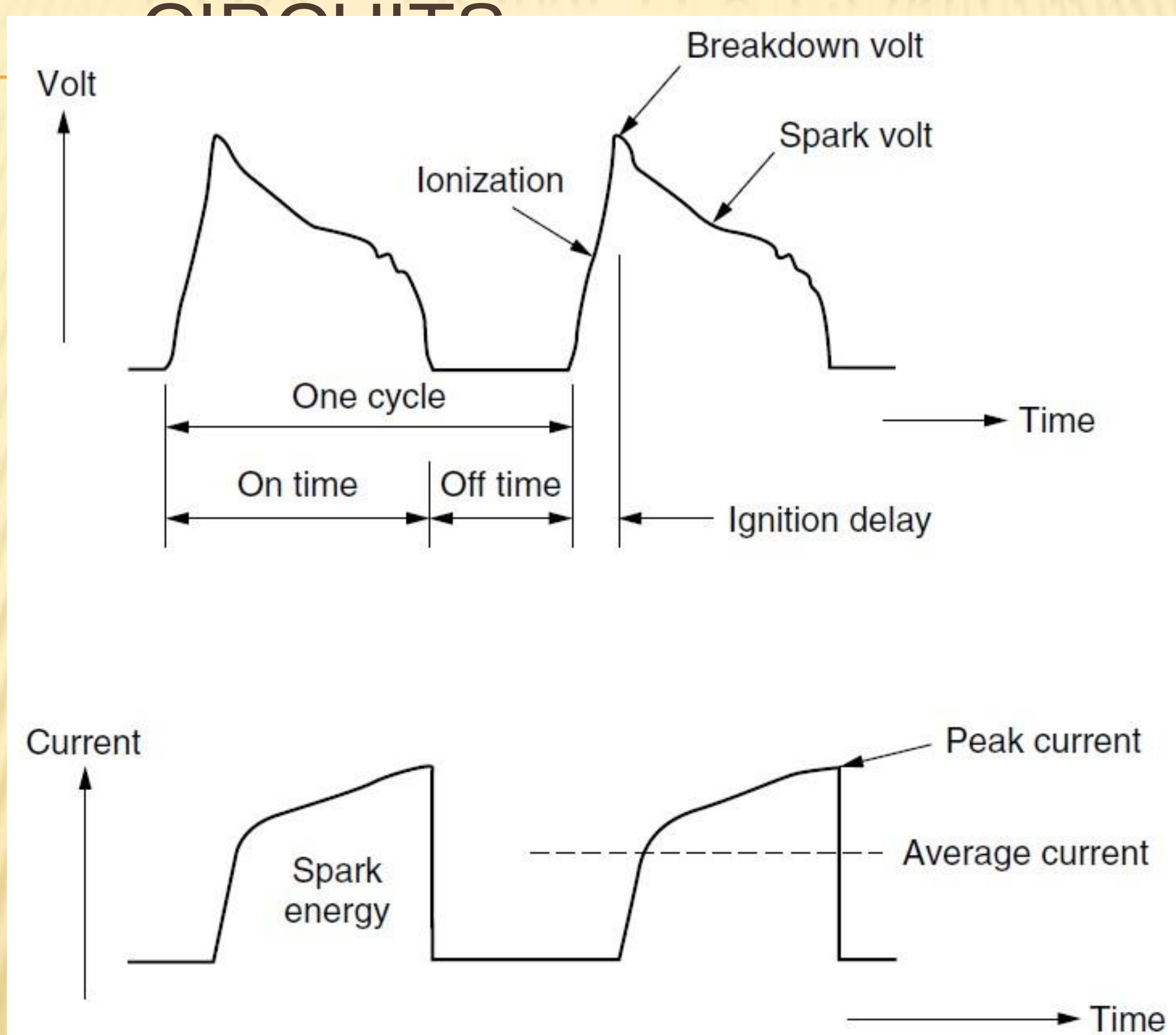
Variation of voltage with time using an RC generator.

EDM – POWER & CONTROL CIRCUITS



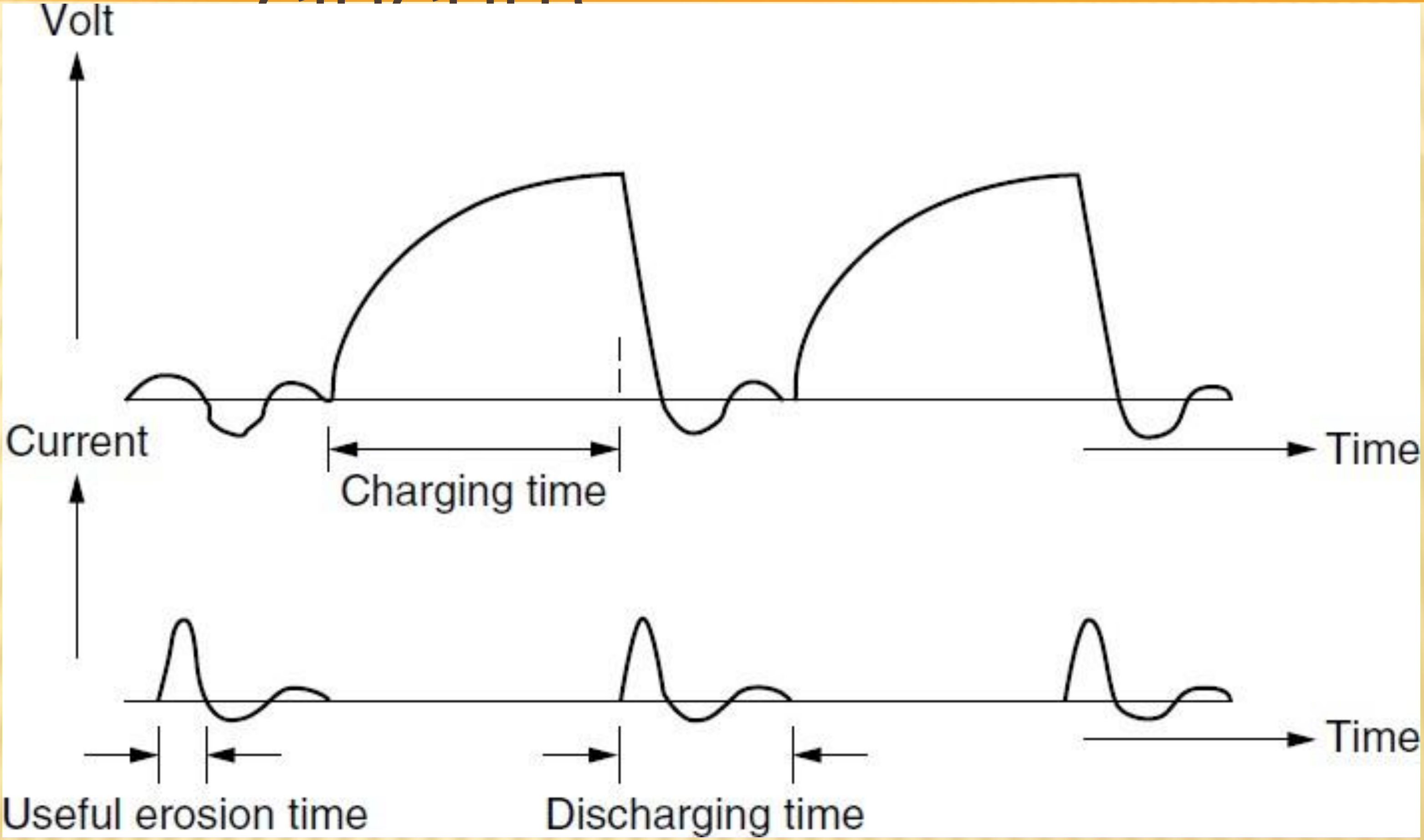
Typical EDM pulse current train for controlled pulse generator.

EDM – POWER & CONTROL CIRCUITS



Voltage and current waveforms during EDM.

EDM – POWER & CONTROL CIRCUITS



Periodic discharges in RC-type generator.

EDM – ELECTRODE MATERIAL

- Electrode material should be such that it would not undergo much tool wear when it is impinged by positive ions.
- Thus the localised temperature rise has to be less by properly choosing its properties or even when temperature increases, there would be less melting.
- Further, the tool should be easily workable as intricate shaped geometric features are machined in EDM.
- Thus the basic characteristics of electrode materials are:
  - High electrical conductivity – electrons are cold emitted more easily and there is less bulk electrical heating
  - High thermal conductivity – for the same heat load, the local temperature rise would be less due to faster heat conducted to the bulk of the tool and thus less tool wear.

EDM – ELECTRODE MATERIAL

- Higher density – for less tool wear and thus less dimensional loss or inaccuracy of tool
- High melting point – high melting point leads to less tool wear due to less tool material melting for the same heat load
- Easy manufacturability Cost – cheap
-

- The followings are the different electrode materials which are used commonly in the industry:
  - Graphite
  - Electrolytic oxygen free copper
  - Tellurium copper – 99% Cu + 0.5% tellurium
  - Brass

EDM – ELECTRODE MATERIAL

- Graphite (most common) - has fair wear characteristics, easily machinable.
- Small flush holes can be drilled into graphite electrodes.
- Copper has good EDM wear and better conductivity.
- It is generally used for better finishes in the range of $R_a = 0.5$ µm.
- Copper tungsten and silver tungsten are used for making deep slots under poor flushing conditions especially in tungsten carbides.

It offers high machining rates as well as low electrode wear. Copper graphite is

- good for cross-sectional electrodes.

It has better electrical conductivity than graphite while the corner wear is higher.

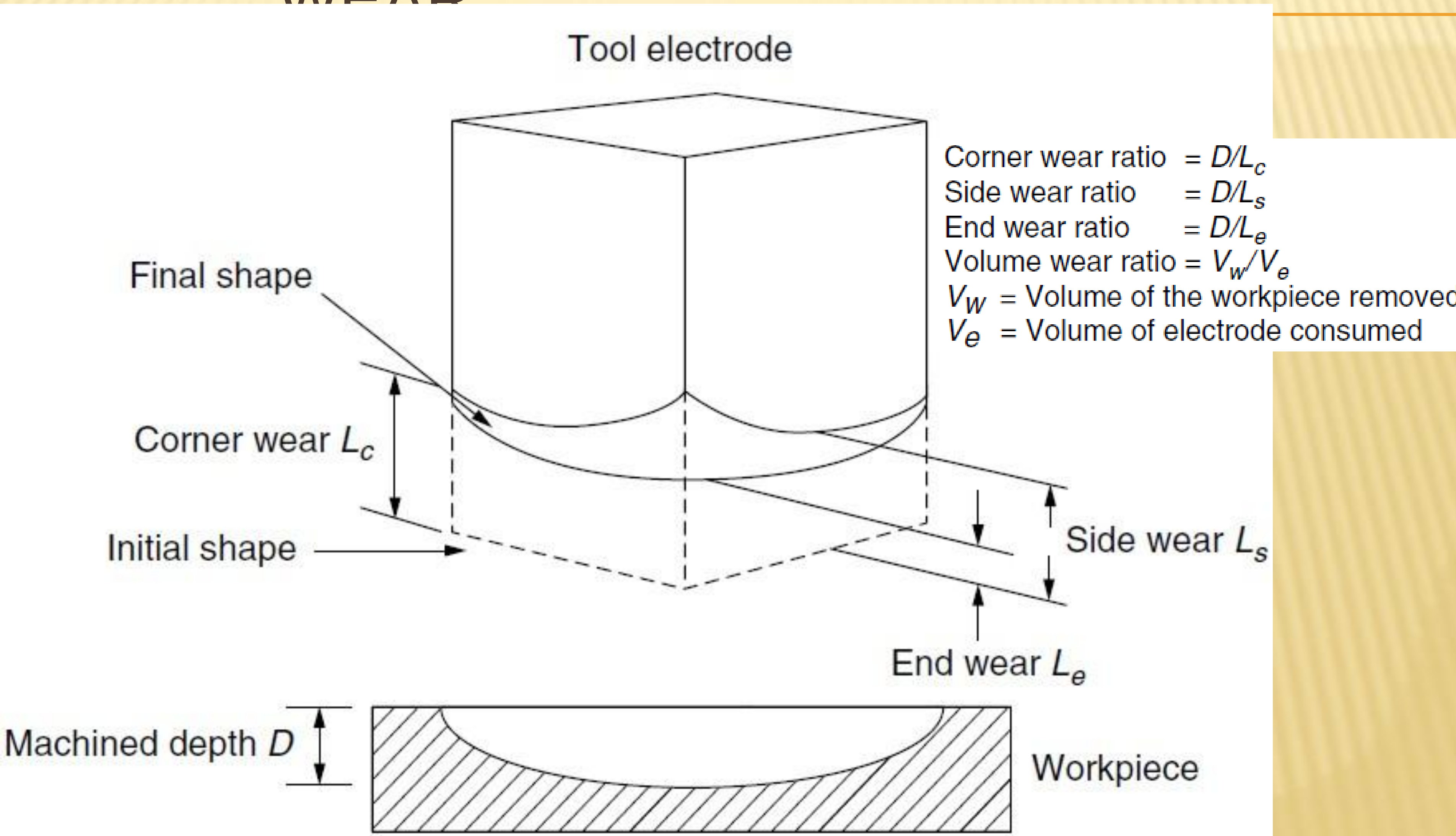
Brass ensures stable sparking conditions and is normally used for specialized

- applications such as drilling of small holes where the high electrode wear is acceptable.

EDM – ELECTRODE MOVEMENT

- In addition to the servo-controlled feed, the tool electrode may have an additional rotary or orbiting motion.
- Electrode rotation helps to solve the flushing difficulty encountered when machining small holes with EDM.
- In addition to the increase in cutting speed, the quality of the hole produced is superior to that obtained using a stationary electrode.
- Electrode orbiting produces cavities having the shape of the electrode.
- The size of the electrode and the radius of the orbit (2.54 mm maximum) determine the size of the cavities.
- Electrode orbiting improves flushing by creating a pumping effect of the dielectric liquid through the gap.

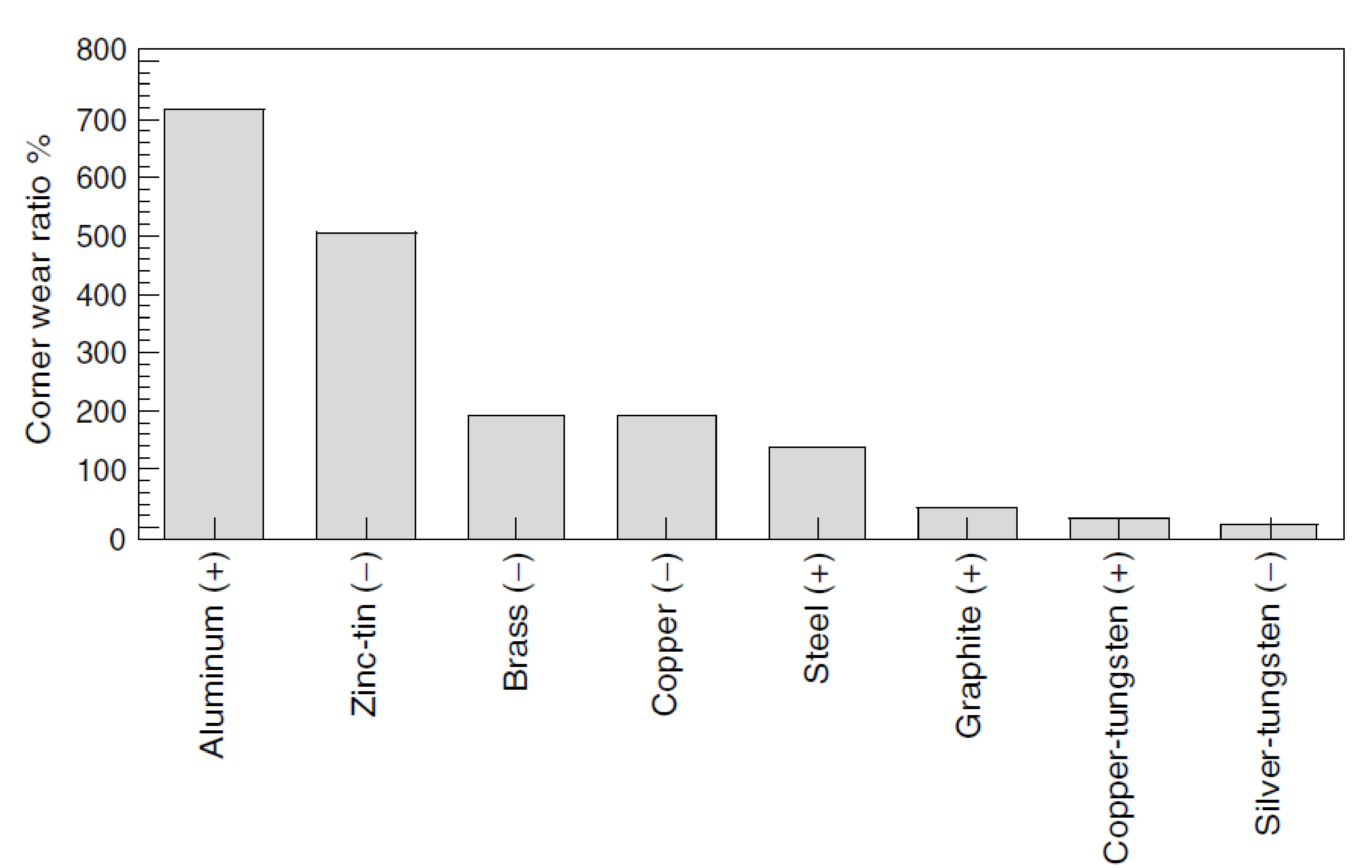
EDM – ELECTRODE WEAR



EDM – ELECTRODE WEAR

- The melting point is the most important factor in determining the tool wear.
- Electrode wear ratios are expressed as end wear, side wear, corner wear, and volume wear.
- "No wear EDM" - when the electrode-to-workpiece wear ratio is 1 % or less.
- Electrode wear depends on a number of factors associated with the EDM, like voltage, current, electrode material, and polarity.
- The change in shape of the tool electrode due to the electrode wear causes defects in the workpiece shape.
- Electrode wear has even more pronounced effects when it comes to micromachining applications.
- The corner wear ratio depends on the type of electrode.
- The low melting point of aluminum is associated with the highest wear ratio.

EDM – ELECTRODE



EDM – ELECTRODE WEAR

- Graphite has shown a low tendency to wear and has the possibility of being molded or machined into complicated electrode shapes.
- The wear rate of the electrode tool material (W_t) and the wear ratio (R_w) are given by Kalpakjian (1997).

$$W_t = (11 \times 10^3) i T_t^{-2.38}$$

$$R_w = 2.25\, T_r^{-2.3}$$

where W_t = wear rate of the tool, mm^3/min

i = EDM current, A

T_t = melting point of the tool electrode, °C

T_r = ratio of the workpiece to tool electrode melting points

EDM – DIELECTRIC

- In EDM, material removal mainly occurs due to thermal evaporation and melting.
- As thermal processing is required to be carried out in absence of oxygen so that the process can be controlled and oxidation avoided.
- Oxidation often leads to poor surface conductivity (electrical) of the workpiece hindering further machining.
- Hence, dielectric fluid should provide an oxygen free machining environment.
- Further it should have enough strong dielectric resistance so that it does not breakdown electrically too easily.
- But at the same time, it should ionize when electrons collide with its molecule.
- Moreover, during sparking it should be thermally resistant as well.
- Generally kerosene and deionised water is used as dielectric fluid in EDM.

EDM – DIELECTRIC

- 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.
- Three important functions of a dielectric medium in EDM:
  1. Insulates the gap between the tool and work, thus preventing a spark to form until the gap voltage are correct.
  2. Cools the electrode, workpiece and solidifies the molten metal particles.
  3. Flushes the metal particles out of the working gap to maintain ideal cutting conditions, increase metal removal rate.
- It must be filtered and circulated at constant pressure.

EDM – DIELECTRIC

- The main requirements of the EDM dielectric fluids are adequate viscosity, high flash point, good oxidation stability, minimum odor, low cost, and good electrical discharge efficiency.
- For most EDM operations kerosene is used with certain additives that prevent gas bubbles and de-odoring.
- Silicon fluids and a mixture of these fluids with petroleum oils have given excellent results.
- Other dielectric fluids with a varying degree of success include aqueous solutions of ethylene glycol, water in emulsions, and distilled water.

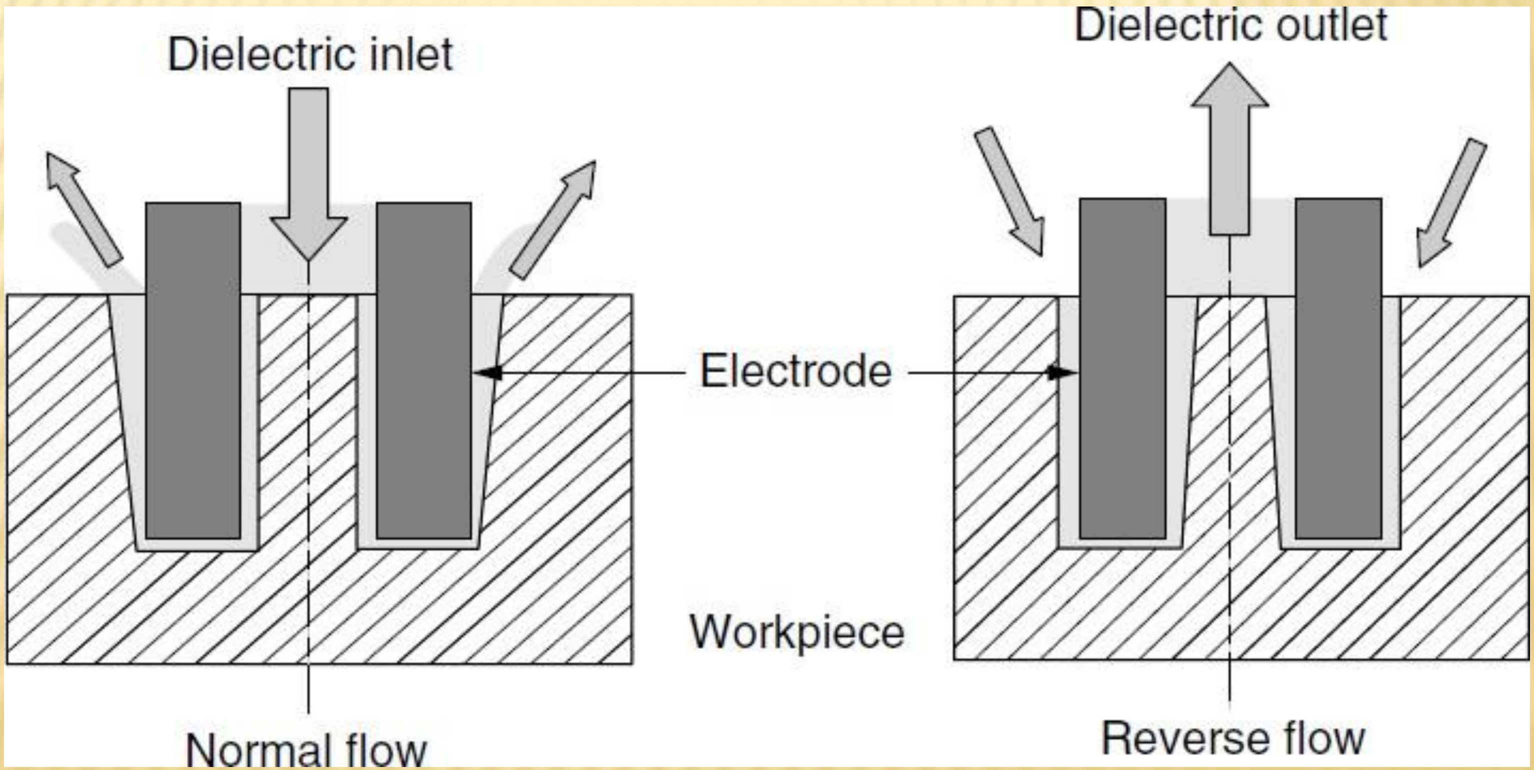
EDM – FLUSHING

- One of the important factors in a successful EDM operation is the removal of debris (chips) from the working gap.
- Flushing these particles out of the working gap is very important, to prevent them from forming bridges that cause short circuits.
- EDMs have a built-in power adaptive control system that increases the pulse spacing as soon as this happens and reduces or shuts off the power supply.
- Flushing – process of introducing clean filtered dielectric fluid into spark gap.
- If flushing is applied incorrectly, it can result in erratic cutting and poor machining conditions.
- Flushing of dielectric plays a major role in the maintenance of stable machining and the achievement of close tolerance and high surface quality.
- Inadequate flushing can result in arcing, decreased electrode life, and increased production time.

EDM – FLUSHING

- **Four methods:**

1. Normal flow
2. Reverse flow
3. Jet flushing
4. Immersion flushing



EDM – FLUSHING

- Normal flow (Majority)
  - Dielectric is introduced, under pressure, through one or more passages in the tool and is forced to flow through the gap between tool and work.
  - Flushing holes are generally placed in areas where the cuts are deepest.
  - Normal flow is sometimes undesirable because it produces a tapered opening in the workpiece.
- Reverse flow
  - Particularly useful in machining deep cavity dies, where the taper produced using the normal flow mode can be reduced.
  - The gap is submerged in filtered dielectric, and instead of pressure being applied at the source a vacuum is used.
  - With clean fluid flowing between the workpiece and the tool, there is no side sparking and, therefore, no taper is produced.

EDM – FLUSHING

- Jet flushing
  - In many instances, the desired machining can be achieved by using a spray or jet of fluid directed against the machining gap.
  - Machining time is always longer with jet flushing than with the normal and reverse flow modes.

- Immersion flushing
  - For many shallow cuts or perforations of thin sections, simple immersion of the discharge gap is sufficient.
  - Cooling and debris removal can be enhanced during immersion cutting by providing relative motion between the tool and workpiece.
  - Vibration or cycle interruption comprises periodic reciprocation of the tool relative to the workpiece to effect a pumping action of the dielectric.

EDM – FLUSHING

- Synchronized, pulsed flushing is also available on some machines.
- With this method, flushing occurs only during the non-machining time as the electrode is retracted slightly to enlarge the gap.
- Increased electrode life has been reported with this system.
- Innovative techniques such as ultrasonic vibrations coupled with mechanical pulse EDM, jet flushing with sweeping nozzles, and electrode pulsing are investigated by Masuzawa (1990).

EDM – FLUSHING

- For proper flushing conditions, Metals Handbook (1989) recommends:

1. Flushing through the tool is more preferred than side flushing.
2. Many small flushing holes are better than a few large ones.
3. Steady dielectric flow on the entire workpiece-electrode interface is desirable.
4. Dead spots created by pressure flushing, from opposite sides of the workpiece, should be avoided.
5. A vent hole should be provided for any upwardly concave part of the tool-electrode to prevent accumulation of explosive gases.
6. A flush box is useful if there is a hole in the cavity.

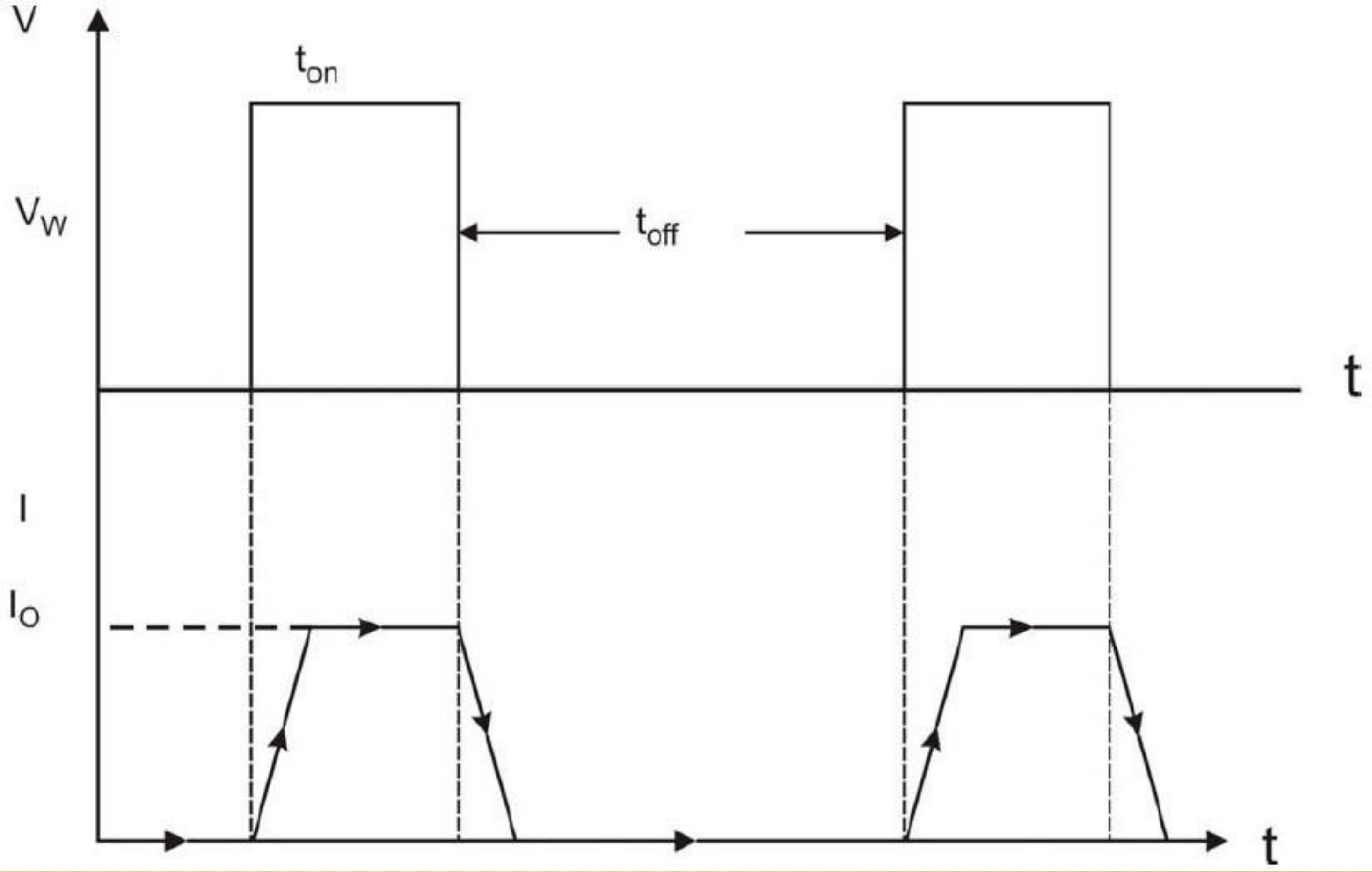
EDM – PROCESS PARAMETERS

The waveform is characterized by the:

- The open circuit voltage – V_o
- The working voltage – V_w
- The maximum current – I_o
- 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.

EDM – PROCESS PARAMETERS

- The process parameters - mainly related to the waveform characteristics.



EDM – TYPES – SINKER EDM

- Sinker EDM, also called cavity type EDM or volume EDM.
- Consists of an electrode and workpiece submerged in an insulating liquid such as oil or other dielectric fluids.
- The electrode and workpiece are connected to a suitable power supply. The
- power supply generates an electrical potential between the two parts.
- As the electrode approaches the workpiece, dielectric breakdown occurs in the fluid, forming a plasma channel, and a small spark jumps.
- These sparks happen in huge numbers at seemingly random locations.
- As the base metal is eroded, and the spark gap subsequently increased, the electrode is lowered automatically so that the process can continue.
- Several hundred thousand sparks occur per second, with the actual duty cycle carefully controlled by the setup parameters.
- These controlling cycles are sometimes known as "on time" and "off time".

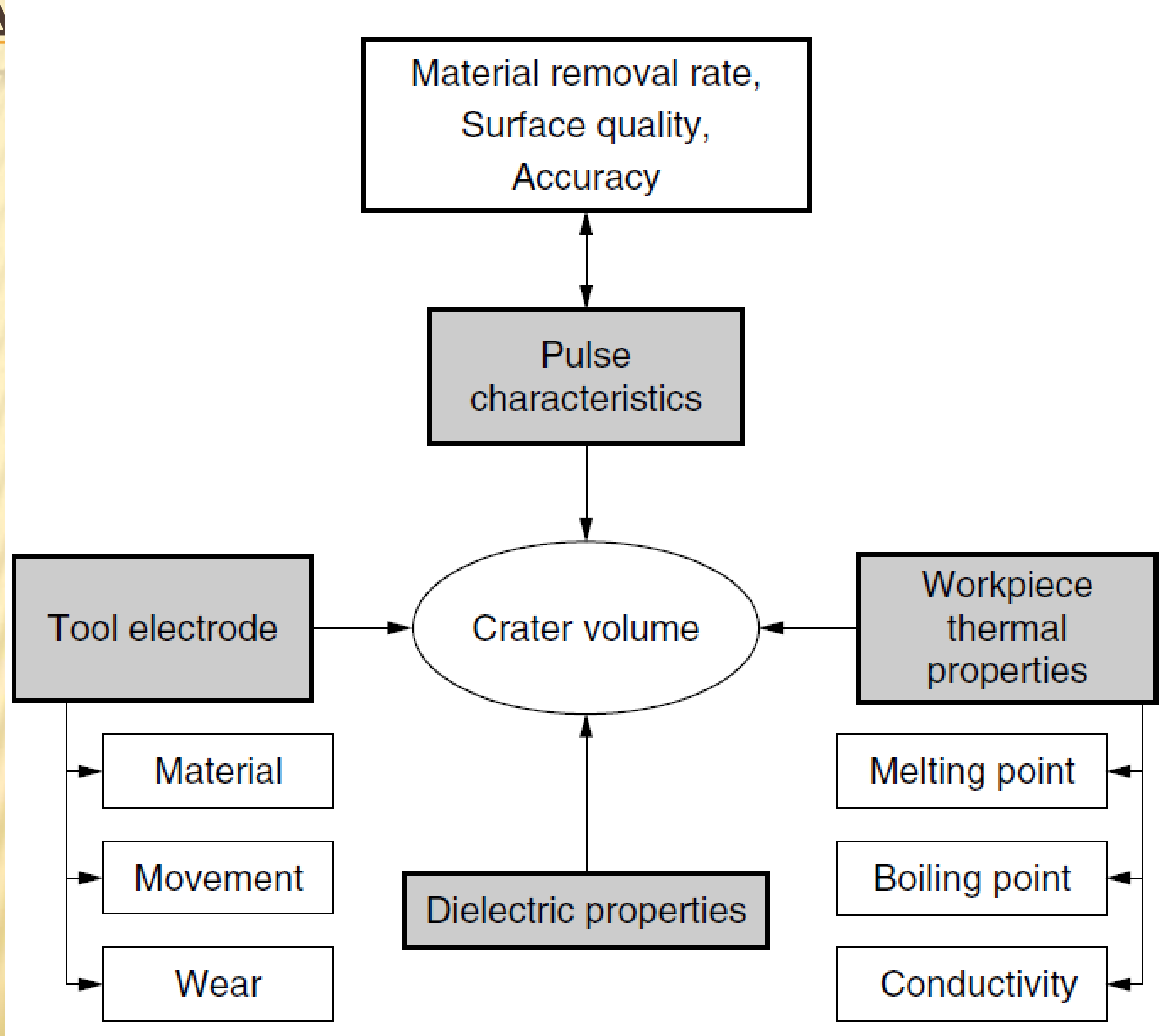
EDM – TYPES – SINKER EDM

- The on time setting determines the length or duration of the spark.
- Hence, a longer on time produces a deeper cavity for that spark and all subsequent sparks for that cycle.
- This creates rougher finish on the workpiece. The reverse is true for a shorter
- on time.
- Off time is the period of time that one spark is replaced by another.
- A longer off time, for example, allows the flushing of dielectric fluid through a nozzle to clean out the eroded debris, thereby avoiding a short circuit.
- These settings can be maintained in micro seconds.
- The typical part geometry is a complex 3D shape, often with small or odd shaped angles.

EDM – TYPES – WIRE EDM (WEDM)

- Also known as wire-cut EDM and wire cutting.
- A thin single-strand metal wire (usually brass) is fed through the workpiece submerged in a tank of dielectric fluid (typically deionized water).
- Used to cut plates as thick as 300 mm and to make punches, tools, and dies from hard metals that are difficult to machine with other methods.
- Uses water as its dielectric fluid; its resistivity and other electrical properties are controlled with filters and de-ionizer units.
- The water flushes the cut debris away from the cutting zone.
- Flushing is an important factor in determining the maximum feed rate for a given material thickness.
- Commonly used when low residual stresses are desired, because it does not require high cutting forces for material removal.

EDM – MATERIAL REMOVAL RATE



Parameters affecting EDM performance.

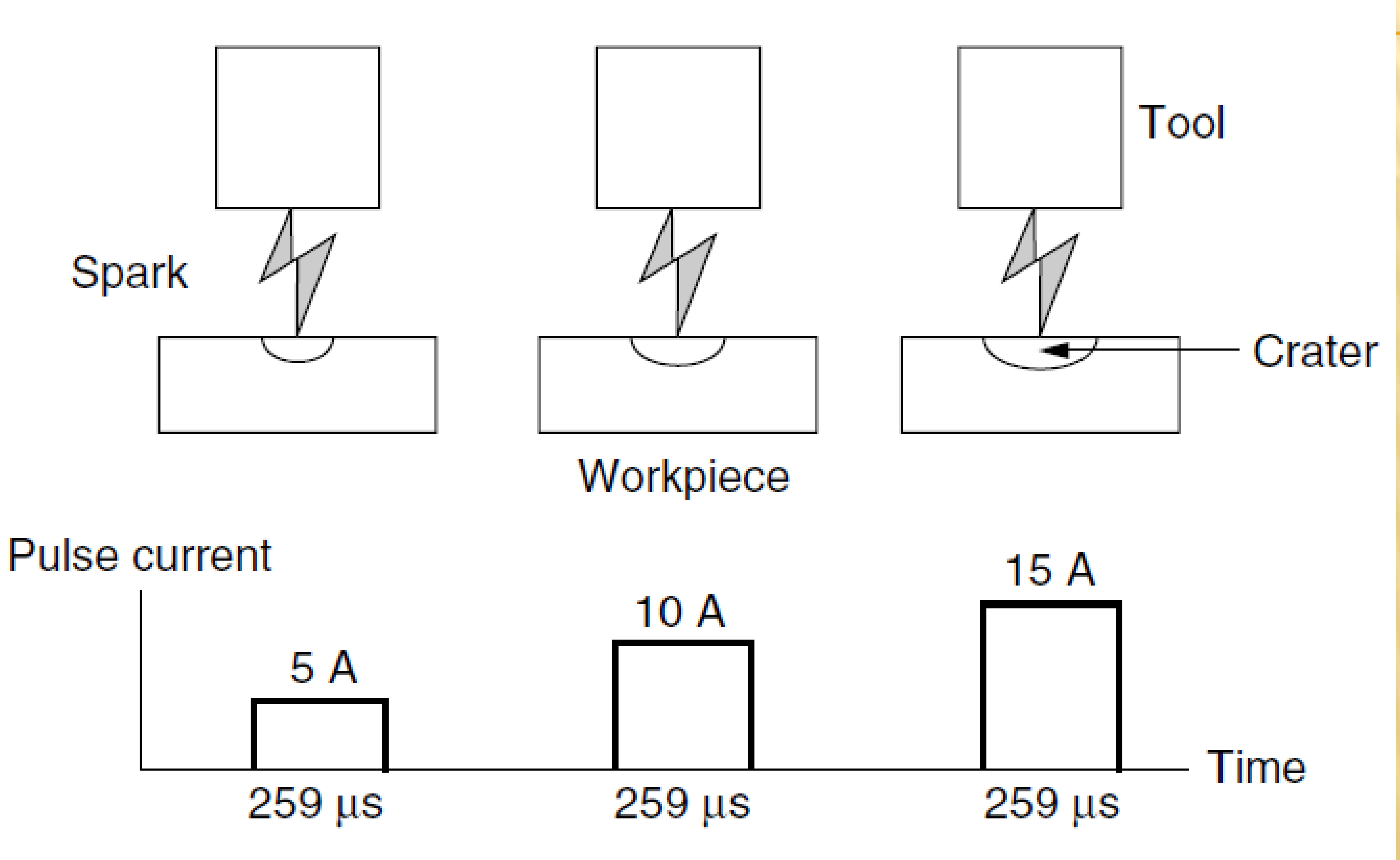
EDM – MATERIAL REMOVAL RATE

- In EDM, the metal is removed from both workpiece and tool electrode.
- MRR depends not only on the workpiece material but on the material of the tool electrode and the machining variables such as pulse conditions, electrode polarity, and the machining medium.
- In this regard a material of low melting point has a high metal removal rate and hence a rougher surface.
- Typical removal rates range from 0.1 to 400 mm^3 /min.
- MRR or volumetric removal rate (VRR), in mm3/min, was described by Kalpakjian (1997):

$$VRR = (4 \times 10^4) i T_w^{-1.23}$$

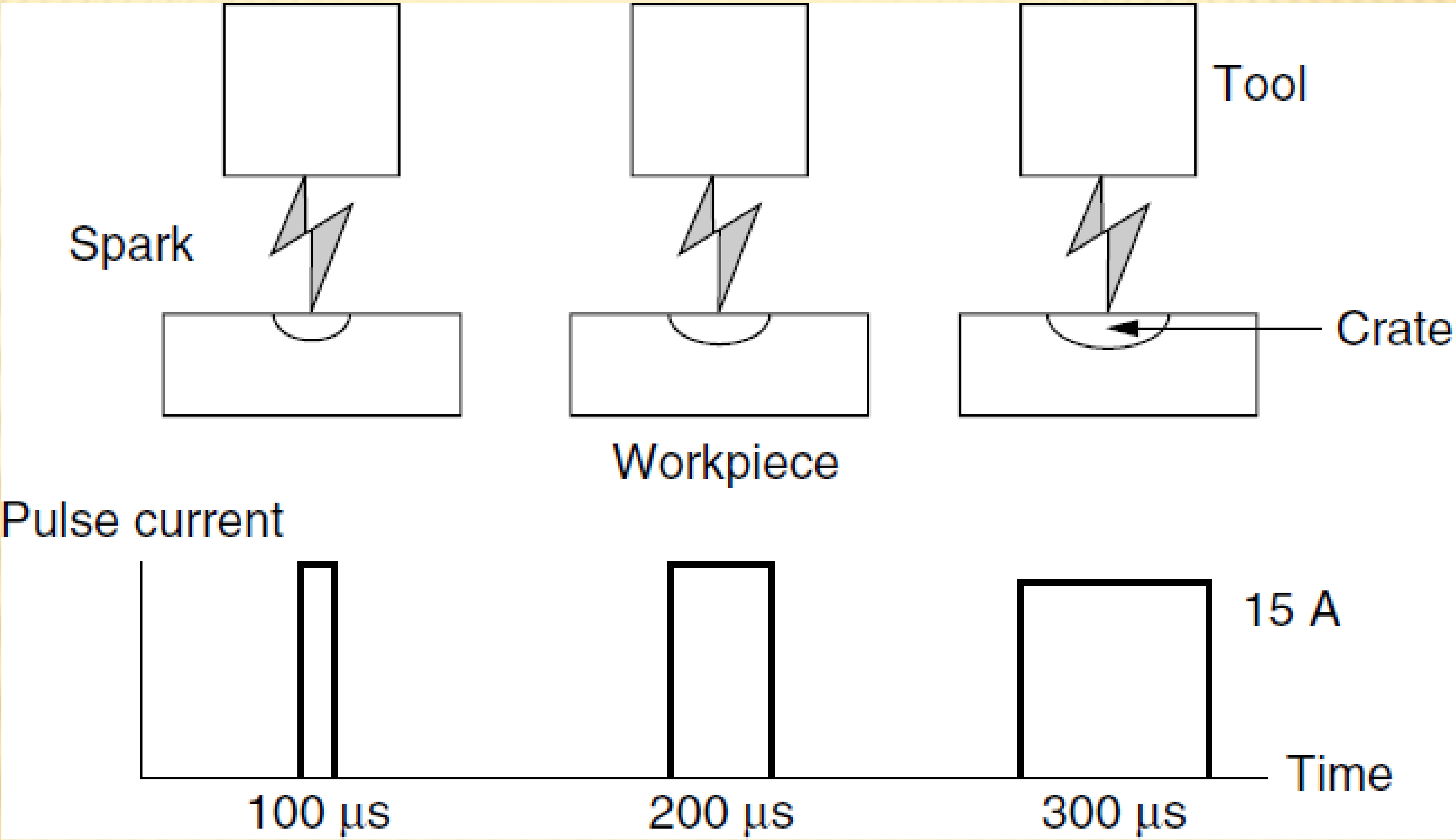
where	I	-	EDM current (A)
	T_w	-	Melting point of the workpiece (°C).

EDM – MATERIAL REMOVAL RATE



Effect of pulse current (energy) on MRR & surface roughness.

EDM – MATERIAL REMOVAL RATE



Effect of pulse on-time (energy) on MRR & surface roughness.

EDM – SURFACE INTEGRITY

- Surface consists of a multitude of overlapping craters that are formed by the action of microsecond-duration spark discharges.
- Crater size depends on
  - physical and mechanical properties of the material
  - composition of the machining medium
  - discharge energy and duration.
- Integral effect of thousands of discharges per second leads to machining with a specified accuracy and surface finish.
  - Depth of craters - the peak to valley (maximum) of surface roughness R_t.
  - Maximum depth of damaged layer can be taken as 2.5 times of roughness R_a.
  - According to Delpreti (1977) and Motoki and Lee (1968), the maximum peak to valley height, R_t, was considered to be 10 times R_a.

EDM – SURFACE INTEGRITY

- AVERAGE ROUGHNESS CAN BE EXPRESSED IN TERMS OF PULSE CURRENT I_P (A) AND PULSE DURATION T_P (MS) BY

$$R_a = 0.0225\ i_p^{0.29}\ t_p^{0.38}$$

- Surface roughness increases linearly with an increase in MRR.
- Jeswani (1978) - Graphite electrodes produce rougher surfaces than metal ones.
- Kuneida and Furuoya (1991) claimed that the introduction of oxygen into discharge gap provides extra power by the reaction of oxygen.
- This in turn increased workpiece melting and created greater expulsive forces that increased MRR and surface roughness.
- Choice of correct dielectric flow has a significant effect in reducing surface roughness by 50 %, increasing the machining rate, and lowering the thermal effects in the workpiece surface.
- Dielectrics having low viscosity are recommended for smooth surfaces.

EDM – SURFACE INTEGRITY

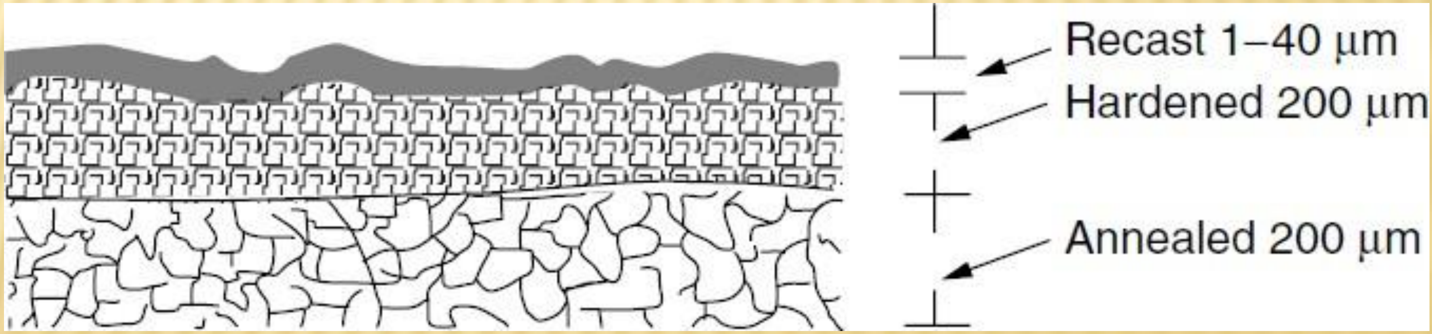
- Metallurgical changes occur in the surface – Temperature 8000 to 12,000°C.
- Additionally, a thin recast layer of 1 μm to 25 μm – depending on power used.
- Delpretti (1977) and Levy and Maggi (1990) claimed that the heat-affected zone (HAZ) adjacent to the resolidified layer reaches 25 μm.
- Some annealing can be expected in a zone just below the machined surface.
- Not all the workpiece melted by discharge is expelled into the dielectric.
- Remaining melted material is quickly chilled, primarily by heat conduction into the bulk of the workpiece, resulting in an exceedingly hard surface.
- Depth of annealed layer is proportional to power used.
- It ranges from 50 μm for finish cutting to ~ 200 μm for high MRR.
- Annealing is usually about two points of hardness below the parent metal for finish cutting.

EDM – SURFACE INTEGRITY

- In roughing cuts, the annealing effect is ~ five points of hardness below the parent metal.
- Electrodes that produce more stable machining can reduce the annealing effect.
- A finish cut removes the annealed material left by the previous rough cut.
- The altered surface layer significantly lowers the fatigue strength of alloys.
- It consists of a recast layer with or without microcracks, some of which may extend into the base metal, plus metallurgical alterations such as rehardened and tempered layers, heat-affected zones, and inter-granular precipitates.
- During EDM roughing, the layer showing microstructural changes, including a melted and resolidified layer, is less than 0.127 mm deep.
- During EDM finishing, it is less than 0.075 mm.
- Post-treatment to restore the fatigue strength is recommended to follow EDM of critical or highly stressed surfaces.

EDM – SURFACE INTEGRITY

- There are several effective processes that accomplish restoration or even enhancement of the fatigue properties.
- These methods include
  - Removal of the altered layers by low-stress grinding or chemical machining
  - Addition of a metallurgical-type coating Re heat-treatment
  - Application of shot peening.



EDM – CHARACTERISTICS

- Can be used to machine any work material if it is electrically conductive.
- MRR depends on thermal properties (job) rather than its strength, hardness etc.
- The volume of the material removed per spark discharge is typically in the range of (1/1,000,000) to (1/10,000) mm^3.
- In EDM, geometry of tool - positive impression of hole or geometric feature.
- Tool wear once again depends on the thermal properties of tool material.
- Local temperature rise is rather high, but there is not enough heat diffusion (very small pulse on time) and thus HAZ is limited to 2 – 4 μm.
- Rapid heating and cooling leads to surface hardening which may be desirable in some applications.
- Tolerance value of $\pm$ 0.05 mm could be easily achieved by EDM.
- Best surface finish that can be economically achieved on steel is 0.40 μm.

APPLICATIONS

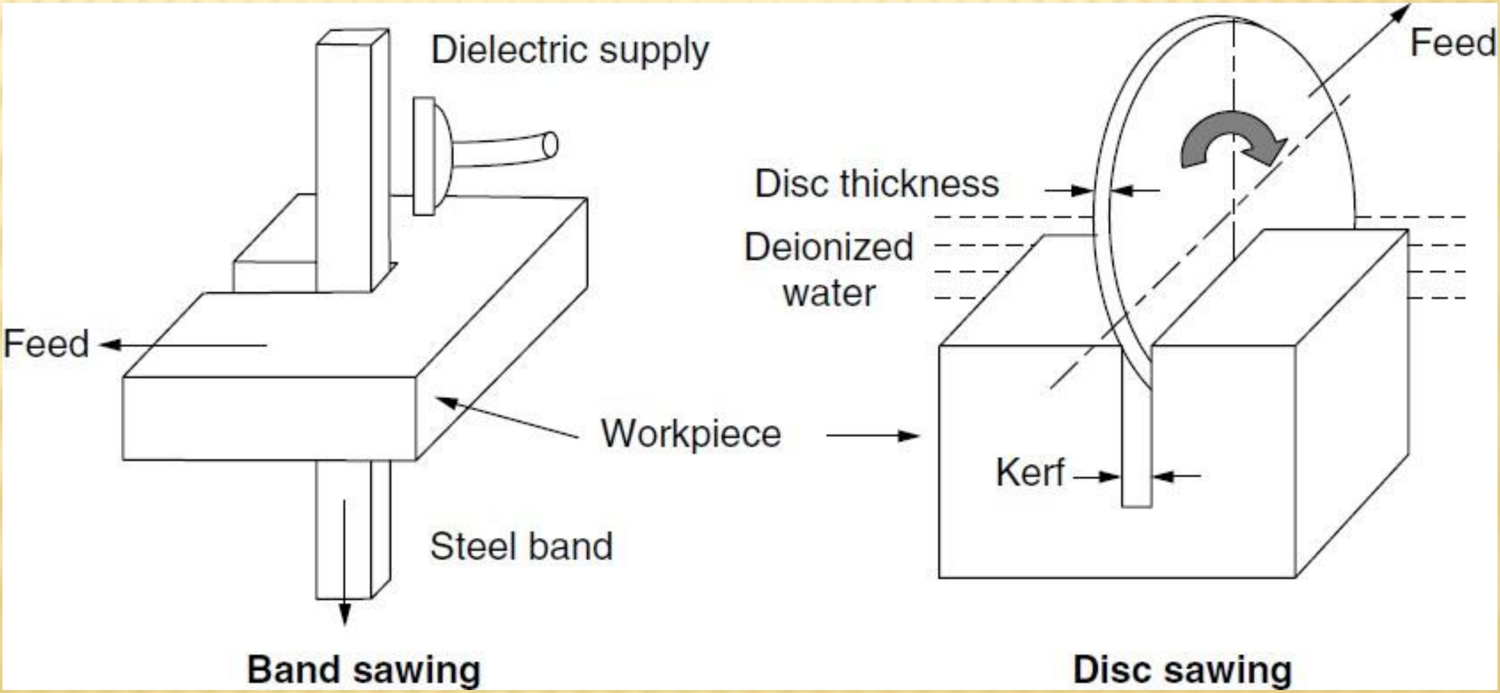
- Drilling of micro-holes, thread cutting, helical profile milling, rotary forming, and curved hole drilling.
- Delicate work piece like copper parts can be produced by EDM.
- Can be applied to all electrically conducting metals and alloys irrespective of their melting points, hardness, toughness, or brittleness.
- Other applications: deep, small-dia holes using tungsten wire as tool, narrow slots, cooling holes in super alloy turbine blades, and various intricate shapes.
- EDM can be economically employed for extremely hardened work piece.
- Since there is no mechanical stress present (no physical contact), fragile and slender work places can be machined without distortion.
- Hard and corrosion resistant surfaces, essentially needed for die making, can be developed.

APPLICATIONS – EDM DRILLING

- Uses a tubular tool electrode where the dielectric is flushed.
- When solid rods are used; dielectric is fed to the machining zone by either suction or injection through pre-drilled holes.
- Irregular, tapered, curved, as well as inclined holes can be produced by EDM.
- Creating cooling channels in turbine blades made of hard alloys is a typical application of EDM drilling.
- Use of NC system enabled large numbers of holes to be accurately located.

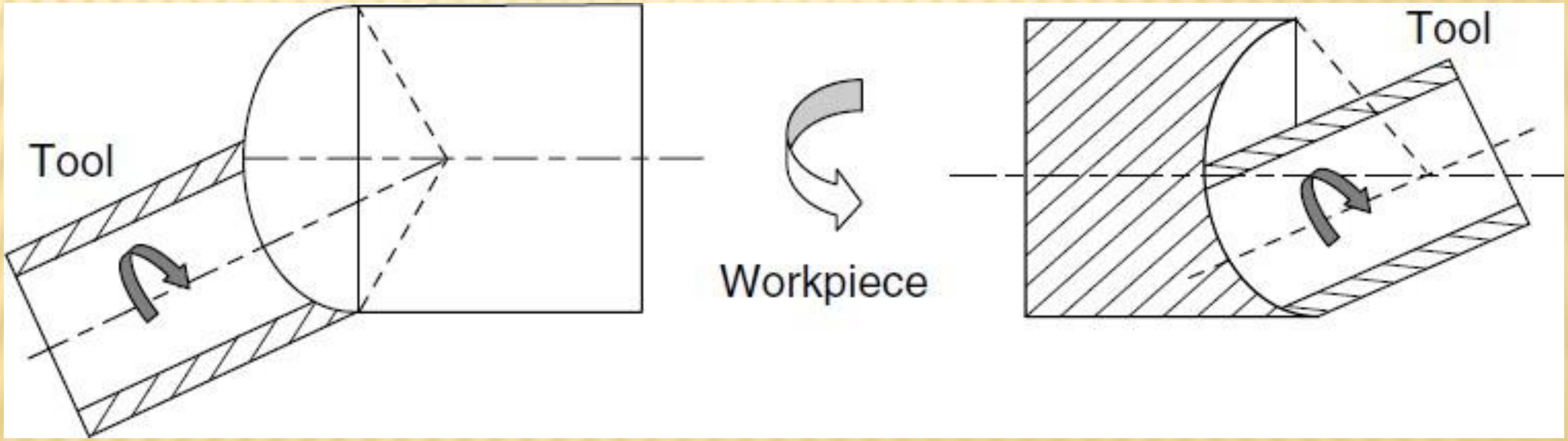
APPLICATIONS – EDM SAWING

- An EDM variation - Employs either a special steel band or disc.
- Cuts at a rate that is twice that of the conventional abrasive sawing method.
- Cutting of billets and bars - has a smaller kerf & free from burrs.
- Fine finish of 6.3 to 10 μm with a recast layer of 0.025 to 0.130 mm



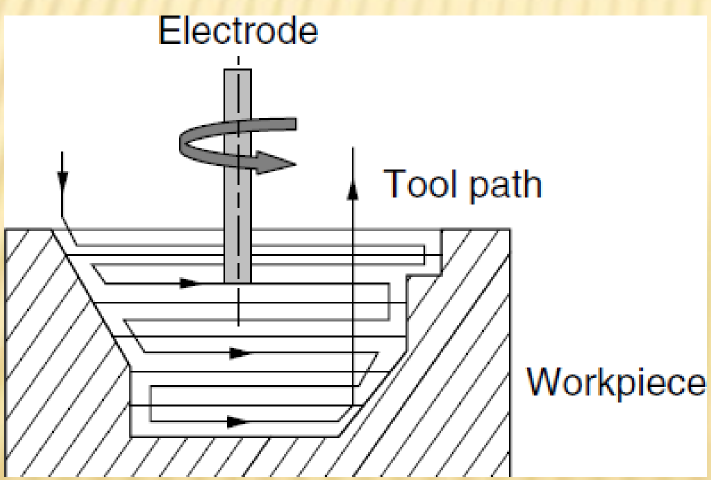
APPLICATIONS - MACHINING OF SPHERES

- Shichun and coworkers (1995) used simple tubular electrodes in EDM machining of spheres, to a dimensional accuracy of ±1 µm and Ra < 0.1 µm.
- Rotary EDM is used for machining of spherical shapes in conducting ceramics using the tool and workpiece arrangement as shown below.

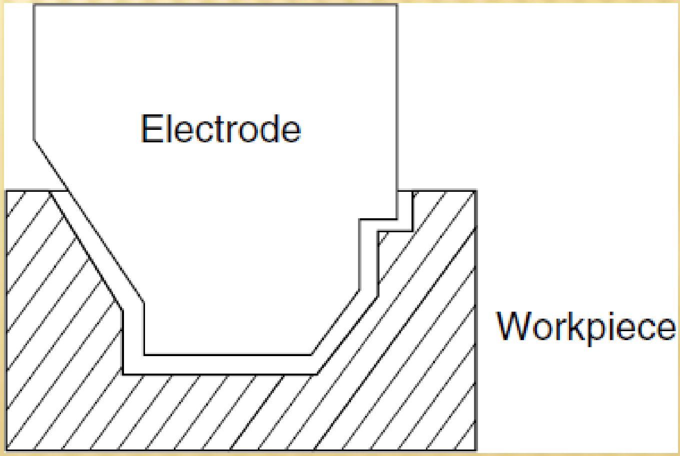


APPLICATIONS - MACHINING OF DIES & MOLDS

- EDM milling uses standard cylindrical electrodes.
- Simple-shaped electrode (Fig. 1) is rotated at high speeds and follows specified paths in the workpiece like the conventional end mills.
- Very useful and makes EDM very versatile like mechanical milling process.
- Solves the problem of manufacturing accurate and complex-shaped electrodes for die sinking (Fig. 2) of three-dimensional cavities.



(Fig. 1)



(Fig. 2)

APPLICATIONS - MACHINING OF DIES & MOLDS

- EDM milling enhances dielectric flushing due to high-speed electrode rotation. Electrode wear can be optimized due to its rotational and contouring motions.

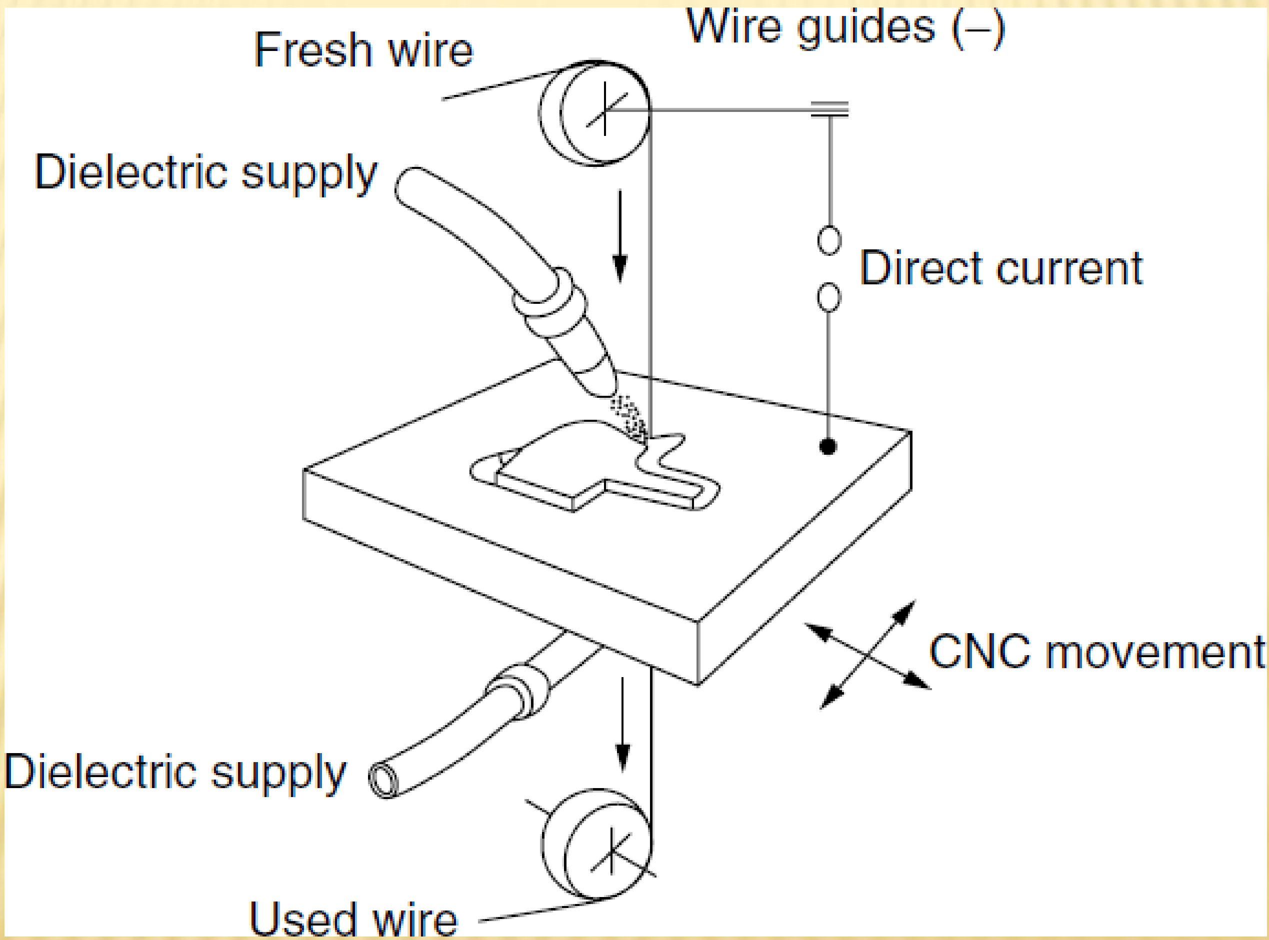
  Main limitation in EDM milling - Complex shapes with sharp corners cannot be machined because of the rotating tool electrode.

  EDM milling replaces conventional die making that requires variety of machines such as milling, wire cutting, and EDM die sinking machines.

APPLICATIONS – WIRE EDM

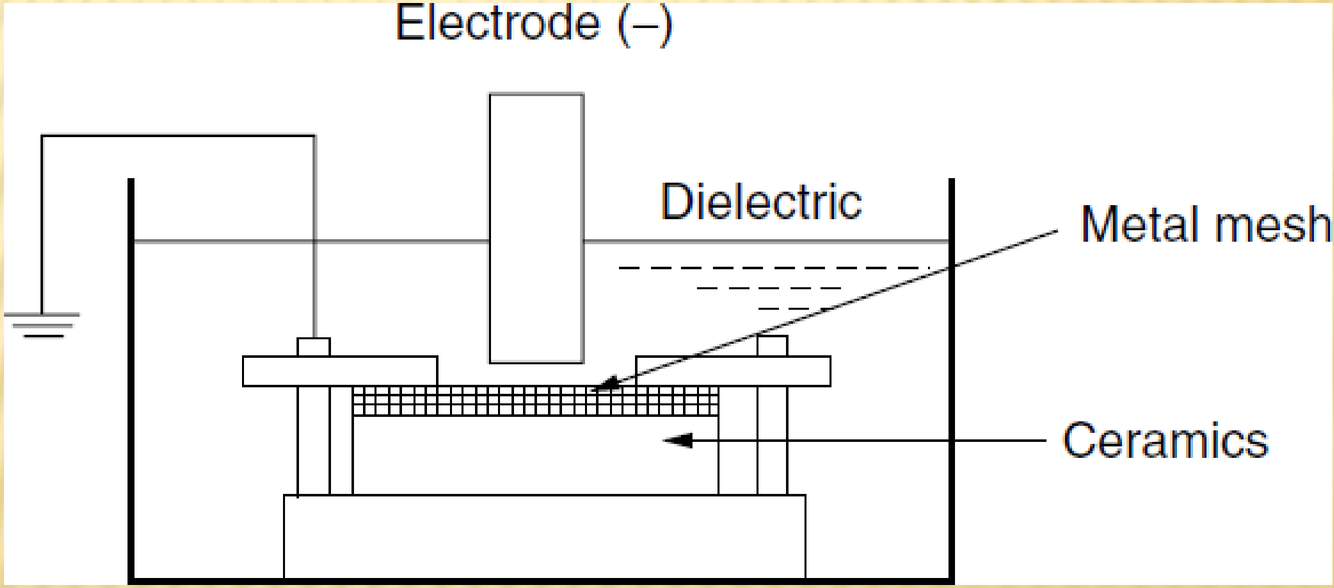
- Special form of EDM - uses a continuously moving conductive wire electrode.
- Material removal occurs as a result of spark erosion as the wire electrode is fed, from a fresh wire spool, through the workpiece.
- Horizontal movement of the worktable (CNC) determines the path of the cut.
- Application - Machining of superhard materials like polycrystalline diamond (PCD) and cubic boron nitride (CBN) blanks, and other composites.
- Carbon fiber composites are widely used in aerospace, nuclear, automobile, and chemical industries, but their conventional machining is difficult.
- Kozak et al. (1995) used wire EDM for accurately shaping these materials, without distortion or burrs.
- Recently used for machining insulating ceramics by Tani et al. (2004).

APPLICATIONS – WIRE EDM



APPLICATIONS – **EDM OF INSULATORS**

- A sheet metal mesh is placed over the ceramic material.
- Spark discharges between the negative tool electrode and the metal mesh.
- These sparks are transmitted through the metal mesh to its interface with the ceramic surface, which is then eroded.



APPLICATIONS – TEXTURING

- Texturing is applied to steel sheets during the final stages of cold rolling. Shot
- blasting (SB) is an inexpensive method of texturing.
- Limitations of SB include its lack of control and consistency of texturing, and the need for protection of other parts of the equipment holding the roll.
- EDT, is a variation of EDM and proved to be the most popular.
- Texturing is achieved by producing electrical sparks across the gap between roll (workpiece) and a tool electrode, in the presence of dielectric (paraffin).
- Each spark creates a small crater by the discharge of its energy in a local melting and vaporization of the roll material.
- By selecting the appropriate process variables such as pulse current, on and off time, electrode polarity, dielectric type, and the roll rotational speed, a surface texture with a high degree of accuracy and consistency can be produced.

ADVANTAGES

Some of the advantages of EDM include machining of:

- Complex shapes that would otherwise be difficult to produce with conventional cutting tools.
- Extremely hard material to very close tolerances.
- Very small work pieces where conventional cutting tools may damage the part from excess cutting tool pressure.
- There is no direct contact between tool and work piece. Therefore delicate sections and weak materials can be machined without any distortion.
- A good surface finish can be obtained.

DISADVANTAGES

Some of the disadvantages of EDM include:

- The slow rate of material removal.
- For economic production, the surface finish specified should not be too fine.
- The additional time and cost used for creating electrodes for ram/sinker EDM.
- Reproducing sharp corners on the workpiece is difficult due to electrode wear.
- Specific power consumption is very high.
- Power consumption is high. "Overcut" is formed.
- Excessive tool wear occurs during machining.
- Electrically non-conductive materials can be machined only with specific set-up of the process

CHEMICAL MACHINING

- The application of a resistant material (acidic or alkaline in nature) to certain portions of the workpiece.
- The desired amount of material is removed from the remaining area of work surface by the subsequent application of an etchant.

ELEMENTS OF PROCESS

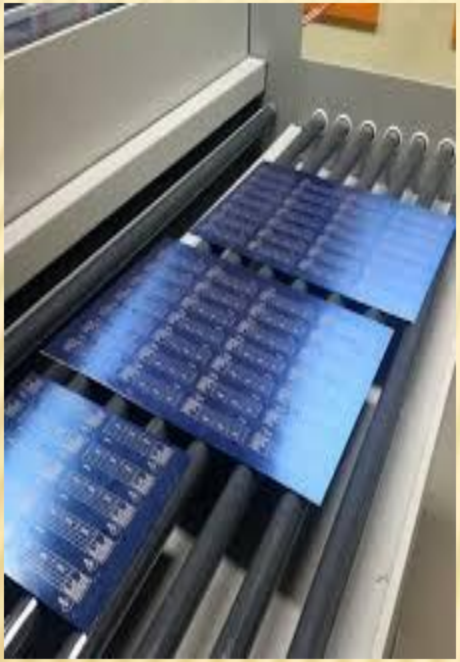
- Only 2 elements of the process

Maskant

Etchant

MASKANTS

3 types



Screen resists

Cut & peel resists

Photographic resists

CUT & PEEL MASKANTS

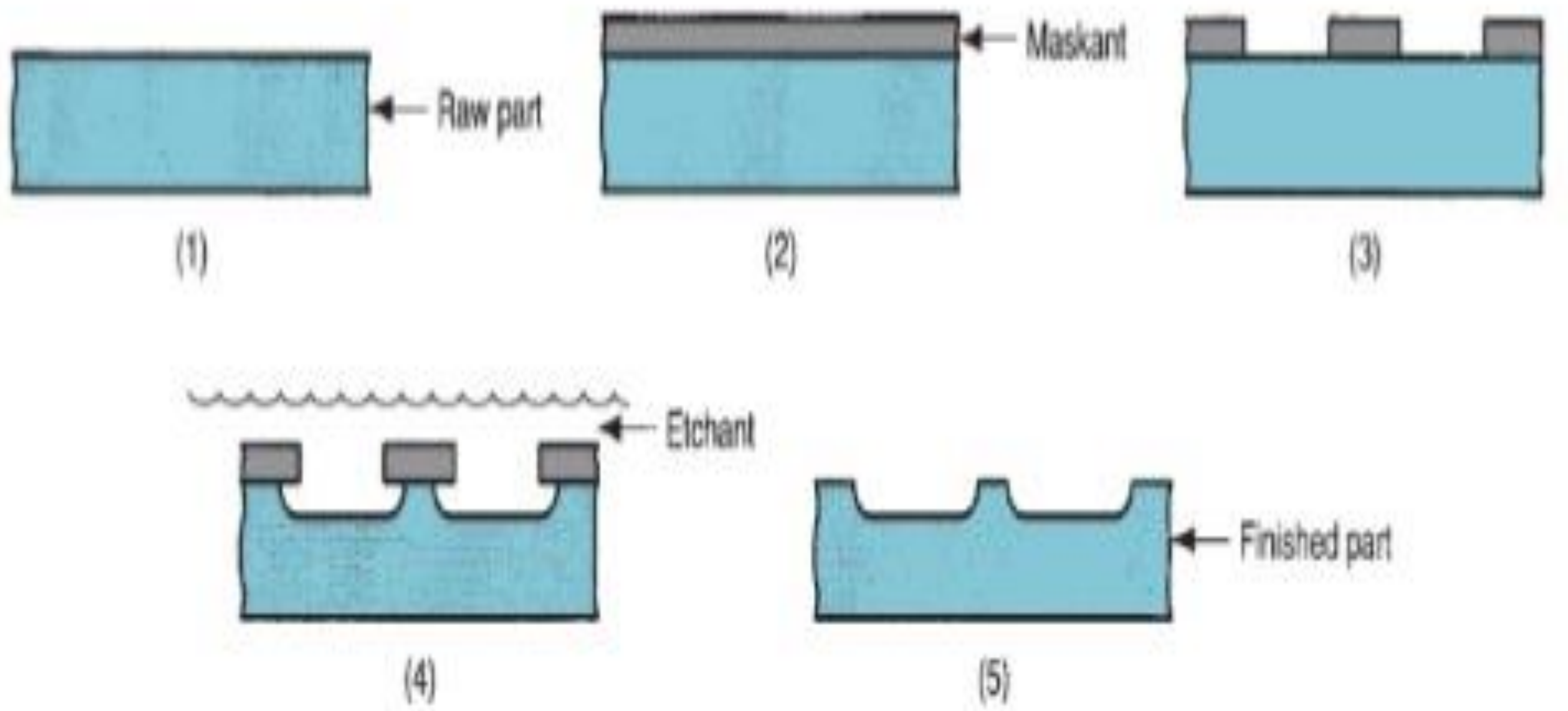


FIGURE 26.16 Sequence of processing steps in chemical milling: (1) clean raw part, (2) apply maskant, (3) scribe, cut, and peel the maskant from areas to be etched, (4) etch, and (5) remove maskant and clean to yield finished part.

CUT & PEEL MASKANTS

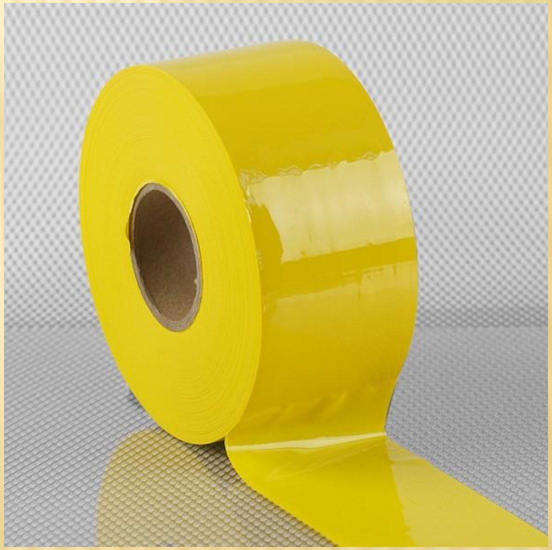
- Cut & peel maskants are first applied to the entire part by the spray or dip method.
- It is then cut from the areas to be etched.
- High chemical resistance is obtained.
- Etching depths upto 1.5mm
- Not used in applications where critical dimensional tolerances are are required.

CUT & PEEL MASKANTS

- Maskant materials

Butyl rubber

Neoprene



vinyl

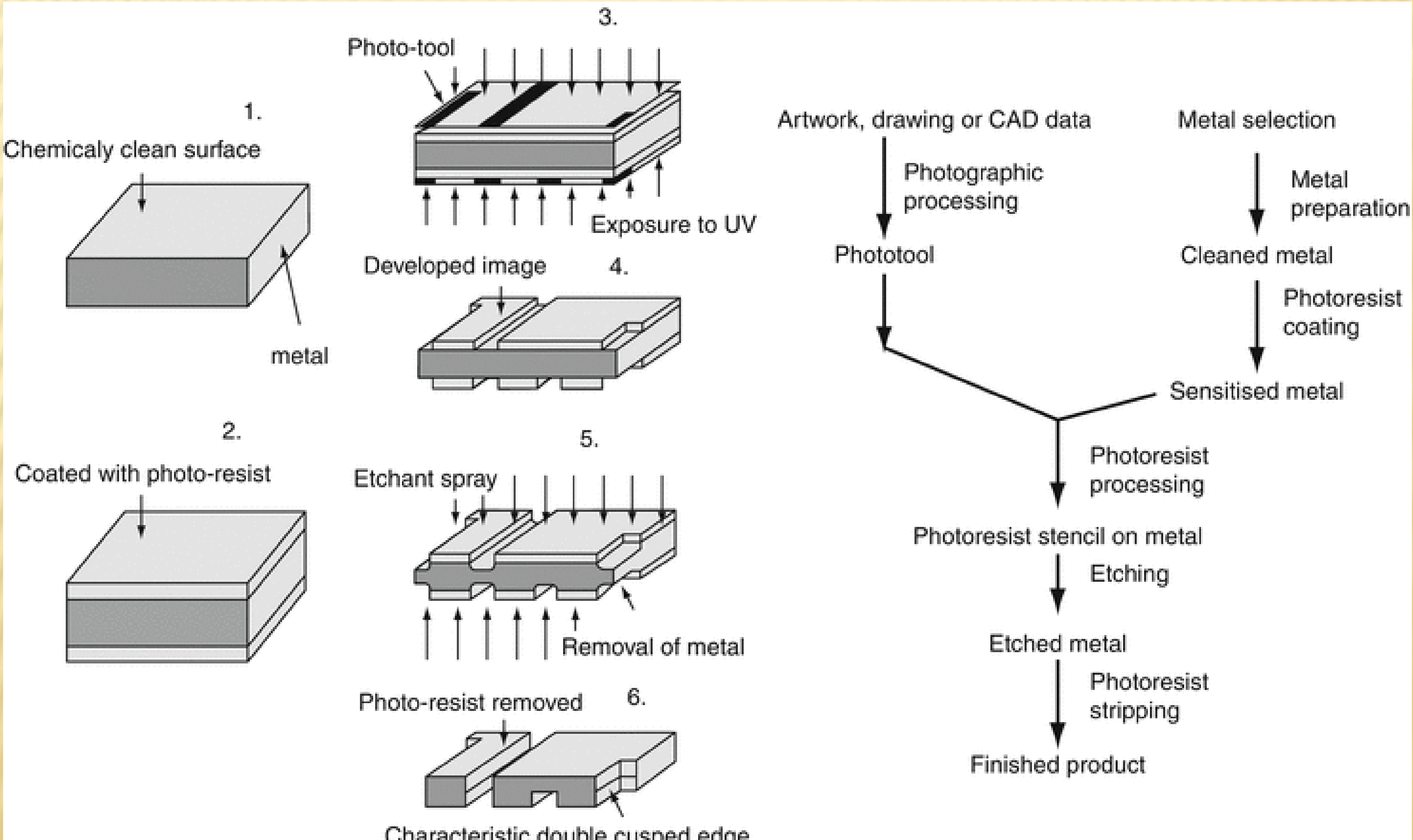
PHOTOGRAPHIC MASKANTS

- These produce etchant resistant images by means of photographic techniques.
- When exposed to a high contrast negative , the materials can produce a positive or negative image of the negative itself.
- Usually applied in liquid form by the spray,dip or roll coating techniques.

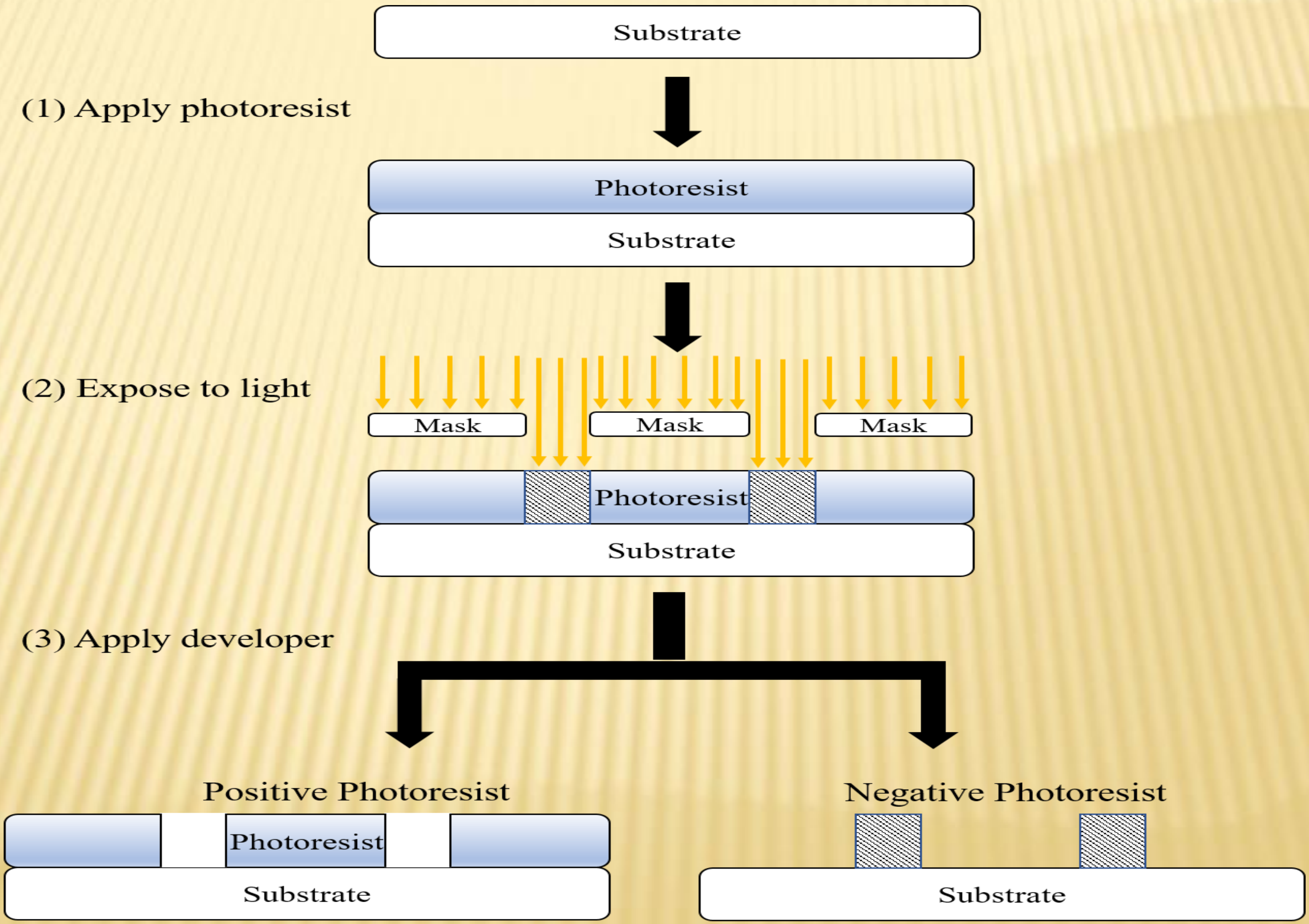
PHOTOGRAPHIC MASKANTS

- Used for
  - Thin materials upto 0.8mm thick
  - Parts requiring dimensional tolerances of the etchant resistant image tighter than ±0.1mm and upto 1 × 1.5.m section
  - Automatic processing of high volume components.

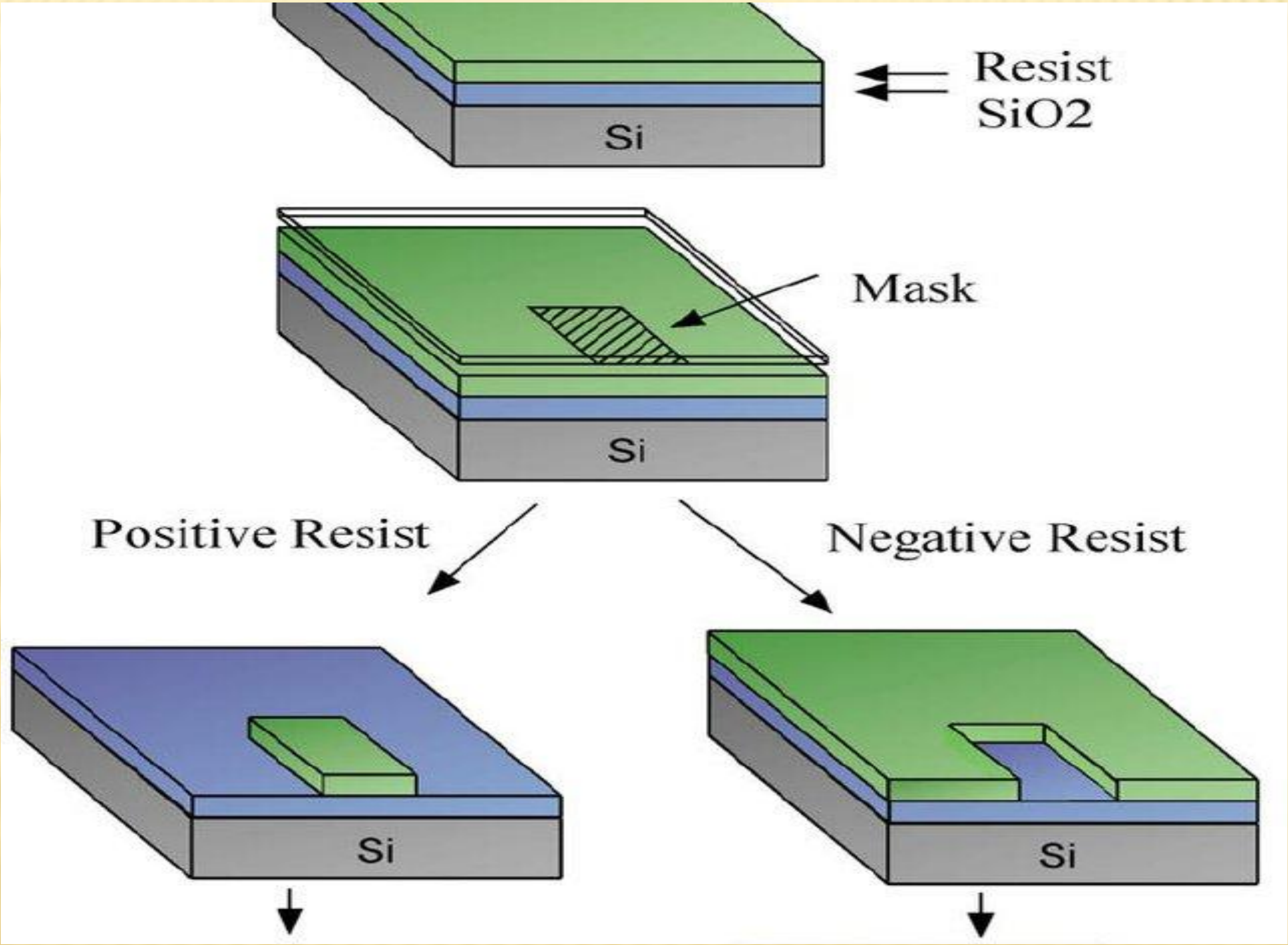
PHOTOGRAPHIC MASKANTS



PHOTOGRAPHIC MASKANTS



PHOTOGRAPHIC MASKANTS



SCREEN MASKANTS

- Screen resists are materials which can be used on the workpiece through normal silk screening techniques
- The image accuracies are better than can generally be achieved by other types of maskants.

SCREEN MASKANTS

- Screen printing is limited to
  - Parts not larger than 1×1 m
  - Parts having only flat surfaces or simple moderate contours
  - Parts where depth of etch does not exceed 1.5mm in depth from one side.
  - Parts which do not require etchant resistant image accuracy greater than ±0.2 mm

FACTORS FOR SELECTION OF RESISTS

- Chemical resistance required
- Number of parts to be produced
- Detail or resolution required
- Shape and size of component
- Ease of removal
- Economics

ETCHANT

- Basic function of an etchant
  - To convert a material (say a metal) into a metallic salt that can be dissolved in the etchant , and thus removed from the work surface.

ETCHANT CHARACTERISTICS & GENERAL APPLICATIONS

Etchant	*Concentration*	*Temp. (K)*	*Etch rate (cm/min) fresh solution*	*Etch factor*	*Metals that etchant will attack*
$FeCl_3$	12 to 18° Bé*	320°	.002	1.5:1 to 2.0:1	Aluminium alloys
HCl, HNO_3H_2O	10:1:9	320°	.002 to .004	2:1 (variable)	
$FeCl_3$	42°Bé	320°	.002	2:1	Cold rolled
HNO_3	10 to 15% (vol.)	320°	.002	1.5 to 2.0:1	steels
$FeCl_3$	42°Bé	320°	.004	2.5 to 3.0:1	Copper and
$(NH_4)_2S_2O_8$	0.22 g/cm³ H_2O	start at 300-320°	.002	2 to 3:1	its alloys
Chromic acid	Commercially available	325°	.0030	2 to 3:1	
$CuCl_2$	35° Bé (regenerated)	325°	.001	2.5 to 3:1	
HNO_3	12 to 15% (vol.)	300°-320°	.002 to .004	—	Magnesium
$FeCl_3$	42°Bé	320°	.001 to .002	1:1 to 3:1	Nickel
$FeCl_3$	42°Bé	325°	.002	1.5 to 2:1	Stainless steel, tin
HNO_3	10 to 15% (vol.)	320 to 325°	.002	—	Zinc

*Baumé specific gravity scale.

FACTORS FOR SELECTION OF AN ETCHANT

- Material to be etched
- Type of maskant or resist used
- Depth of etch
- Surface finish required
- Potential damage to metallurgical properties of work
- Rate of material removal
- Economics

ADVANTAGES - CHM

- Several parts can be machined simultaneously
- Can produce thinner web sections than obtainable by conventional methods
- Castings are chemically machined to achieve final desired dimensions.
- Extrusions, forgings, castings,formed sections , and deep drawn parts can be lightened considerably by ChM.

APPLICATIONS - CHM

- Remove metal from a portion or the entire surface of formed or irregularly shaped parts, such as forgings, castings,extrusions, or formed wrought stock
- In many cases where the depth of material removal is critical to a few microns and the tolerances are close.
- The surface finish obtained is of the order of 0.5 – 2 microns.

APPLICATIONS - CHM

- Reduce web thickness below practical machining , forging casting or forming limits
- Taper sheets and preformed shapes
- Produce stepped webs
- Engraving on any metal piece.

THANK YOU