ME8073 UNCONVENTIONAL MACHINING PROCESSES

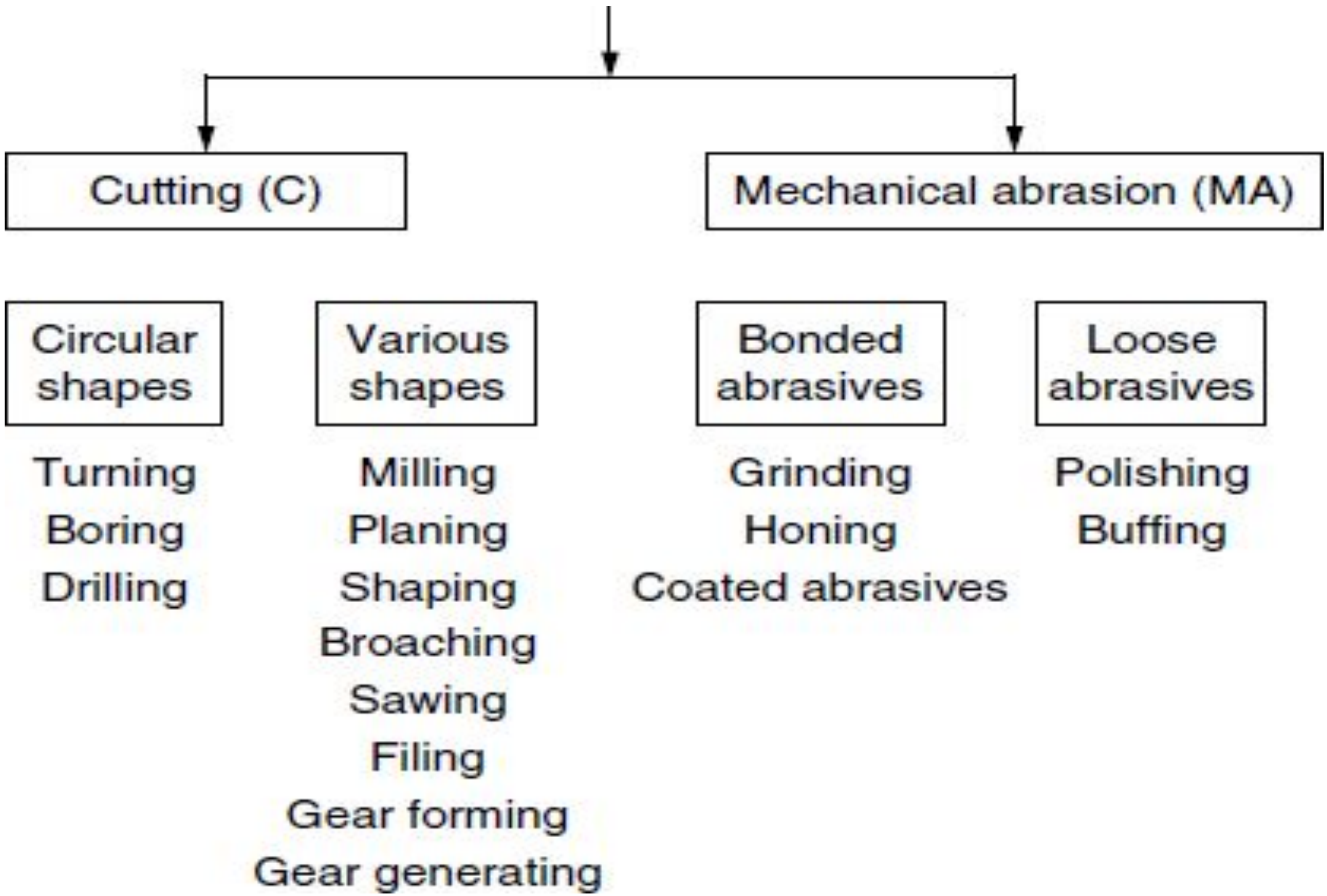
UNIT-1

INTRODUCTION AND MECHANICAL ENERGY PROCESSES

- Unconventional machining Process
  -Need, classification, merits, demerits and applications.
- Abrasive Jet Machining –
- Water Jet Machining –
- Abrasive Water Jet Machining –
- Ultrasonic Machining.

(Working Principles – equipment used – Process parameters – MRR- Applications)

Traditional or Conventional Machining



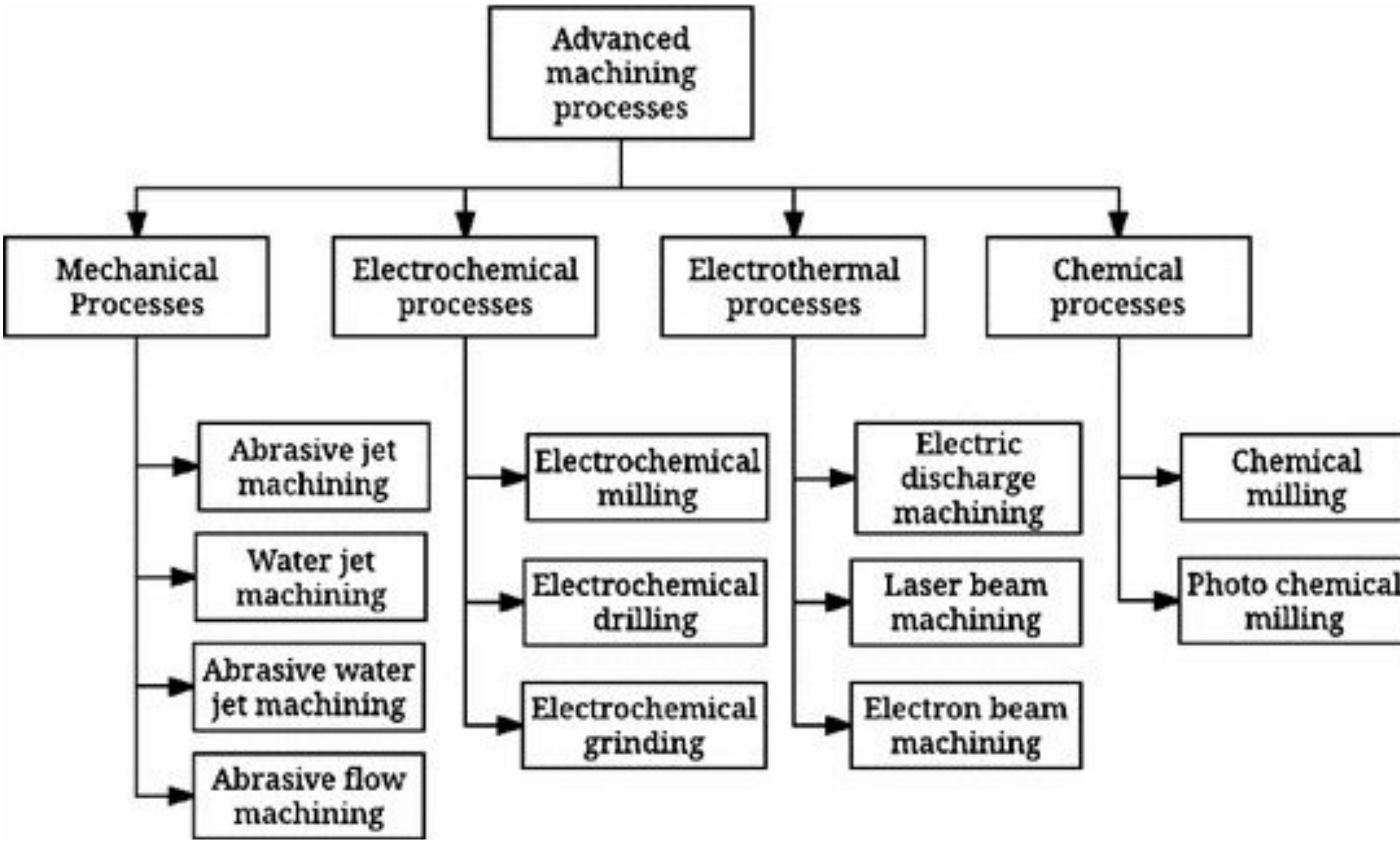
Need for Unconventional Machining

- Greatly improved thermal, mechanical and chemical properties of modern materials – Not able to machine thru conventional methods. (Why???)
- Ceramics & Composites – high cost of machining and damage caused during machining – big hurdles to use these materials.
- In addition to advanced materials, more complex shapes, low rigidity structures and micro-machined components with tight tolerances and fine surface finish are often needed.
- To meet these demands, new processes are developed.
- Play a considerable role in aircraft, automobile, tool, die and mold making industries.

Need for Unconventional Machining

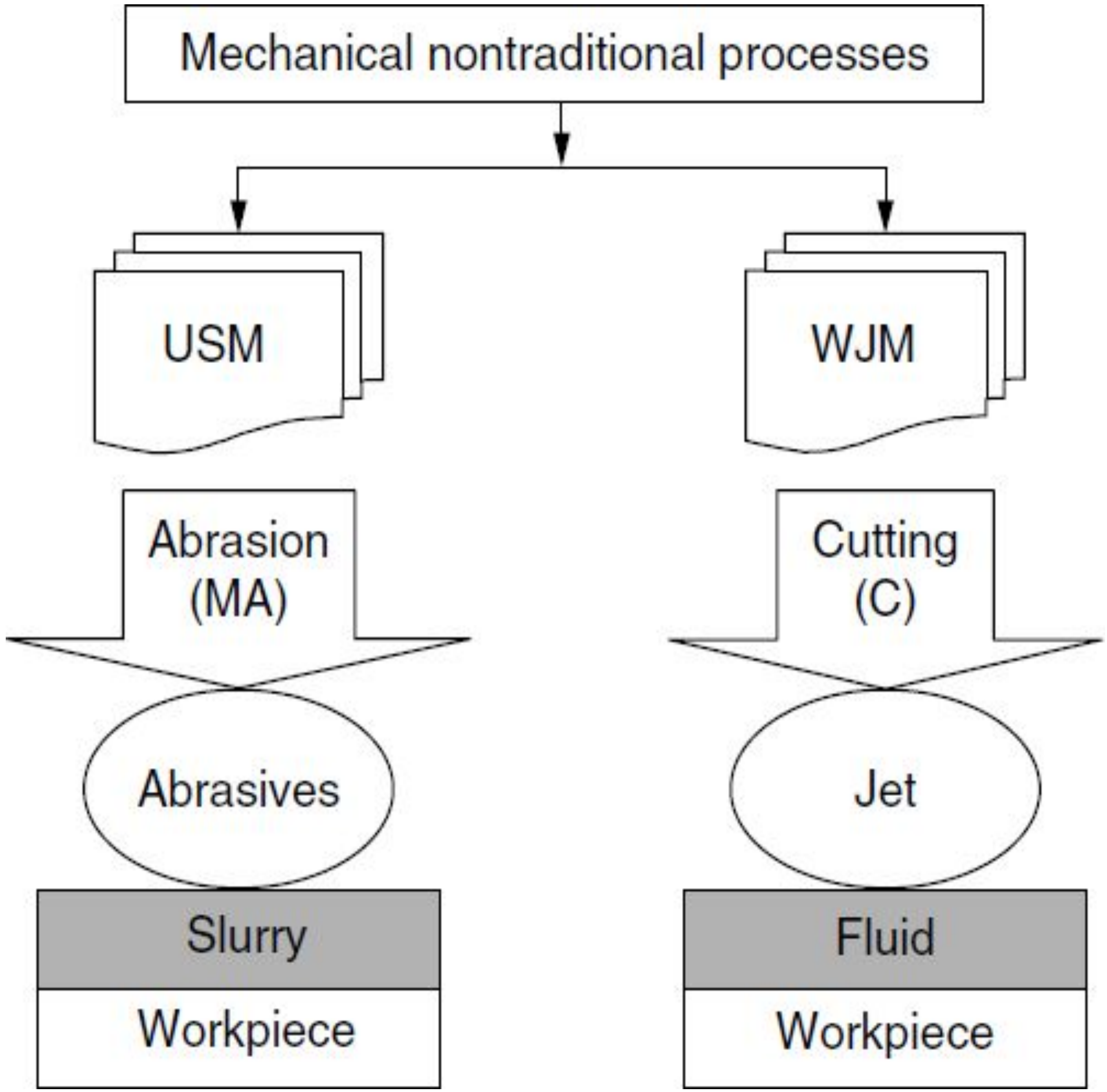
- Very high hardness and strength of the material. (above 400 HB.)
- The work piece is too flexible or slender to support the cutting or grinding forces.
- The shape of the part is complex, such as internal and external profiles, or small diameter holes.
- Surface finish or tolerance better than that obtainable conventional process.
- Temperature rise or residual stress in the work piece is undesirable.

Unconventional Machining Processes - Classification



Mechanical Based Processes

- USM – through mechanical abrasion in a medium (solid abrasive particles suspended in the fluid)
- WJM – Cutting by a jet of fluid.
- AWJM – Abrasives in fluid jet.
- IJM – Ice particles in fluid jet.
- Abrasives or ice – Enhances cutting action.


Mechanical nontraditional processes
USM
WJM
Abrasion
(MA)
Cutting
(C)
Abrasives
Jet
Slurry
Fluid
Workpiece
Workpiece

Thermal based Unconventional Processes

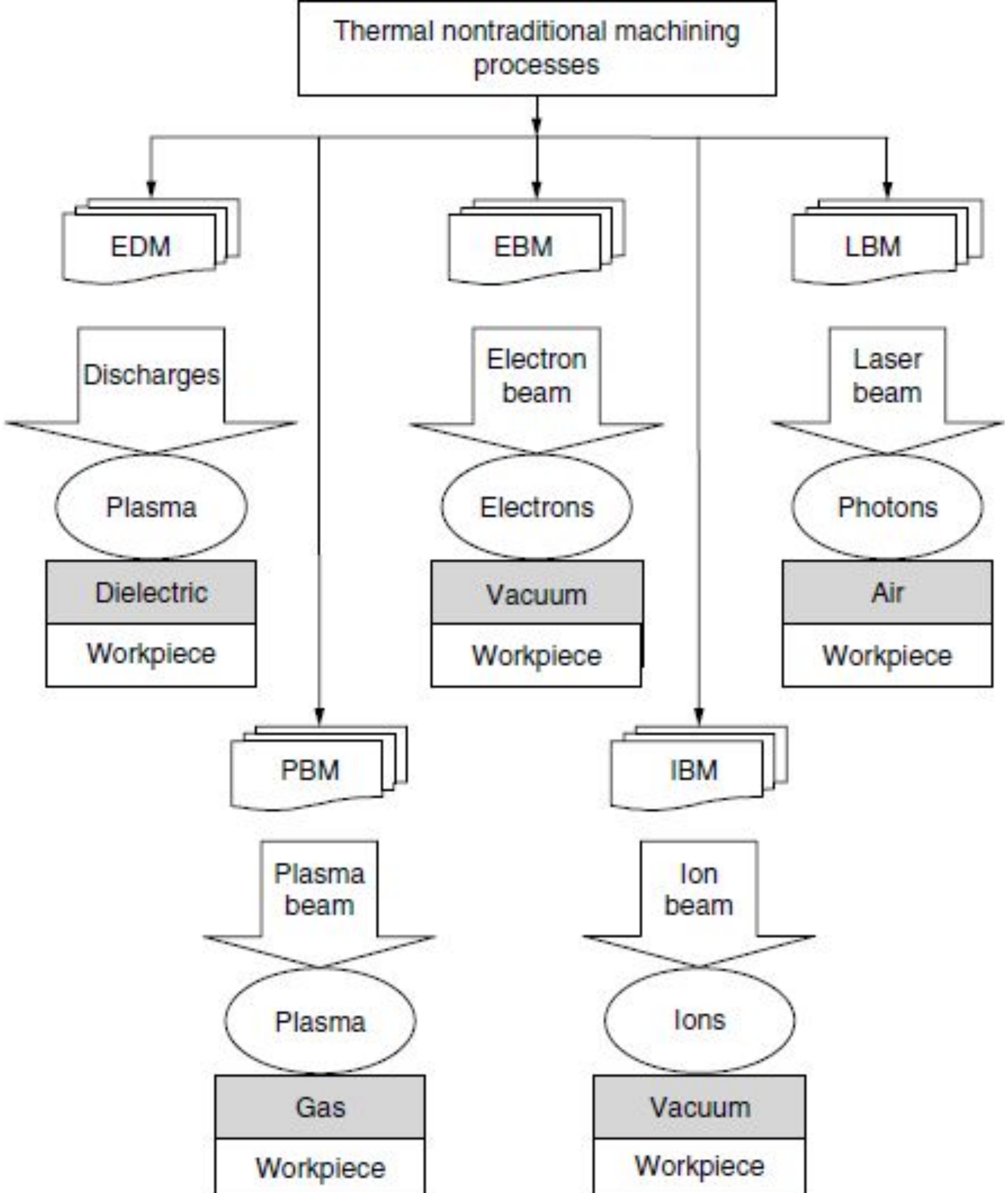
- **Thru – melting & vaporizing**

  Many secondary phenomena – surface cracking, heat affected zone and striations.

<u>Heat Source:</u>

Plasma – EDM and PBM.
Photons – LBM
Electrons – EBM
Ions – IBM

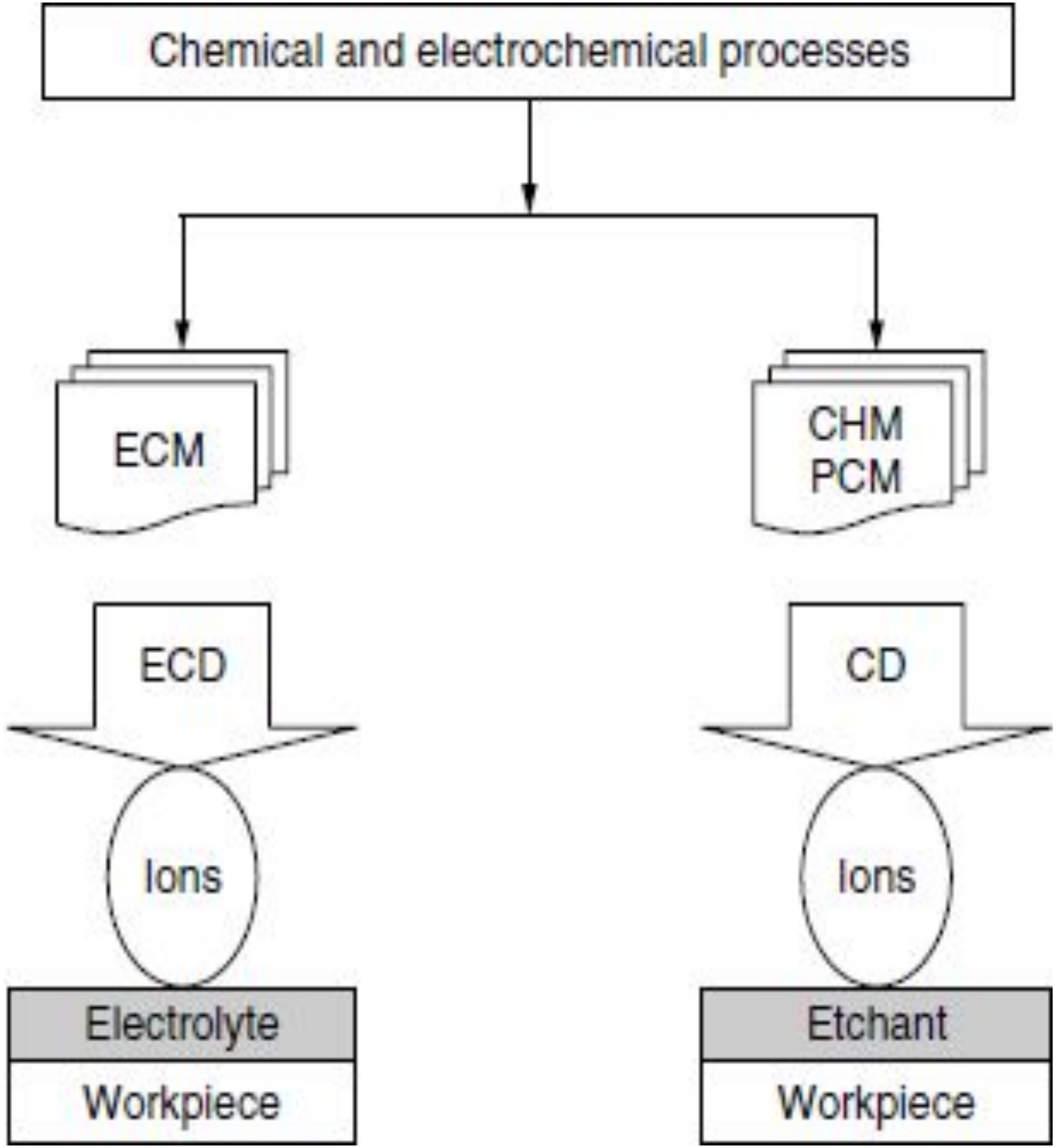
Machining medium: different for different processes.


Thermal nontraditional machining processes
EDM
EBM
LBM
Discharges
Electron beam
Laser beam
Plasma
Electrons
Photons
Dielectric
Vacuum
Air
Workpiece
Workpiece
Workpiece
PBM
IBM
Plasma beam
Ion beam
Plasma
Ions
Gas
Vacuum
Workpiece
Workpiece

Chemical & Electrochemical based Unconventional Processes

- CHM – uses Chemical dissolution action in an etchant.

- ECM – uses electrochemical dissolution action in an electrolytic cell.


Chemical and electrochemical processes
ECM
CHM
PCM
ECD
CD
Ions
Ions
Electrolyte
Workpiece
Etchant
Workpiece

Requirements that lead to the development of nontraditional machining.

- Very high hardness and strength of the material.
- The work piece: too flexible or slender to support the cutting or grinding forces.
- The shape of the part is complex, such as internal and external profiles, or small diameter holes.
- Surface finish or tolerance better than those obtainable conventional process.

Requirements that lead to the development of nontraditional machining.

- Temperature rise or residual stress in the work piece are undesirable.

- Conventional machining involves the direct contact of tool and work - piece, whereas unconventional machining does not require the direct contact of tool and work piece.

- Conventional machining has many disadvantages like tool wear which are not present in Non-conventional machining.

Advantages of Non-conventional machining

- Less/no wear
- Tool life is more
- Quieter operation
- High accuracy and surface finish

Disadvantages of non-conventional machining

- High cost
- Complex set-up
- Skilled operator required

Selection Process

Selection Process is based of following parameters

- Physical Parameter
- Shapes to be Machined
- Process Capability
- Economic consideration

Physical Parameters

Process	Machines
Holes (Micro, Small, deep,Shallow)	LBM, EBM,ECM, USM & EDM
Precision Work	USM & EDM
Horning	ECM
Etching	ECM & EDM
Grinding	AJM & EDM
Deburring	USM & AJM
Threading	EDM
Profile Cut	PAM

Process Capability or Machining Characteristics

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

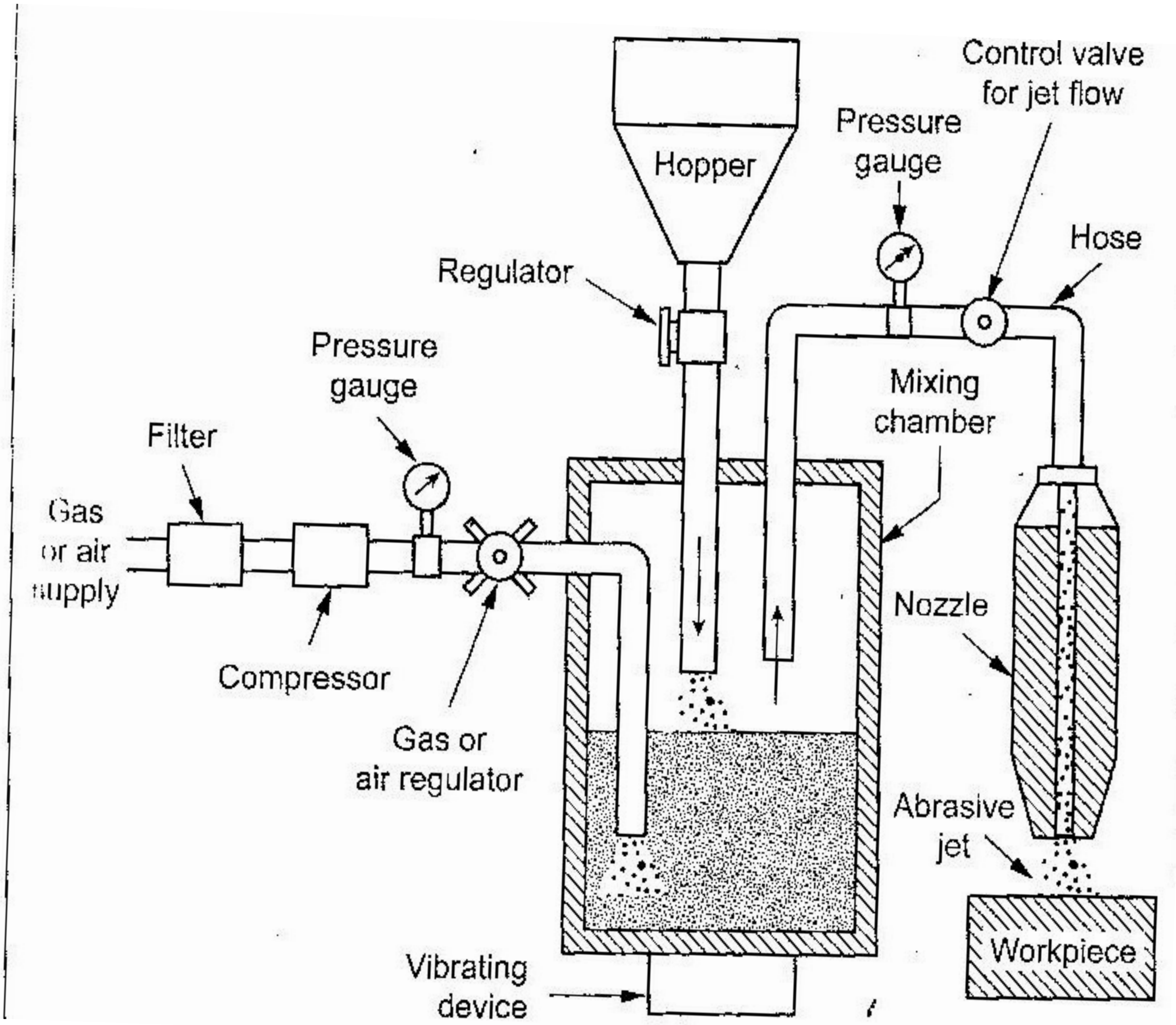
PROCESS ECONOMY

Process	Capital Cost	Tool & Fixtures	Power Requirement	Efficiency
EDM	Medium	High	Low	High
CHM	Medium	Low	High	Medium
ECM	V. High	Medium	Medium	V. Low
AJM	V. Low	Low	Low	Low
USM	High	High	Low	Medium
EBM	High	Low	Low	V. High
LBM	Medium	Low	V. Low	V. High
PAM	V. Low	Low	V. Low	V. Low
Conventional	V. Low	Low	Low	V. Low

MECHANICAL ENERGY BASED PROCESSES

ABRASIVE JET MACHINING (AJM)

- In Abrasive Jet Machining (AJM), abrasive particles are made to impinge on Athe work material at a high velocity.
- The high velocity abrasive particles remove the material by micro-cutting action as well as brittle fracture of the work material.
- In AJM, generally, the abrasive particles of around 50 µm grit size would impinge on the work material at velocity of 200 m/s from a nozzle of I.D. of 0.5 mm with a standoff distance of around 2 mm.
- The kinetic energy of the abrasive particles would be sufficient to provide material removal due to brittle fracture of the work piece or even micro.



Control valve
for jet flow
Pressure
gauge
Hopper
Hose
Regulator
Pressure
gauge
Mixing
chamber
Filter
Gas
or air
supply
Nozzle
Compressor
Gas or
air regulator
Abrasive
jet
Workpiece
Vibrating
device

ABRASIVE JET MACHINING (AJM)

- It is the material removal process where the material is removed by high velocity stream of air/gas or water and abrasive mixture.
- An abrasive is small, hard particle having sharp edges and an irregular shape.
- High velocity jet is aimed at a surface under controller condition .

Components Of Abrasive Jet Machining

- Abrasive delivery system
- Control system
- Pump
- Nozzle
- Mixing tube
- Motion system

Abrasive Delivery System

- Auto abrasive delivery system has the capability of storing abrasive & delivery the abrasive to the bucket . It’s works auto programming system by help of once measuring record & no adjustment or fine tuning system . High sensitive sensor gives extremely reliable & repeatable .

Control system

- The control algorithm that computes exactly how the feed rate should vary for a given geometry in a given material to make a precise part .
- The algorithm actually determines desired variation in the feed rate & the tool path to provide an extremely smooth feed rate

Pump

- Crankshaft & intensifier pump are mainly use in the abrasive jet machine
- The intensifier pump was the only pump capable of reliably creating pressures high.
- Crankshaft pumps are more efficient than intensifier pumps because they do not require a power robbing hydraulic system ultra high pressure & more stroke per minute .

Advantages

- Extremely fast setup & programming
- No start hole required
- There is only one tool
- Low capital cost
- Less vibration
- No heat generated in work piece
- Environmentally friendly

- **Disadvantages**
  - Low metal removal rate
  - Due to stay cutting accuracy is affected
  - Abrasive powder cannot be reused
  - Tapper is also a problem

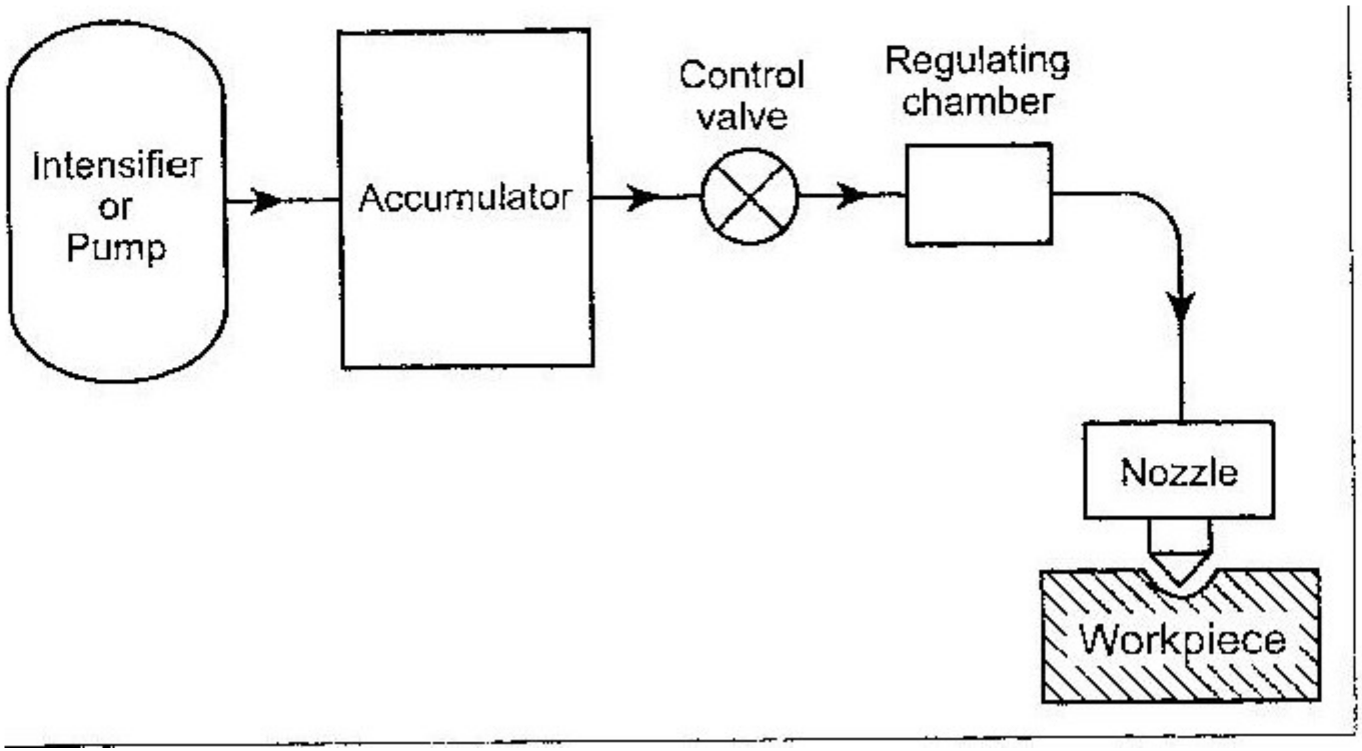
WATER JET MACHINING

- Water jet cutting can reduce the costs and speed up the processes by eliminating or reducing expensive secondary machining process.
- Since no heat is applied on the materials, cut edges are clean with minimal burr.
- Problems such as cracked edge defects,Crystallization, hardening, reduced weald ability and machinability are reduced in this process.
- Water jet technology uses the principle of pressurizing water to extremely high pressures,and allowing the water to escape through a very small opening called “orifice” or “jewel”.

WATER JET MACHINING

- Water jet cutting uses the beam of water exiting the orifice to cut soft materials.
- This method is not suitable for cutting hard materials.
- The inlet water is typically pressurized between1300 –4000 bars.
- This high pressure is forced through a tiny hole in the jewel, which is typically0.18 to 0.4 mm in diameter.

WATER JET MACHINING



There are **six main process characteristics** to water jet cutting:

- Uses a high velocity stream of Ultra High Pressure Water 30,000–90,000 psi (210–620 MPa) which is produced by an with possible abrasive particles suspended in the stream.

- Is used for machining a large array of materials, including heat-sensitive, delicate or very hard materials.

- Produces no heat damage to workpiece surface or edges.
- Nozzles are typically made of sintering.

- Produces a taper of less than 1 degree on most cuts, which can be reduced or eliminated entirely by slowing down the cut process or tilting the jet.

- Distance of nozzle from workpiece affects the size of the kerf and the removal rate of material. Typical distance is .125 in (3.2 mm).

APPLICATIONS OF WJM

- 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.
- .

• APPLICATIONS OF WJM

- 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.
- Both the produced surface roughness and tolerance depend on the machining speed

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.

ADVANTAGES

- Hazardous airborne dust contamination and waste disposal problems that are common when using other cleaning methods are eliminated.
- There is multiple head processing.
- The process is environmentally safe.
- Simple fixturing eliminates costly and complicated tooling, which reduces turnaround time and lowers the cost.
- Grinding and polishing are eliminated, reducing secondary operation costs.

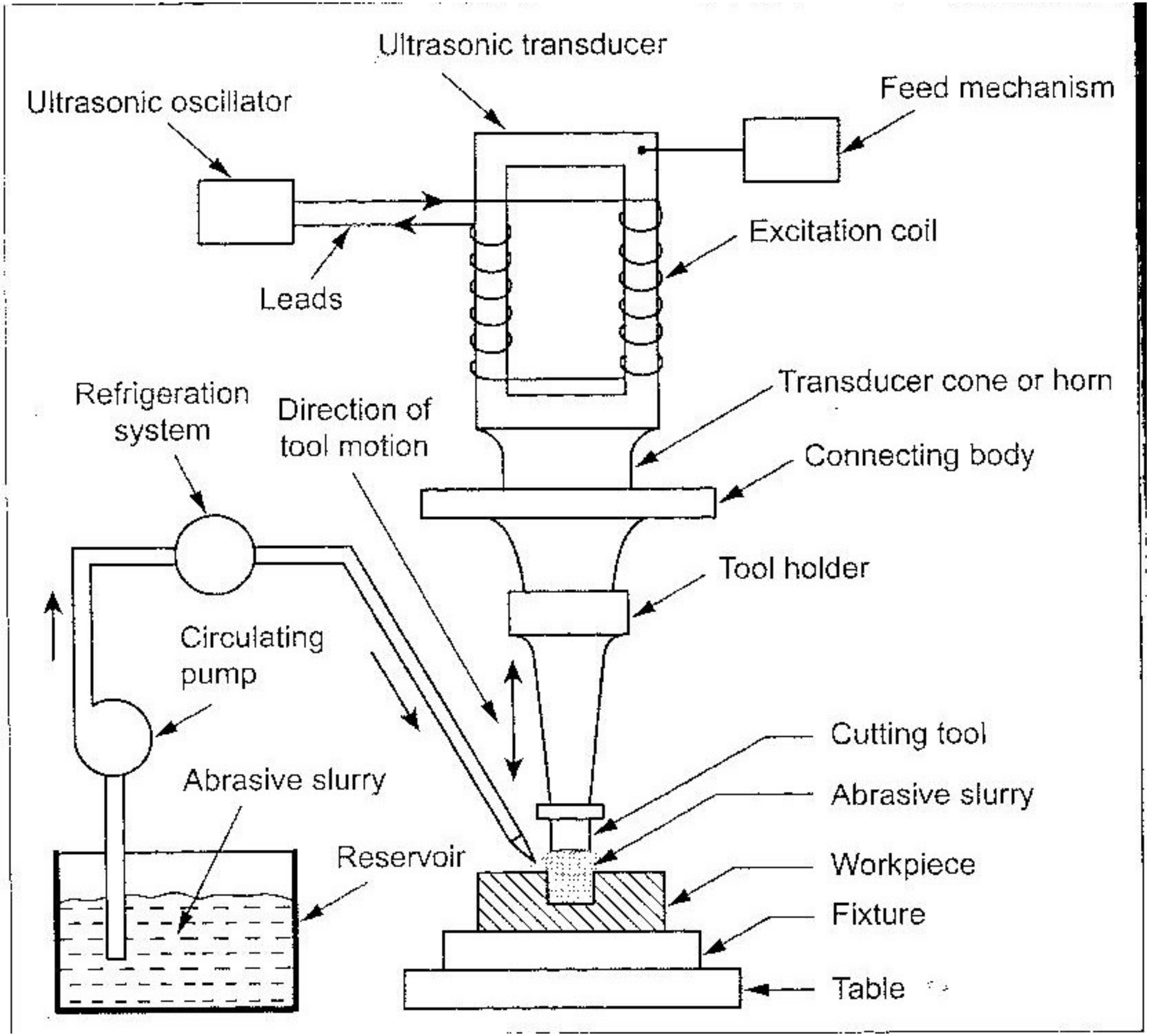
LIMITATIONS

- Very thick 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.

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

• ULTRASONIC MACHINING

- Ultrasonic machining, or strictly speaking "Ultrasonic vibration machining", is a subtraction manufacturing process that removes material from the surface of a part through **high frequency, low amplitude vibrations** of a tool against the material surface in the presence of fine abrasive particles.
- The tool travels vertically or orthogonal to the surface of the part at amplitudes of 0.05 to 0.125 mm (0.002 to 0.005 in.)
- The fine abrasive grains are mixed with water to form a slurry that is distributed across the part and the tip of the tool.
- Typical grain sizes of the abrasive material range from 100 to 1000, where smaller grains (higher grain number) produce smoother surface finishes.


Ultrasonic transducer
Ultrasonic oscillator
Feed mechanism
Excitation coil
Leads
Refrigeration system
Direction of tool motion
Transducer cone or horn
Connecting body
Tool holder
Circulating pump
Abrasive slurry
Reservoir
Cutting tool
Abrasive slurry
Workpiece
Fixture
Table

PRINCIPLE OF ULTRASONIC MACHINING

- During one strike, the tool moves down from its most upper remote position with a starting speed at zero, then it speeds up to finally reach the maximum speed at the mean position.
- Then the tool slows down its speed and eventually reaches zero again at the lowest position.
- When the grit size is close to the mean position, the tool hits the grit with its full speed.
- The smaller the grit size, the lesser the momentum it receives from the tool.
- Therefore, there is an effective speed zone for the tool and, correspondingly there is an effective size range for the grits.

PIEZOELECTRIC TRANSDUCER

- Piezoelectric transducers utilize crystals like quartz whose dimensions alter when being subjected to electrostatic fields.

- The charge is directionally proportional to the applied voltage.

- To obtain high amplitude vibrations the length of the crystal must be matched to the frequency of the generator which produces resonant conditions.

ABRASIVE SLURRY

- The abrasive slurry contains fine abrasive grains. The grains are usually boron carbide, aluminum oxide, or silicon carbide ranging in grain size from 100 for roughing to 1000 for finishing.
- It is used to microchip or erode the work piece surface and it is also used to carry debris away from the cutting area.

- An ultrasonically vibrating mill consists of two major components, a transducer and a sonotrode attached to an electronic control unit with a cable.
- An electronic oscillator in the control unit produces an alternating current oscillating at a high frequency usually between 18 and 40 kHz in the ultrasonic range.
- The transducer usually consists of a cylinder made of piezoelectric ceramic.
- The oscillating voltage is applied to electrodes attached to the transducer, which converts the electrical energy into mechanical vibrations.
- The transducer then vibrates the sonotrode at low amplitudes and high frequencies.
- The sonotrode is usually made of low carbon steel. A constant stream of abrasive slurry flows between t and work piece.
- This flow of slurry allows debris to flow away from the cutting area.

- The slurry usually consists of water (20 to 60% by volume) and boron carbide, aluminum oxide and silicon carbide particles.

- The sonotrode removes material from the work piece by abrasion where it contacts it, so the result of machining is to cut a perfect negative of the sonotrode's profile into the work piece.
- Ultrasonic vibration machining allows extremely complex and non-uniform shapes to be cut into the workpiece with extremely high precision.

Advantages

- Machined all sorts of hard materials
- Produces fine finished and structured results
- Produces less heat
- Various hole cut shapes due to vibratory motion of the tool

Disadvantages

- Requires a higher degree of integrity and skills
- No certified record of radiography
- Unnecessary large grain sizes causes defects
- Additional repairs might be required due to spurious signs and misunderstanding of the process.

APPLICATIONS

It is mainly used for

- drilling
- grinding,
- Profiling
- coining
- piercing of dies
- welding operations on all materials which can be treated suitably by abrasives.

UNIT II THERMAL AND ELECTRICAL ENERGY BASED PROCESS

- **Electric Discharge Machining (EDM)**
- **Wire cut EDM** – Working Principle-equipments-Process -Parameters-Surface Finish and MRR- electrode / Tool – Power and control Circuits-Tool Wear -Dielectric – Flushing –– Applications.
- **Laser Beam machining** and drilling, (LBM),
- **Plasma Arc machining (PAM)** and
- **Electron Beam Machining (EBM).** (Principles – Equipment –Types - Beam control techniques – Applications.)

Electric Discharge Machining (EDM)

- 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.

EDM - WORKING

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

EDM - WORKING

- 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.
- 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 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.

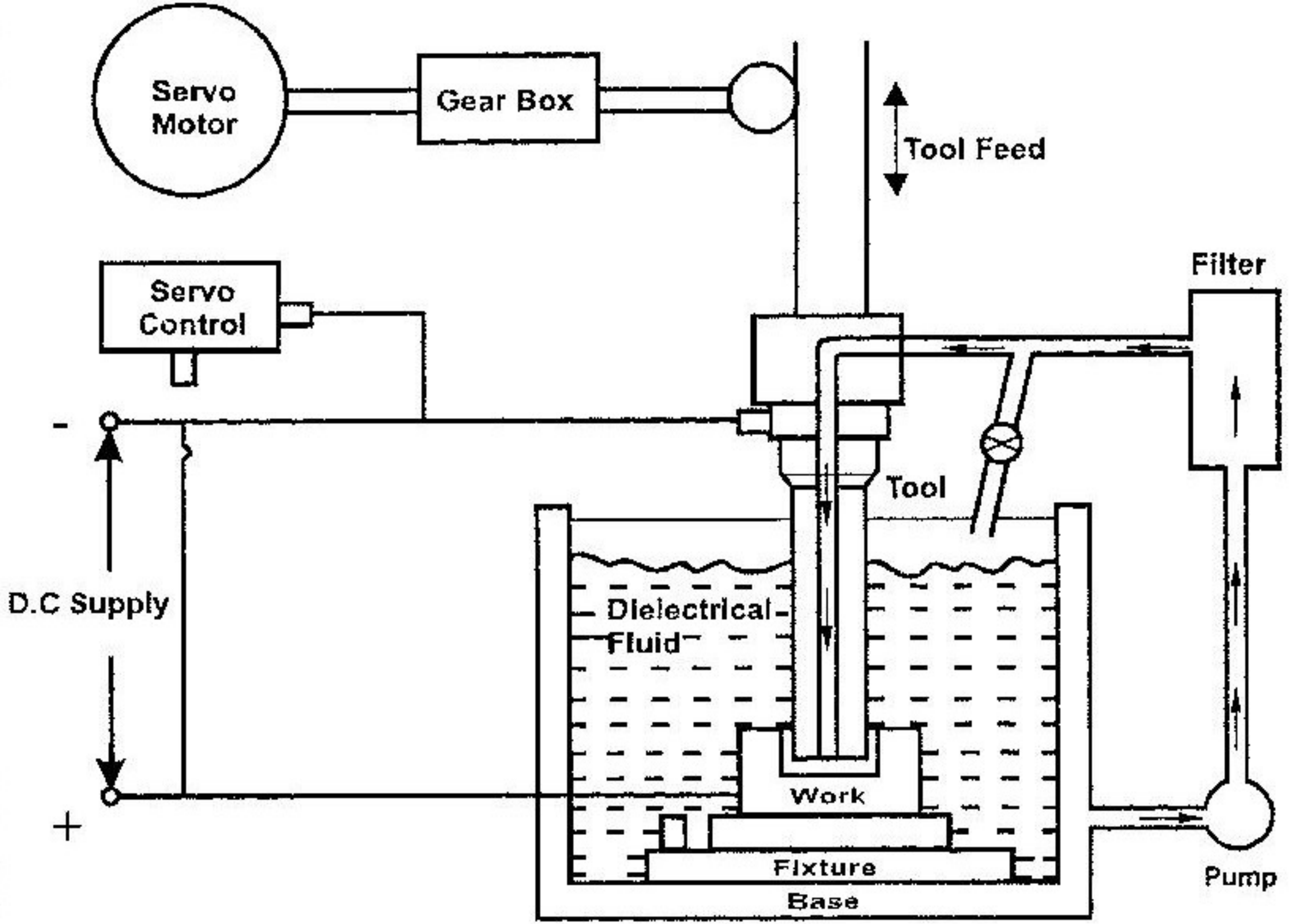


Fig 3.1. Schematic layout of EDM

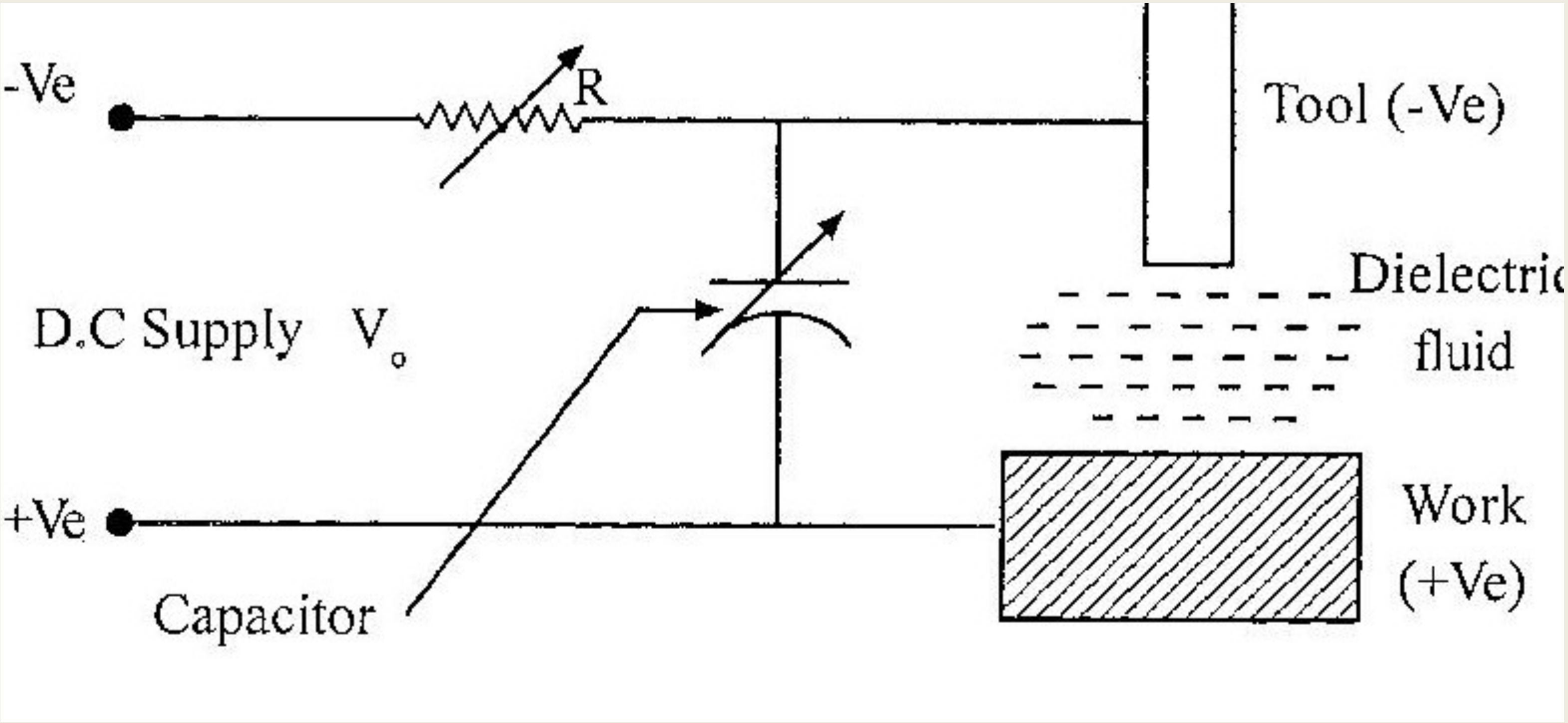
EDM - WORKING

- 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.
- 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

EDM - WORKING

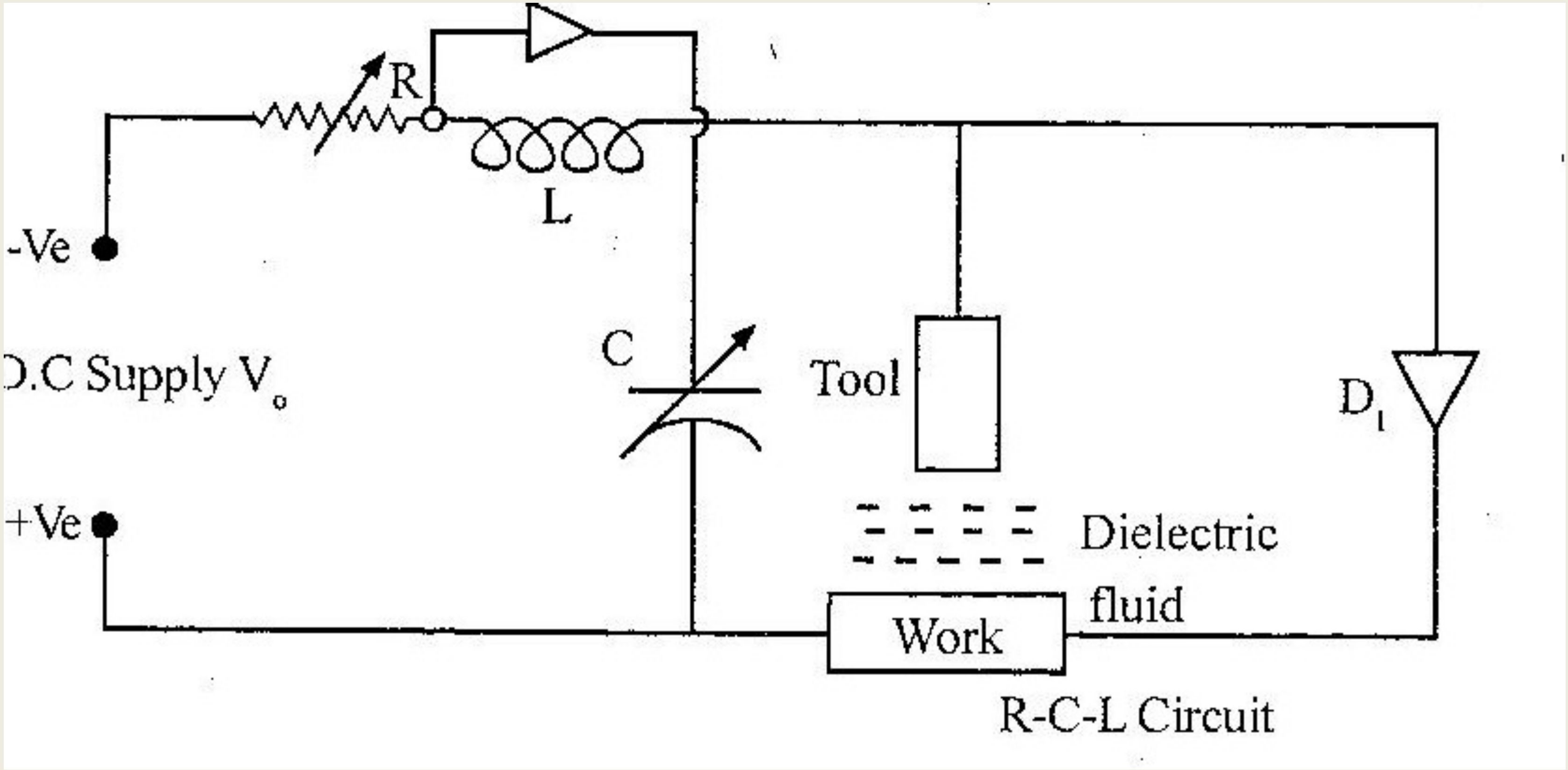
- This is called avalanche motion of electrons.
- Such movement of electrons and ions can be visually seen as a spark.
- Thus the electrical energy is dissipated as the thermal energy of the spark.
- The high speed electrons then impinge on the job and ions on the tool.
- The kinetic energy of the electrons and ions on impact with the surface of the job and tool respectively would be converted into thermal energy or heat flux.

EDM - WORKING



-Ve
R
Tool (-Ve)
D.C Supply V_o
Dielectric
fluid
Work
(+Ve)
+Ve
Capacitor

EDM - WORKING


R
L
-Ve
D.C Supply V_o
+Ve
C
Tool
D_1
Dielectric fluid
Work
R-C-L Circuit

EDM - WORKING

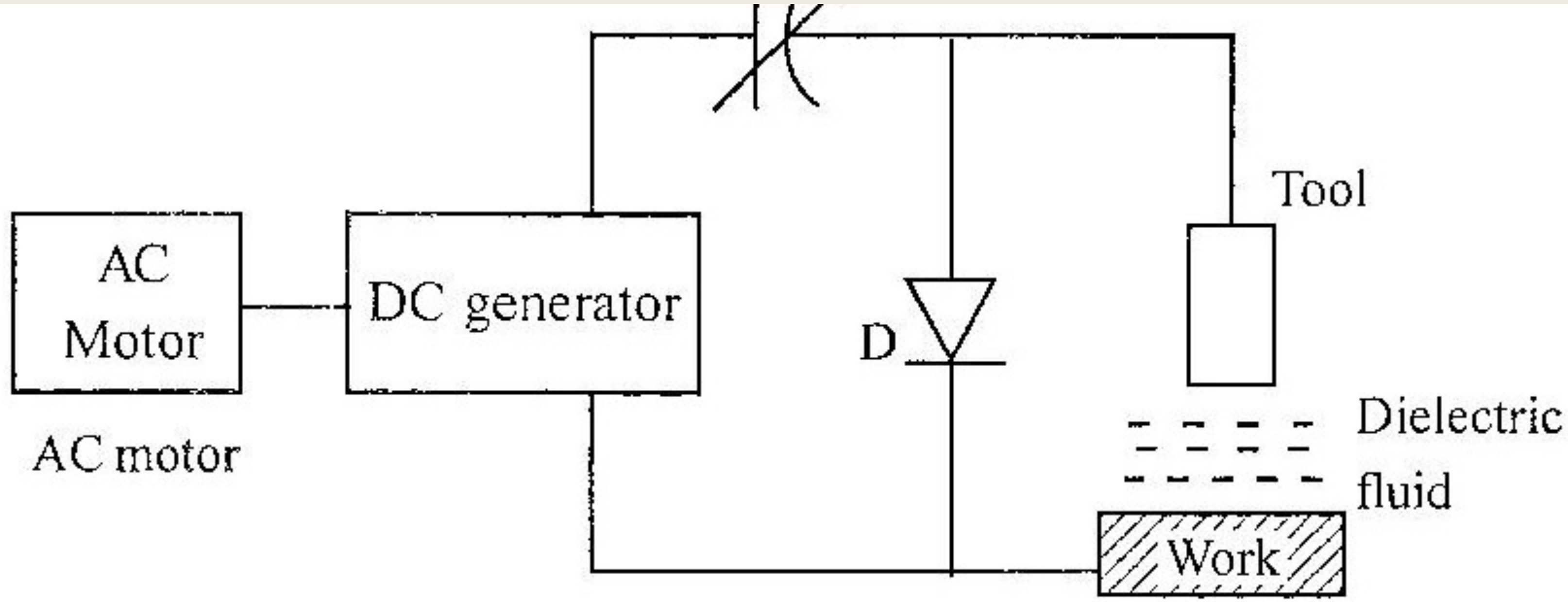


Fig 3.5 Rotary Pulse generator

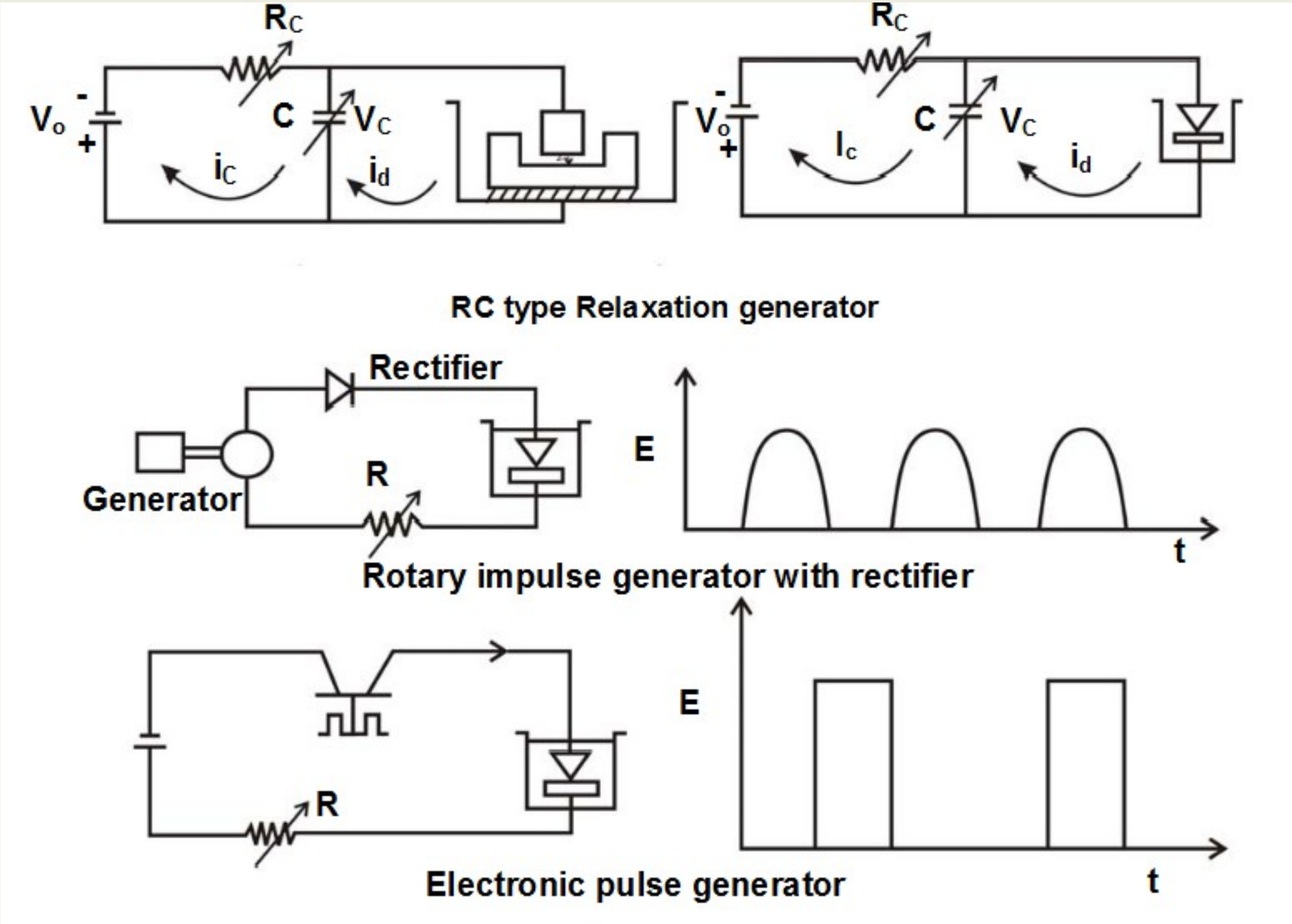
EDM - WORKING

- 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.

EDM - WORKING

- 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.

EDM - WORKING



RC type Relaxation generator

Rotary impulse generator with rectifier

Electronic pulse generator

EDM - WORKING

- In EDM, the generator is used to apply voltage pulses between the tool and the job.
- A constant voltage is not applied.
- Only sparking is desired in EDM rather than arcing.
- Arcing leads to localised material removal at a particular point whereas **sparks get distributed all over the tool surface leading to uniformly distributed material** removal under the tool.

EDM - CHARACTERISTICS

- The process can be used to machine any work material if it is electrically conductive.
- Material removal depends on mainly thermal properties of the work material rather than its strength, hardness etc.
- In EDM there is a physical tool and geometry of the tool is the positive impression of the hole or geometric feature machined.
- The tool has to be electrically conductive as well. The tool wear once again depends on the thermal properties of the tool material.
- 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.

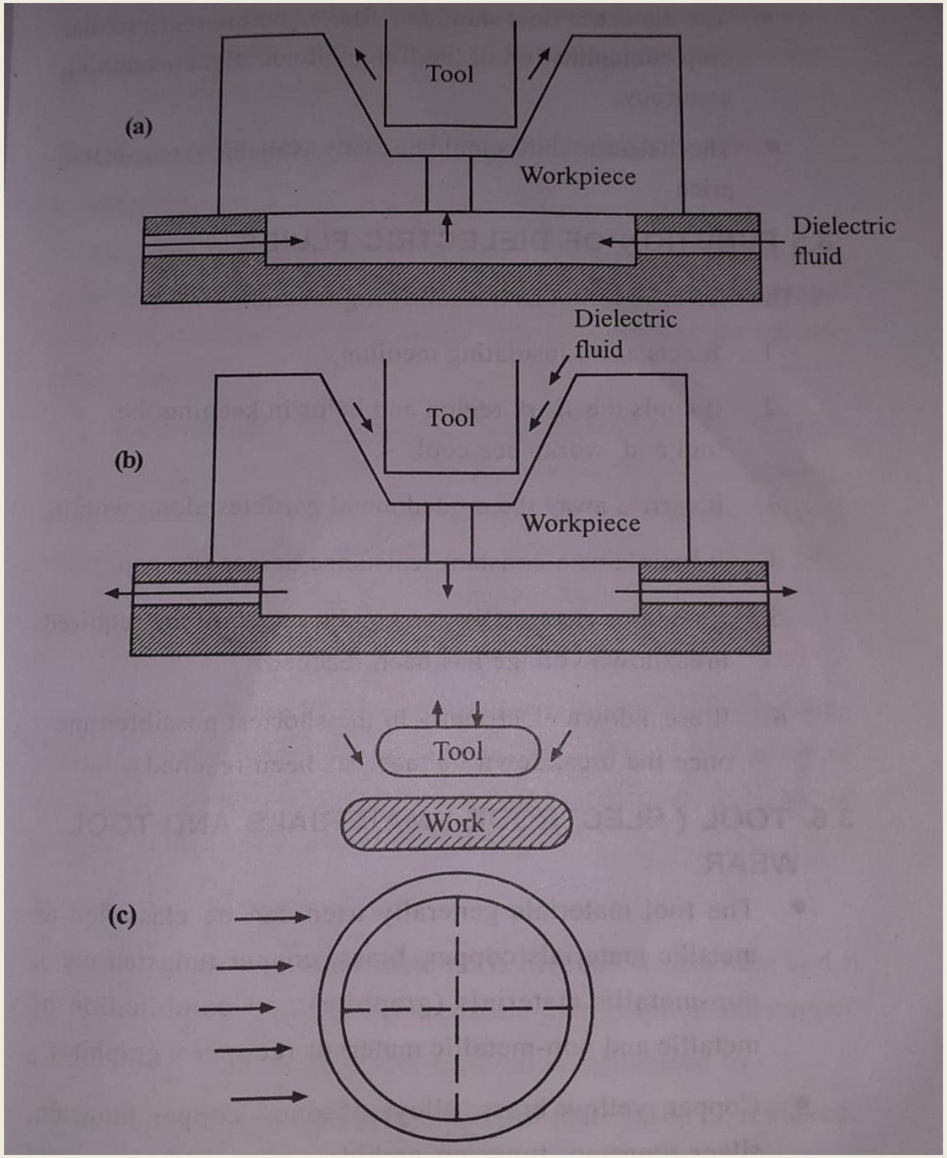
EDM – DIELECTRIC FLUID

- 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 ionise when electrons collide with its molecule.
- Moreover, during sparking it should be thermally resistant as well.

EDM – DIELECTRIC FLUID

- 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.

EDM – DIELECTRIC FLUID – Flushing System



(a) PRESSURE FLUSHING (b) SUCTION FLUSHING (c) SIDE FLUSHING

EDM – DIELECTRIC FLUID - Function

- It acts as a **insulating medium**
- It **cools the spark region** and helps in keeping the tool and work piece.
- It carries the eroded materials /particles along the fluid.
- It remains **electrically non conductive** until the required break down voltage has been reached.

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 tailoring or 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.

EDM – ELECTRODE CHARACTERISTICS

- 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
- Higher density – for the same heat load and same tool wear by weight there would be less volume removal or tool wear and thus less dimensional loss or inaccuracy
- 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

EDM – ELECTRODE MATERIALS

The followings are the different electrode materials which are used commonly in the industry:

- Graphite
- Electrolytic oxygen free copper
- Tellurium copper
- Brass
- Copper –graphite
- Copper -tungsten

EDM – PROCESS PARAMETER

1. Operating parameters

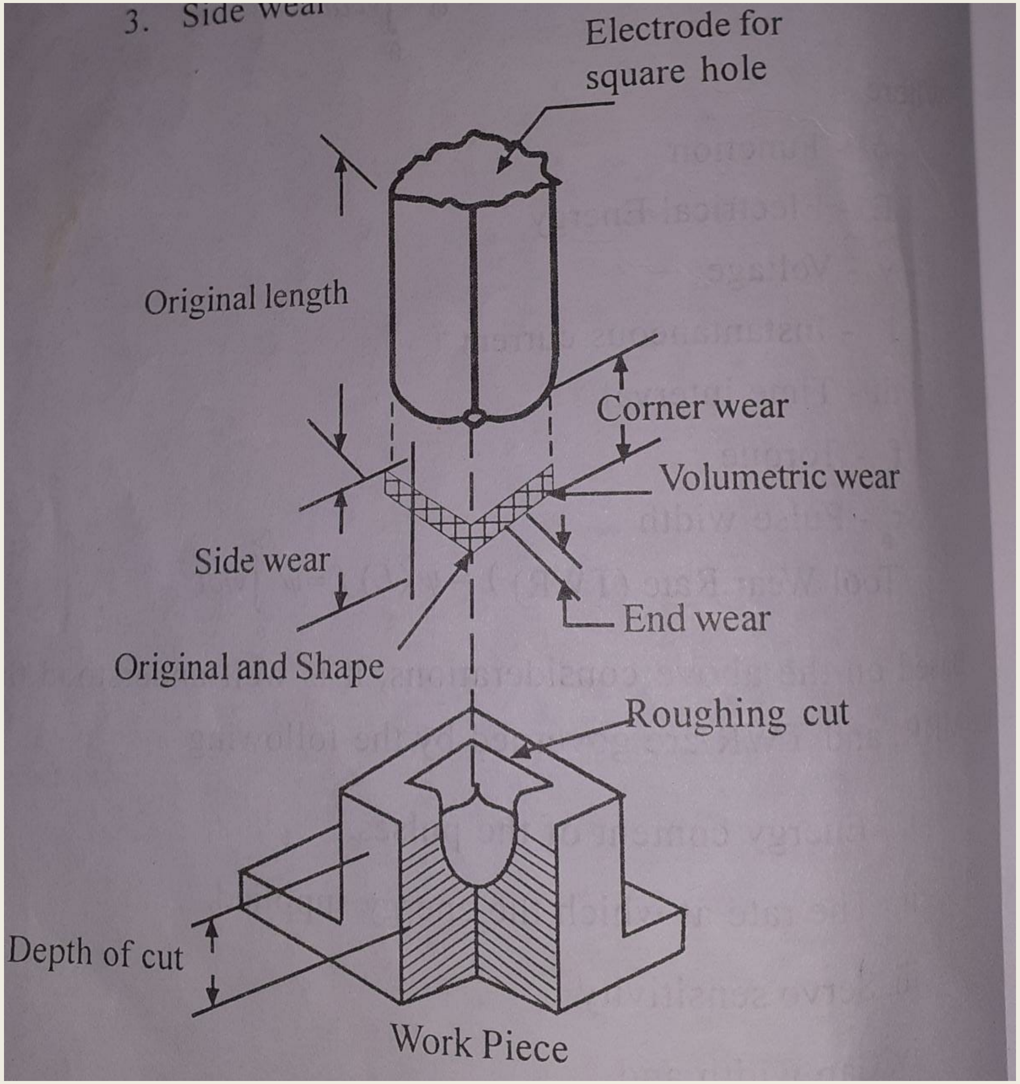
Operating parameters involves the removal of metal from the workpiece and tool as a measure of electrical energy input.

- End wear
- Corner wear
- Side wear

Tool wear Rate is required to calculate tooling cost, machining accuracy and time of machining.

EDM – PROCESS PARAMETER

1. Operating parameters



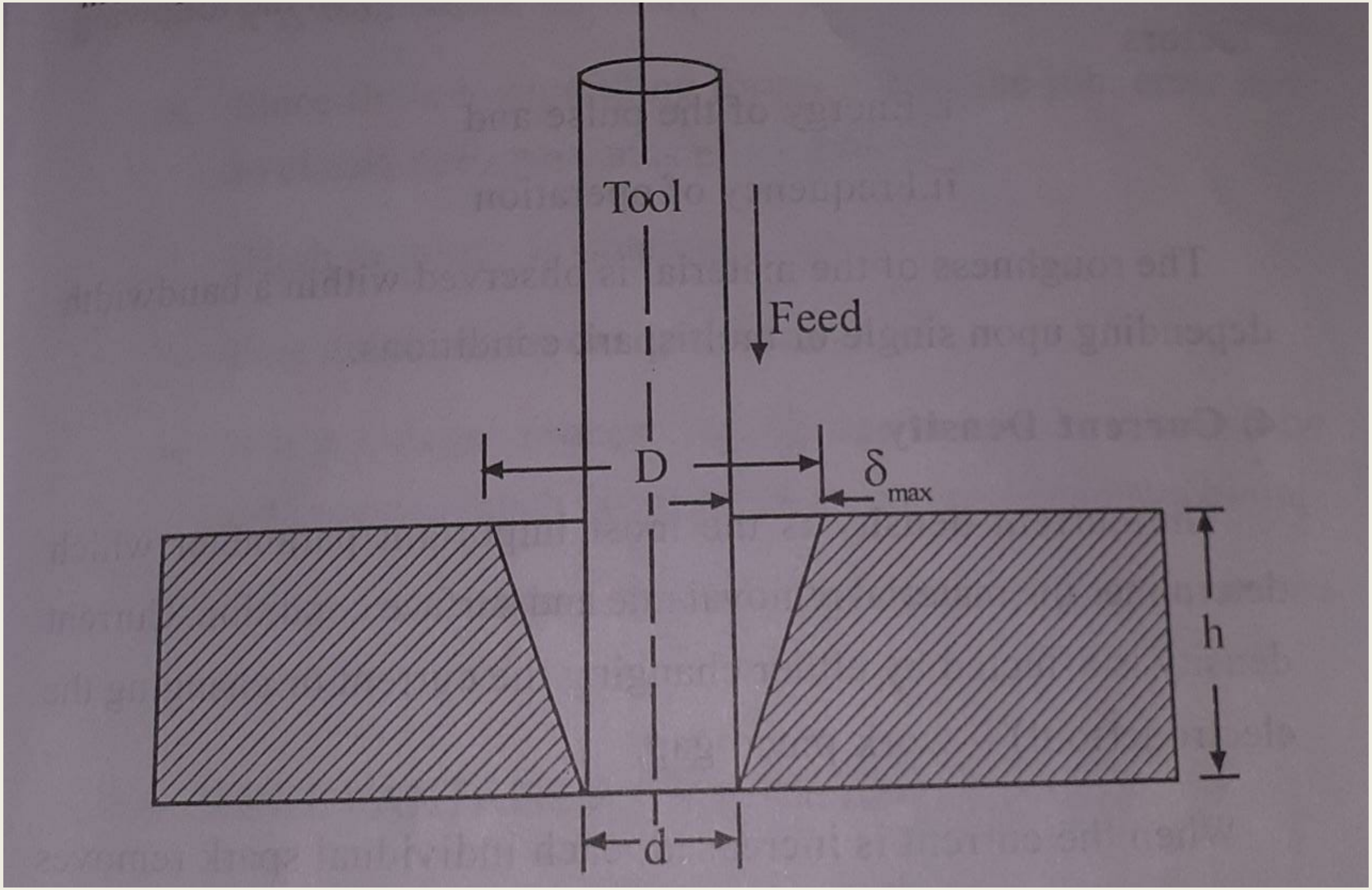
EDM – PROCESS PARAMETER

2. Taper.

- Tapering effect is observed due to the side sparks .
- Under high dielectric pollution, side sparks are more pronounced as compared to frontal sparks.

EDM – PROCESS PARAMETER

2. Taper.



EDM – PROCESS PARAMETER

3. Surface finish:

- Surface finish of the material depends upon the following factors
  1. Energy of the pulse
  2. Frequency of the operation

The roughness of the material is observed within a band width depending upon single or multi spark conditions.

EDM – PROCESS PARAMETER

4.Current Density:

- Determines the MRR and surface condition.
- Current density is affected by either by changing the current or changing the electrode to workpiece gap.
- Increasing spark-Decreasing surface Roughness
- Small gap produces more accuracy with better surface finish and slower removal rate.

EDM – APPLICATION

- Production of complicated and irregular shaped profiles.
- Thread cutting in Jobs.
- Drilling of micro Holes.
- Helical profile Drilling
- Curved Hole Drilling
- Resharpening of cutting tools and broaches.
- Remachining of Die cavities without annealing.

EDM – ADVANTAGES

- Gives good surafce finish
- High accuracy is obtained
- Fine holes can be easily drilled.
- Well suited for complicated components.
- It does not leave any chips or burs on the work piece
- Machining of very thin section is possible.
- No cutting forces – eliminates error due to plastic deformation
- Quicker process (hard materials easily machined)
- For machining conductive materials like tungsten carbides, etc.,

EDM – DISADVANTAGES

- Only for machining small work pieces.
- Problems- Electrode wear and overcut.
- MRR is low.
- Power consumption is high.
- Suitable only for conductive materials(non metallics cannot be machined ex. Plastics, Ceramics,etc.,)
- Micro cracks in the metal surface.

UNIT II THERMAL AND ELECTRICAL ENERGY BASED PROCESS

- **Electric Discharge Machining (EDM)**
- **Wire cut EDM** – Working Principle-equipments-Process -Parameters-Surface Finish and MRR- electrode / Tool – Power and control Circuits-Tool Wear -Dielectric – Flushing –– Applications.
- **Laser Beam machining** and drilling, (LBM),
- **Plasma Arc machining (PAM)** and
- **Electron Beam Machining (EBM).** (Principles – Equipment –Types - Beam control techniques – Applications.)

WIRE CUT – ELECTRICAL DISCHARGE MACHINING

- Construction
- Working
- Advantages
- Disadvantages
- Applications
- Characteristics of EDM

WIRE CUT – EDM - Construction

- Workpiece movement control unit
- Workpiece mouting table
- Wire drive section for accurately moving the wire at constant section.
- Dielectric fluid supply unit
- Power supplying unit.

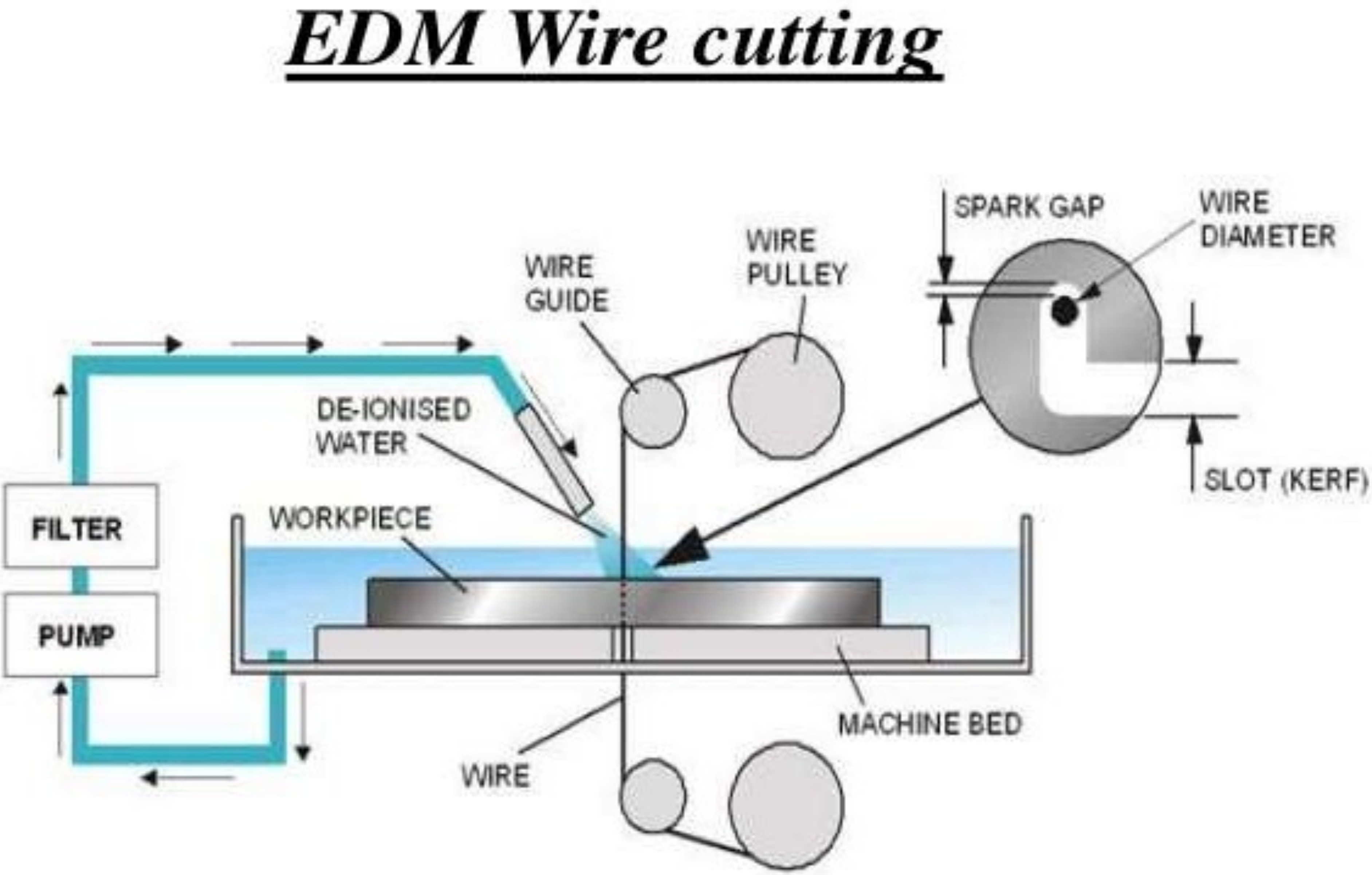
WIRE CUT – EDM - PRINCIPLE

- Controlled metal-removal technique where electric spark used to cut (erode) workpiece.
- Takes shape opposite to that of cutting tool
- Electrode (cutting tool) made from electrically conductive material
- Dielectric fluid surrounds both tool and work
- Servo mechanism gives gap .005 to .001 in. between work and tool
- Direct current of low voltage.

WIRE CUT – EDM

- Uses thin brass or copper wire as electrode
- Makes possible cutting most shapes and contours from flat plate materials.
- Complex shapes: tapers, involutes, parabolas, and ellipses
- Process commonly used for:
  - Machining tungsten carbide,
  - polycrystalline diamond,
  - polycrystalline cubic boron nitride,
  - pure molybdenum,
  - difficult-to-machine material

WIRE CUT – EDM

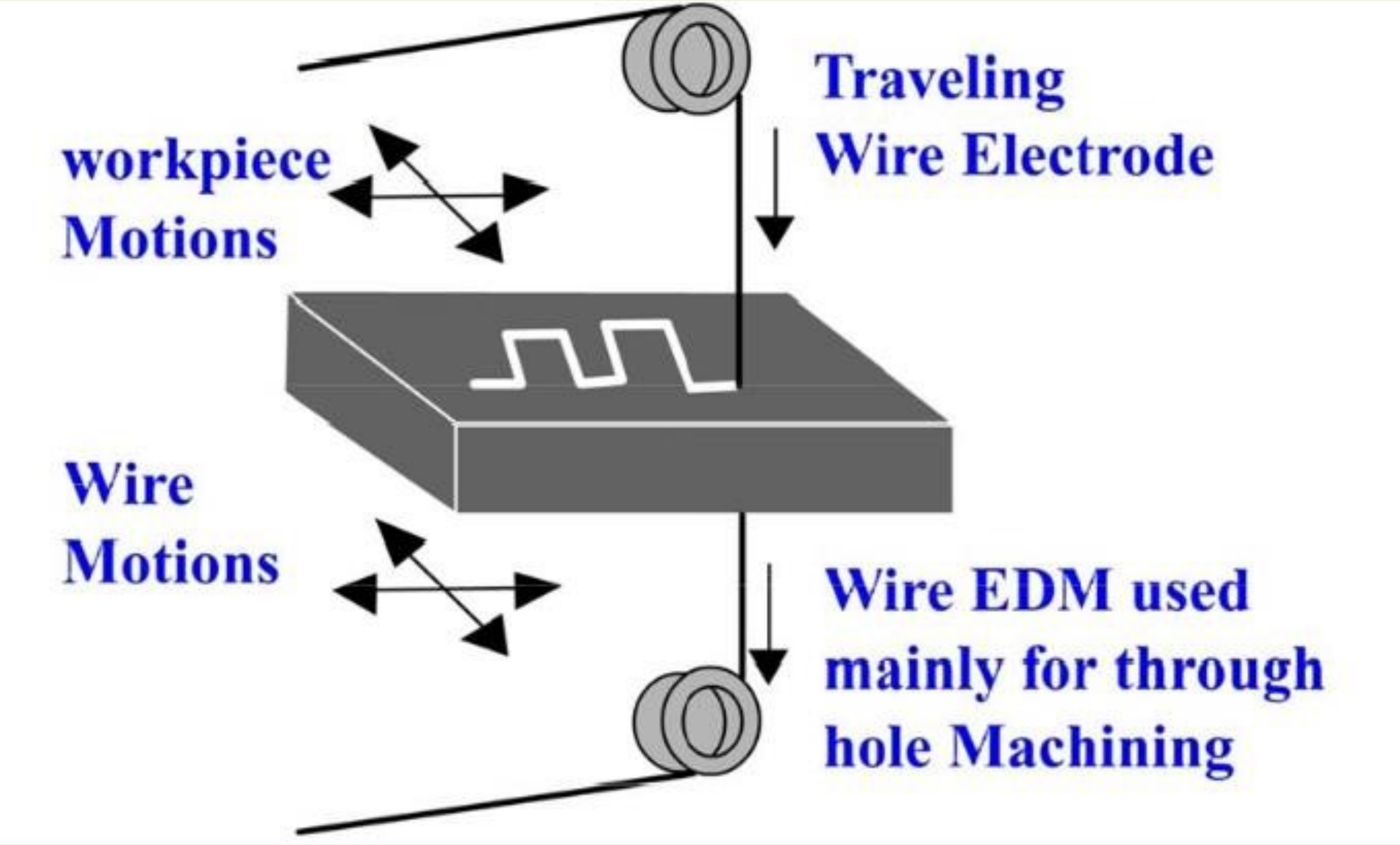

EDM Wire cutting
SPARK GAP
WIRE DIAMETER
WIRE PULLEY
WIRE GUIDE
DE-IONISED WATER
SLOT (KERF)
FILTER
WORKPIECE
PUMP
MACHINE BED
WIRE

WIRE CUT – EDM

Four main operating systems of wire-cut electrical discharge machines

- Servo mechanism
- Dielectric fluid
- Electrode
- Machine control unit

EDM – WIRE CUT


Traveling
Wire Electrode
workpiece
Motions
Wire
Motions
Wire EDM used
mainly for through
hole Machining

WIRE CUT – EDM - Servo Mechanism

- **Servo Mechanism**
- Controls cutting current levels, feed rate of drive motors, and traveling speed of wire
- Automatically maintains constant gap of .001 to
- in. between wire and workpiece Important there be no physical contact
- Advances workpiece into wire, senses work-wire spacing, and slows or speeds up drive motors to maintain proper arc gap

❖ .

WIRE CUT – EDM - Dielectric Fluid

Usually deionized water Serves several functions:

- Helps initiate spark between wire and work
- Serves as insulator between wire and work
- Flushesaway particles of disintegrated wire and work from gap to prevent shorting
- Acts as coolant for both wire and workpiece

WIRE CUT – EDM - Electrode

- Spool of brass, copper, tungsten, molybdenum, or zinc wire ranging from .002 to .012 in. in diameter.
- Continuously travels from supply spool to takeup spool so new wire always in spark area
- Both electrode wear and material-removal rate from workpiece depend on:
  - Material's electrical and thermal conductivity,
  - its melting point and duration and
  - intensity of electrical pulses

WIRE CUT – EDM - Electrode

Characteristics of Electrode Materials

- Be good conductor of electricity
- Have high melting point
- Have high tensile strength
- Have good thermal conductivity
- Produce efficient metal removal from workpiece

WIRE CUT – EDM

- The Wire Electric Discharge Machining (WEDM) is a variation of EDM and is commonly known as wire-cut EDM or wire cutting.
- In this process, a thin metallic wire is fed on-to the workpiece, which is submerged in a tank of dielectric fluid such as de-ionized 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.
- The 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 ransitioning shapes (example: square at the bottom and circle on the top).
- The upper guide can control axis movements in x–y–u–v–i–j–k–l–. This helps in programming the wire-cut EDM,for cutting very intricate and delicate shapes.

EDM – WIRE CUT

- ❖ This helps in programming the wire-cut EDM,for cutting very intricate and delicate shapes.
- ❖ In the wire-cut EDM process, water is commonly used as the dielectric fluid.
- ❖ Filters and de-ionizing units are used for controlling the resistivity and other electrical properties.
- ❖ Wires made of brass are generally preferred. The water helps in flushing away the debris from the cutting zone.
- ❖ The flushing also helps to determine the feed rates to be given for different thickness of the materials.

EDM – WIRE CUT

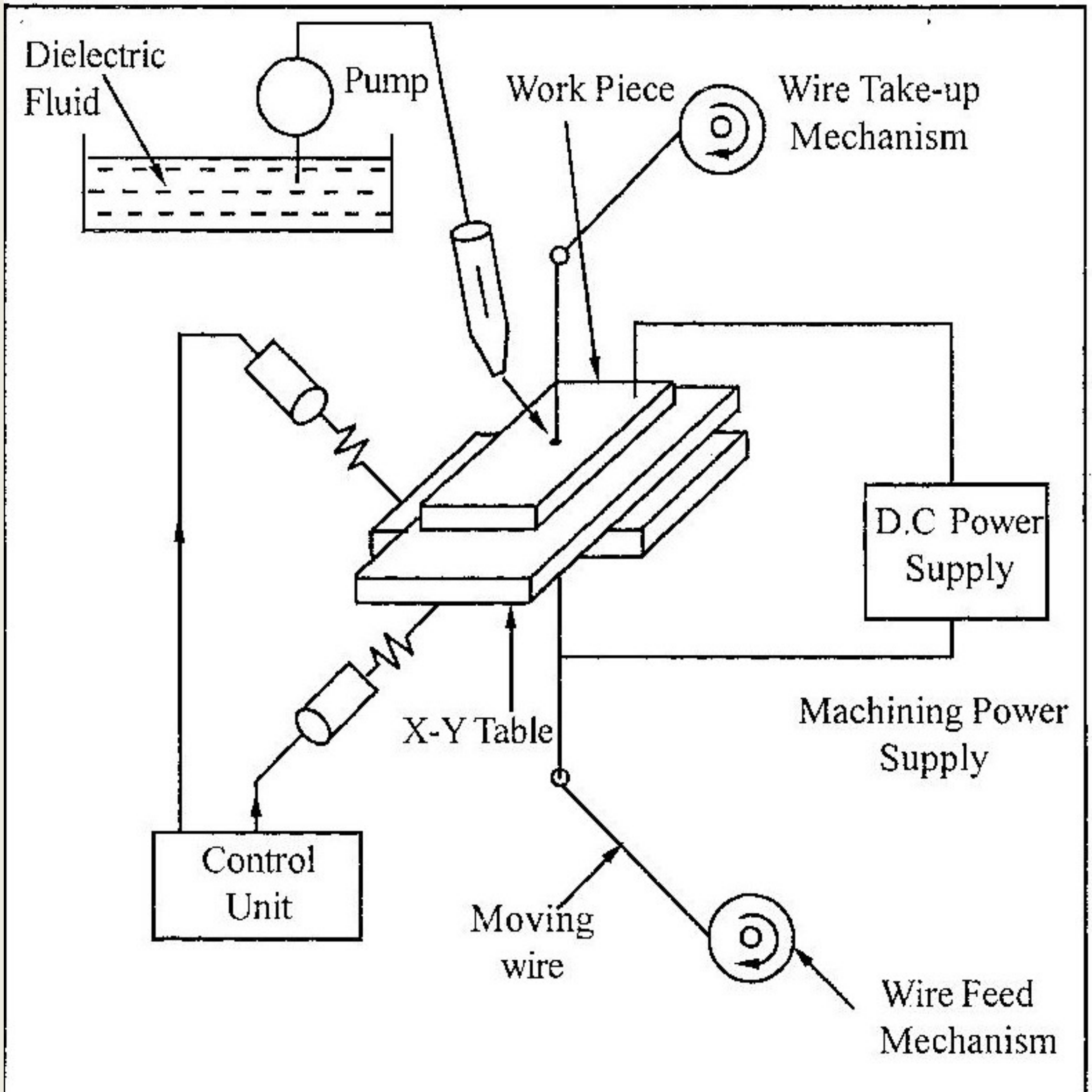


Fig. 3.9 Wire Cut EDM Process

EDM – WIRE CUT

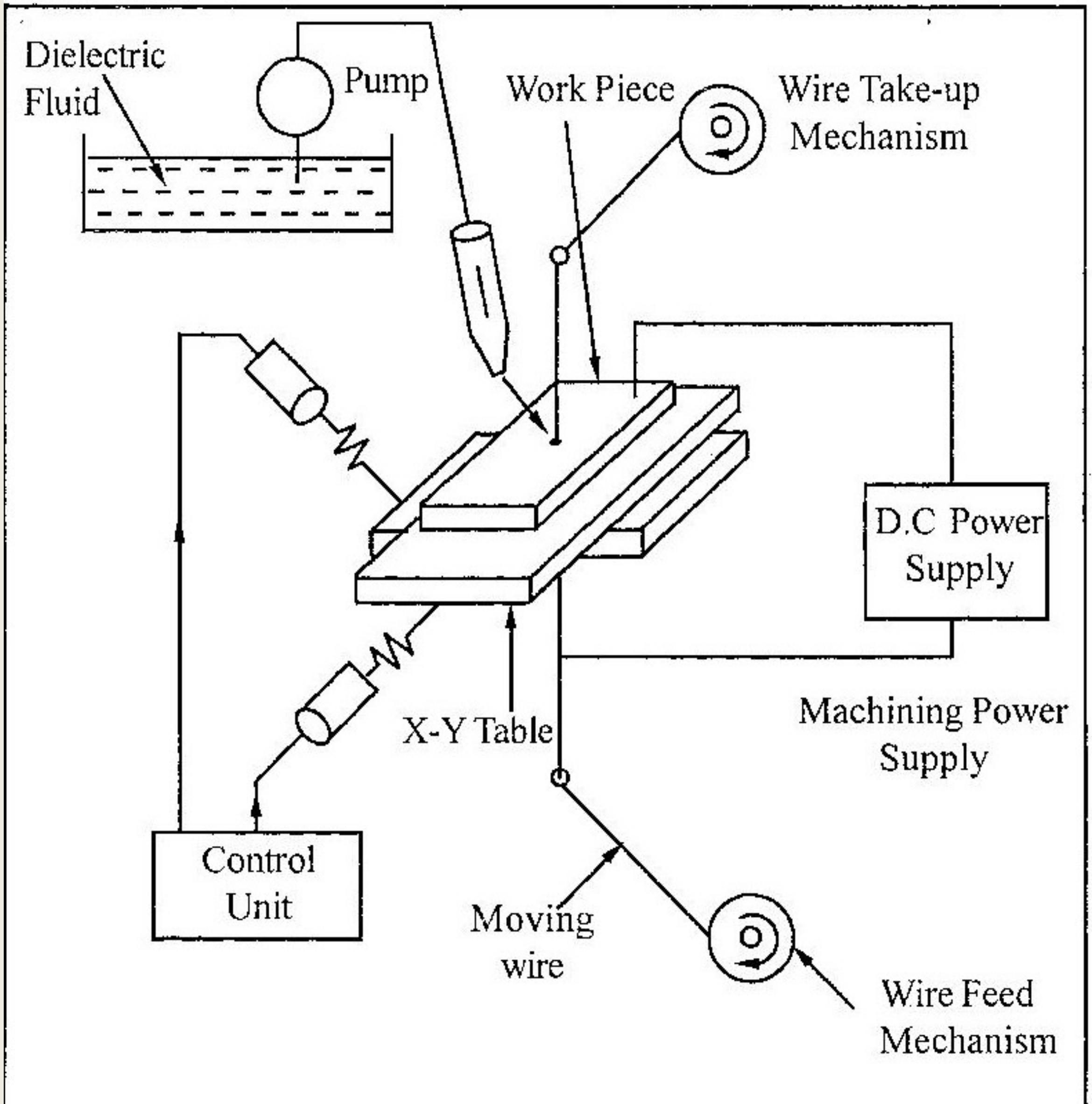


Fig. 3.9 Wire Cut EDM Process

EDM – WIRE CUT – WORKING

- During the EDM process, a metal part is placed into dielectric fluid.
- A wire is fed through the submerged metal component.
- An electric current is sent through the part to create the sparks that will ultimately help form the desired shape of the component.
- When the distance separating the electrodes narrows.
- It increases the intensity of the electric field, and thus increases the strength of the dielectric fluid.

EDM – WIRE CUT

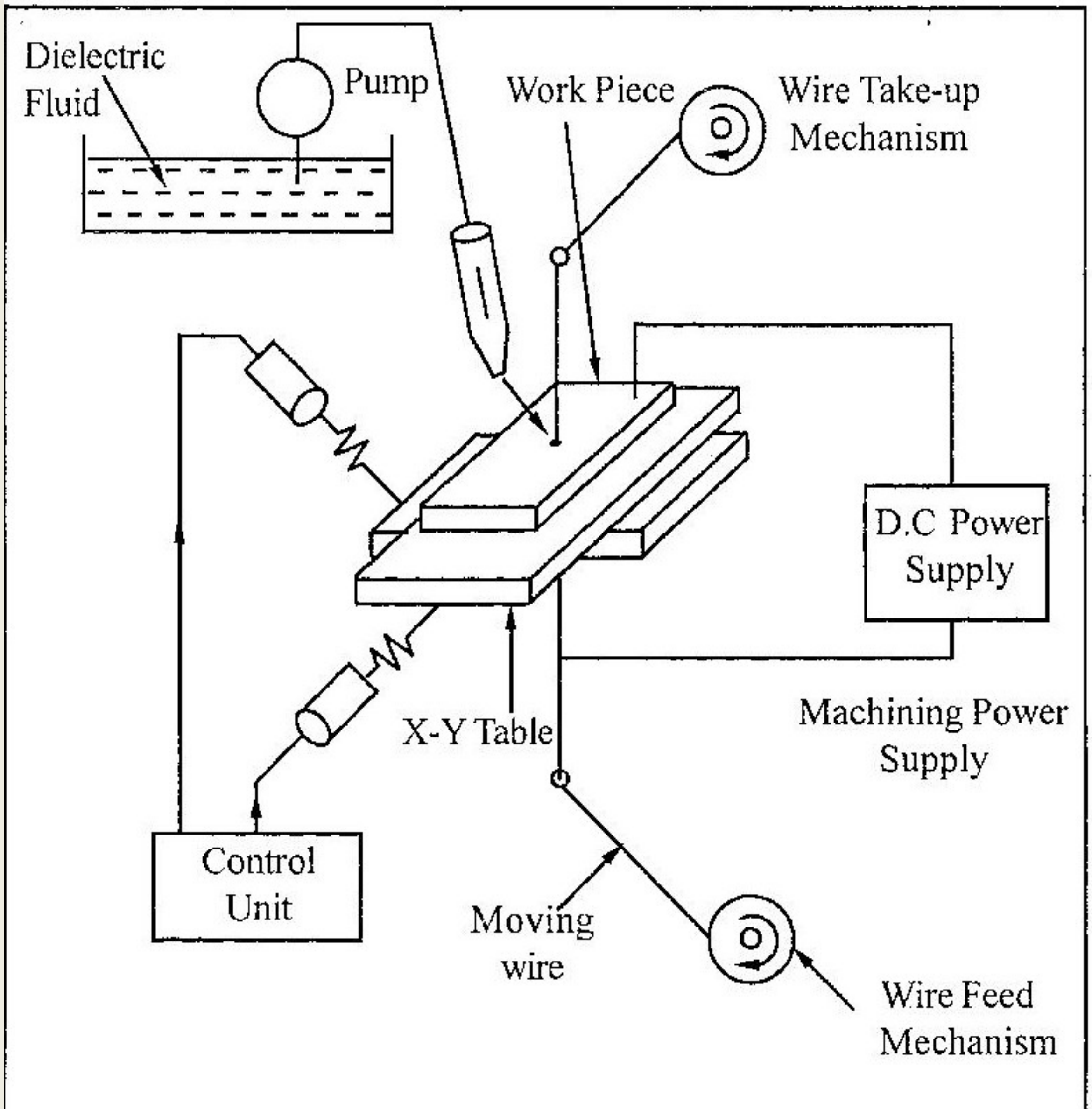
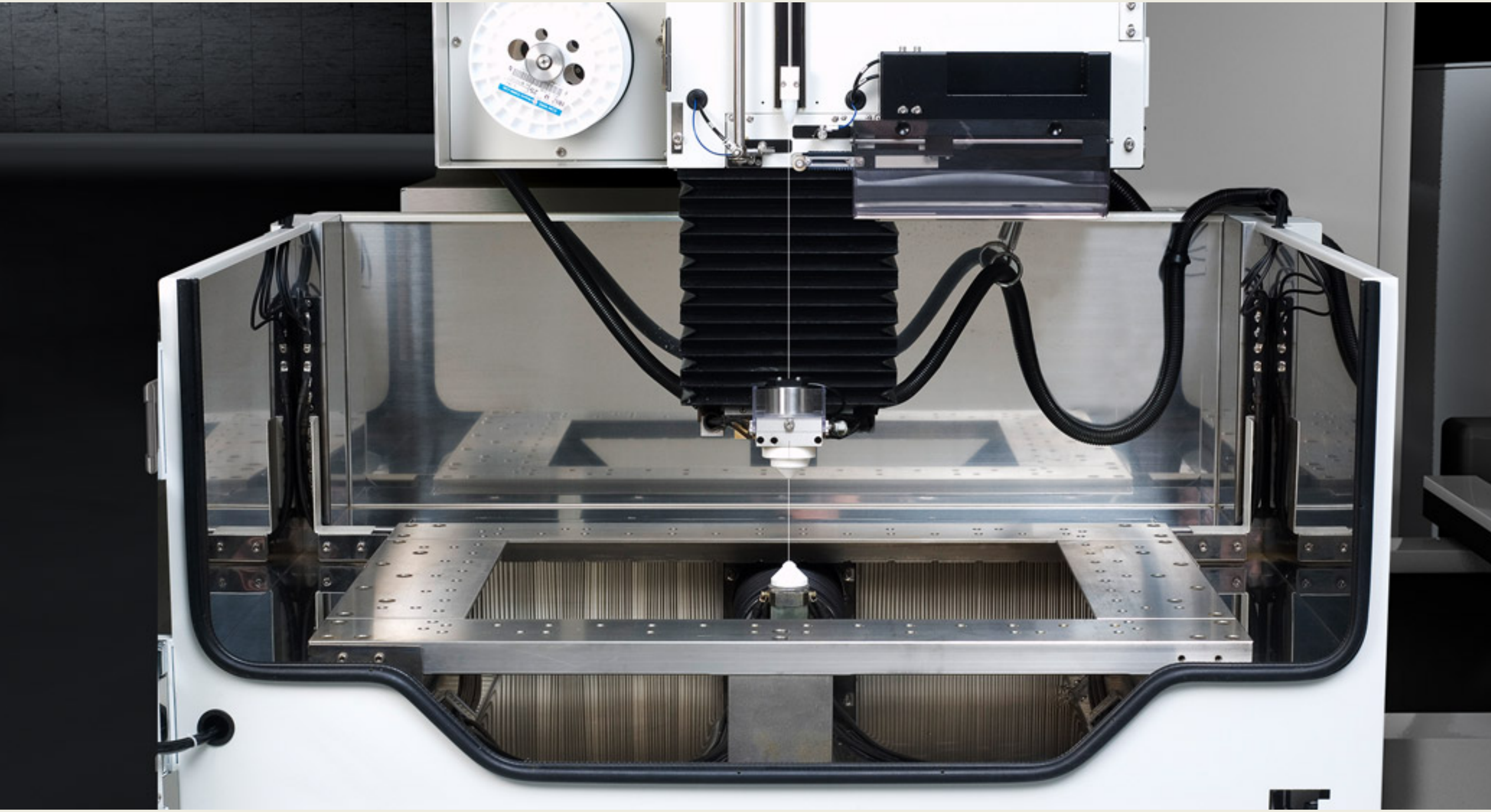
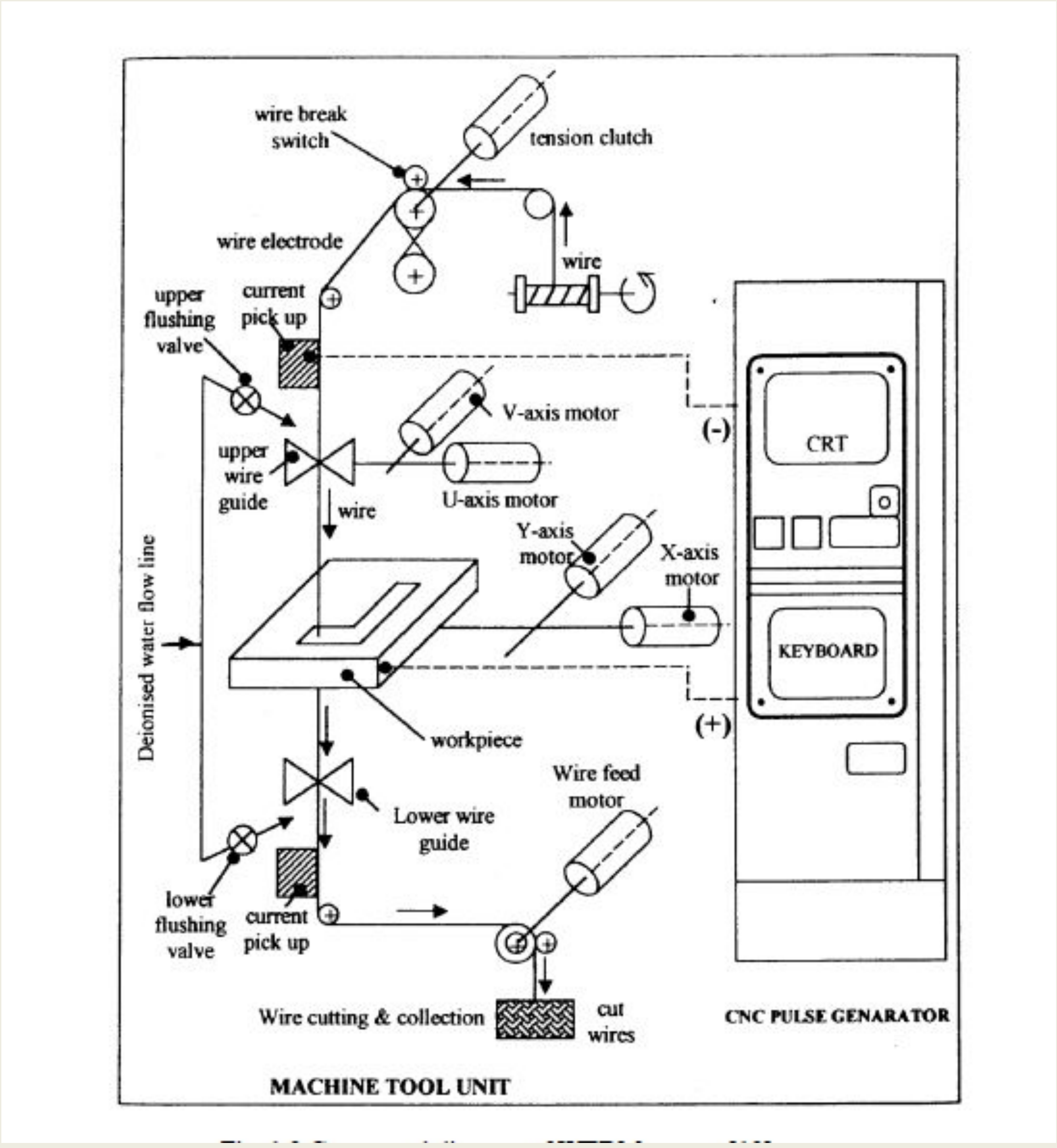


Fig. 3.9 Wire Cut EDM Process

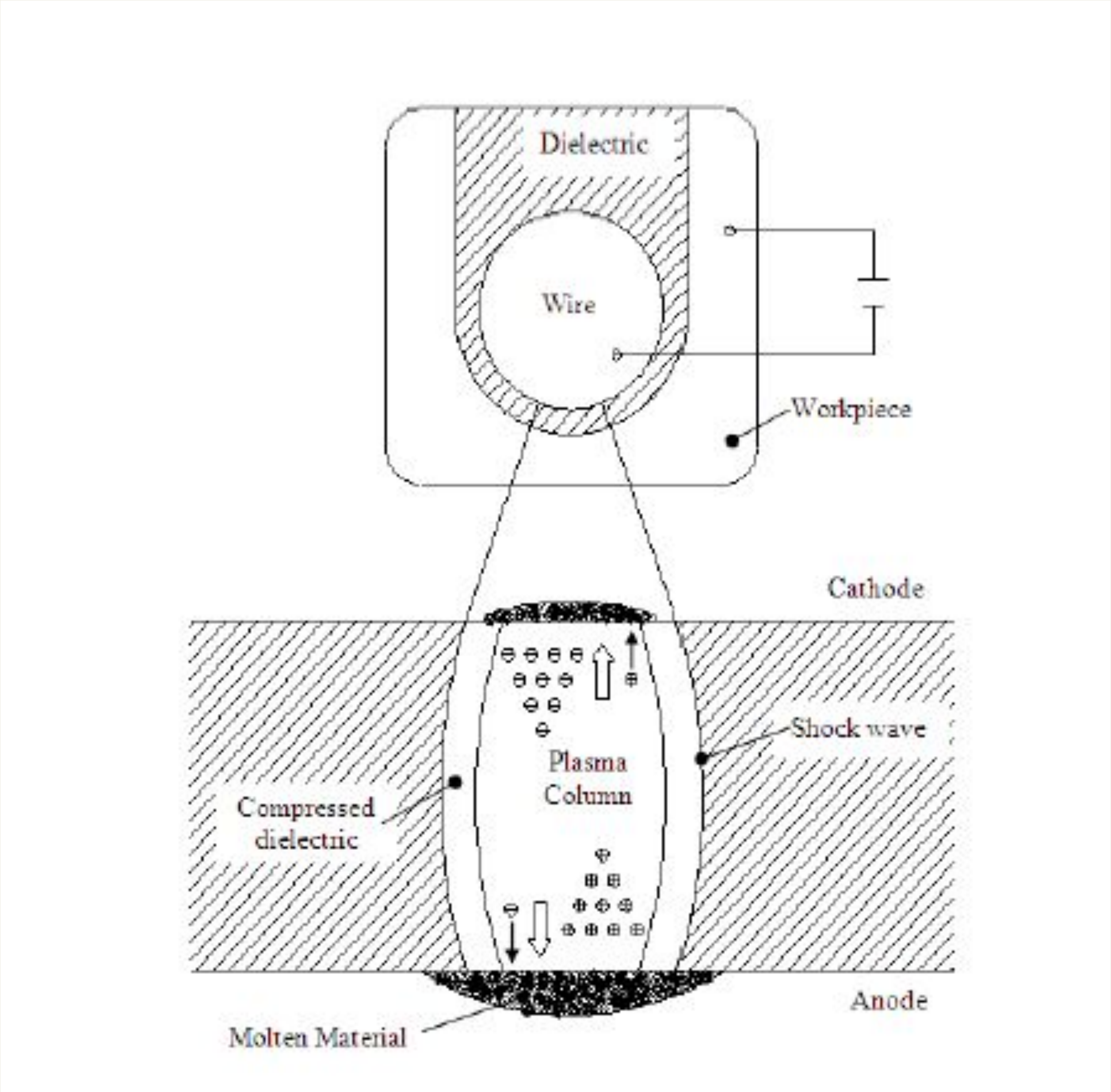
EDM – WIRE CUT



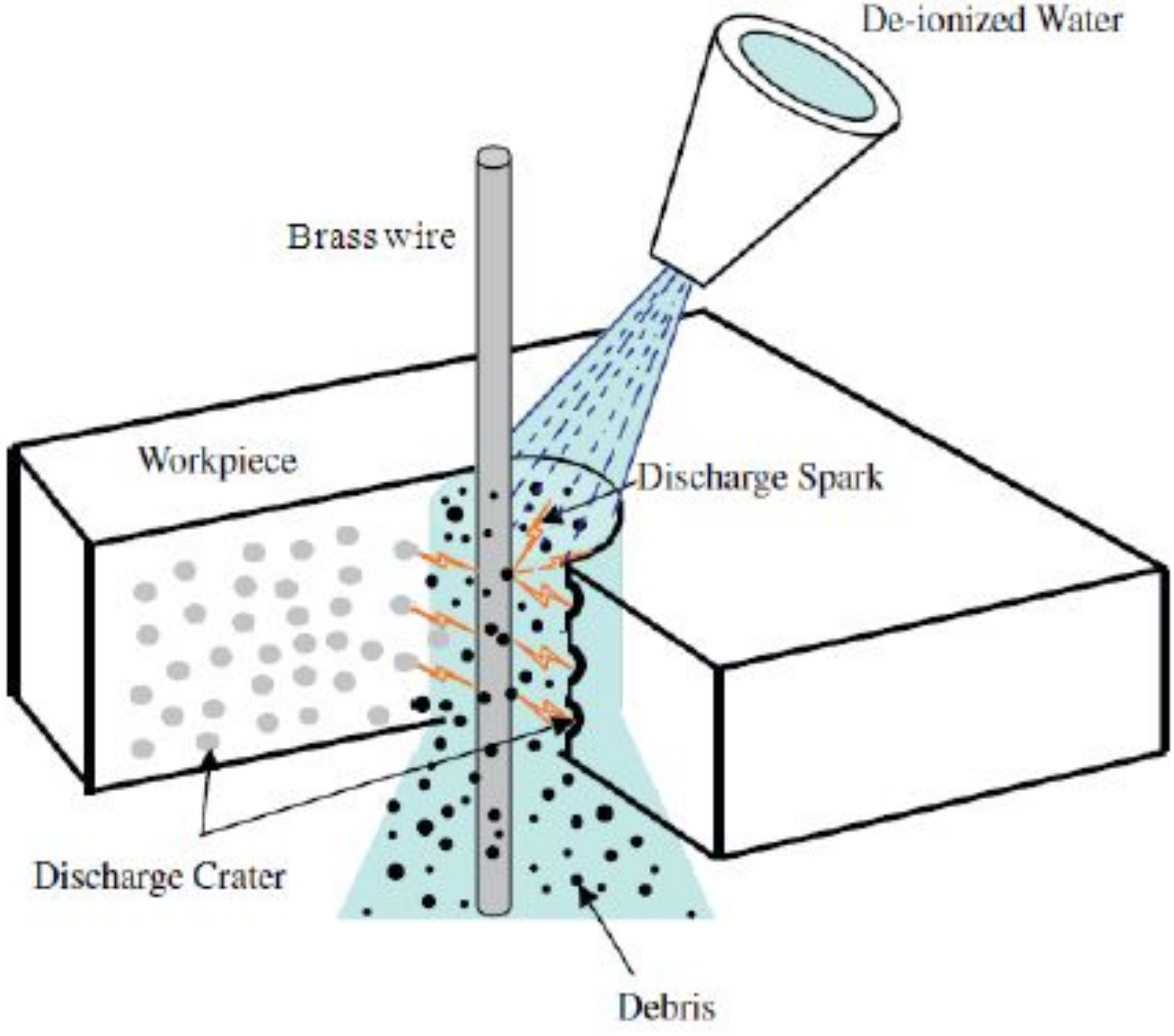
EDM – WIRE CUT


wire break switch
tension clutch
wire electrode
wire
upper flushing valve
current pick up
V-axis motor
(-)
CRT
upper wire guide
U-axis motor
wire
Y-axis motor
X-axis motor
Deionised water flow line
KEYBOARD
workpiece
(+)
Wire feed motor
Lower wire guide
lower flushing valve
current pick up
Wire cutting & collection
cut wires
CNC PULSE GENARATOR
MACHINE TOOL UNIT

EDM – WIRE CUT

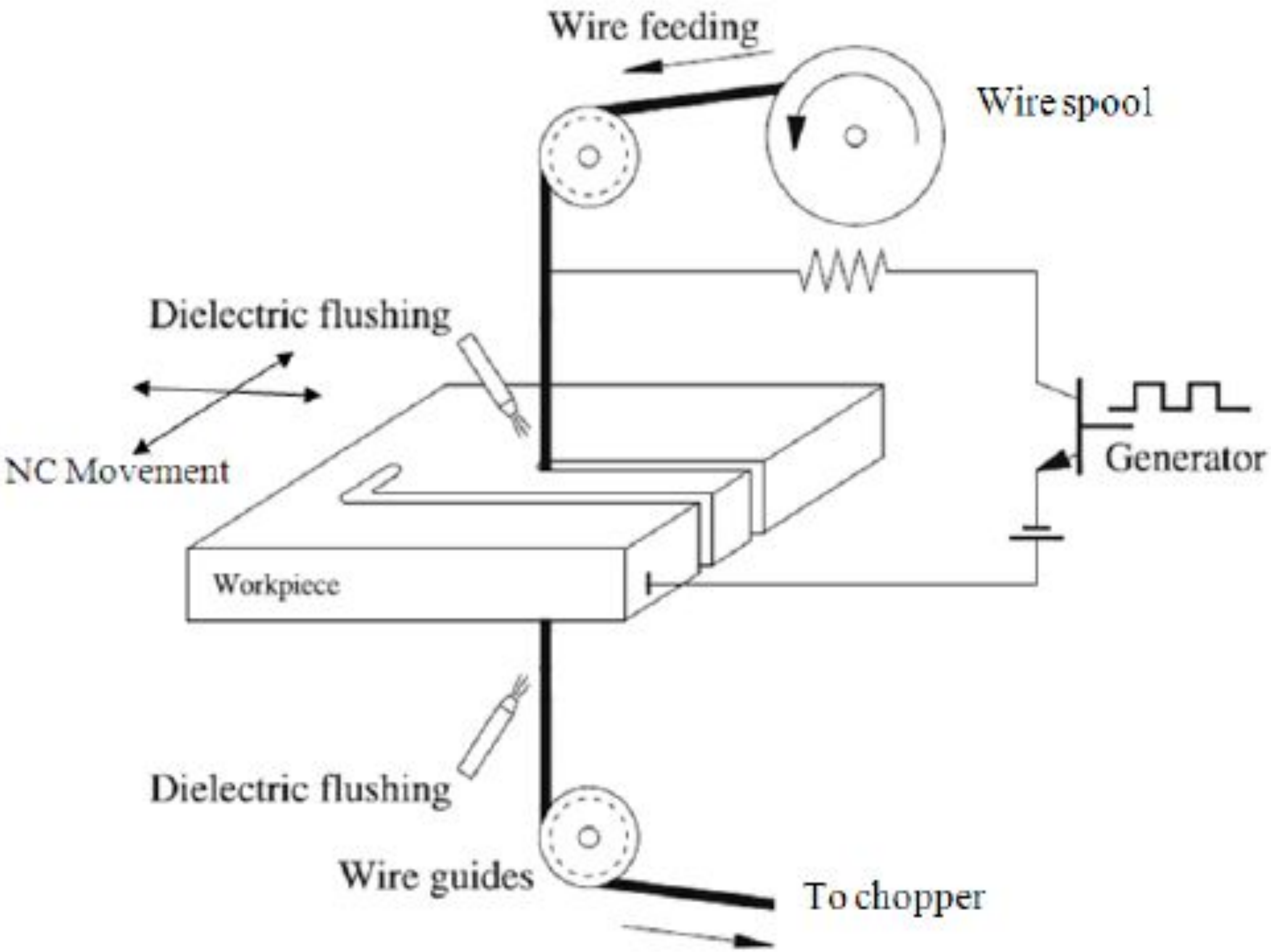

Dielectric
Wire
Workpiece
Cathode
Shock wave
Plasma
Column
Compressed
dielectric
Anode
Molten Material

EDM – WIRE CUT



De-ionized Water
Brass wire
Workpiece
Discharge Spark
Discharge Crater
Debris

EDM – WIRE CUT



Wire feeding
Wire spool
Dielectric flushing
NC Movement
Generator
Workpiece
Dielectric flushing
Wire guides
To chopper

EDM – WIRE CUT – WORKING

- The current more easily passes between the two electrodes under these conditions, leading to the separation of the component from the metal sheet with each spark.
- After the currents have passed through and the desired shape has been achieved, manufacturers will sometimes perform a process called "flushing," using a dielectric liquid to help remove any leftover material or waste from the finished product.

EDM – WIRE CUT - ADVANTAGES

- .Process is burr-free.
- Thin, fragile sections easily machined without deforming.
- Process is automatic – servo mechanism advances electrode into work as metal removed.
- One person can operate several EDM machines at one time.
- Better dies and molds can be produced at lower cost.
- A die punch can be used as electrode to reproduce its shape in matching die plate, complete with necessary clearance.

EDM – WIRE CUT - DISADVANTAGES

- Metal-removal rates are low.
- Material to be machined must be electrically conductive.
- Rapid electrode wear can become costly.
- Electrodes smaller than .003 in. in diameter are impractical

EDM – WIRE CUT - APPLICATIONS

- Wire EDM is most commonly used in mold and die manufacturing processes, particularly for extrusion dies and blanking punches.
- EDM can be used in everything from prototypes to full production runs, and is most often used to manufacture metal components and tools.
- The process is best suited for applications requiring low levels of residual stress.

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Laser Beam Machining (LBM)

Laser Beam Machining – An Introduction

- LASER stands for Light Amplification by Stimulated Emission of Radiation.

- The underline working principle of laser was first put forward by Albert Einstein in 1917 though the first industrial laser for experimentation was developed around 1960s.

- Laser beam can very easily be focused using optical lenses as their wavelength ranges from half micron to around 70 microns.

- Focussed laser beam can have power density in excess of 1 MW/mm^2.

- Laser Beam Machining or more broadly laser material processing deals with machining and material processing like heat treatment, alloying, cladding, sheet metal bending etc.

- Such processing is carried out utilizing the energy of coherent photons or laser beam, which is mostly converted into thermal energy upon interaction with most of the materials.

- As laser interacts with the material, the energy of the photon is absorbed by the work material leading to rapid substantial rise in local temperature. This in turn results in melting and vaporisation of the work material and finally material removal.

- Nowadays, laser is also finding application in regenerative machining or rapid prototyping as in processes like stereo-lithography, selective laser sintering etc.

Laser Beam Machining – The Lasing Process

- Lasing process describes the basic operation of laser, i.e. generation of coherent beam of light by “light amplification” using “stimulated emission”.

- In the model of atom, negatively charged electrons rotate around the positively charged nucleus in some specified orbital paths.

- The geometry and radii of such orbital paths depend on a variety of parameters like number of electrons, presence of neighbouring atoms and their electron structure, presence of electromagnetic field etc. Each of the orbital electrons is associated with unique energy levels.

- At absolute zero temperature an atom is considered to be at ground level, when all the electrons occupy their respective lowest potential energy.

- The electrons at ground state can be excited to higher state of energy by absorbing energy from external sources like increase in electronic vibration at elevated temperature, through chemical reaction as well as via absorbing energy of the photon.

- Fig. 1 depicts schematically the absorption of a photon by an electron. The electron moves from a lower energy level to a higher energy level.

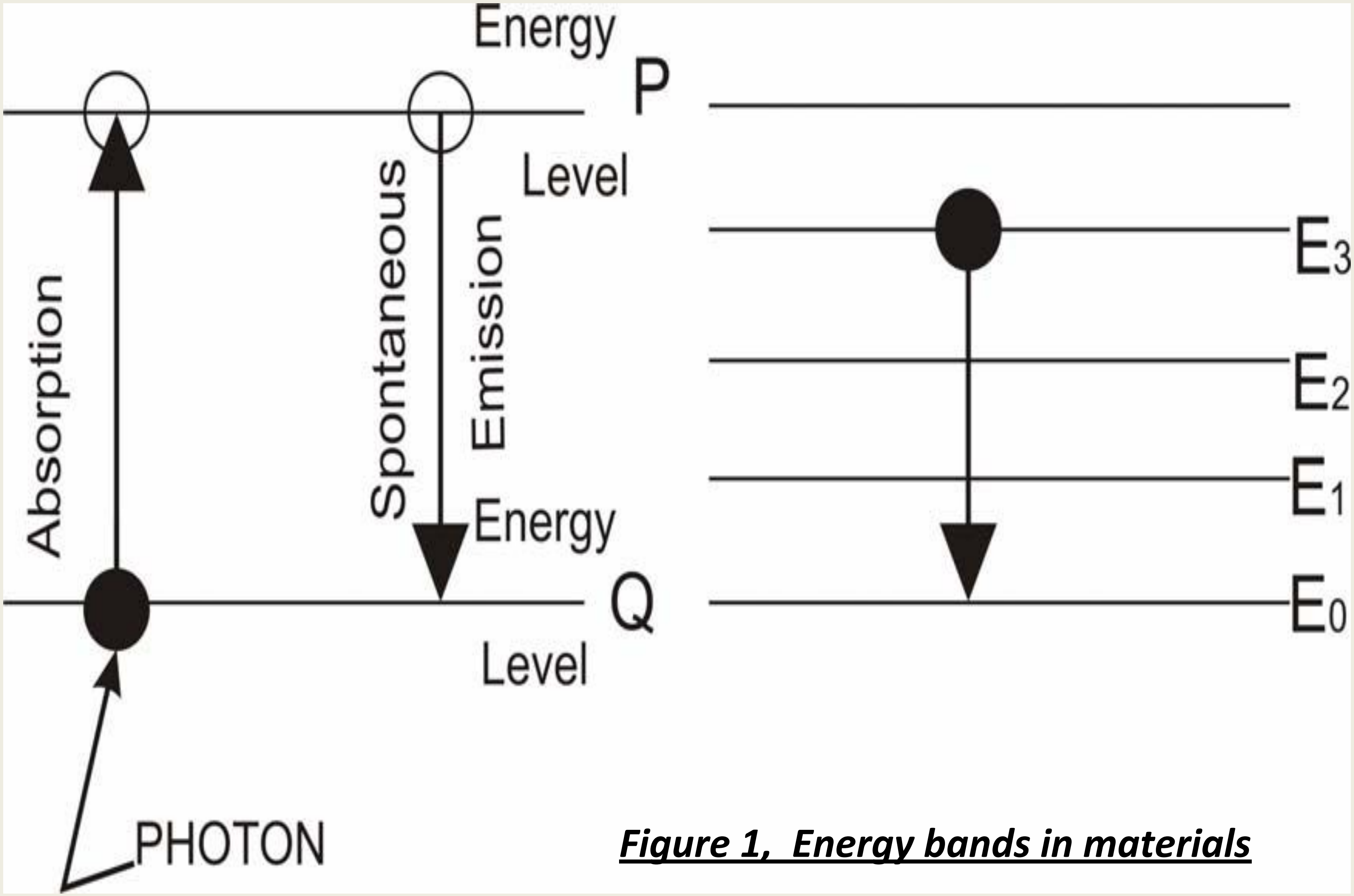

Figure 1, Energy bands in materials

- On reaching the higher energy level, the electron reaches an unstable energy band. And it comes back to its ground state within a very small time by releasing a photon. This is called **spontaneous emission**.

- Schematically the same is shown in Fig. 1 and Fig. 2. The spontaneously emitted photon would have the same frequency as that of the “exciting” photon.

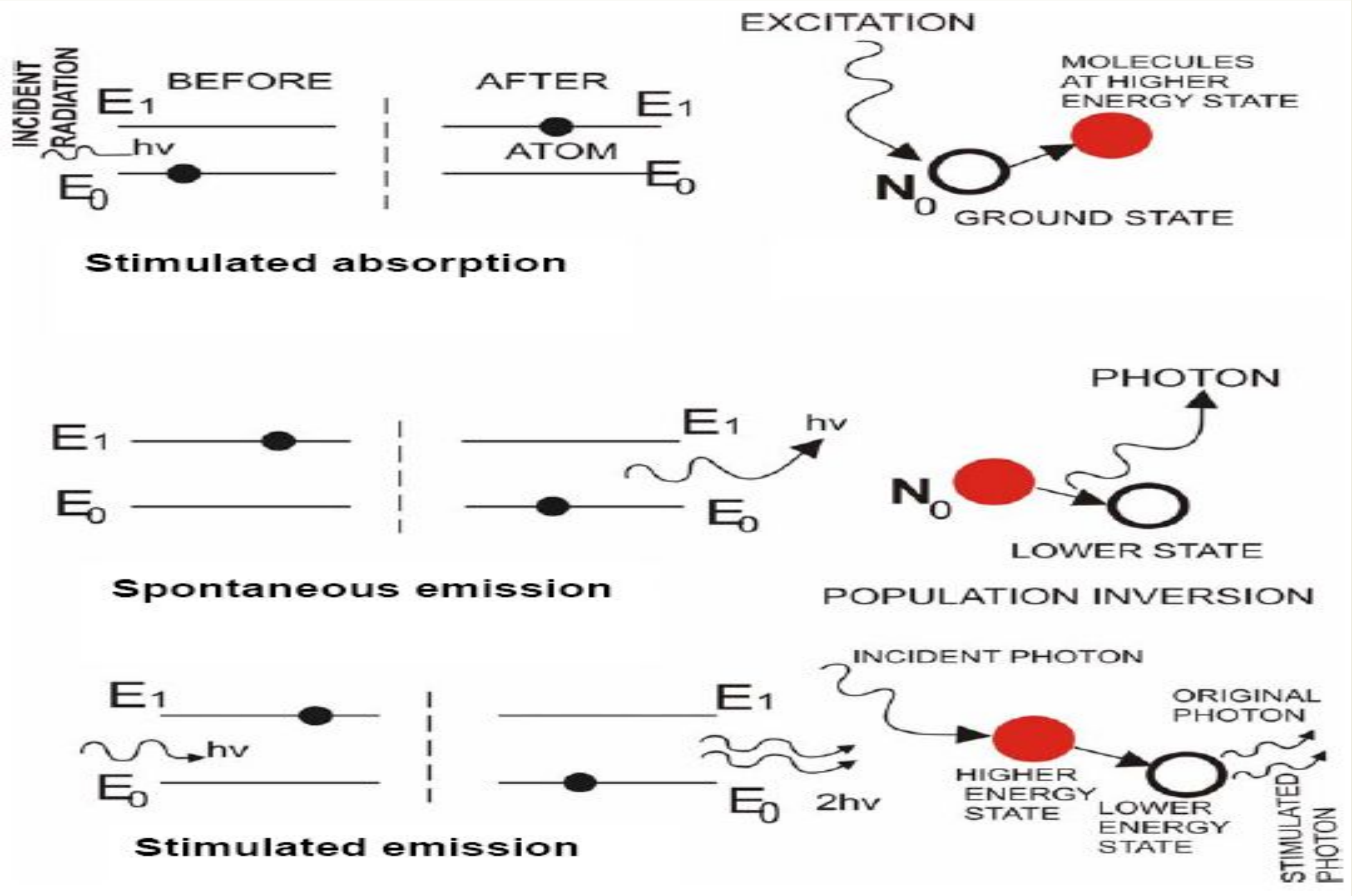

Fig. 2 Spontaneous and Stimulated emissions

- Sometimes such change of energy state puts the electrons in a meta-stable energy band. Instead of coming back to its ground state immediately it stays at the elevated energy state for micro to milliseconds.

- In a material, if more number of electrons can be somehow pumped to the higher meta-stable energy state as compared to number of electrons at ground state, then it is called “population inversion”.

- Such electrons, at higher energy meta-stable state, can return to the ground state in the form of an avalanche provided stimulated by a photon of suitable frequency or energy. This is called **stimulated emission**. Fig.2 shows one such higher state electron in meta-stable orbit.

- If it is stimulated by a photon of suitable energy then the electron will come down to the lower energy state and in turn one original photon will be produced. In this way **coherent laser beam can be produced**.

- Fig. 3 schematically shows working of a laser.

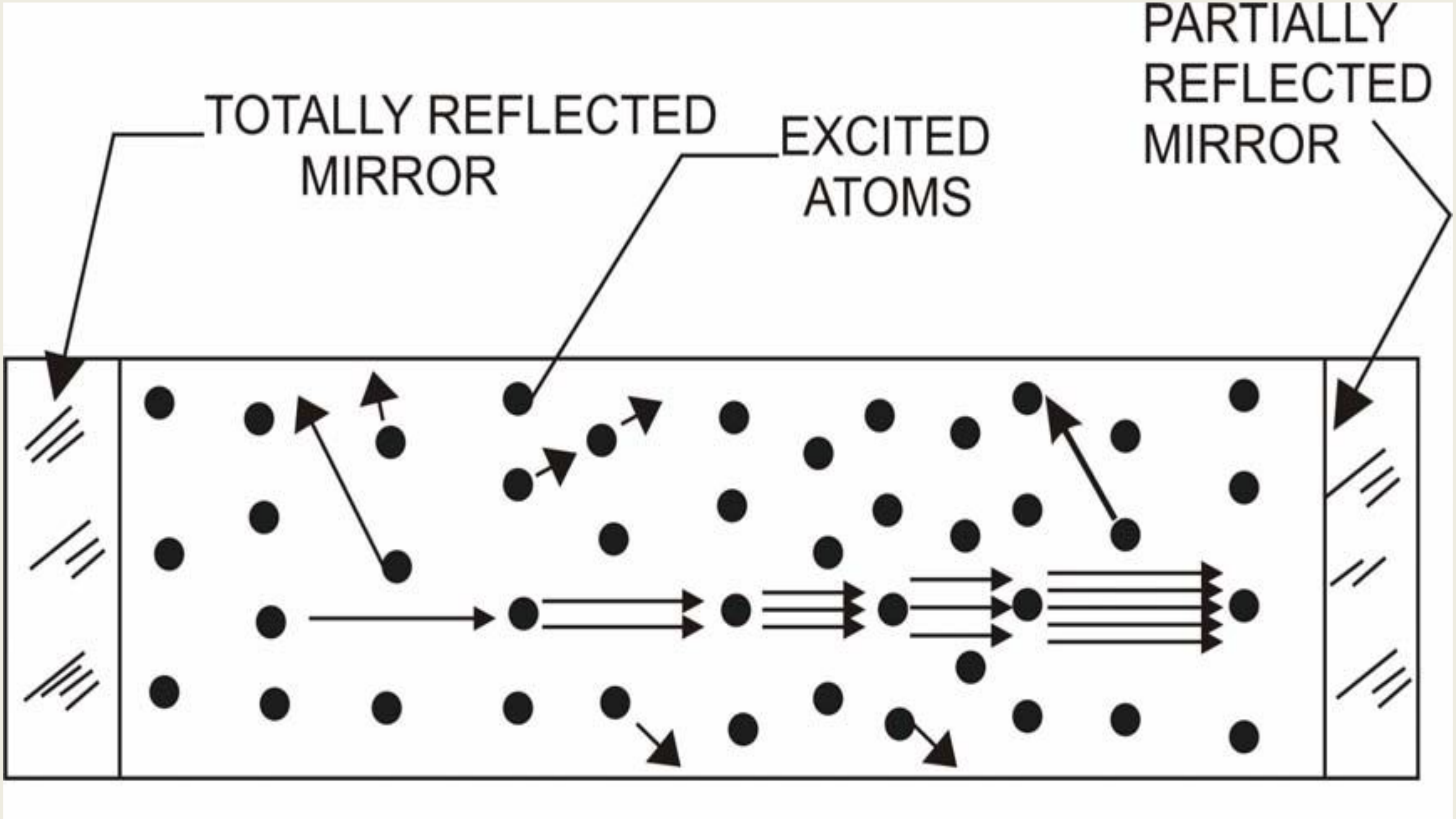

Fig. 3 Lasing Action

- There is a gas in a cylindrical glass vessel. This gas is called the lasing medium.

- One end of the glass is blocked with a 100% reflective mirror and the other end is having a partially reflective mirror. Population inversion can be carried out by exciting the gas atoms or molecules by pumping it with flash lamps.

- Then stimulated emission would initiate lasing action. Stimulated emission of photons could be in all directions.

- Most of the stimulated photons, not along the longitudinal direction would be lost and generate waste heat. The photons in the longitudinal direction would form coherent, highly directional, intense laser beam.

Lasing Medium- Heart Of LASER

- Many materials can be used as the heart of the laser. Depending on the lasing medium lasers are classified as solid state and gas laser.

- Solid-state lasers are commonly of the following type
  - Ruby which is a chromium – alumina alloy having a wavelength of 0.7 µm
  - Nd-glass lasers having a wavelength of 1.64 µm.
  - Nd-YAG laser having a wavelength of 1.06 µm.

  (Nd-YAG stands for neodymium-doped yttrium aluminium garnet; **Nd:$Y_3Al_5O_{12}$**)

- These solid-state lasers are generally used in material processing.

- The generally used gas lasers are:
  - Helium – Neon
  - Argon
  - CO_2 etc.

- Lasers can be operated in continuous mode or pulsed mode. Typically CO_2 gas laser is operated in continuous mode and Nd – YAG laser is operated in pulsed mode.

Schematic diagram of Laser Beam Machine

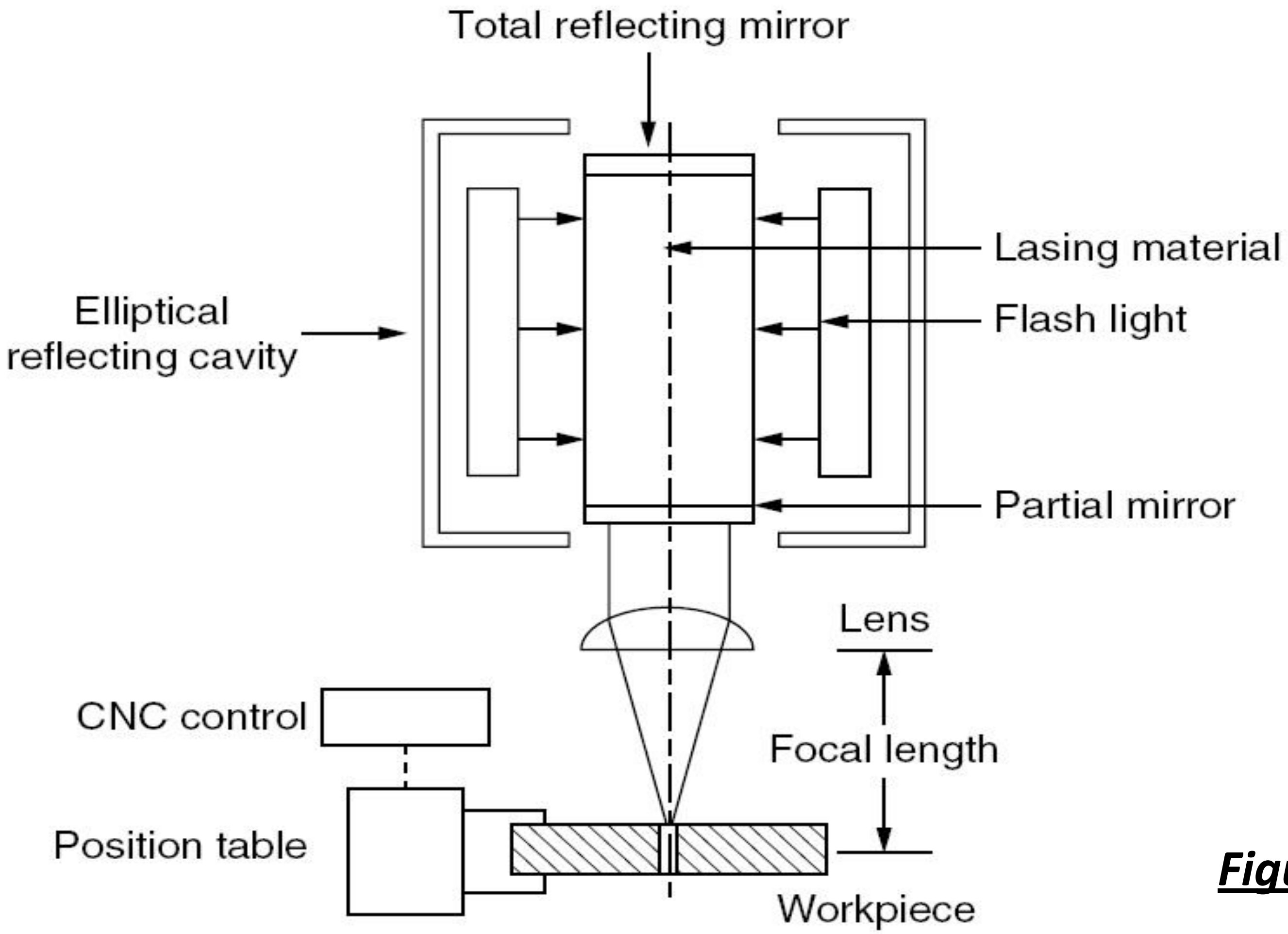

Figure 4

Material Removal Mechanism In LBM

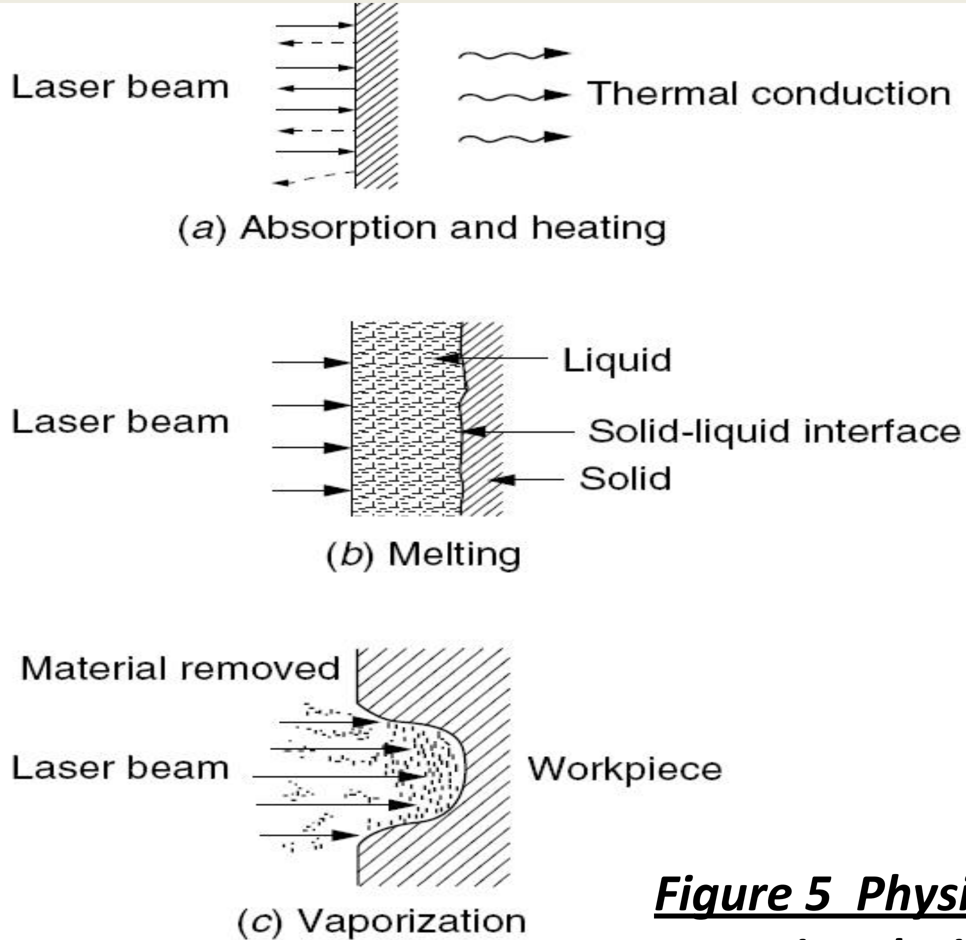

Figure 5 Physical processes occurring during LBM

- As presented in Fig. 5, the unreflected light is absorbed, thus heating the surface of the workpiece.
- On sufficient heat the workpiece starts to melt and evaporates.
- The physics of laser machining is very complex due mainly to scattering and reflection losses at the machined surface. Additionally, heat diffusion into the bulk material causes phase change, melting, and/or vaporization.
- Depending on the power density and time of beam interaction, the mechanism progresses from one of heat absorption and conduction to one of melting and then vaporization.

- Machining by laser occurs when the power density of the beam is greater than what is lost by conduction, convection, and radiation, and moreover, the radiation must penetrate and be absorbed into the material.

- The power density of the laser beam, P_d, *is given by*

$$P_d = \frac{4L_p}{\pi F_l^2 \alpha^2 \Delta T}$$

- The size of the spot diameter d_s *is*

$$d_s = F_l \alpha$$

- The machining rate ϕ (mm/min) can be described as follows:

$$\phi = \frac{C_l L_P}{E_v A_b h}$$

Where A_b = area of laser beam at focal point, mm^2

$$A_b = \frac{\pi}{4} (F_l \alpha)^2$$

Therefore,

$$\phi = \frac{4 C_l L_P}{\pi E_v (F_l \alpha)^2 h}$$

- The volumetric removal rate (VRR) (mm^3/min) can be calculated as follows:

$$VRR = \frac{C_l L_P}{E_v \, h}$$

where P_d = power density, W/cm^2

L_p = laser power, W

F_l = focal length of lens, cm

ΔT = pulse duration of laser, s

α = beam divergence, rad

C_l = constant depending on the material and conversion efficiency

E_v = vaporization energy of the material, W/mm^3

A_b = area of laser beam at focal point, mm^2

h = thickness of material, mm

d_s = spot size diameter, mm

LASER Beam Machining – Application

- Laser can be used in wide range of manufacturing applications
  - Material removal – drilling, cutting and tre-panning
  - Welding
  - Cladding
  - Alloying

- Drilling micro-sized holes using laser in difficult – to – machine materials is the most dominant application in industry. In laser drilling the laser beam is focused over the desired spot size. For thin sheets pulse laser can be used. For thicker ones continuous laser may be used.

Parameters Affecting LBM

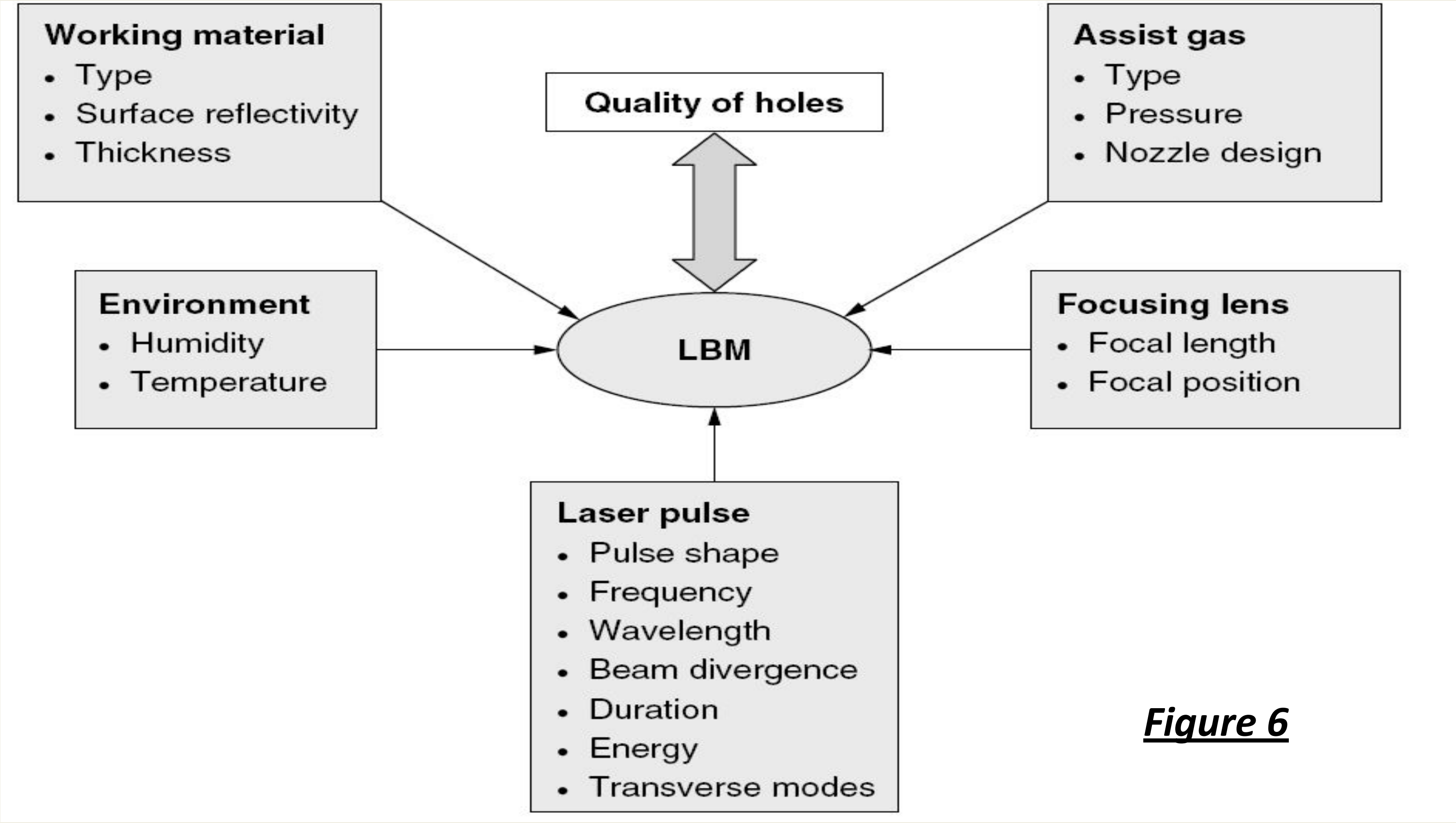

Figure 6

- Fig. 6 presents the factors which affect the LBM process. The factors can be related to LBM Drilling process and are discussed below:

- Pulse Energy: It is recommended that the required peak power should be obtained by increasing the pulse energy while keeping the pulse duration constant. Drilling of holes with longer pulses causes enlargement of the hole entrance.

- Pulse Duration: The range of pulse durations suitable for hole drilling is found to be from 0.1 to 2.5 millisecond. High pulse energy (20J) and short pulse duration are found suitable for deep hole drilling in aerospace materials.

- <u>Assist Gases:</u> The gas jet is normally directed with the laser beam into the interaction region to remove the molten material from the machining region and obtain a clean cut. Assist gases also shield the lens from the expelled material by setting up a high-pressure barrier at the nozzle opening. Pure oxygen causes rapid oxidation and exothermic reactions, causing better process efficiency. The selection of air, oxygen, or an inert gas depends on the workpiece material and thickness.

- <u>Material Properties and Environment:</u> These include the surface characteristics such as reflectivity and absorption coefficient of the bulk material. Additionally, thermal conductivity and diffusivity, density, specific heat, and latent heat are also considered.

Laser Beam Selection Guide

Application		Laser type
Drilling	Small holes, 0.25 mm	Ruby, Nd-Glass, Nd-YAG
	Large holes, 1.52 mm	Ruby, Nd-Glass, Nd-YAG
	Large holes, trepanned	Nd-YAG, CO_2
	Drilling, percussion	Ruby, Nd-YAG
Cutting	Thick cutting	CO_2 + gas assistance
	Thin slitting, metals	Nd-YAG
	Thin slitting, plastics	CO_2
	Plastics	CO_2
Materials	Metals	Ruby, Nd-Glass, Nd-YAG
	Organics and nonmetals	Pulsed CO_2
	Ceramics	Pulsed CO_2 , Nd-YAG

Laser Beam Machining: New Developments

- In 1994 Lau et al., introduced the ultrasonic assisted laser machining technique not only to increase the hole depth but also to improve the quality of holes produced in aluminium-based metal matrix composites (MMC). Using such a method, the hole depth was increased by 20 percent in addition to the reduced degree of hole tapering.

- In 1995 Hsu and Molian, developed a laser machining technique that employs dual gas jets to remove the viscous stage in the molten cutting front and, thereby, allowing stainless steel to be cut faster, cleaner, and thicker.

- In 1997, Todd and Copley developed a prototype laser processing system for shaping advanced ceramic materials. This prototype is a fully automated, five-axis, closed-loop controlled laser shaping system that accurately and cost effectively produces complex shapes in the above-mentioned material.

- **Laser Assisted EDM:** In 1997, Allen and Huang developed a novel combination of machining processes to fabricate small holes. Before the micro-EDM of holes, copper vapour laser radiation was used to obtain an array of small holes first. These holes were then finished by micro-EDM. Their method showed that the machining speed of micro-EDM had been increased and electrode tool wear was markedly reduced while the surface quality remained unchanged.

Laser Beam Machining – Advantages

- Tool wear and breakage are not encountered.
- Holes can be located accurately by using an optical laser system for alignment.
- Very small holes with a large aspect ratio can be produced.
- A wide variety of hard and difficult-to-machine materials can be tackled.
- Machining is extremely rapid and the setup times are economical.
- Holes can be drilled at difficult entrance angles (10° to the surface).
- Because of its flexibility, the process can be automated easily such as the on-the-fly operation for thin gauge material, which requires one shot to produce a hole.
- The operating cost is low.

Laser Beam Machining – Limitations

- High equipment cost.
- Tapers are normally encountered in the direct drilling of holes.
- A blind hole of precise depth is difficult to achieve with a laser.
- The thickness of the material that can be laser drilled is restricted to 50 mm.
- Adherent materials, which are found normally at the exit holes, need to be removed.

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Plasma Arc Machining (PAM)

- Introduction
- Principle
- Mechanism of material removal
- Process - types
- Process parameters
- Advantages
- Limitations
- Applications

Introduction

- A plasma is defined as a superheated, electrically ionized gas
- PAC uses a plasma stream operating at temperatures in the range from 10,000 to 14,000 ºC to cut metal by melting.
- The cutting action takes place by directing the high-velocity plasma stream at the work, thus melting it and blowing the molten metal through the kerf
- Plasma is encountered in electrical discharges, such as fluorescent tubes and electric arcs, lightning, high temperature combustion flames and the sun.
- Most application of PAC involve cutting of flat metal sheets and plates. Operations include hole piercing and cutting along a defined path.
- PAC was initially employed to cut metals that are difficult to machine by conventional methods.

Principle

- When heated to elevated temperatures, gases turn into a distinctly different type of matter, which is plasma
- When gases are heated by an applied electric field, an igniter supplies the initial electrons, which accelerate in the field before colliding and ionizing the atoms. The free electrons, in turn, get accelerated and cause further ionization and heating of the gases. The avalanche continues till a steady state is obtained in which the rate of production of the free charges is balanced by recombination and loss of the free charges to the walls, and

Mechanism of Material removal

- The metal removal in PAM is basically due to the high temperature produced.
- The heating of the work piece is, as a result of anode heating, due to direct electron bombardment plus convection heating from the high temperature plasma that accompanies the arc.
- The heat produced is sufficient to raise the work piece temperature above its melting point and the high velocity gas stream effectively blows the molten metal away.

Typical plasma torch construction

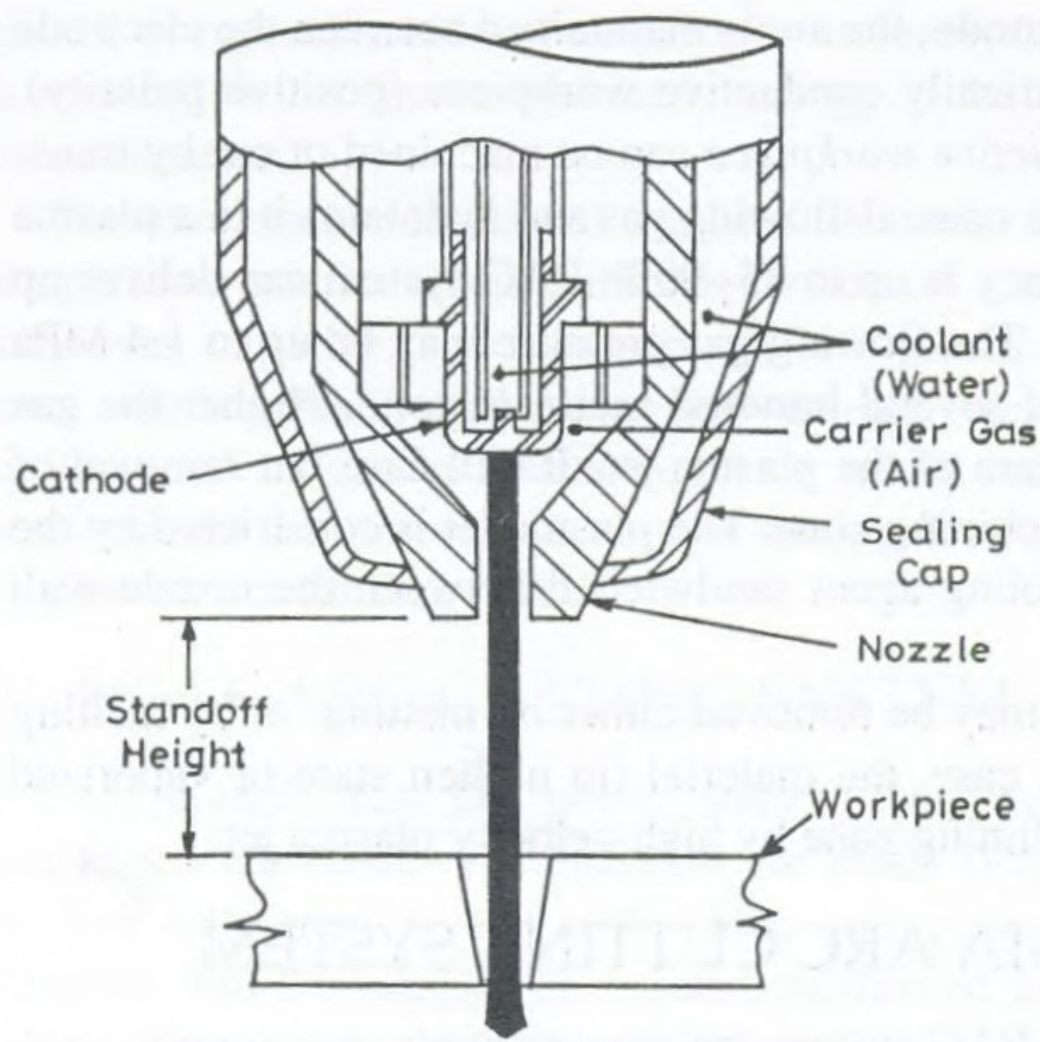


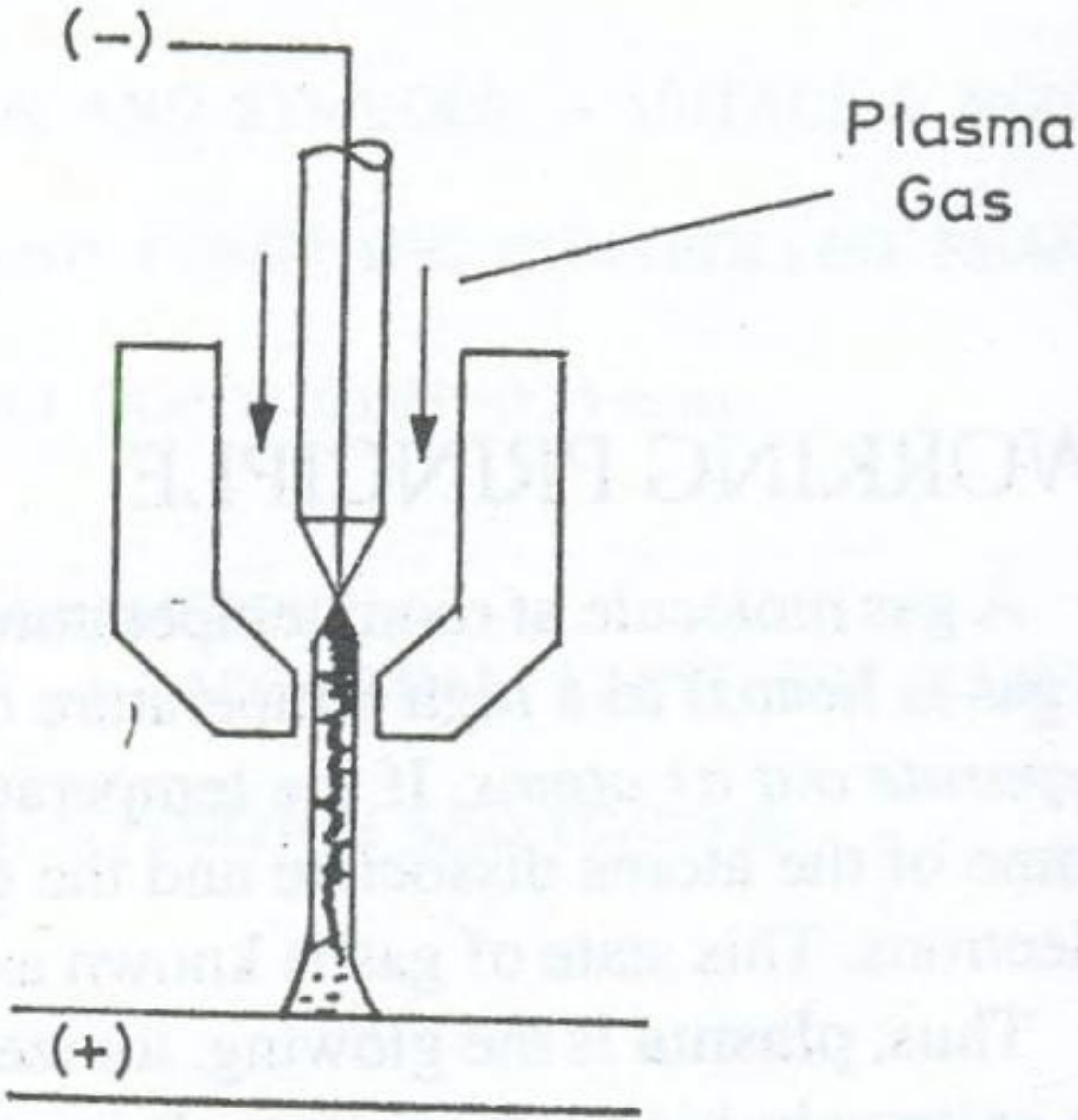
Fig. 9.2 Details of air plasma torch construction [*Benedict*, 1987; Courtesy: W.A. Whitney Corp. Rockford, III.]

Process - types

- Plasma generating torches are of two general designs – **transferred plasma torch** and **non-transferred plasma torch**.

Transferred plasma torch

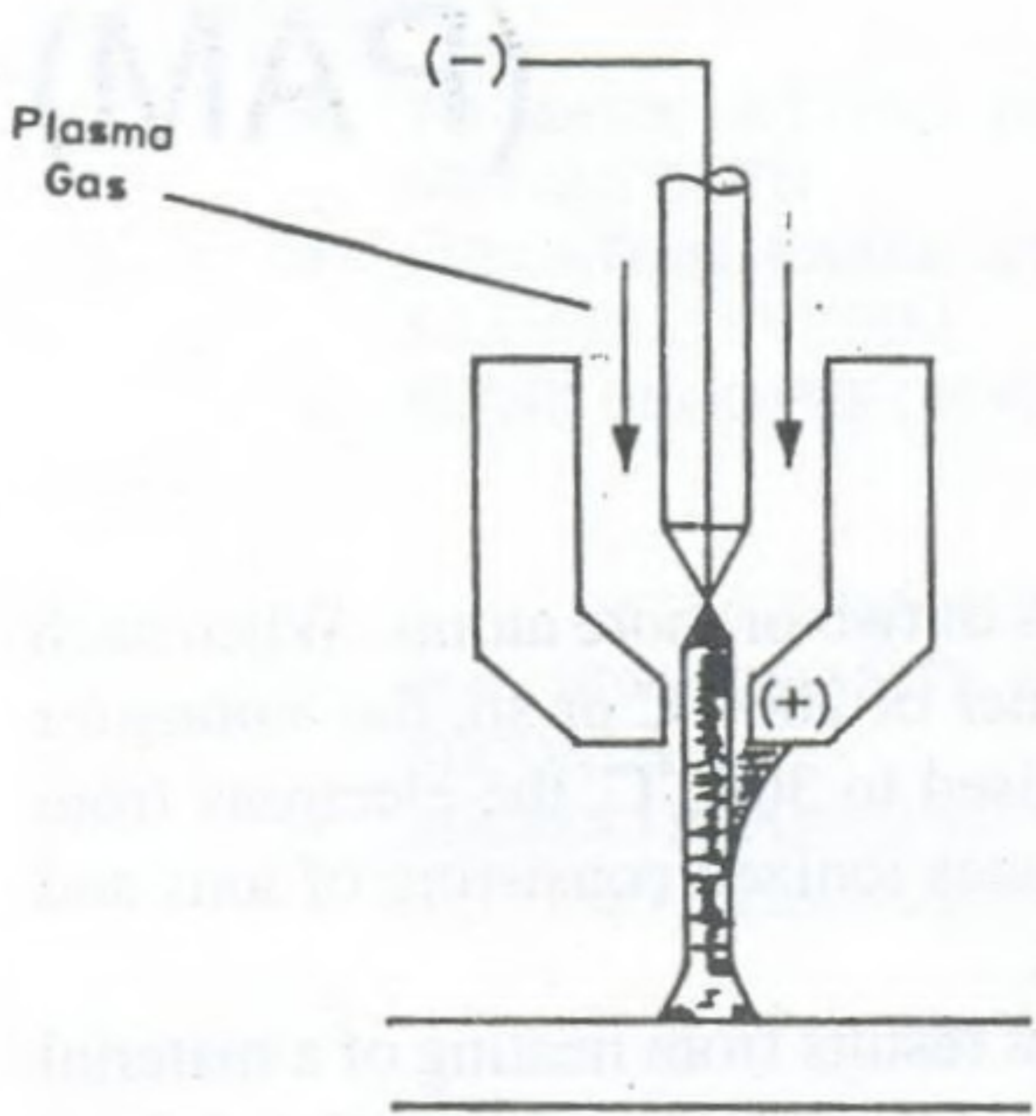
- In this torch, the cathode is connected directly to the negative of the D.C. source, while the anode nozzle is connected to the positive of the supply through a suitable resistor to limit the current through the nozzle to about 50amps.
- The metal workpiece to be processed is then connected directly to the positive of the supply. When ignited, a pilot plasma flame is established between the cathode and nozzle, which provides a conducting path for a high current constricted arc between the cathode and workpiece. Once this arc is struck, the pilot flame circuit is disconnected.
- This method is limited to cutting, welding and hard surfacing of metals.
- The electro thermal efficiency is about 85-90%



TRANSFERRED

Non-transferred plasma torch

- In this torch, the D.C power source is connected directly across the cathode and the nozzle, thus ionizing a high velocity gas that is streaming towards the workpiece.
- The anode dissipation is lost in useless heating of the nozzle.
- The electro thermal efficiency is about 65-75%



NON-TRANSFERRED

Process parameters

- Parameters that govern the performance of PAM can be divided into three categories:

1. Those associated with the design and operation of the torch – eletrical power delievered , the gases used to form the plasma, the flow rate of the gases through the torch, the orifice diameter through the nozzle duct
2. Those associated with the physical configuration of the set up – torch standoff, angle to the work, depth of cut, feed into the work and speed of the work toward the torch
3. Environment in which the work is performed – cooling that is done on the bar, any protective type of atmosphere used to reduce oxidation fo the exposed high temperature machined surface and any means that might be utilized to spread out or deflect the arc and plasma impingment area

Gas Cutting	PAM
1.Oxidation of the work piece melted generates the heat to melt the matl for (e.g) in cutting steel, fuel gas is used to heat it to 760□-870□C at while steel reacts rapidly with oxygen to form iron oxide. The heat generated by the burning iron is sufficient ot melt the iron oxide. 2.Oxy-fuel gas cutting is mostly limited to only ferrous metal especially plain carbon steels. 3.Cutting speed are lower for (e.g) in cutting mild steel 19mm thick can be cut at 500 mm /min. 4. Operating costs are higher 5.Limited to the max. temparature of the chemical reaction (burning) 6.Cost of equipment is lower. Surfaces are less smoother than those cut by PAM	1.Plasma is generated by subjecting a volume of gas to electron bombardment of an electric arc. The anode heating due to direct electron bombardment plus convective heating from the high temp plasma raises the matl to the molten point and the high velocity gas stream effectively blows the matl away. 2.Because of the high temp involved, the process can be used on almost all matl including those white are resistant to oxy- fuel gas cutting 3.Cutting speeds ae higher and leave a narrower kerf. They can cut mild steel 19mm thick at the rate of 1775mm /min. 4.Operating costs are lower.Ratio of savings in favor of PAM is about 3:1 5.Seems to be unlimited. The greater the power used, the greater the vol.of kerf matl that can be removed. 6.High initial cost of the equipment. 7.Surfaces cut by plasma torch are smoother but the edges are rounded

Advantages

1. The main advantage of PAM is speed. For example, mild steel of 6mm thick can be cut at 3m/min
2. The plasma arc can be used to cut any metal or even to non- conducting materials like concrete etc., since it is primarily a melting process
3. Due to high speed of cutting the deformation of sheet metals is reduced while the width of the cut is minimum
4. Owing to the high productivity of the plasma arc cutting coupled with the tendency to use cheap and easily available plasma-forming media (air, water, ammonia etc.,), PAC is finding ever increasing application.
5. Smooth cuts free from contaminants are obtained in the process
6. Profile cutting of metals especially of stainless steel and aluminium can be very easily done by PAM
7. Operating costs are less when compared to oxy-fuel torch
8. Can be automated

Limitations

- The main disadvantage of PAC is the high initial cost of the equipment. However, it can be made economical, if the quantity involved is large and the thickness is up to 50mm.
- Well-attached drops on the underside of the cut can be a problem and there will be heat- affected zone (HAZ). The depth of HAZ depends on the material and its thickness
- Smoke and noise
- Sharp corners are difficult to produce because of the wide diameter of the plasma stream

Applications

1. Chiefly used to cut stainless steel and aluminium alloys. It is preferred to oxy-fuel cutting because it produces comparatively smoother cuts and is free from contamination
2. Other metals which are resistant to oxy-fuel cutting and hence cut by PAC are magnesium, titanium, copper, nickel and alloys of copper and nickel
3. PAC can be used for stack cutting, plate beveling, shape cutting and piercing.
4. It can also be used for underwater cutting.
5. The plasma jets are used for welding materials like titanium, stainless steel etc.,
6. Plasma arc is used for depositing filler metal on surface to obtain desired properties like corrosion resistance, wear resistance, toughness or anti-friction properties – Plasma arc

UNIT II THERMAL AND ELECTRICAL ENERGY BASED PROCESS

- **Electric Discharge Machining (EDM)**
- **Wire cut EDM** – Working Principle-equipments-Process -Parameters-Surface Finish and MRR- electrode / Tool – Power and control Circuits-Tool Wear -Dielectric – Flushing –– Applications.
- **Laser Beam machining** and drilling, (LBM),
- **Plasma Arc machining (PAM)** and
- **Electron Beam Machining (EBM).** (Principles – Equipment –Types - Beam control techniques – Applications.)

Electron Beam Machining (EBM)

- Introduction
- Principle
- Characteristics of EBM
- Equipment – gun construction
- Types of gun (vacuum system)
- Beam control
- Process parameters
- Advantages
- Limitations
- Applications

Introduction

- Invented in Germany in 1952
- Thermal material removal process that utilizes a focused beam of high-velocity electrons to perform high-speed drilling and cutting
- Types: Thermal (beam is used to heat the material up to the point where it is selectively vaporized) and non-thermal (utilizes the beam to cause a chemical reaction)
- Able to drill materials up to 10mm thick at perforation rates that far exceed all other manufacturing processes
- Although EBM is capable of producing almost any programmable hole shape, it is often applied for high-speed drilling of round holes

Principle

- A stream of high-speed electrons impinges on the work surface whereby the kinetic energy, transferred to the work material, produces intense heating. Depending on the intensity of the heat thus generated, the material can melt or vaporize

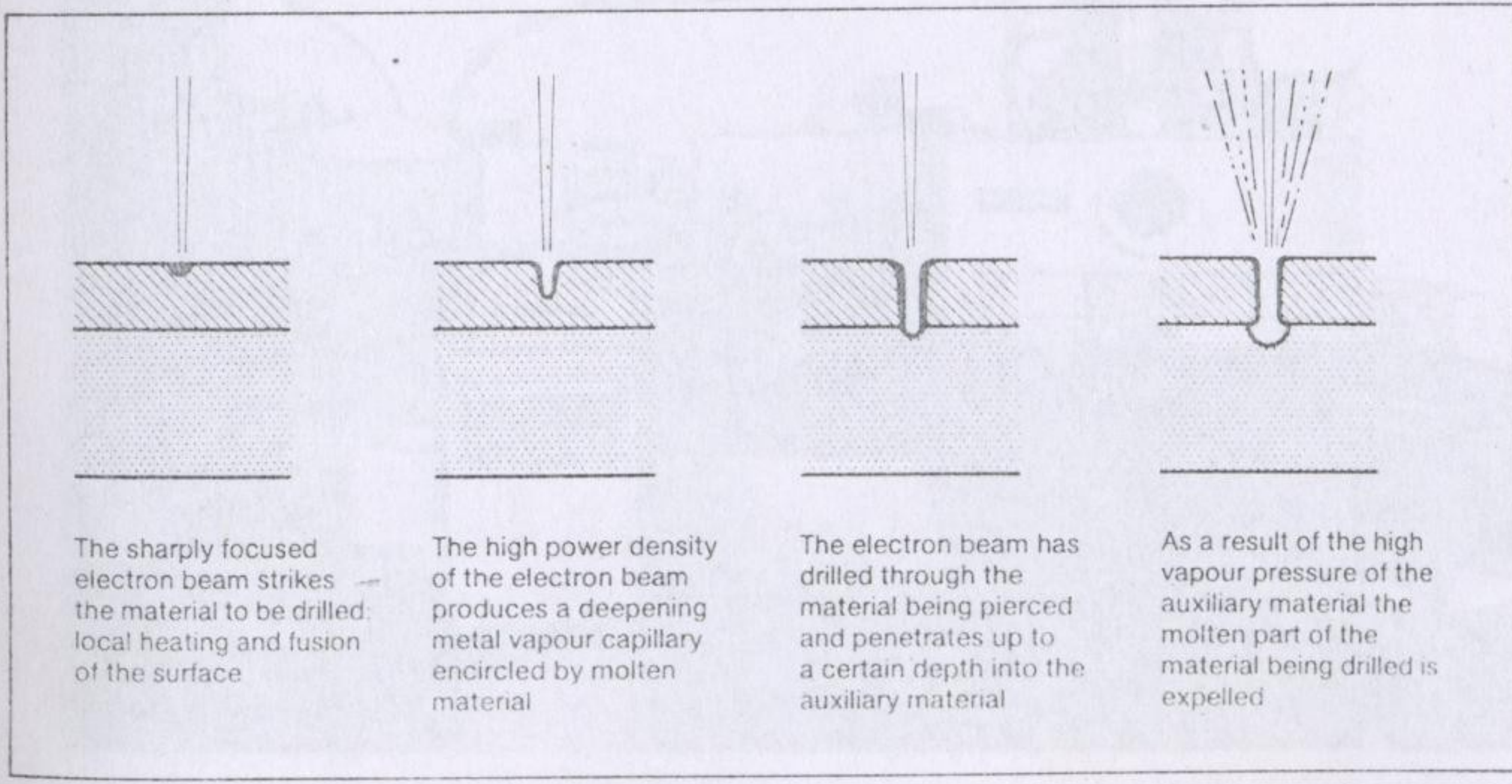


Figure 19.1 The four steps that lead to material removal by electron beam drilling (*Source*: courtesy, Messer Griesheim GmbH, Puchheim, W. Ger.).

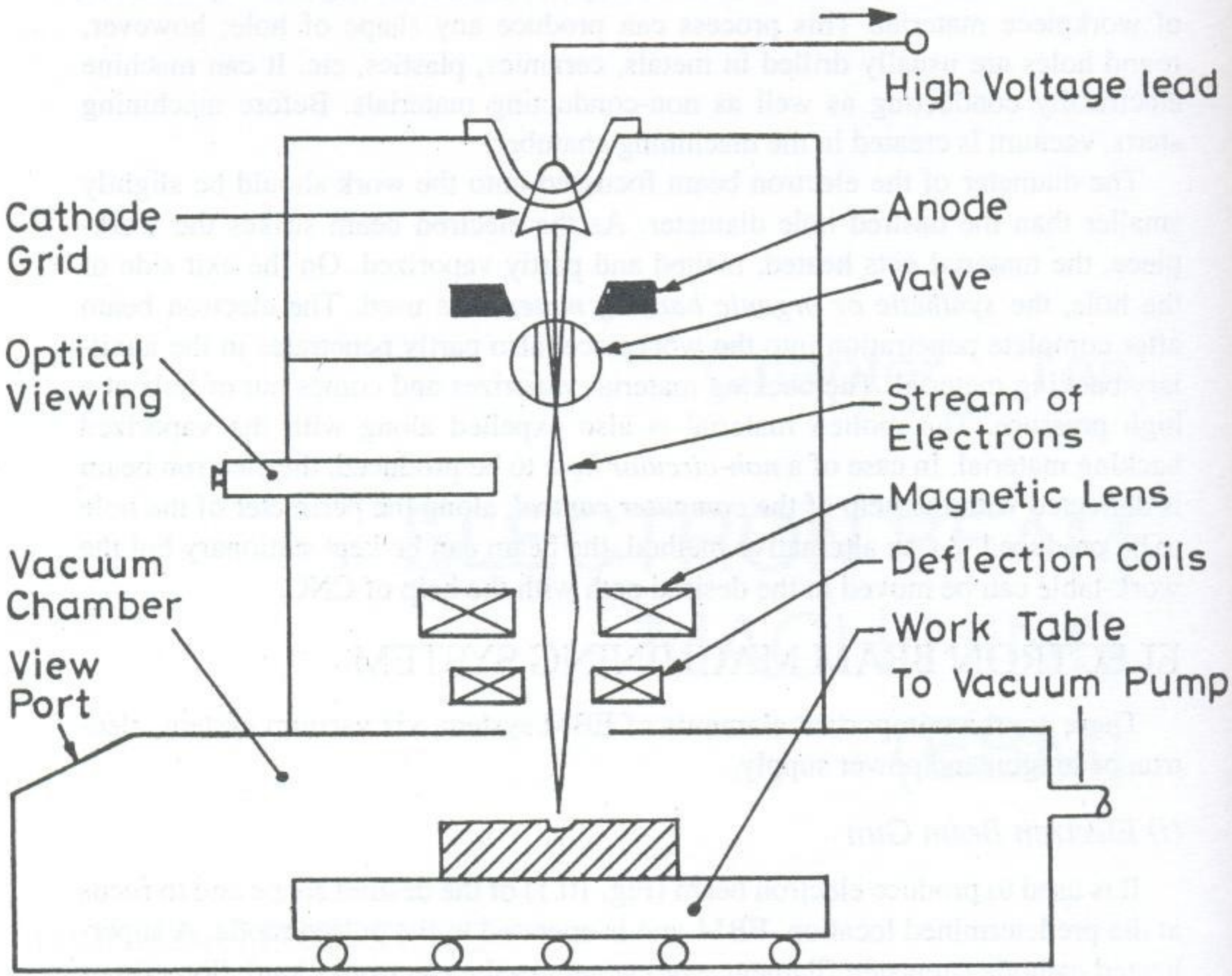
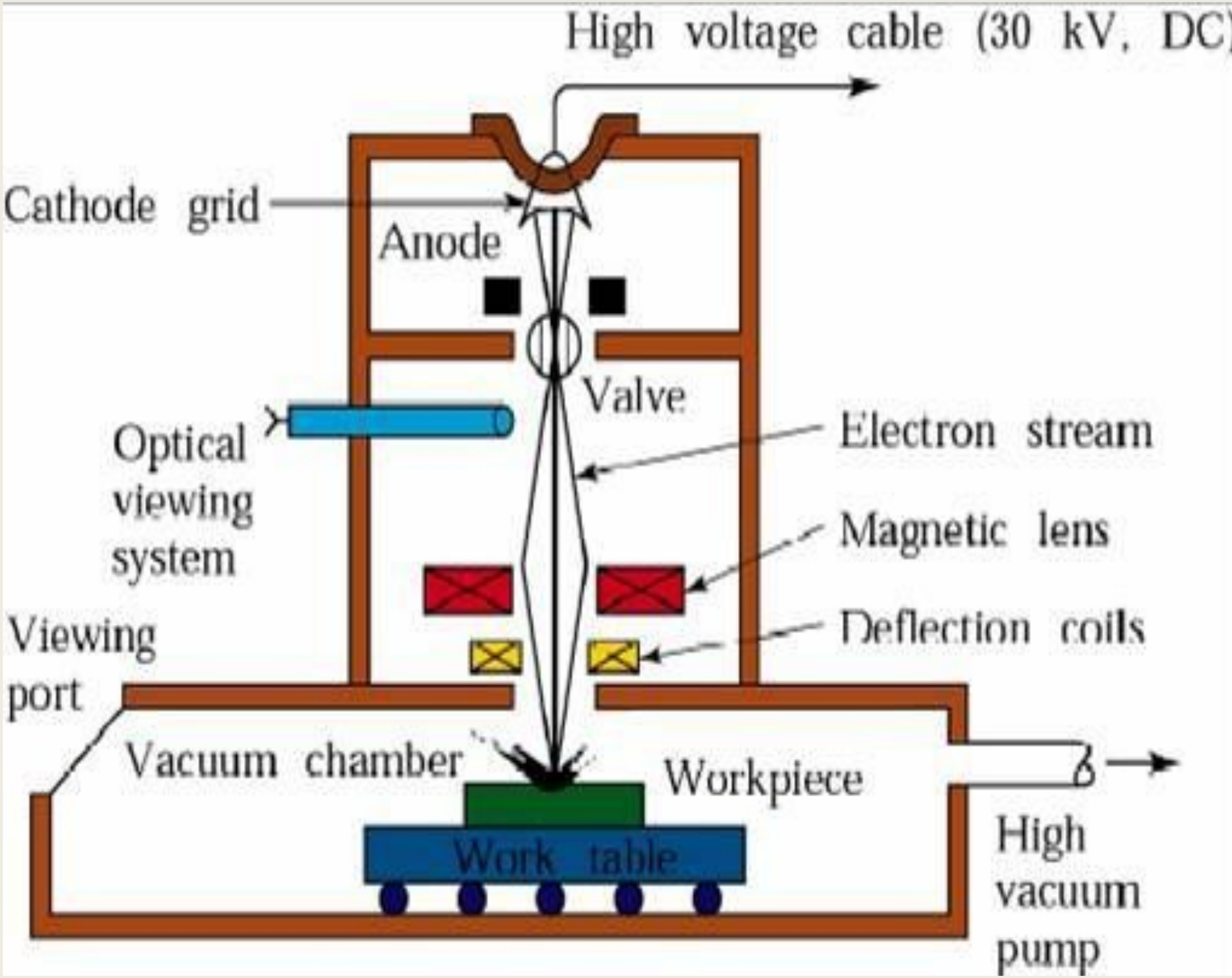


Fig. 10.1 Schematic diagram of electron beam machining system.


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

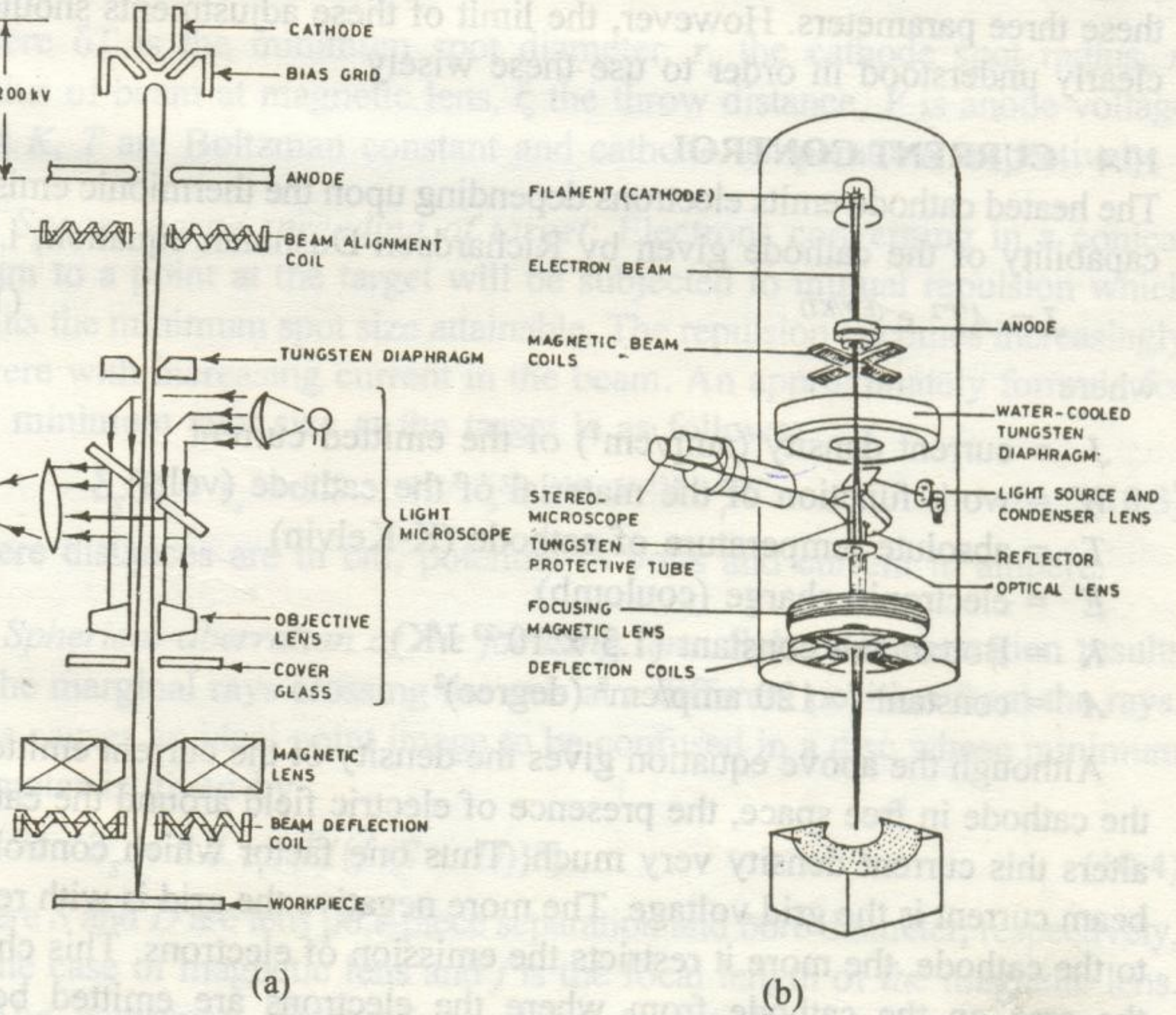


Fig. 10.1 Electron Beam Gun Construction Scheme

Major components of the system

- Three important elements of EBM system:

1. Electron beam gun: Function is to generate, shape and deflect the electron beam to drill or machine the workpiece

- The essential constituents of the electron gun are:
- Cathode- source of the electrons
- Bias Grid- to control the no. of electrons and acts as a switch for generating pulses
- Anode- to accelerate the electrons
- Magnetic coil that functions as a magnetic lens, repels and shapes the electron beam into a converging beam
- Tungsten diaphragm- removes stray electrons and cools the set- up
- Rotating slotting disks mounted directly below the gun exit opening to protect the EBM gun from metal spatter and vapor
- Light microscope- to view the machining area
- Three magnetic coils : Magnetic lens, deflection coil and stigmator that are respectively used to focus the beam, small amount of

Major components of the system

2. Power supply: voltages of up to 150kV is generated to accelerate the electrons;

- All power supply variables are controlled by a microcomputer
- To ensure process repeatability, the process variables are monitored and compared with set-points by the power supply computer. If a discrepancy arises, the operator is alerted

3. Vacuum system and machining chamber:

- A vacuum chamber is required for EBM and should have a volume of at least $1m^3$ to minimize the chance of spatter sticking to the chamber walls
- Inside the chamber a positioning system is used for the controlled manipulation of the workpiece
- The positioning system may be as simple as a single, motor-driven rotary axis or as complex as a fully CNC, closed-loop, five- axis system

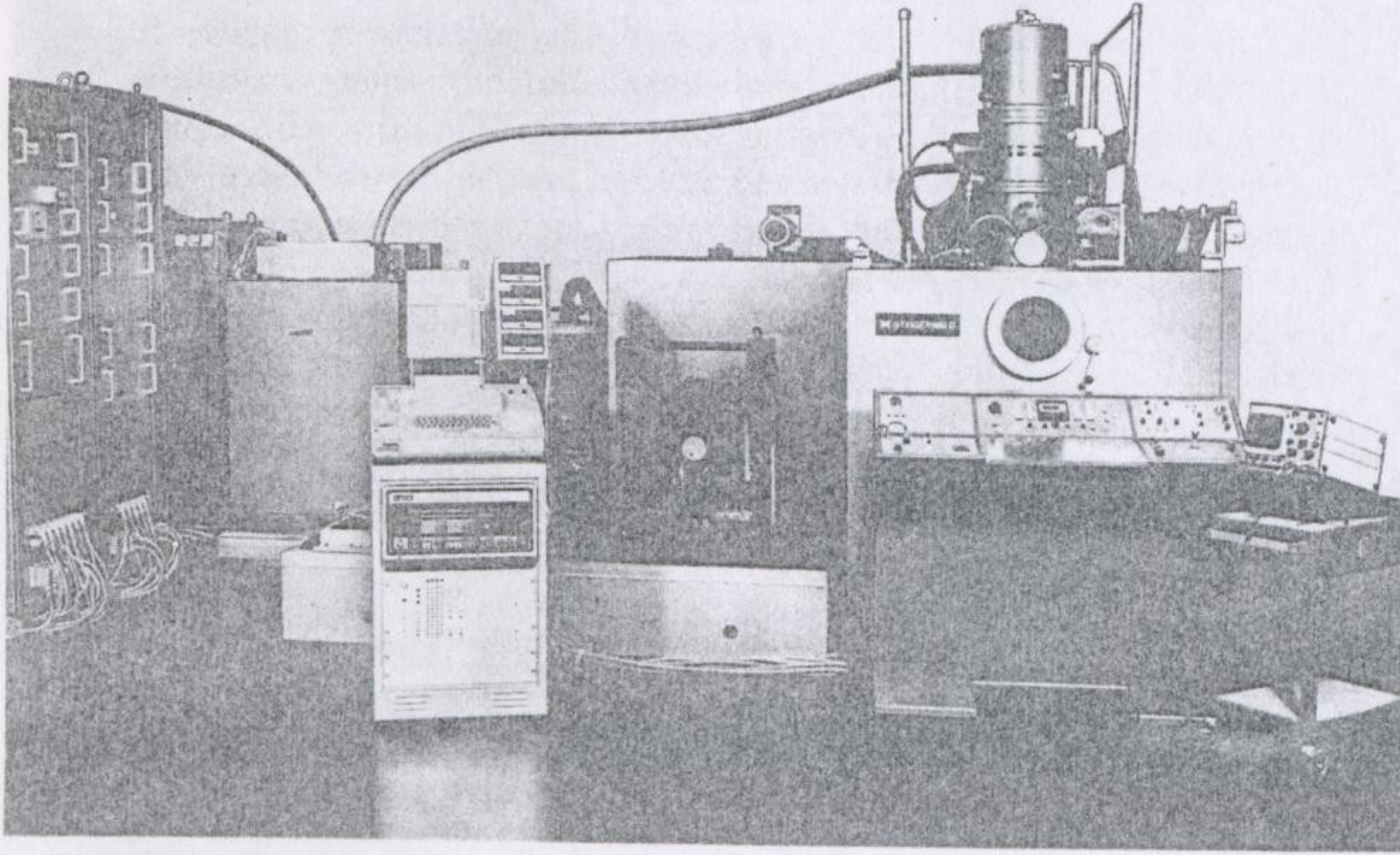
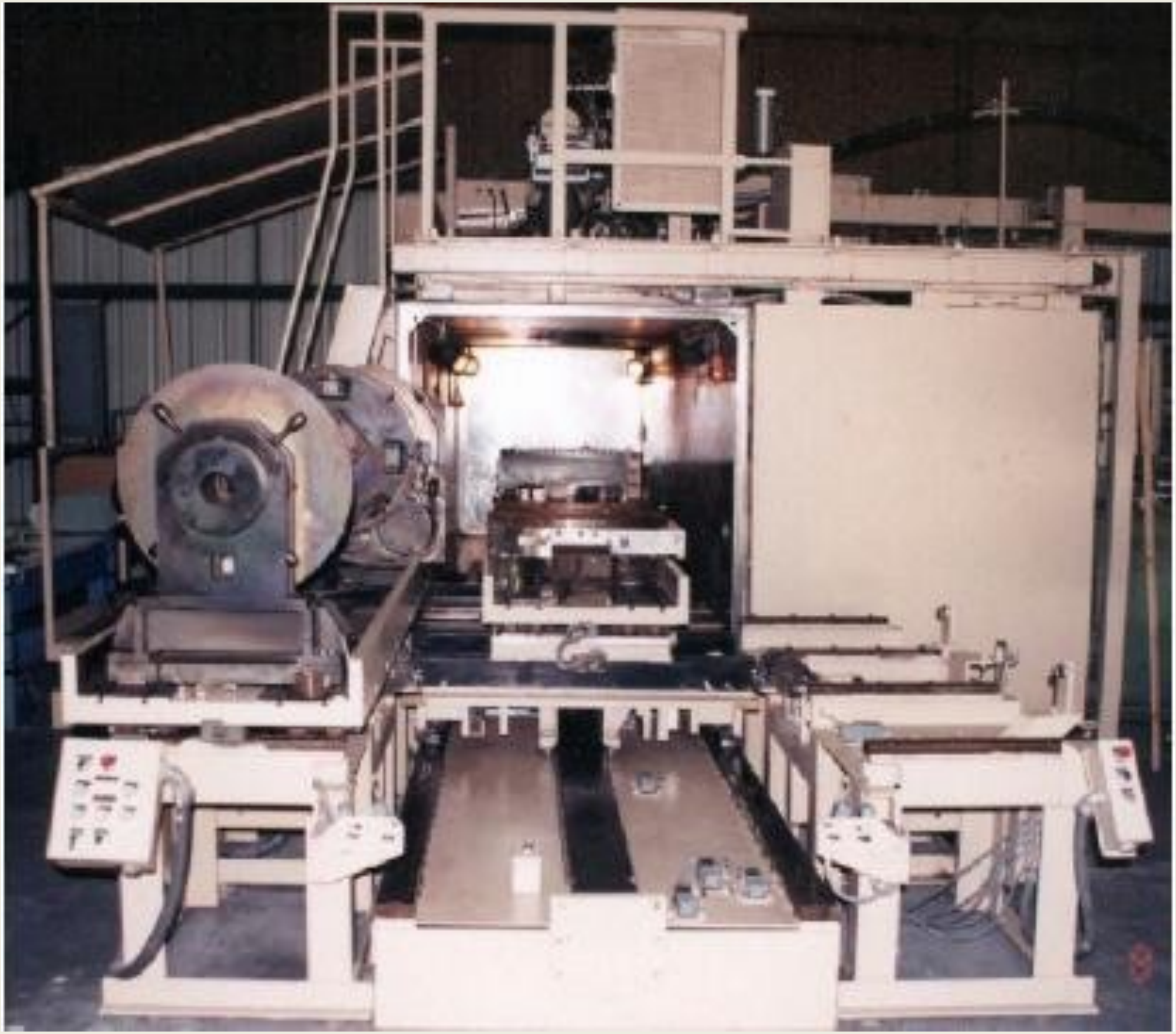


Figure 19.2 Computer-controlled multiaxis EBM system (*Source*: courtesy, Messer Griesheim GmbH, Puchheim, W. Ger.).



Characteristics of EBM

- Important characteristic: high resolution and the long depth of field that is obtained because of the short wavelength of high energy electrons;
- Extraordinary energy (power densities of 10^6 kW/cm2 have been achieved)
- Ability to catalyze many chemical reactions, controllability and compatability with high vacuum
- For conductive as well as non-conductive materials
- At entry side of beam, a small burr
- Workpiece material properties do not affect performance
- Small diameter holes (0.1 to 1.4mm)
- Aspect ratio = 15:1
- No mechanical force and hence fragile, thin, low strength components can be easily machined
- Off-axis holes easily made
- Residual thermal stresses generated on the workpiece due to high temperature gradient

Types of vacuum system

1. High vacuum (HV)
2. Medium vacuum (MV)
3. Non vacuum (NV)

- Still requires a high vacuum in the electron gun, but deliver the beam to a workpiece at atmospheric pressure, thus avoiding non- productive pumpdown cycles completely
- Construction much different from the HV
- The beam path from the cathode consists of a series of individually pumped stages that are all connected by small apertures – this construction produces a pressure gradient that ranges from atmospheric pressure to high vacuum
- Although NV system can increase productivity dramatically, they are somewhat limited since the interaction of the electron beam with air spreads and diffuses the beam thus lowering the power density at the workpiece – this results in an increase of the thermal effects of the process, the effects are still far less than those of conventional processes
- Standoff distance between the gun and the workpeice is limited to a maximum of 19mm

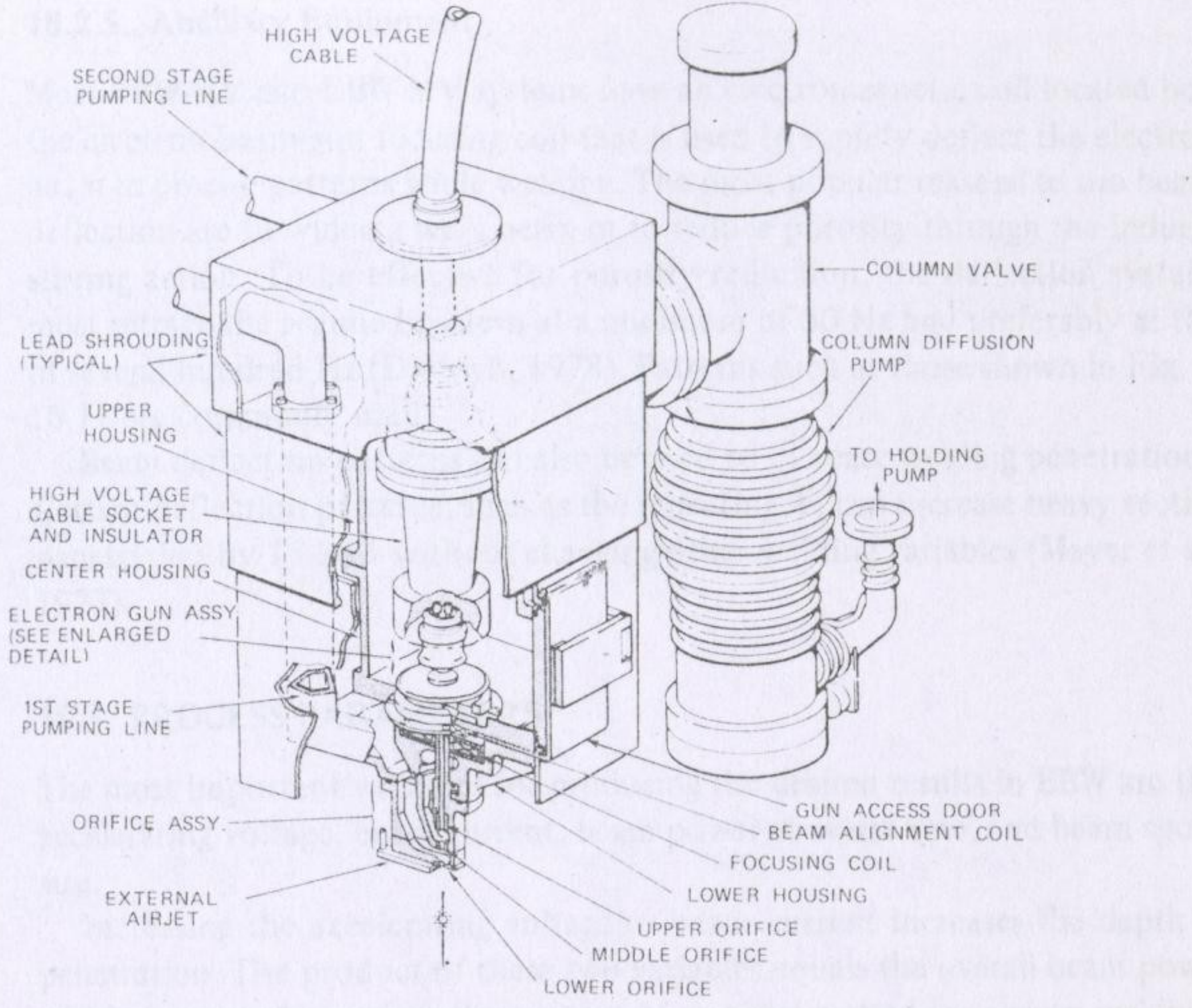


Figure 18.9 Construction of EBW-NV assembly (*Source*: courtesy, Leybold-Heraeus Vacuum Systems, Inc., Enfield, Conn.).

Beam control

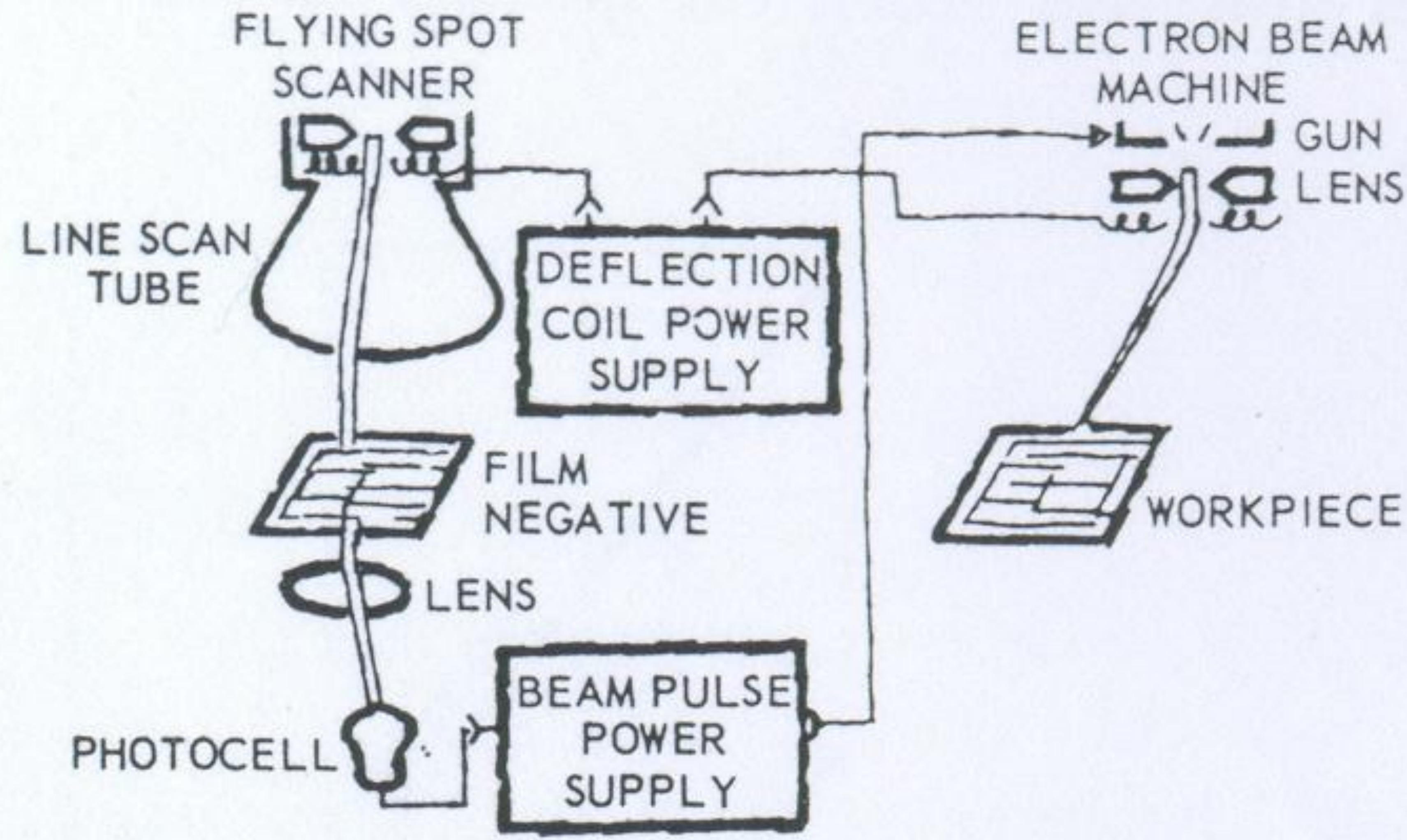
- The electron beam is controlled with optical precision
- The beam consists of negatively charged particles whose energy content is determined by the mass and velocity of the individual particles.
- The negatively charged particles can be accelerated in an electrostatic field to extreme high velocities. During the process, the specific energy content of the electron beam can be increased beyond the emission energy, thus producing a beam of energy, the intensity of which far exceeds that obtainable from light.
- Due to the precise electron optics, large amounts of energy can be manipulated with optical precision.

1. Electromagnetic lens:

- Before the electrons collide with the workpiece, a variable strength electromagnetic lens is used to refocus the beam to any desired diameter down to less than 0.025 mm at a precise location on the workpiece and thus attains an extremely high power density.
- This extremely, high power density immediately vaporizes any material on which the beam impinges.

2. Magnetic deflection coil:

- Mounted below the magnetic lens, is used to bend the beam and direct it over the desired surface of the workpiece. This deflection system permits programming of the beam in any specific geometrical pattern, using the proper deflection coil current input
- At the point of beam impingement, the kinetic energy in the beam is converted to thermal energy in workpiece.
- Another interesting deflection control technique is the flying spot scanner or optical tracing device. Using this device, the electron beam can be deflected to cover almost any conceivable pattern over a 0.25 sq.in. area. The desired pattern is drawn, then photographed, and the photographic negative acts as the master.
- The electron beam can also be deflected in a predetermined pattern by a relay tray or a flying spot scanner mounted in a control cabinet, which consists of a saw-tooth square wave and sine wave generator.


FLYING SPOT
SCANNER
ELECTRON BEAM
MACHINE
GUN
LENS
LINE SCAN
TUBE
DEFLECTION
COIL POWER
SUPPLY
FILM
NEGATIVE
WORKPIECE
LENS
BEAM PULSE
POWER
SUPPLY
PHOTOCELL

Process parameters

Beam current, pulse duration, lens current and the beam deflection signal are the four important parameter associated with EBM

- 1. Beam current:
  - Continuously adjustable from approximately 100μamp to 1amp
  - As beam current ias increased, the energy per pulse delivered to the workpiece is also increased
- 2. Pulse duration:
  - Affects both the depth and the diameter of the hole
  - The longer the pulse duration, the wider the diameter and the deeper the drilling depth capability will be
  - To a degree, the amount of recast and the depth of HAZ will be governed by the pulse duration – shorter pulse durations will allow less interaction time for thermal effects to materialize

Process parameters

3. Lens current:

- Determines the distance between the focal point and the electron beam gun (working distance) and also determines the size of the focused spot on the workpiece
- The diameter of the focused electron beam spot on the workpiece will, in turn, determine the diameter of the hole produced
- The depth to which the focal point is positioned beneath the workpiece surface determines the axial shape of the drilled hole
- By selecting different focal positions, the hole produced can be tapered, straight, inversely tapered or bell shaped

4. Deflection coil:

- When the hole shapes are required to be other than round, the beam deflection coil is programmed to sweep the beam in the pattern necessary to cut out the shape at the

Advantages

- Very high drilling rates – up to 4000 holes/sec
- Drills in many different configurations
- Drills any material - Hardness, thermal capactiy, ductility, electrical conductivity or surface properties (reflectivity) etc, are not barriers
- No mechanical distortion
- Limited thermal effects because only one pulse is required to generate each hole and pulse durations are short
- Computer controlled parameters
- High accuracy – capability to maintain high accuracy and repeatability
  ±0.1mm for position of the hole and ±5% for the hole diameter
- Drilling parameters can easily be changed even during drilling of single workpiece from one to the other.
- No tool wear
- Best obtainable finish, compared to the other unconventional processes used to drill precision holes

Limitations

- High capital equipment cost
- Holes produced in materials of thickness >0.13mm are tapered. So can machine thinner parts only
- Limited to 10mm material thickness
- Requires vacuum – nonproductive pump down time
- Availability limited
- Presence of a thin recast layer which may be a consideration in some applications
- High level of operator skill required
- Necessity for auxiliary backing material

Applications

- High-speed perforations in any kind of material – fluid and chemical industries use EBM to produce a multitude of holes for filters and screens
- Perforation of small diameter holes in thick materials
- Drilling of tapered holes
- Non-circular hole drilling
- Engraving of metals, ceramics and vaporised layers.
- Machining of the thin films to produce resistor networks in the IC chip manufacture

CHEMICAL MACHINING (CHM)

Synopsis

- Introduction
- Etchant
- Maskant
- Techniques of applying maskants
- Process parameters
- Advantages
- Limitations
- Applications

Introduction

- Use of chemicals to remove material is an old art
- Dates back to approximately 4500 years
- During those eras, CHM was more an art form than an industrial tool
- Limited use started in 1930s by the American industry
- In 1940, North American Aviation, Inc, patented a process called Chem-Mill, which was used for the fabrication of aircraft wing panels
- Today, CHM is characterized as a process that uses acidic or alkaline solutions to dissolve materials in a controlled manner for the purpose of milling or blanking parts;
- Chemically resistant coatings (or masks) are used to protect the surfaces that are not to be machined
- Two major CHM processes are:

1. Chemical milling - eroding material to produce blind details – pockets, channels etc.,
2. Chemical blanking – for producing details that penetrate the material entirely (holes, slots, etc.)

Chemical machining

Principle: Chemical attacks metals and etch them by removing small amounts of material from the surface using reagents or etchants

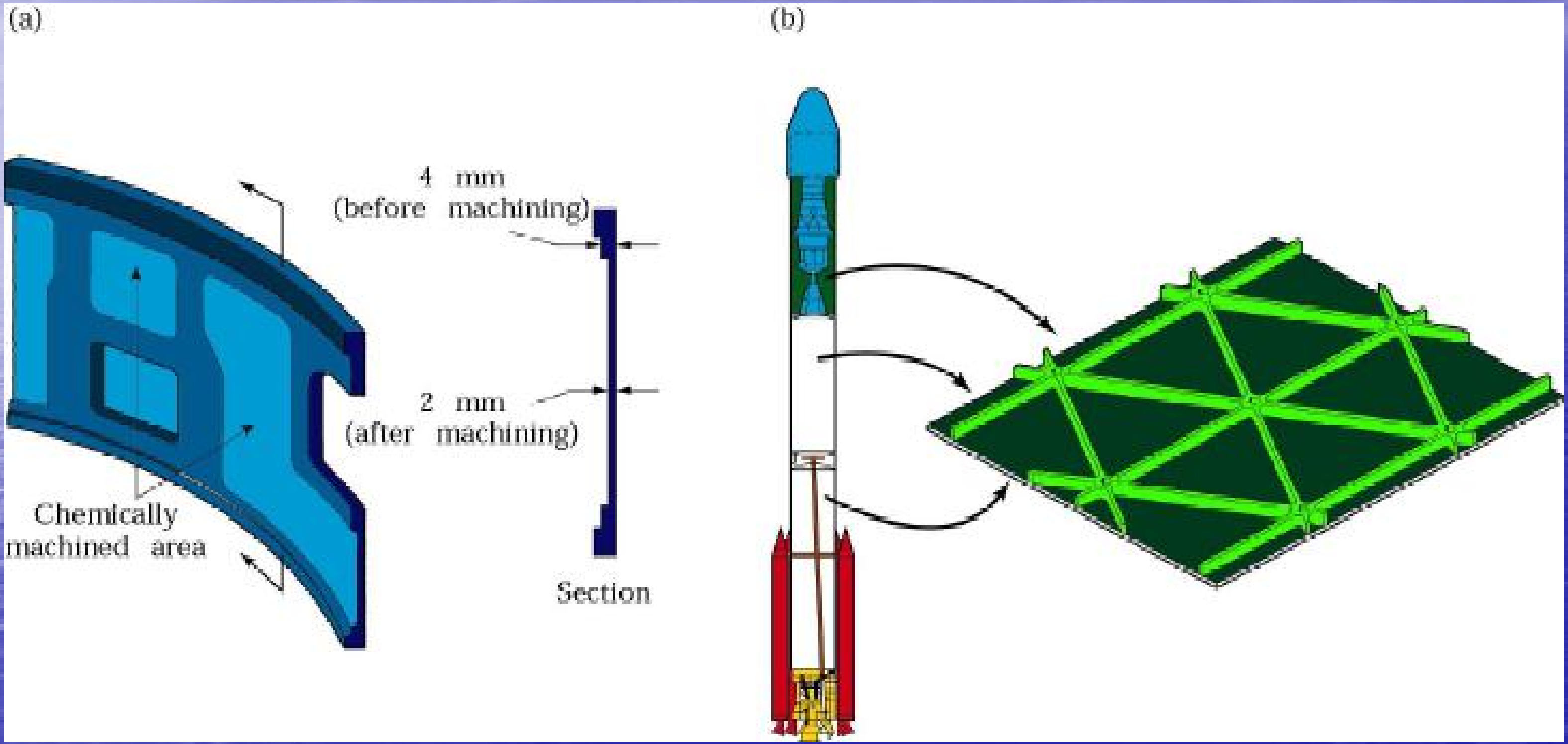
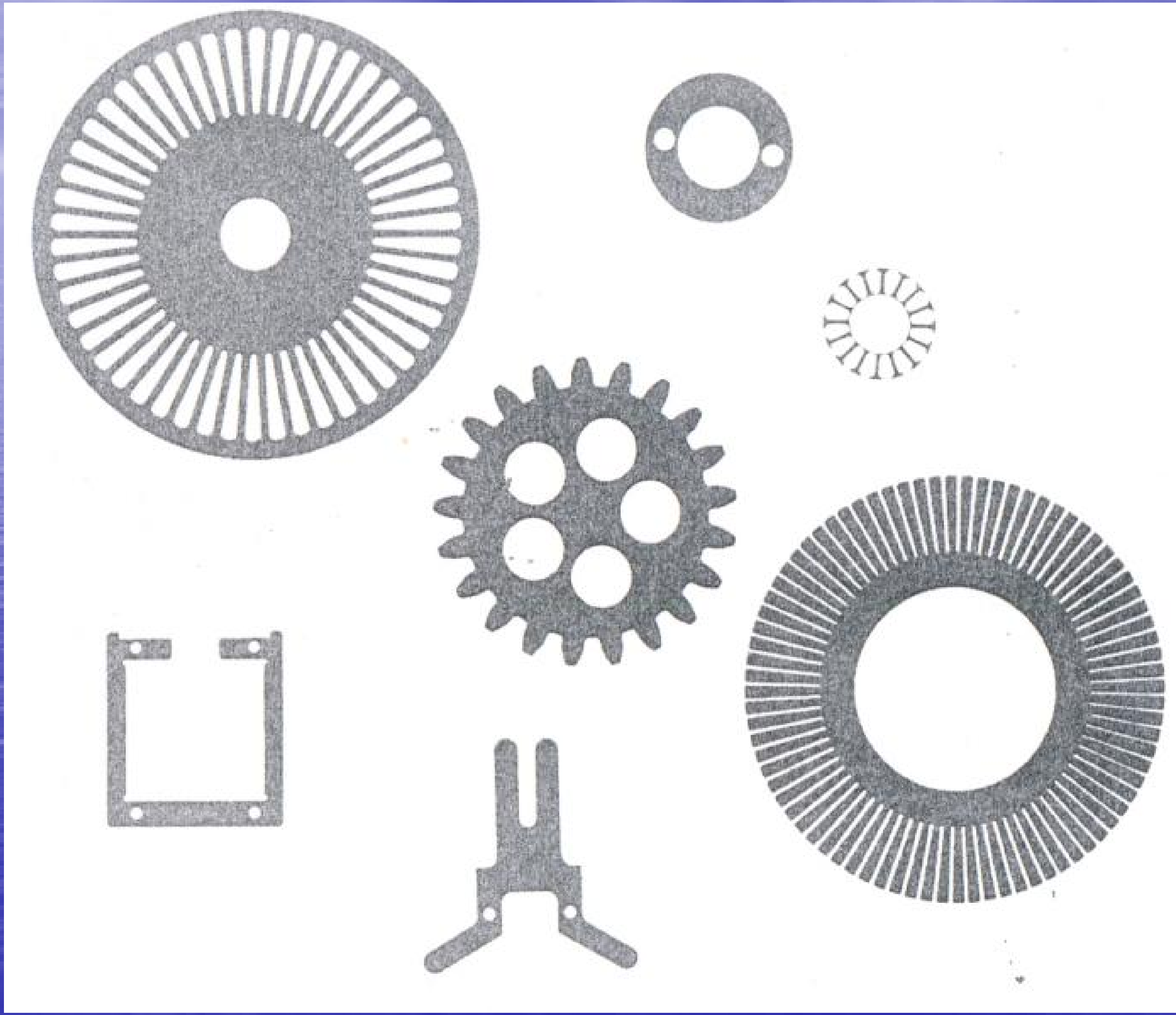


Fig : (a) Missile skin-panel section contoured by chemical milling to improve the stiffness-to weight ratio of the part. (b) Weight reduction of space launch vehicles by chemical milling aluminum-alloy plates. These panels are chemically milled after the plates have first been formed into shape by processes such as roll forming or stretch forming. The design of the chemically machined rib patterns can be modified readily at minimal cost.

Example of parts shaped by blanking



Processing steps

1. Preparing: precleaning
2. Masking : application of chemically resistant material (if selective etching is desired)
3. Etch: dip or spray exposure to the etchant
4. Remove Mask: strip remaining mask and clean
5. Finish: inspection and post processing

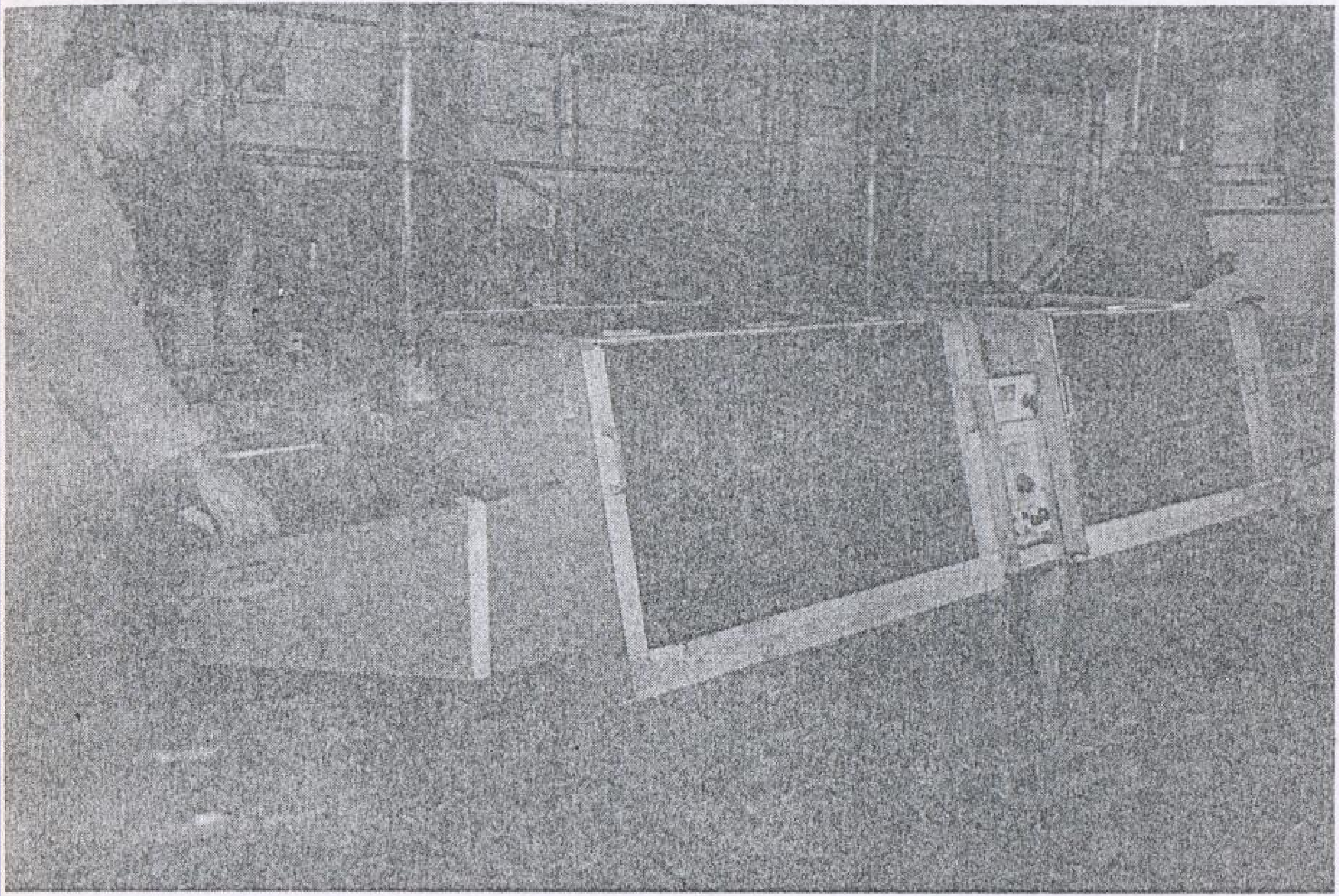
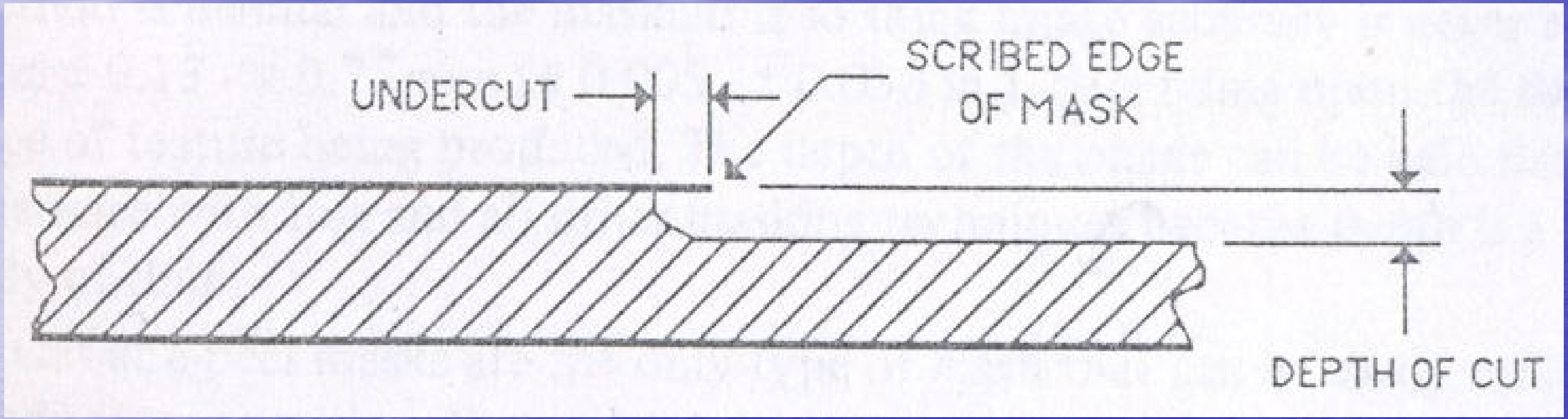


Figure 14.2 Spray-etching system. Workpieces travel through etchant spray on conveyor (*Source*: courtesy, Fotofabrication Corp., Chicago, Ill).

Under cut in CHM



- Amount of undercut that occurs in a particular application is a function of many factors including the depth of cut, the type and strength of the etchant and the workpiece material
- To ensure proper final size of details, it is important to quantify the undercut for a particular combination of variables – etch factor
- Etch factor – ratio of undercut to depth of cut

Etchant

- Purpose: to dissolve a metal by turning it into a metallic salt, which then goes into solution
- Many chemical are available as etchants:$FeCl_3$, Chromic acid, $FeNO_3$, HF, HNO_3
- Etchant selection is based on various criteria

Table 14.2 Etchant Applications and Characteristics

Metal	Preferred etchant	Etch rate (mm/min)	Etch factor
Aluminum	$FeCl_3$	0.025	1.7:1
Copper	$FeCl_3$	0.050	2.7:1
Nickel alloys	$FeCl_3$	0.018	2.0:1
Phosphor-bronze	Chromic acid	0.013	2.0:1
Silver	$FeNO_3$	0.020	1.5:1
Titanium	HF	0.025	2.0:1
Tool steel	HNO_3	0.018	1.5:1

Source: adapted from Bellows, 1977.

Table 14.3 Etchant Selection

Required surface finish.	Some combinations of material and etchant result in the formation of surface oxides, which degrade the finish.
Removal rate	Faster rates lower the cost, but attack the resist bond, result in poor finish, or produce high heat.
Material type	Etchant must attack the material without causing IGA, H_2 embrittlement, or stress corrosion cracking.
Etch depth	Some etchants produce surface finishes that worsen with increasing depth.
Type of resist	Etchant must not destroy resist during the process time.
Cost	Cost of the etchant, maintenance, and disposal must be considered.

Maskant or resist

- Three major categories of chemically resistant masks are available for use in chemical machining
- Selection of proper maskant for a particular application is accomplished by evaluation of the job with respect to six factors – chemical resistance, part configuration, quantity of parts, cost, ease of removal and required resolution

Classification of maskants

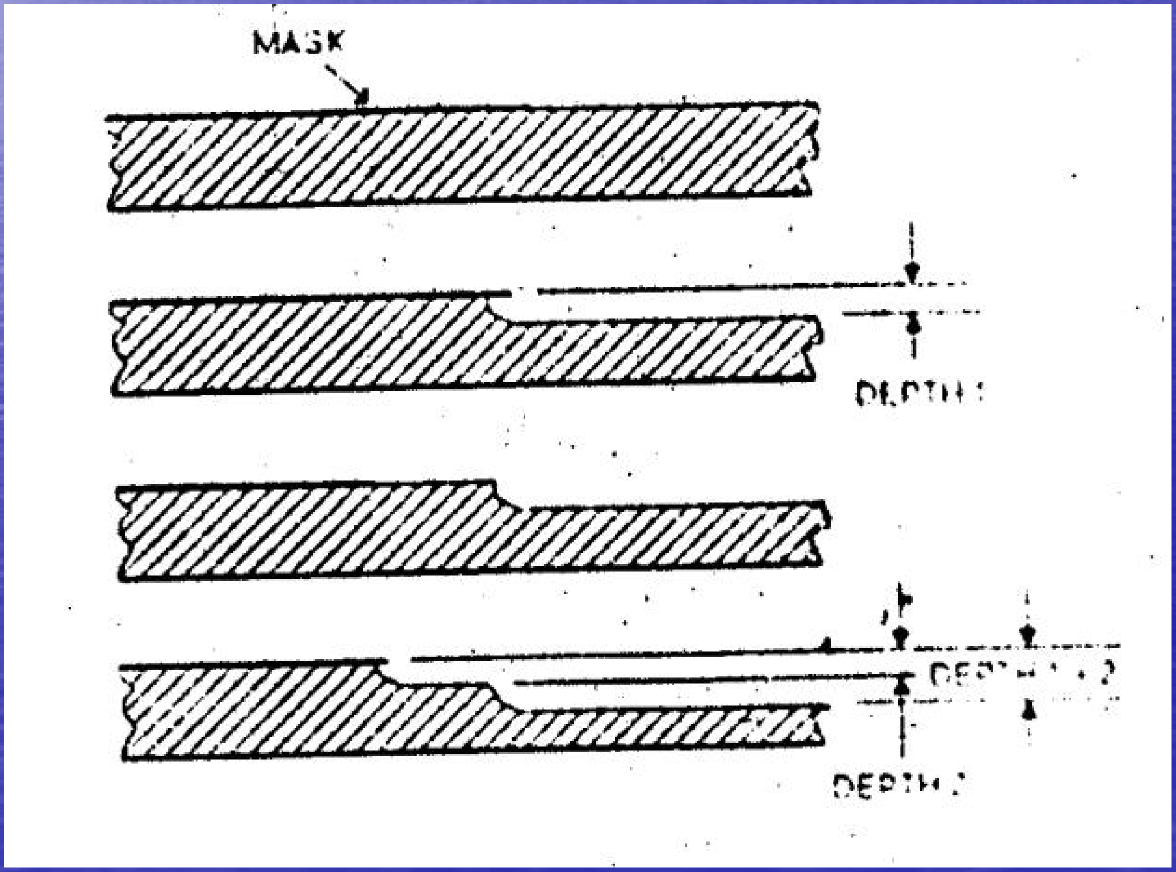
- Cut and peel
- Screen printing
- Photoresist masks

Cut and peel - 1

- Involve the use of relatively thick material which is scribed and removed to create a selective exposure to the etchant
- Neoprene, butyl or vinyl-based material
- Almost exclusively used for chemical milling of aircraft, missile and structural parts and components for chemical industries
- Maskant is applied to the entire part to be processed by flow, dip or spray coating
- Materials are relatively thick in nature, being 0.001 to 0.005 inch thick in dry film form
- Materials are removed from areas to be etched by cutting the maskant with a scribe knife (generally with a template to aid accuracy) and peeling away unwanted areas
- Because of the inherent nature of the maskant and the thickness of the coating, extremely high chemical resistance is achieved, permitting etching depths of 0.5 in. or more
- Generally used where extremely critical dimensional tolerances are not required
- Used for parts that are extremely large, have many irregularities, require depth of etch in excess of 0.05 n and have multiple steps in the removal areas

Cut and peel - 2

- The materials used for maskants afford flexibility in the processing – after a certain area has been etched, additional maskant may be removed so that step etching is possible
- Only type of mask that can be easily rescribed to produce step etching



Screen printing - 1

- Mask application technique that draws on conventional silk-screen printing technology
- A fine mesh silk or stainless steel screen, which has areas blocked-off to allow selective passage of the maskant is used
- The blocked pattern corresponds to the image that is to be etched
- The screen is pressed against the surface of the workpiece and the maskant is rolled on
- When the screen is removed, the maskant remains on the part in the desired pattern
- The maskant is ready for etching after it has been dried by baking

Screen printing - 2

- Screen printing is a fast, economical masking method for high-volume production when high accuracy is not required
- The mask thickness is typically less than 0.05mm and so life in the etchant is relatively short, limiting the etching depth to 1.5mm
- Screen printing is desirable if part size is less than 1.2m x 1.2m; surfaces are flat or with only moderate contours; etch depth does not exceed 1.5mm per side; or when a high degree of accuracy is not required

Photoresist masks

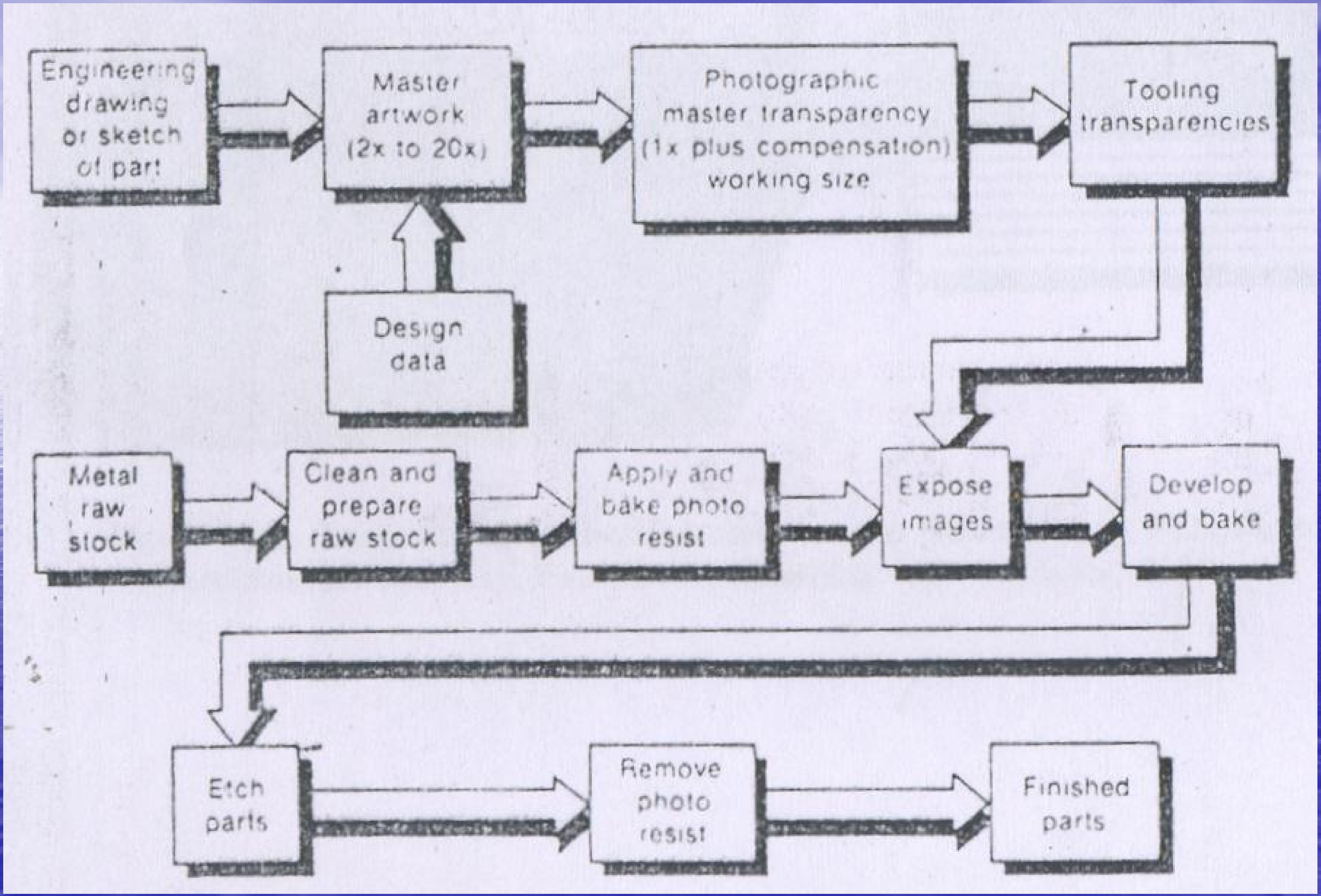
- Photoresist masking is so versatile and in such widespread use that it has almost become a separate nontraditional process
- Commonly known as photochemical machining (PCM), it is used to produce intricate and precise mask on a workpiece
- Capable of producing extremely high detail but lack the chemical resistance necessary for deep etching
- Poor bonding of the resist film to the material being etched, unless the material is very carefully cleaned prior to application of the resist
- Sensitivity to light and susceptibility to damage by rough handling and exposure to dirt and dust, necessitating careful handling and a clean environment for successful operation
- More complicated processing than required by the scribe and peel maskants
- PCM is generally used for:

1. Alternative to conventional stamping when intricate patterns or low production volumes are involved
2. Thin materials
3. Parts requiring dimensional tolerances of the etchant resistant image tighter than ±0.005 in
4. Parts produced in high volume where the chemical resistance of the photographic resists is adequate

- PCM are not generally used for:

1. Depths in excess of 0.05in thick
2. Parts larger than 3ft by 5ft
3. Materials requiring the use of extremely-active etchants that will degrade or strip the photoresists

PCM process



Engineering drawing or sketch of part
Master artwork (2x to 20x)
Photographic master transparency (1x plus compensation) working size
Tooling transparencies
Design data
Metal raw stock
Clean and prepare raw stock
Apply and bake photo resist
Expose images
Develop and bake
Etch parts
Remove photo resist
Finished parts

Table 14.1 Mask Selection

Factor	Consideration
Chemical Resistance	The thicker the maskant, the longer the exposure time before the maskant is destroyed. Thus deeper etching is possible with thicker masks.
Part Configuration	Some maskants are only applicable to flat parts.
Quantity of parts	The higher the production quantity, the less labor intensive the masking process should be.
Cost	Actual resist material costs vary. Higher-priced maskants are usually easier to remove.
Ease of removal	The maskant is usually removed before part use. Delicate parts require easy removal.
Required resolution	Accuracy varies with maskant and application method. Thicker masks generally result in less accuracy.

Process parameters

- Two most important factors in the process are the maskant and the selection of etchant

Advantages

- Metal removal is completely stress free
- Complex shapes and deeply recessed areas can be uniformly chemically milled
- Extremely thin sections can be chemically milled
- Metal hardness or brittleness is not a factor
- Part size is only limited by tank dimension
- Many parts can be chemically milled at one time either by processing a large workpiece before cutting out the parts, or by milling many separate pieces in the tank at one time
- Tapered sections can be chemically milled
- Most alloys and forms can be chemically milled
- Fine surface finishes are produced on many alloys
- Extremely close thickness tolerance are achievable
- Tooling and tool maintenance costs are low
- Cutouts and the periphery of difficult to machine parts can be rough trimmed by etching through the metal, at minimum added cost
- Extrusions, forgings, castings, formed sections and deep drawn parts can be lightened considerably by CHM
- Company logos, part numbers or other identifying marks can easily be etched into the surface during manufacture at no extra cost
- PCM can be used to make one or a million parts, with the same tooling used every time. This allows the engineer or designer to develop their concept from prototype to pilot to full production quickly and easily
- PCM process produces burr free components, thus removing the need for costly time-consuming de-burring
- Setup and tooling costs are extremely low
- Design change costs are low, because only art work is altered – allows great design flexibility

Limitations

- Fillet radius is approximately equal to depth of cut
- Extremely deep cuts are usually not cost effective
- A homogenous metal structure is normally required for good results
- Welds and castings often produce pitted surfaces when chemically milled
- Process costs depend on the quality of the original workpiece (thickness variation, presence of surface scratches and corrosion)
- It is impractical to make grooves of width less than twice the depth
- Hazardous chemicals used in the process present difficult safety, waste disposal and air pollution problems
- A relatively high level of operator skill is required for PCM
- Suitable photographic facilities are not always available

Applications – Chemical Milling

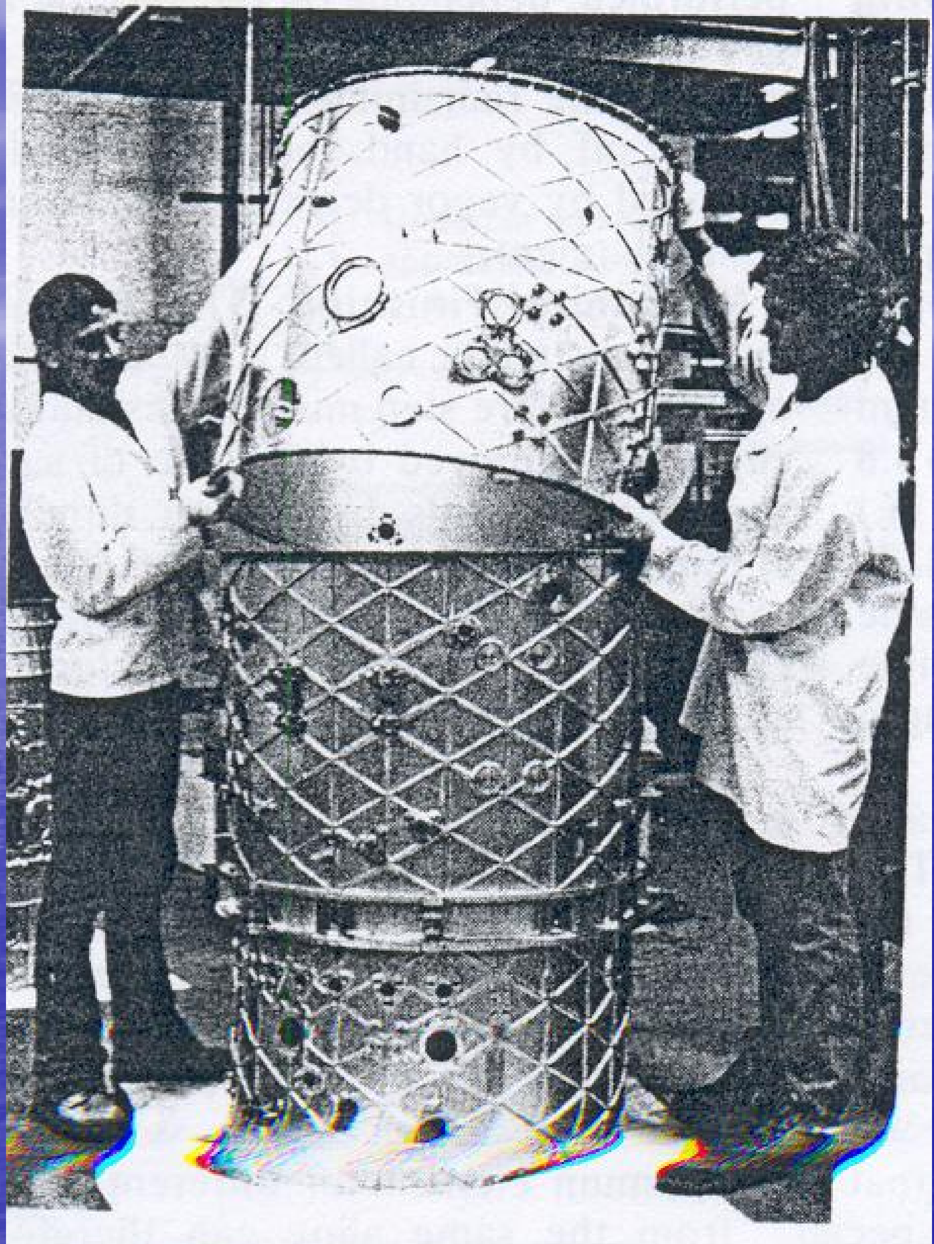
Used extensively to etch preformed aerospace parts to obtain maximum strength to weight ratios:

- Integrally stiffened Titanium engine ducts
- Spray etching a rotating tube for cruise missile launch tubes
- Thinning and sizing of a delta booster tank bulkhead
- Chemical sizing of engine cowl inlet duct skins
- Undercut on clad aluminium
- Removing the alpha case from a Titanium casting
- Elimination of decarburized layer from low-alloy steel forgings
- Elimination of recast layers from EDM

Applications - PCM

It plays a valuable role world-wide in the production of precision parts and decorative items, mainly sheets and foils. Such products include:

- color television shadow masks
- integrated circuit lead frames
- surface mount paste screens
- heat ladders, plates and sinks
- optical attenuators, choppers and encoder disks
- grills, grids, sieves and meshes
- washers, shims and gaskets
- jewellery
- decorative ornaments
- signs, plaques and nameplates
- Manufacture of burr-free intricate thin stampings



g. 2 Integrally stiffened engine tan and exhaust ducts

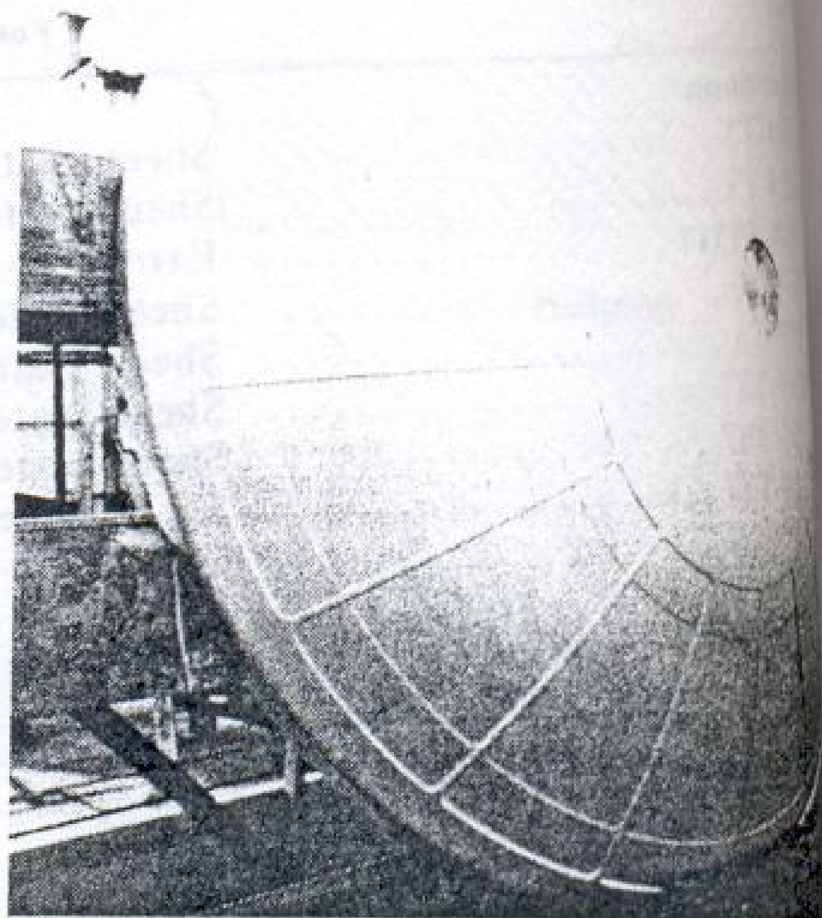


Fig. 11 Delta booster tank bulkhead

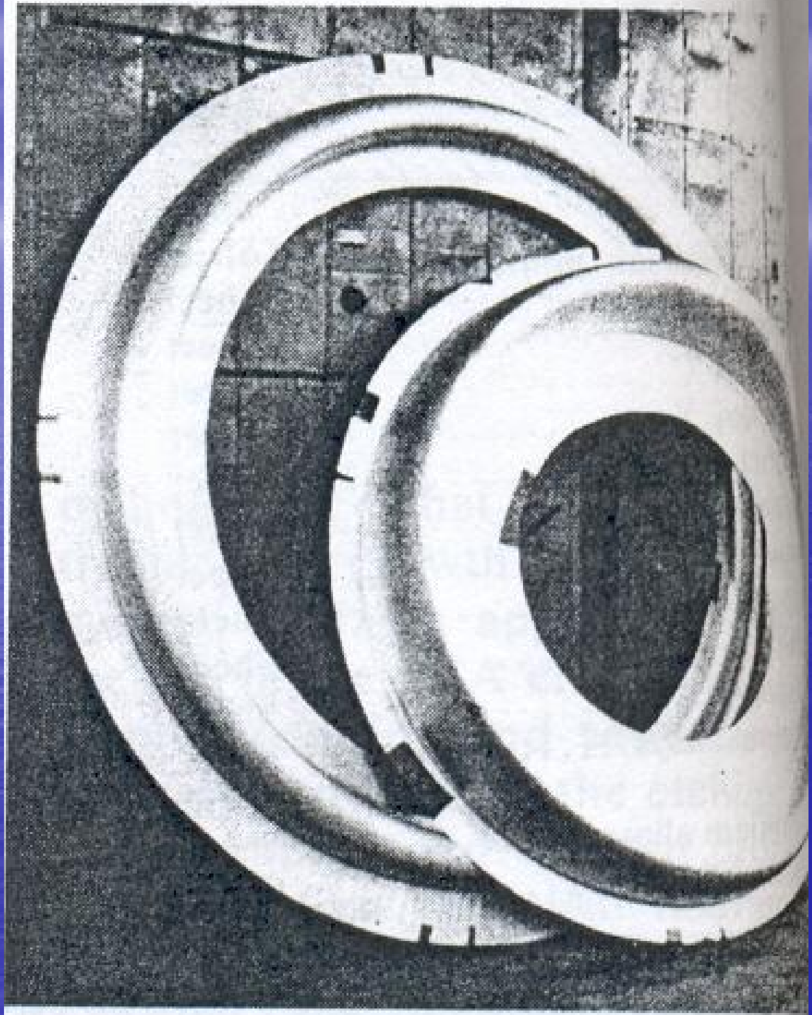


Fig. 12 Engine cowl inlet duct skins

Fig. 13 Engine cowl access door

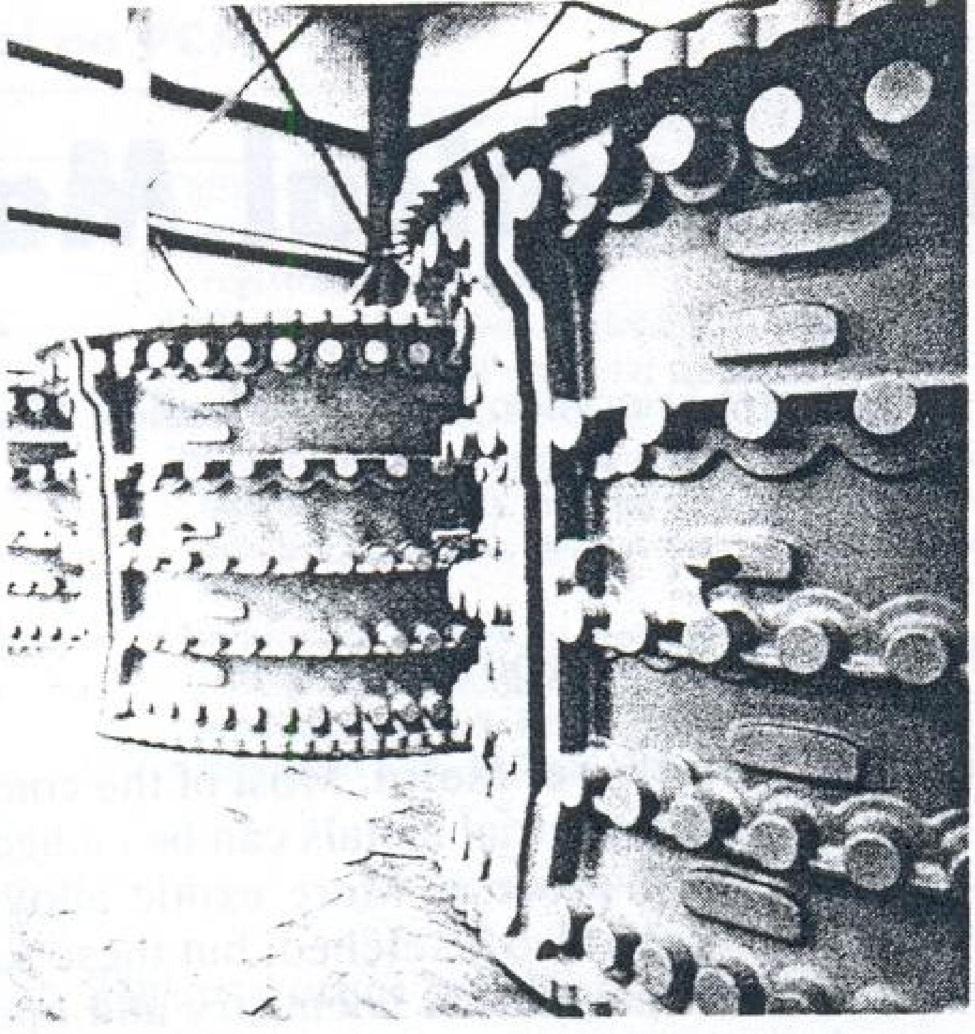


Fig. 14 Titanium casting for combustor case

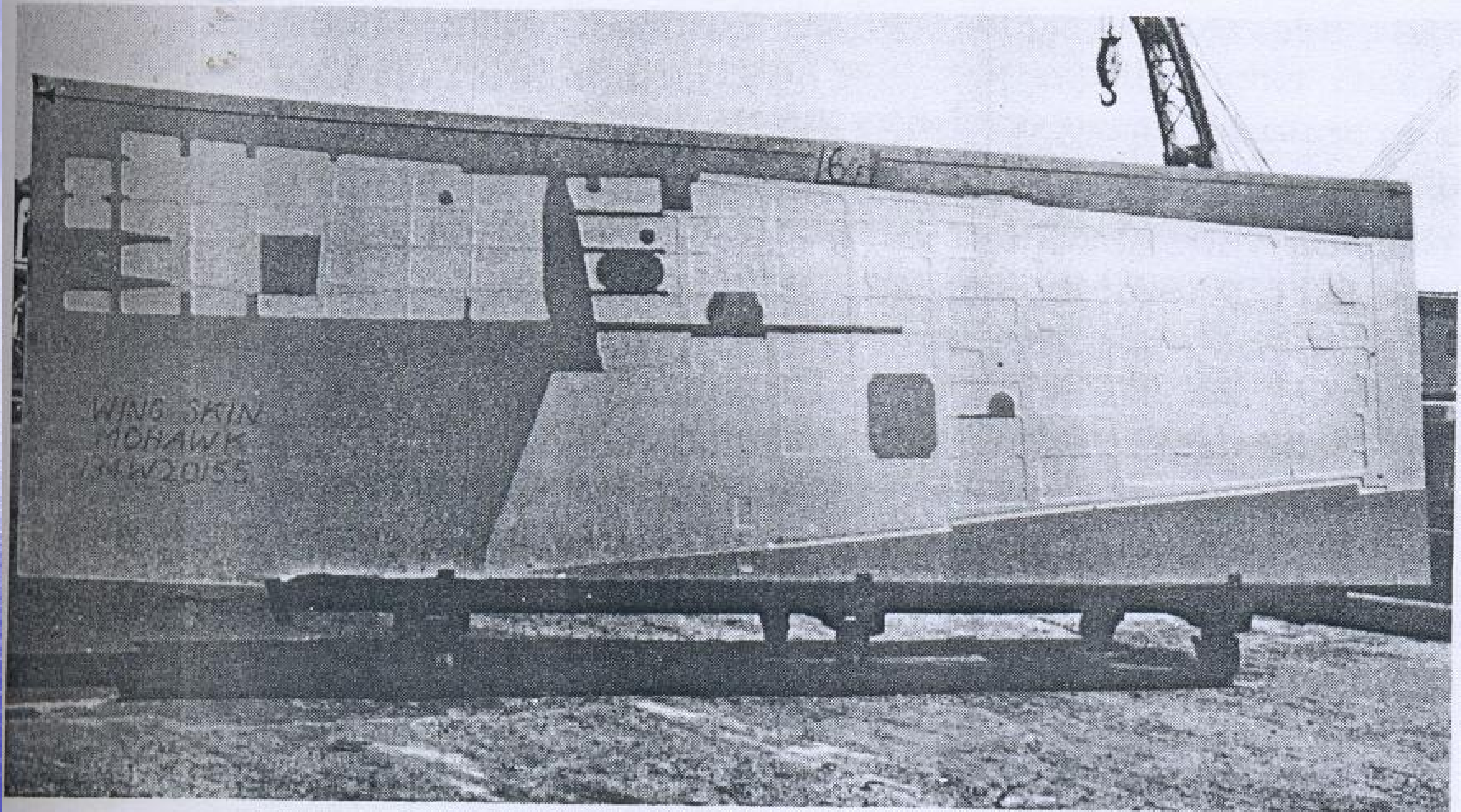


Fig. 4-1. Aluminum aircraft wing skin with numerous surface areas etched to remove unnecessary metal for better strength-to-weight ratio. *(Courtesy, Grumman Aircraft Engineering Corporation)*

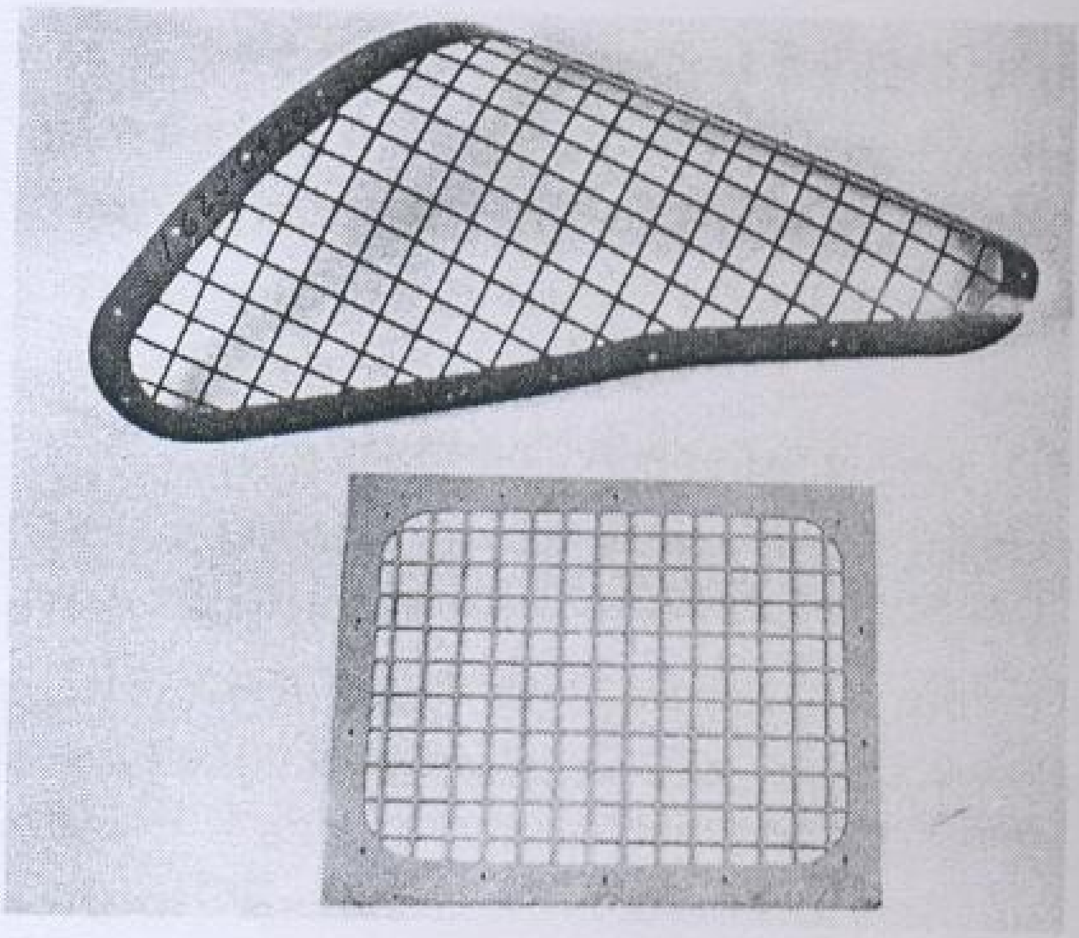


Fig. 4–2. Aluminum helicopter vent screens. *(Courtesy, Chemcut Corporation)*

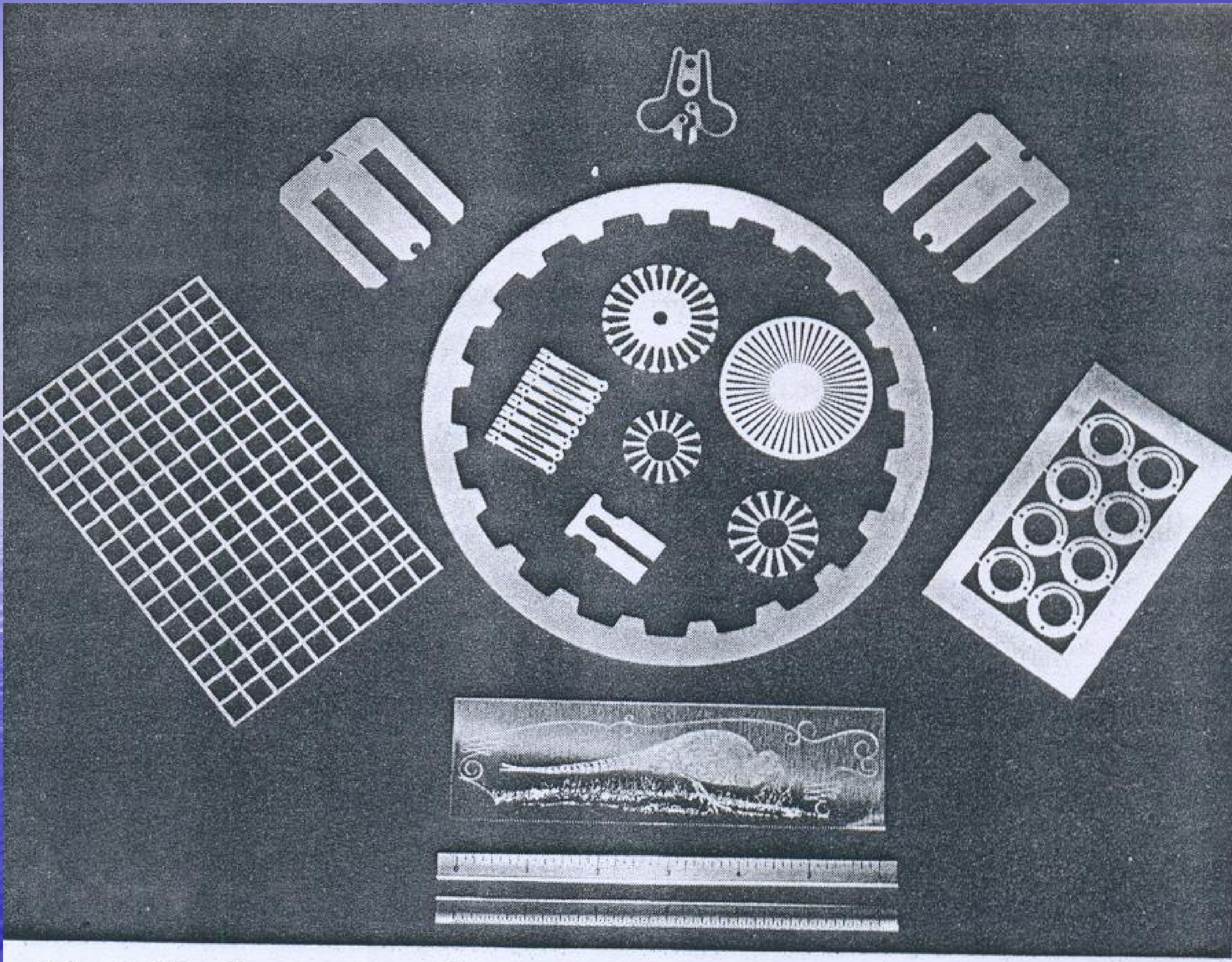


Fig. 4–27. Parts produced by chemical blanking. *(Courtesy, Chemcut Corporation)*

Parts produced by PCM

Electrochemical Machining (ECM)

Synopsis

- Introduction
- Principle
- Equipment
- MRR
- Tool material
- Electrolyte
- Insulation
- Electrical circuit
- Process parameters
- Advantages
- Limitations
- Applications

Introduction

- Electrical energy used in combination with chemical reactions to remove material
- Relies on the principle of electrolysis for material removal
- Michael Faraday discovered that if two electrodes are placed in a bath containing a conducting liquid and a DC potential is applied across them, then metal can be depleted from the anode and plated on the cathode – process universally used in electroplating by making the workpiece the cathode
- In ECM, the material is removed and hence electroplating is reveresed, i.e. workpiece is made the anode
- Work material must be a conductor
- Machines having current capacities as high as 40,000 A and as low as 5A are available
- Processes:

1. Electrochemical machining (ECM)
2. Electrochemical deburring (ECD)
3. Electrochemical grinding (ECG)

Principle of ECM - 1

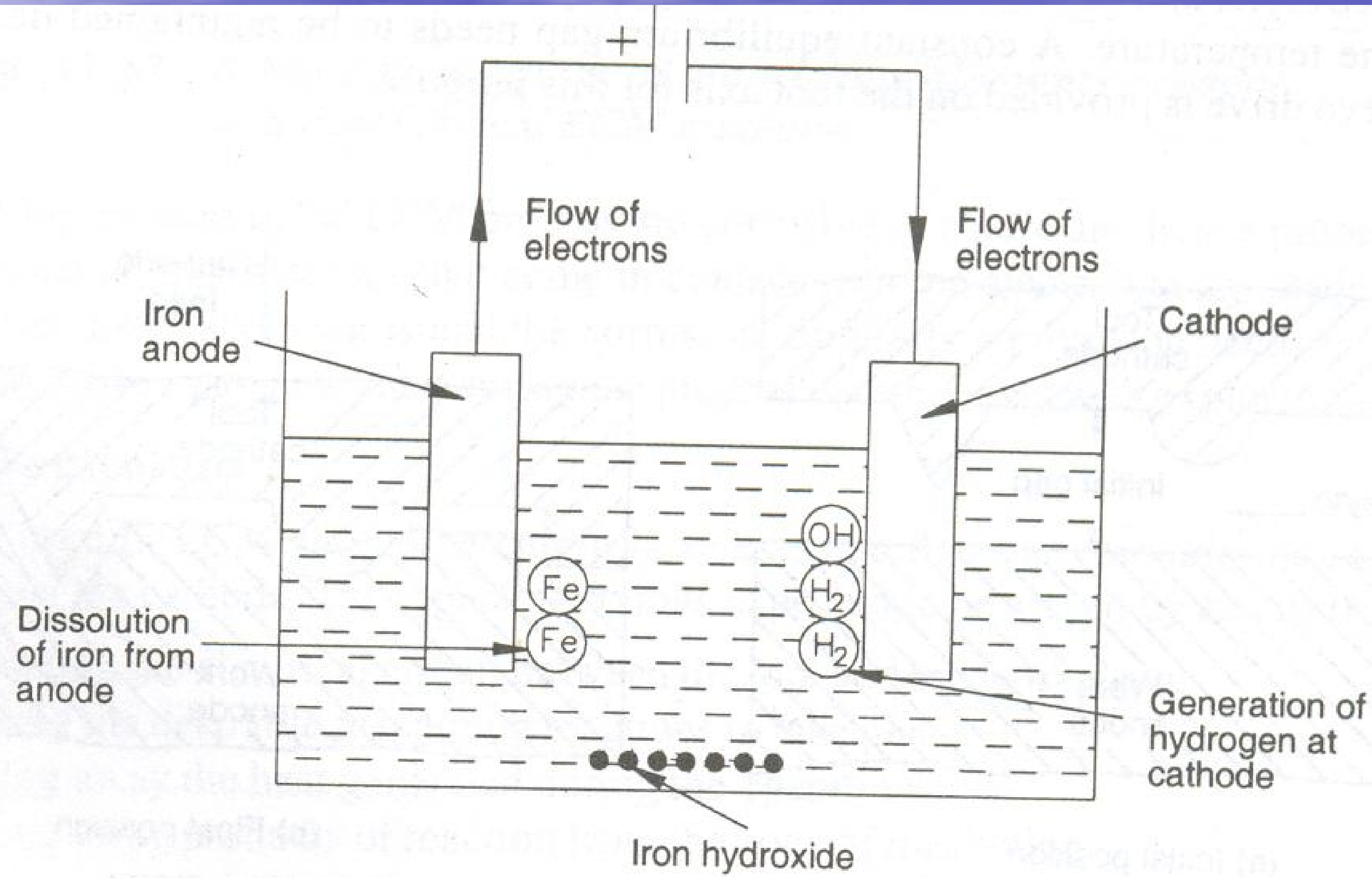


Fig. 11.15 *Principle of electrolysis*

Principle of ECM - 2

- Net result of electrolysis: Iron gets dissolved from the anode and forming the residue consuming electricity and water, and nothing else. Reaction products are ferric hydroxide and hydrogen gas
- Metal from the anode is dissolved electrochemically and hence the MRR based on Faraday's laws will depend upon atomic weight, valency, the current passed and the time for which the current passes
- At the cathode only hydrogen gas is evolved and no other reaction takes place, hence the shape of the cathode remains unaffected

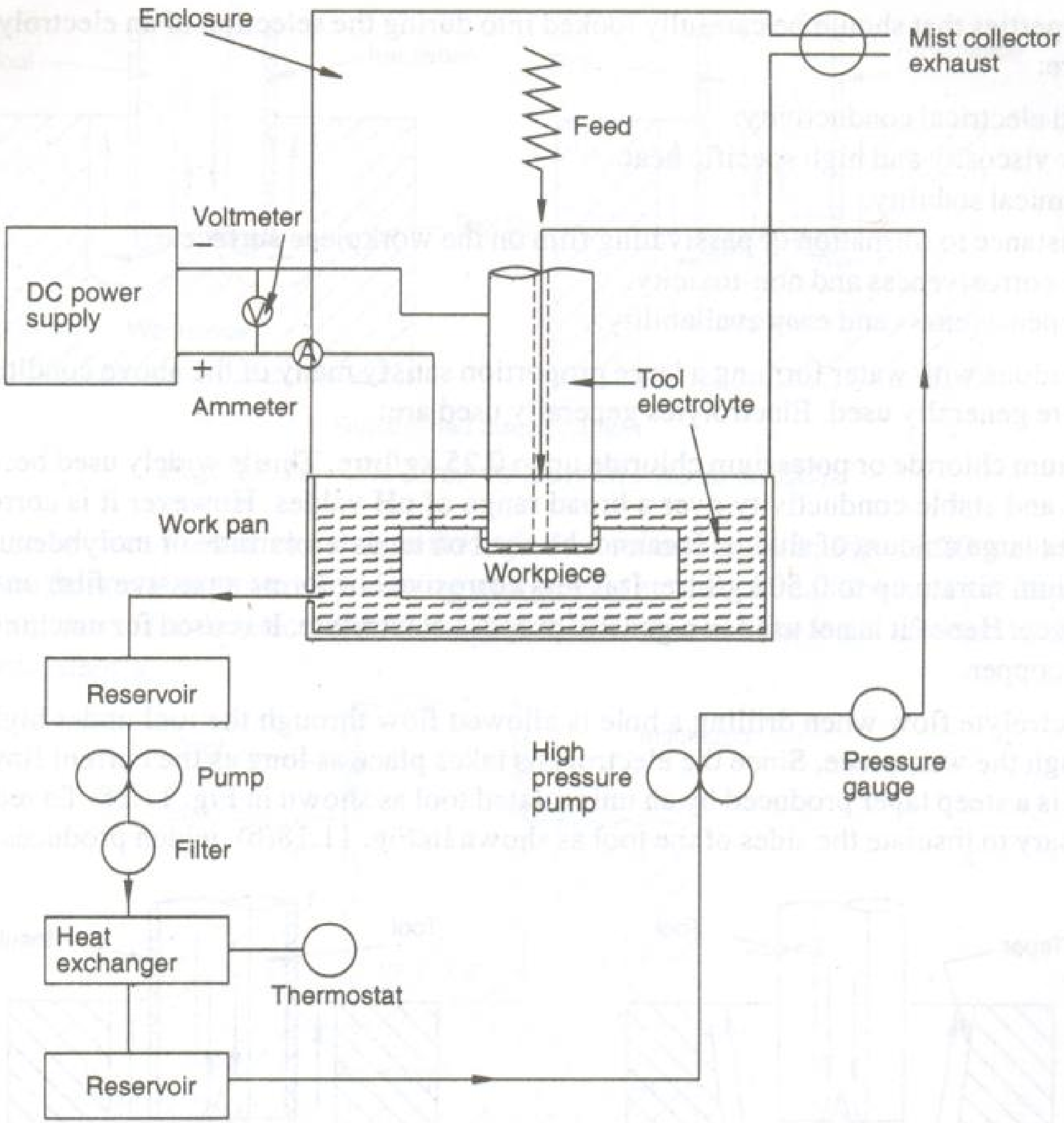


Fig. 11.17 *Schematic diagram of the various elements present in a commercial ECM machine*

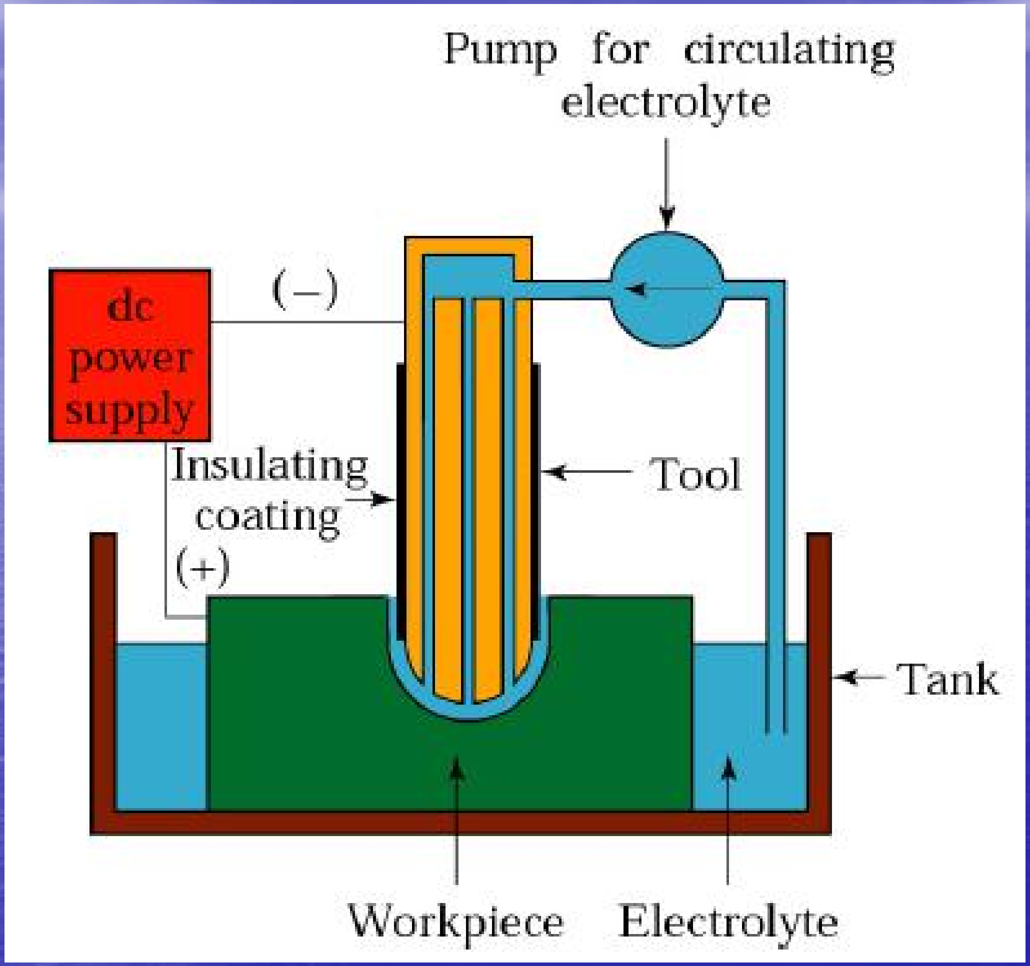


Fig : Schematic illustration of the electrochemical-machining process. This process is the reverse of electroplating.

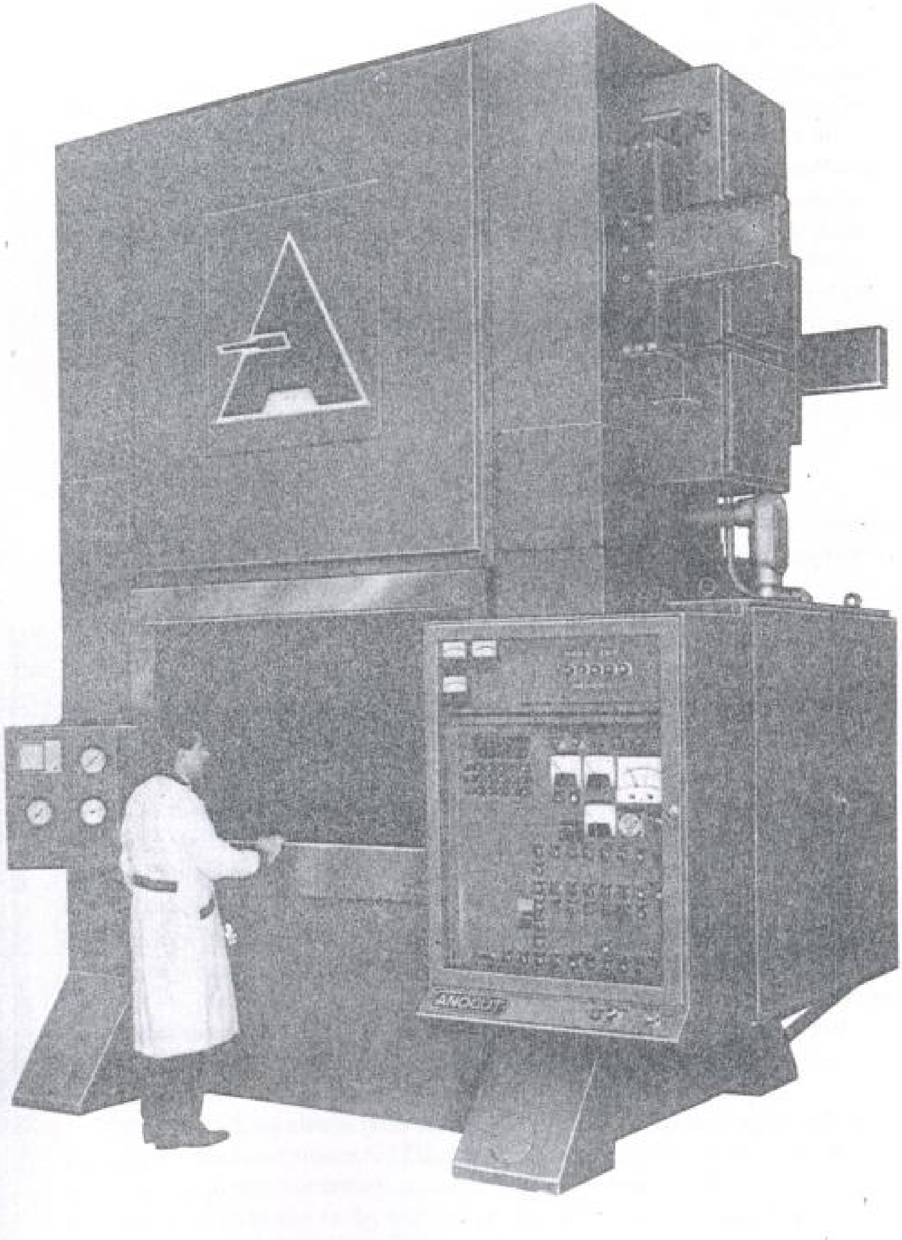


Figure 9.4 Large-capacity vertical ECM machine rated at 40,000 amp (*Source:* courtesy, Anocut Inc., Elk Grove Village, Ill.).

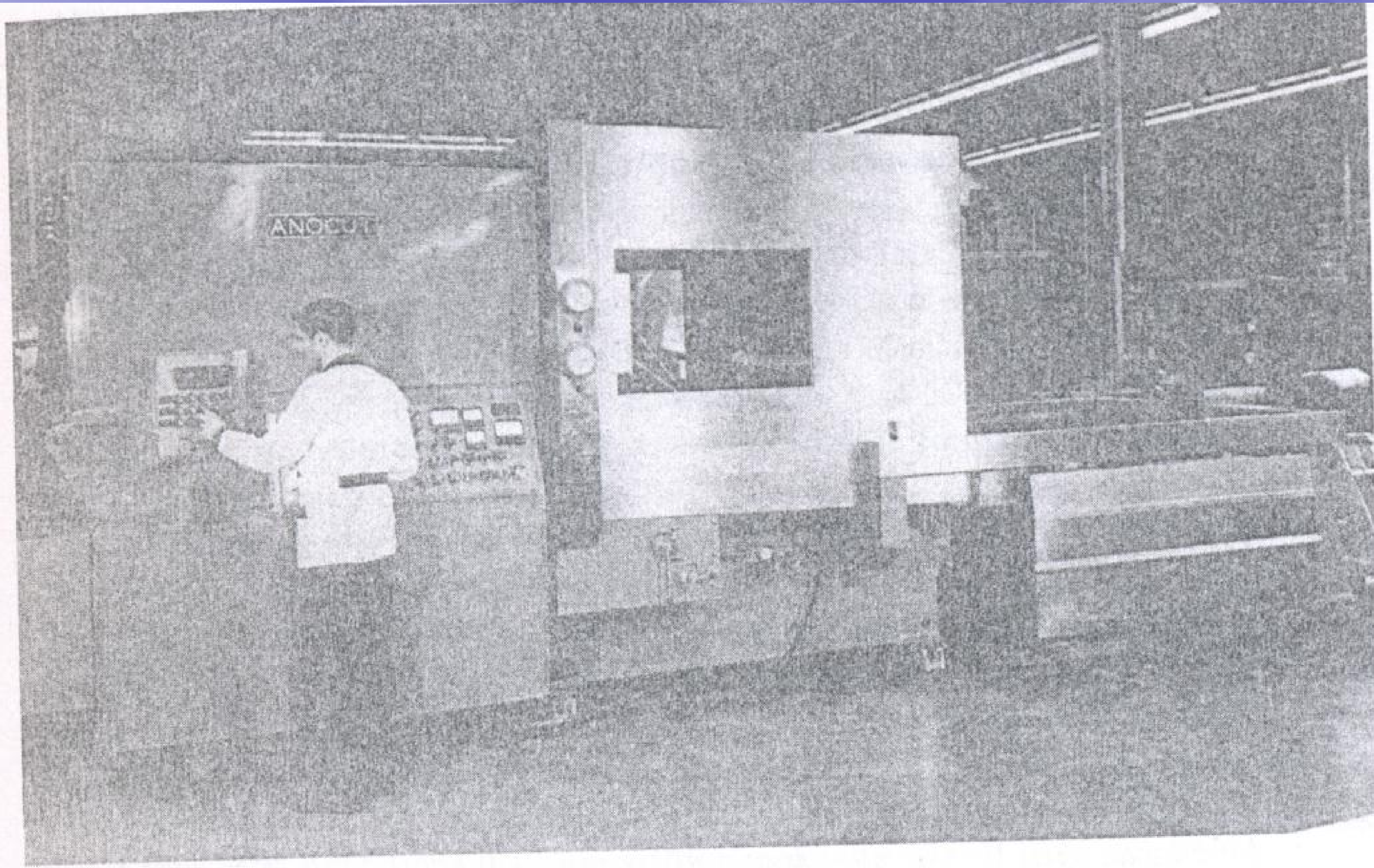


Figure 9.5 Horizontal configuration, 20,000-amp ECM machine (*Source:* courtesy, Anocut Inc., Elk Grove Village, Ill.).

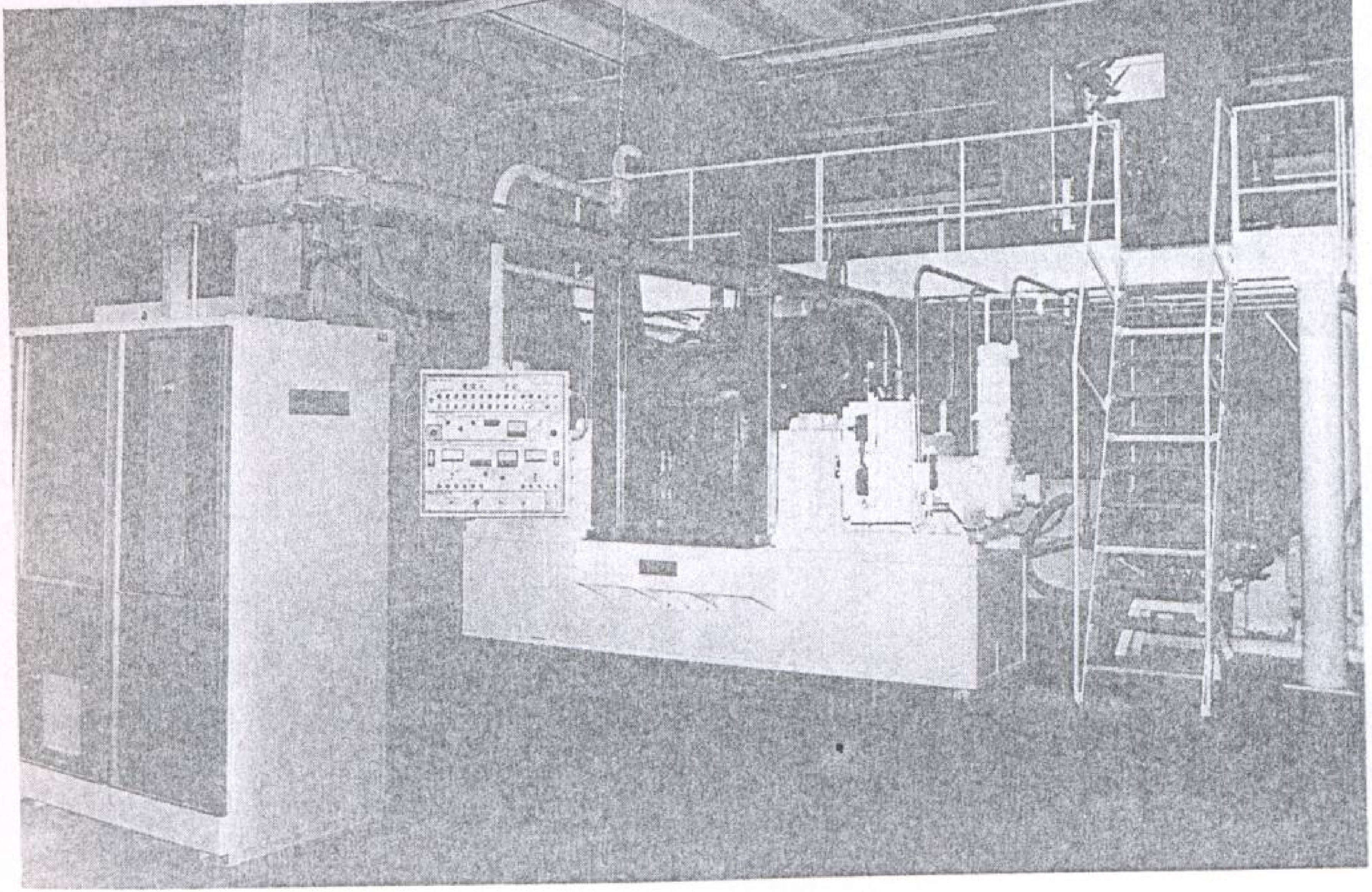


Figure 9.6 A CNC tri-ram ECM system used for machining turbine engine blades (*Source:* courtesy, Chemform, Pompano Beach, Fla).

Sub-systems

1. Power source
- High value DC (may be as high as 40,000A) and a low value of electric potential (in the range of 5-25V) across the IEG is desirable
- With the help of a rectifier and a transformer, three phase AC is converted to low voltage, high current DC
- Silicon controlled rectifiers (SCR) are used both for rectification as well as for voltage regulation
2. Electrolyte supply and cleaning system
- Consists of pump, filters, piping, control valves, heating or cooling coils, pressure gauges and a storage tank
3. Tool and tool-feed system
4. Workpiece and work-holding system
- Only electrically conductive workpieces can be machined by this process – the chemical properties of anode material largely govern the MRR
- Workholding devices are made of electrically non-conductive materials having good thermal stablility, and low moisture absorption properties. For example, graphite fibres-reinforced plastics, plastics, perspex, etc

Operation

- Material is depleted from anode workpiece (positive pole) and transported to a cathode tool (negative pole) in an electrolyte bath
- Electrolyte flows rapidly between the two poles to carry off depleted material, so it does not plate onto tool
- Electrode materials: Aluminium, Cu, brass, titanium, cupro-nickel and stainless steel
- Tool has inverse shape of part
- Tool size and shape must allow for the gap

Process capabilities

- Used to machine complex cavities in high strength material
- Applications in aerospace industry, jet engines parts and nozzles
- ECM process gives a burr free surface
- No thermal damage
- Lack of tool forces prevents distortion of the part
- No tool wear
- Capable of producing complex shapes and hard materials

Tool material

Properties expected out of the tool material:

- High electrical and thermal conductivity
- Good stiffness
- Easy machinability - particularly important if complex shaped tools are required
- High corrosion resistance - to protect itself from the highly corrosive electrolyte solution
- Rigidity - Rigidity of the tool construction and material is important because the high pressure can cause deflection of the tool
- Easily available

Generally aluminium, copper, brass, bronze, carbon, copper -manganese, copper-tungsten, titanium, cupro-nickel and stainless steel are used

Tool design considerations

Two major aspects of tool design:

1. Determining the tool shape so that the desired shape of the job is achieved
2. Other considerations such as electrolyte flow, insulation, strength and fixing arrangements

- Modification of the tool profile to get the required final surface is relatively complex - FEM can be used to get the final tool design
- Designer must determine the nature and the extent of the required deviation or gap allowances from the mirror image configuration, while providing for a uniform and sufficiently high flow rate of electrolyte in the gap to allow a practical MRR
- Tool dimensions must be slightly different from the nominal mirror dimensions of the completed part to allow for ECM overcut
- Part and the cathode must have adequate current-carrying capacity
- ECM cell must have strength and rigidity to avoid flutter and arcing

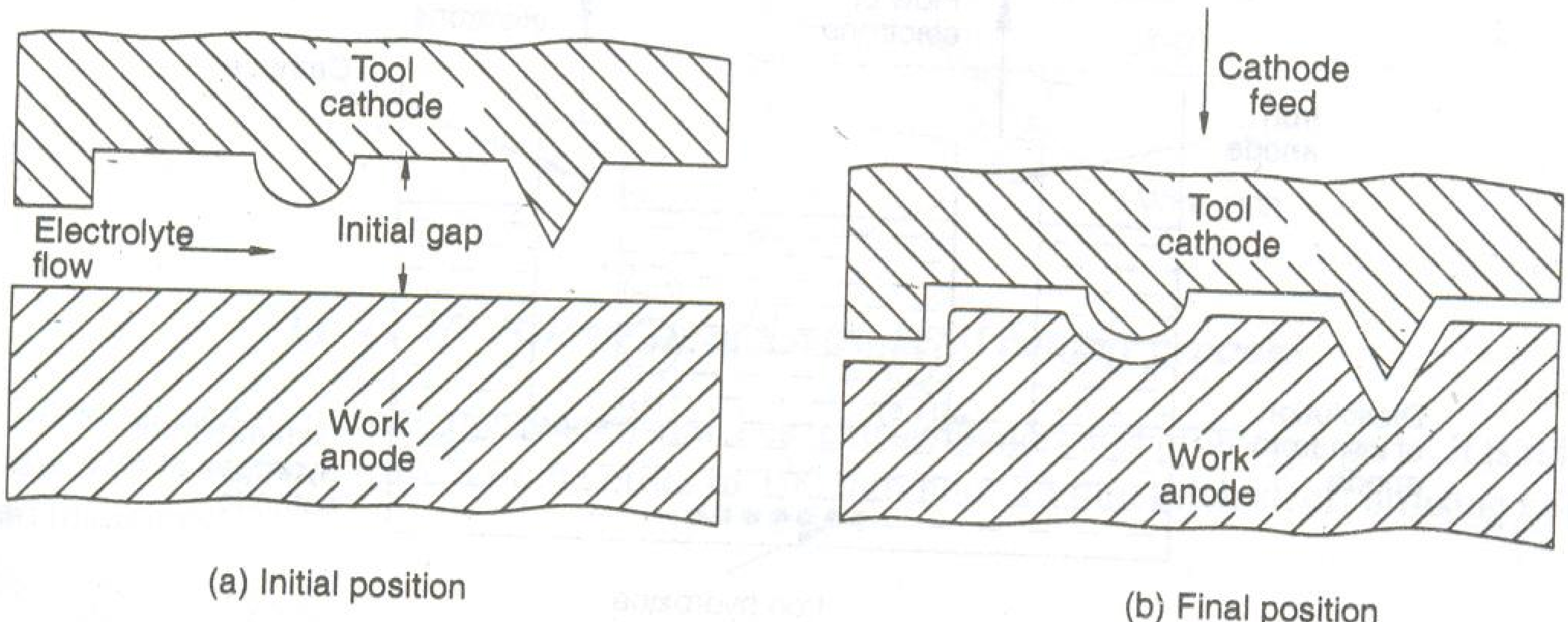
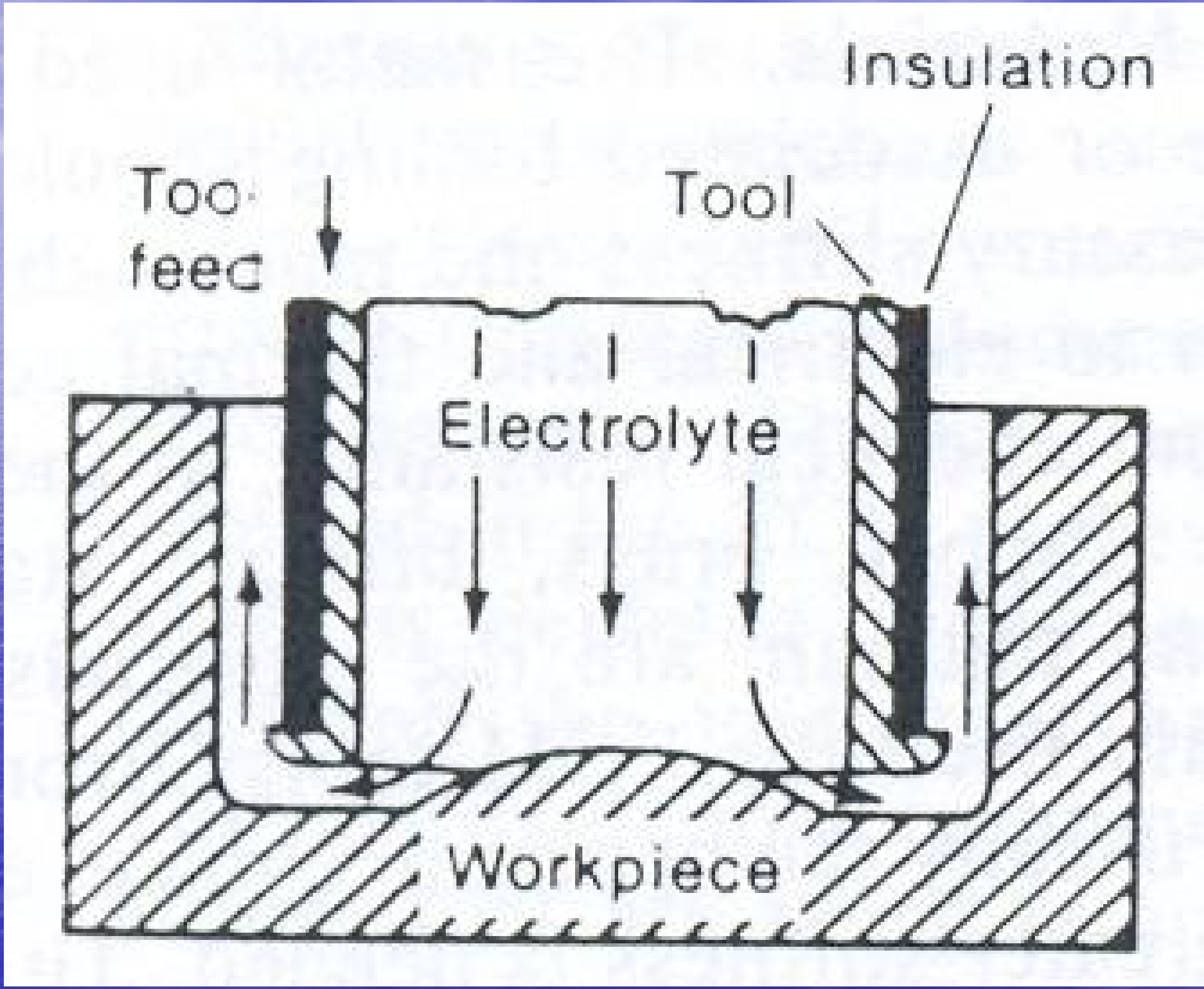


Fig. 11.16 *Complimentary shape produced by ECM*

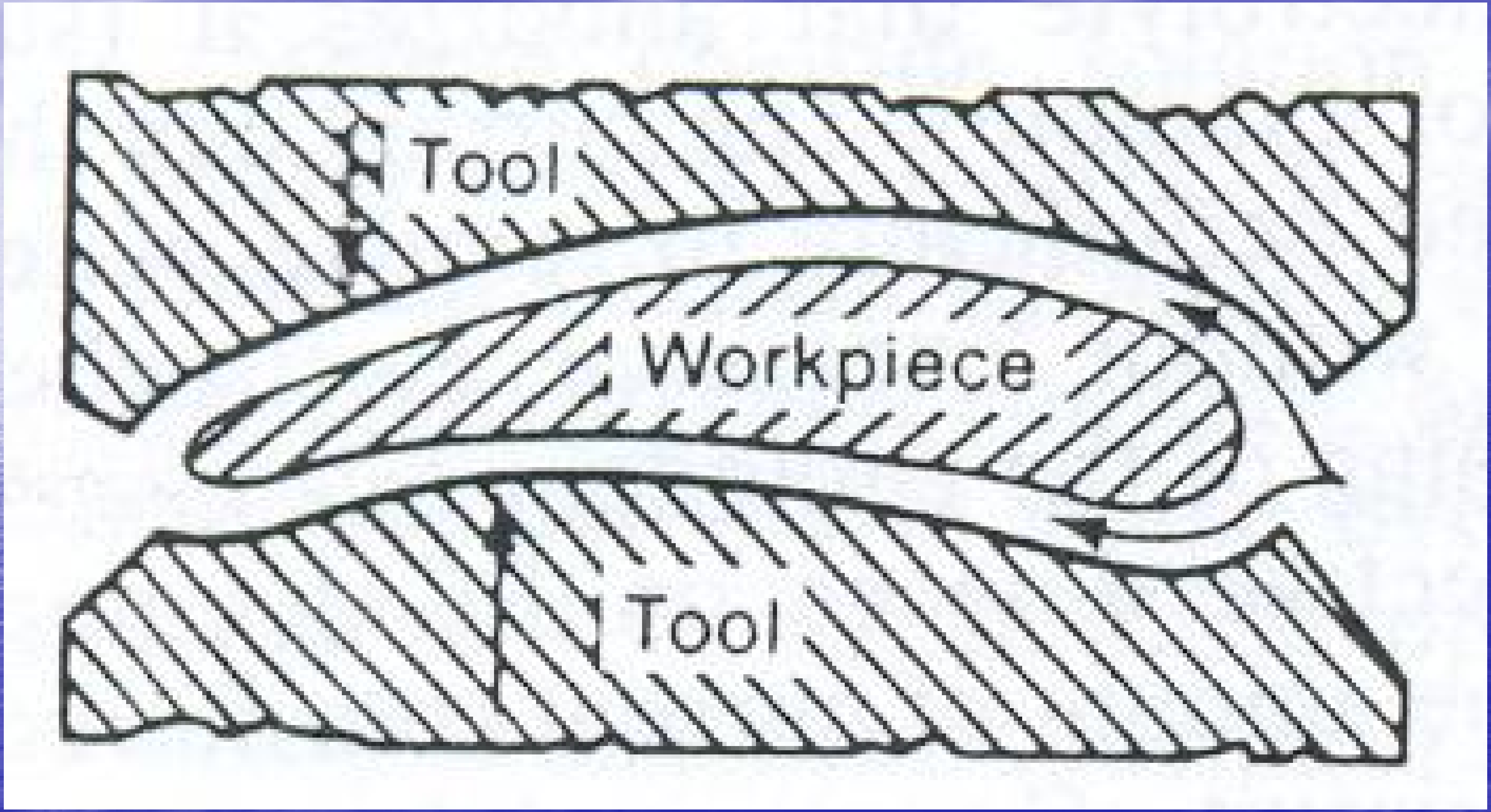
Tool design types

- Most common – open-flow type
- Cross-flow type for external machining
- Because of the interaction of working-tip shape and dimensions, location of insulation, current density and feed rate, the design of tools for machining complex shapes requries understanding of fluid flow, electrcial and electrochemical principles as well as experience and ingenuity
- Although tool design may be difficult and time consuming, the cost of additional or replacement ECM tooling is usually much less than that for conventional machining

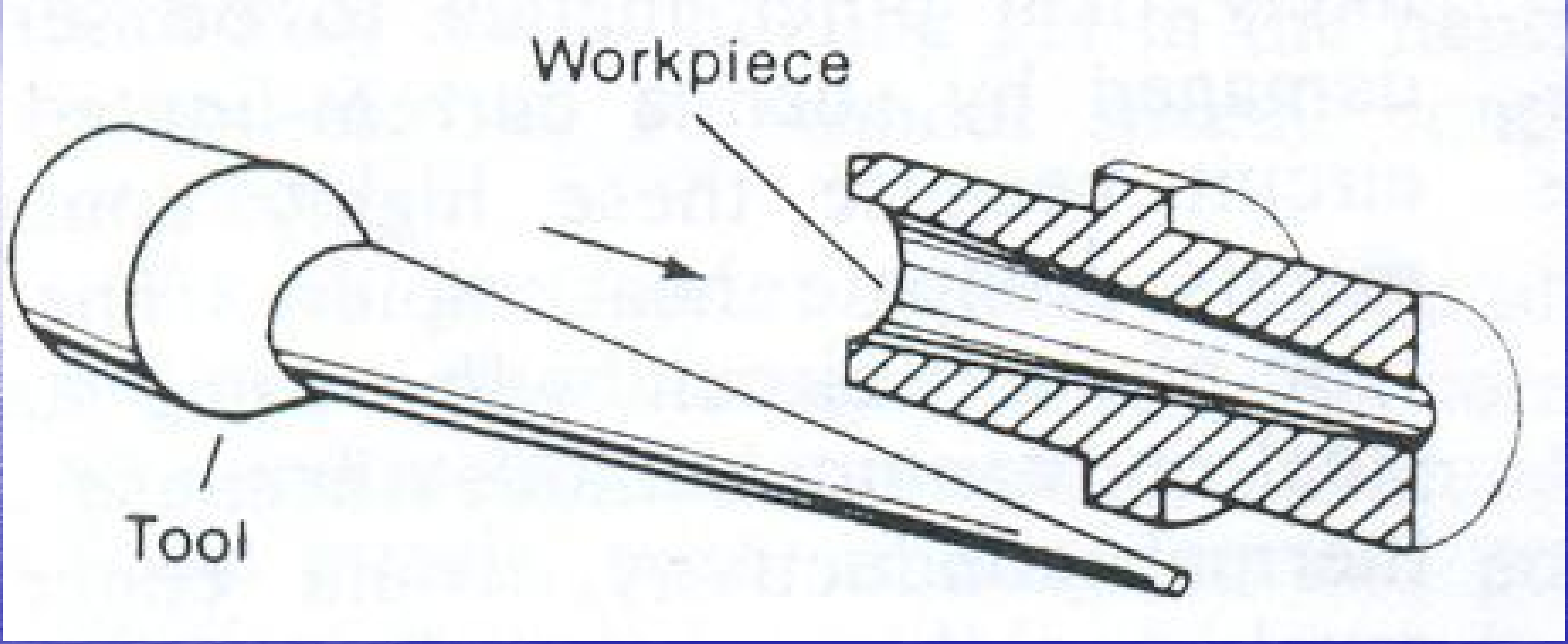
Hole-sinking tool of the open-flow type with insulated side wall



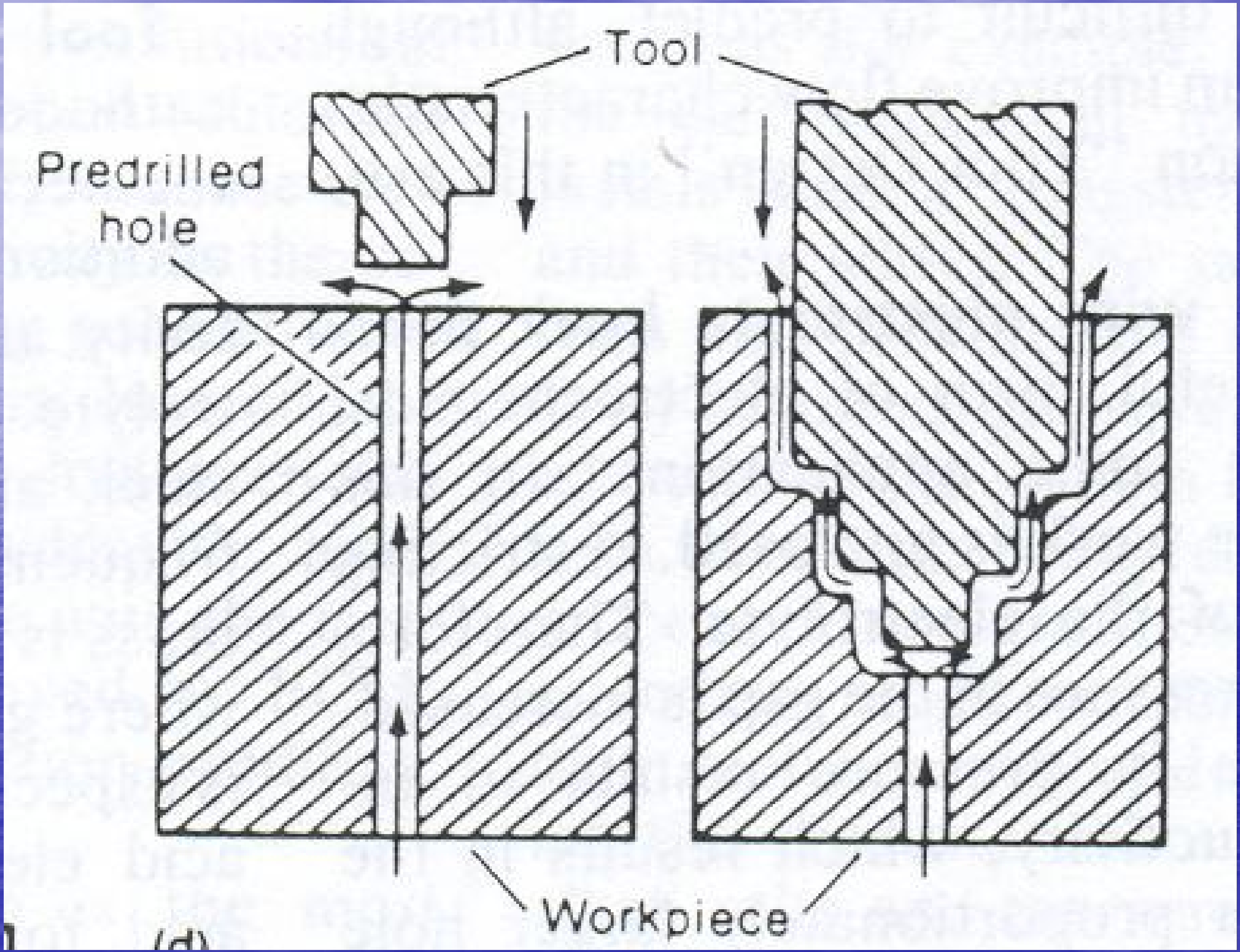
Dual external cutting tool, cross-flow type



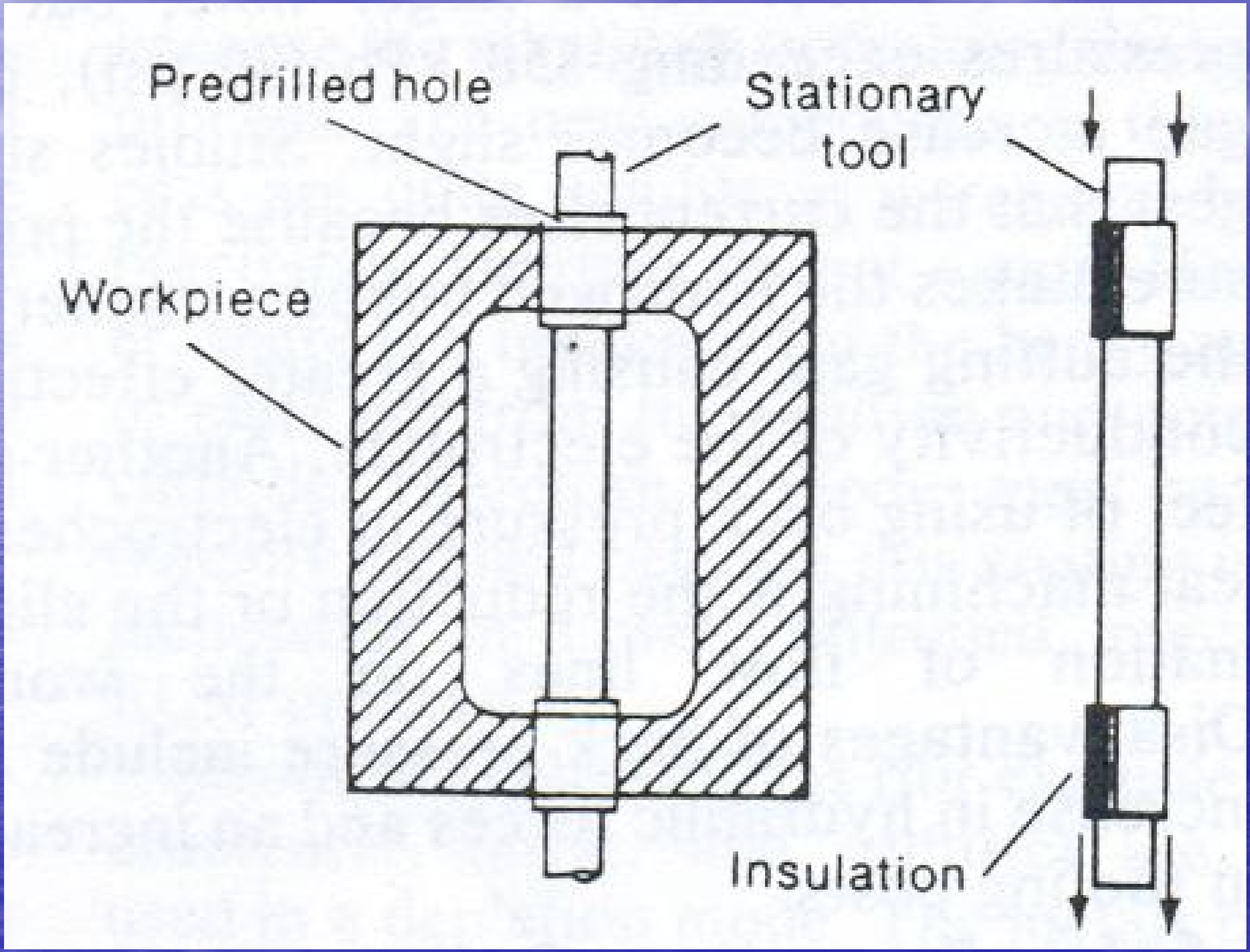
Tool for tapering a predrilled hole



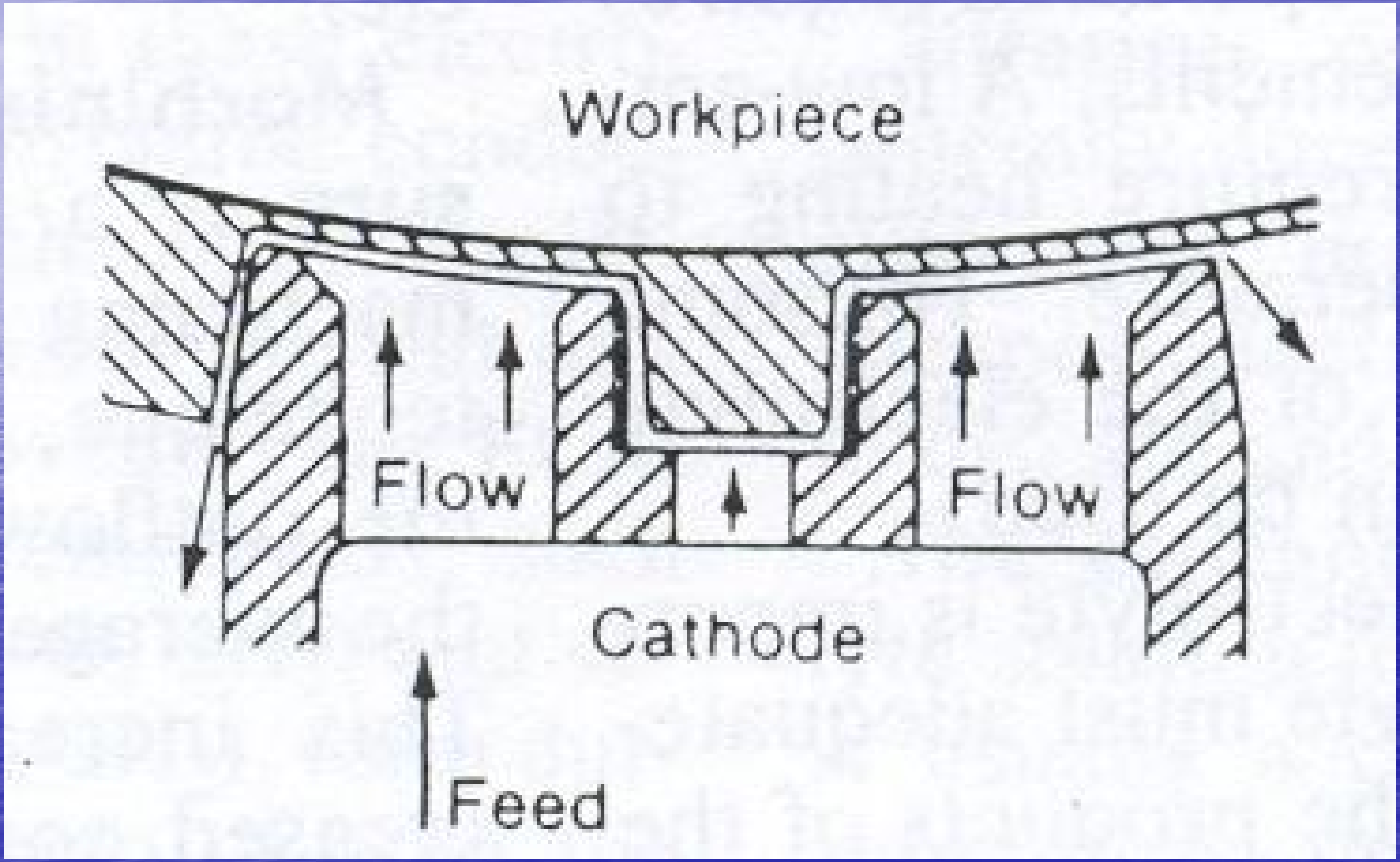
Tool for sinking a stepped through hole



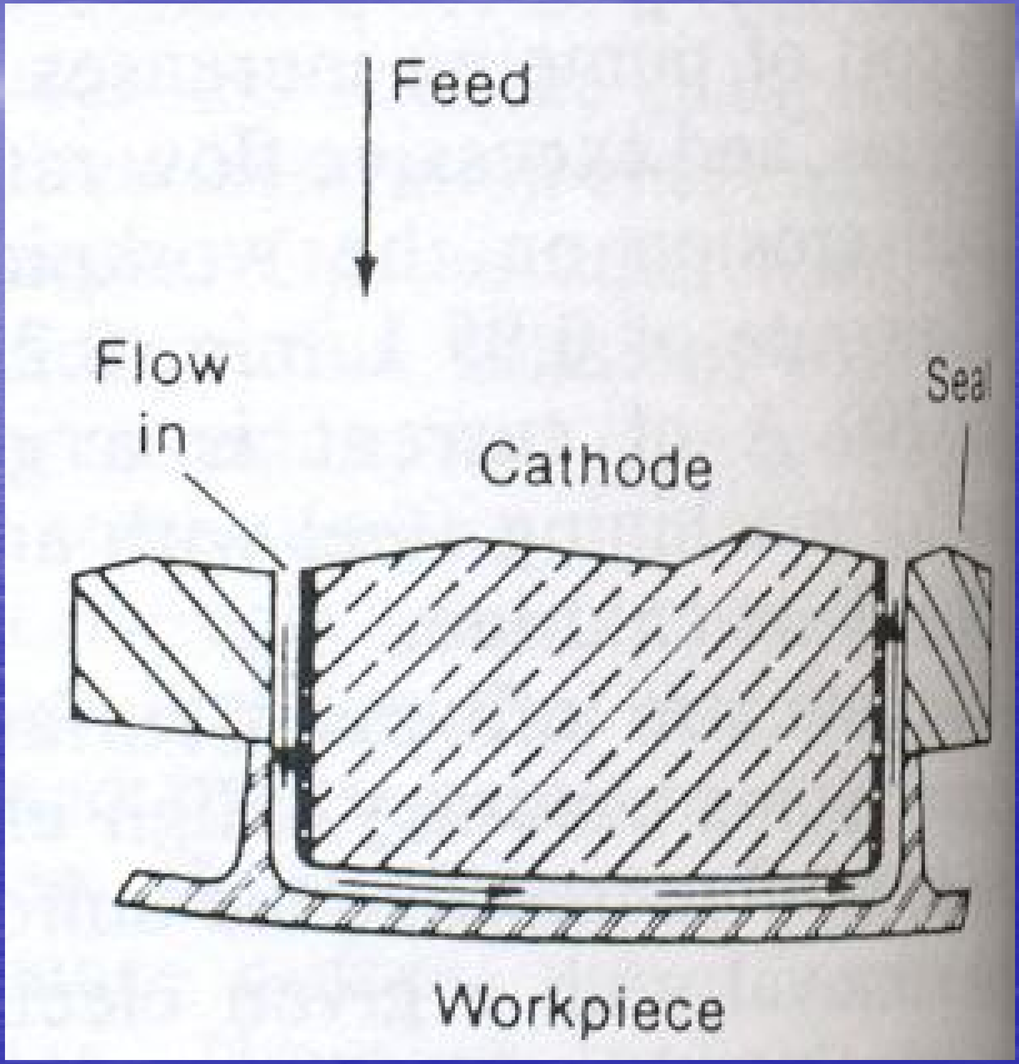
Tool for enlarging interior section of a hole



Open-flow cathode used to generate the outside diameter wall and leave an embossment



Cross-flow tool used to generate ribs on a surface without leaving flow lines on the part



Electrolyte

Electrolytes used in ECM should be carefully selected so that they provide the necessary reactions without plating the cathode

Functions expected:

- Completing the electrical circuit between the tool and the workpiece
- Allowing the desirable machining reactions to take place
- Carrying away the heat generated during the operation
- Carrying away products of reaction from the zone of machining

Desirable electrolyte properties

- High electrical conductivity - easy ionisation
- Low viscosity - for easy flow
- High specific heat - to carry more heat
- Chemical stability - to be chemically neutral or does not disintegrate during the reaction
- Resistance to formation of passivating film on the workpiece surface
- Non corrosiveness and non-toxicity
- Inexpensiveness and easy availability

Salt solutions with water forming a large proportion satisfy many of the above conditions and therefore they are generally used

Electrolytes

Types: Sludging and Nonsludging

1. Sludging: solutions of typical salts such as NaCl

- Salts are generally not depleted and they provide substantial conductivity to the solutioning water
- Hydroxide ions combine with the metal ions that are being removed thus forming insoluble reaction products or sludge

a. Sodium chloride or potassium chloride up to 0.25kg/litre

- Widely used because of its low cost and stable conductivity over a broad range of pH values
- However its corrosive and produces large amount of sludge

b) Sodium nitrate up to 0.50kg/lit

- Less corrosive but forms a passive film on the workpiece surface – hence not used as a general purpose electrolyte
- Used for machining aluminium and copper

2. Nonsludging:

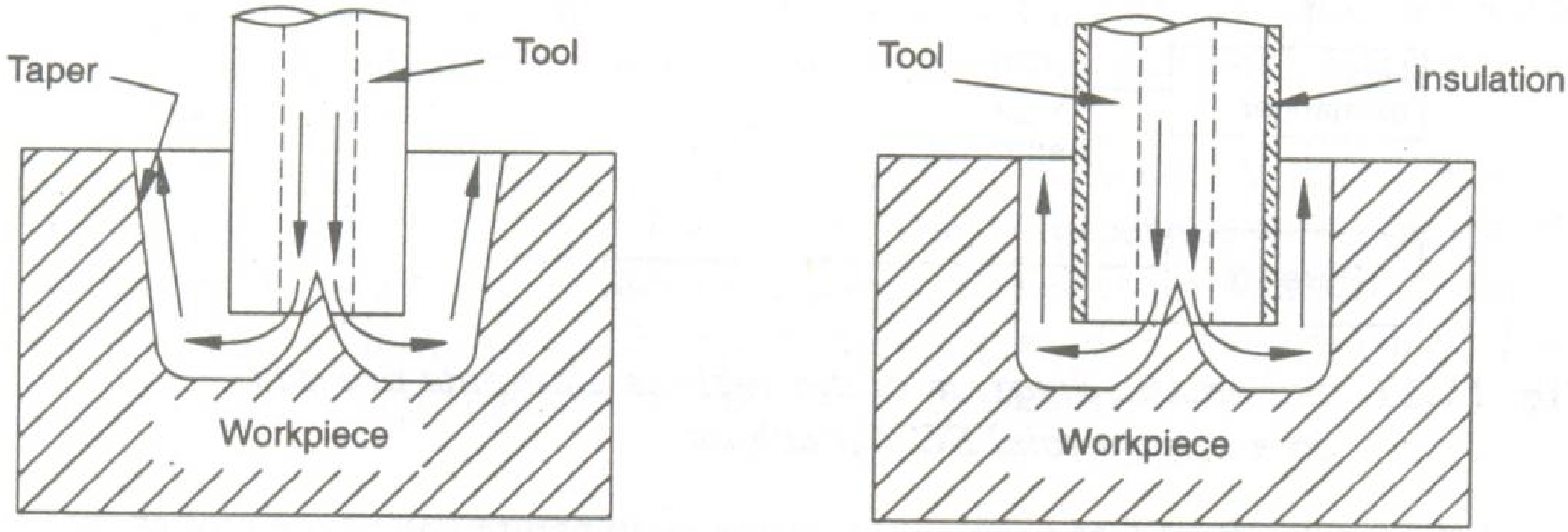
- Strong alkali solutions for e.g. NaOH are used in ECM of heavy metals (such as tungsten and molybdenum) and their alloys
- Salts are depleted because the sodium ions of the salt join with the metals being removed
- New compounds such as sodium tngstate form during the process and makeup of both the alkali salts and water are required
- The new compounds in the process are quite soluble in water and heavy precipitate volumes do not occur. However, there is a tendency for the heavy metals to plate onto the cathode

Design for electrolyte flow

Need for sufficient electrolyte flow between the tool and the workpiece:

- To carry away the heat and the products of machining
- To assist the machining process at the required feed rate, producing a satisfactory surface finish
- Cavitation, stagnation and vortex formation should be avoided since these lead to bad surface finish
- There should be no sharp corners in the flow path. All corners in the flow path should have a radius

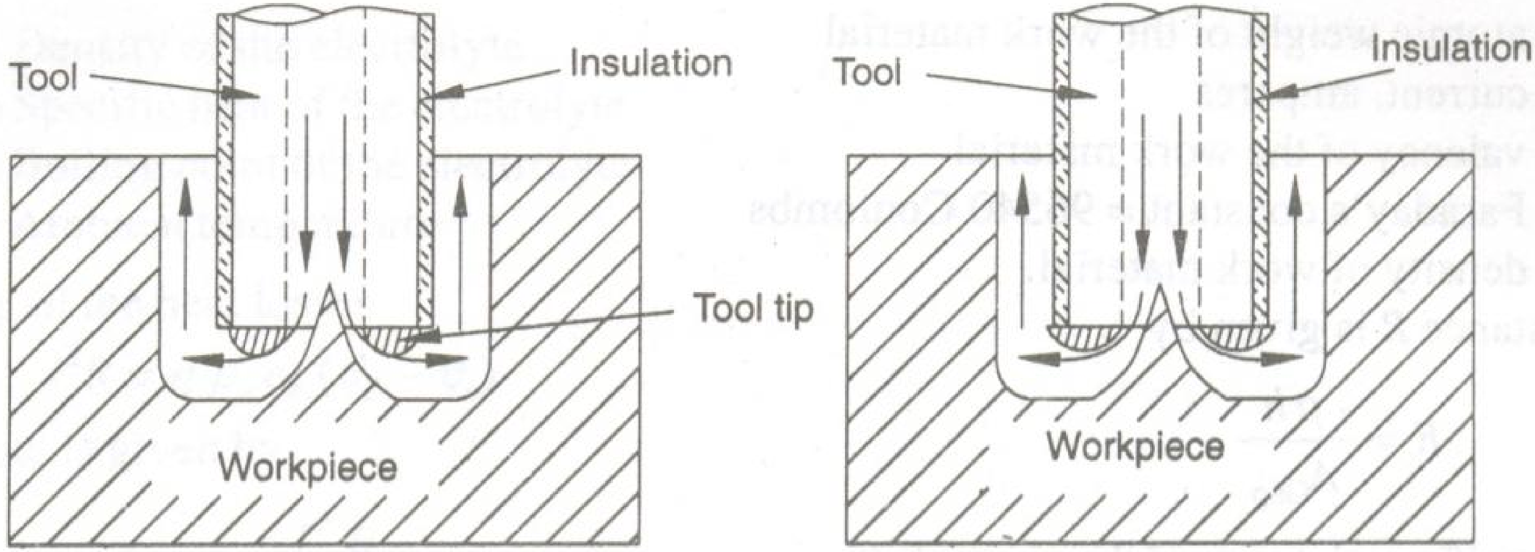
When drilling a hole – flow through the hole under high pressure and exits through the workpiece



(a) Electrolyte through electrode

(b) Insulated electrode

Fig. 11.18 *Electrolyte flow methods in ECM*



Streamlined electolyte flow

Fig. 11.19 *Electrolyte flow methods in ECM*

Reverse flow would be useful since it decreases the metal removed, by leaving a large slug at the centre of the hole produced; Also best arrangement for the electrolyte flow since the finished surface is not affected by the electrolyte with the metal debris

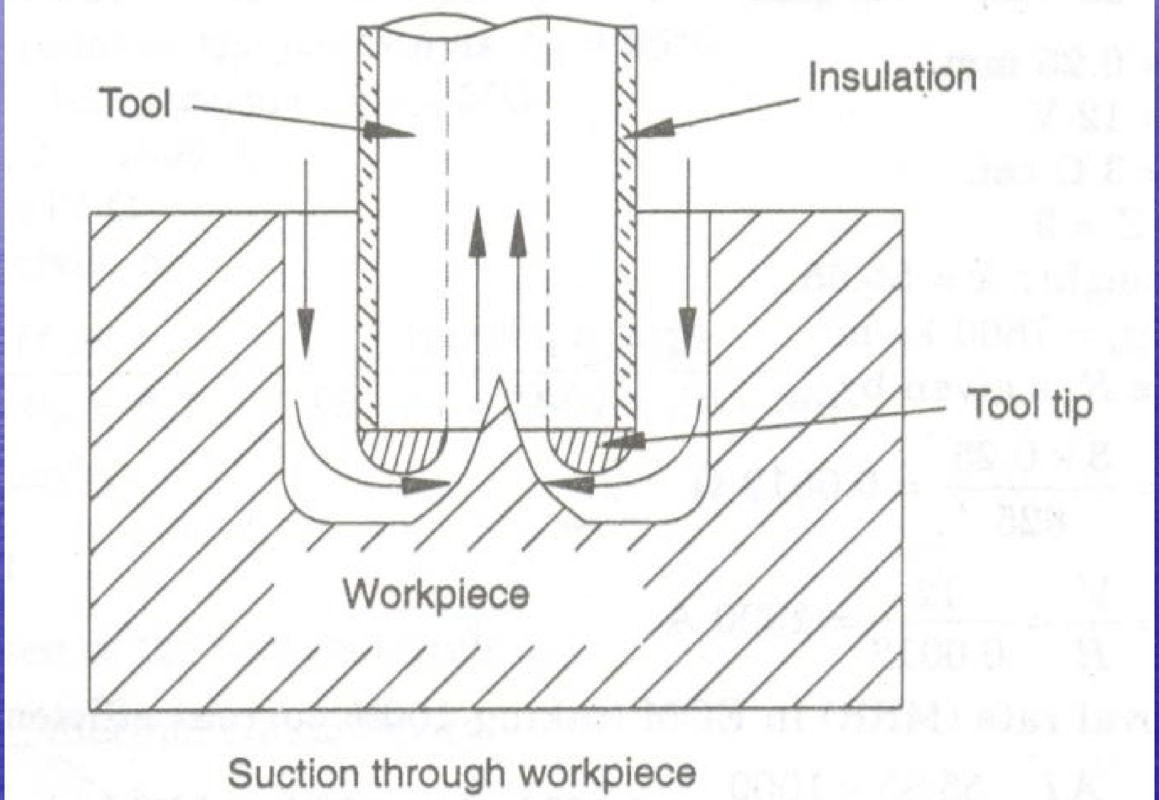


Fig. 11.20 *Electrolyte flow method in ECM*

Initial shape of the component generally may not comply with the tool shape and only a small fraction of the area is close to the tool surface at the beginning – the problem of supplying the electrolyte over such area is overcome by using the flow restriction technique

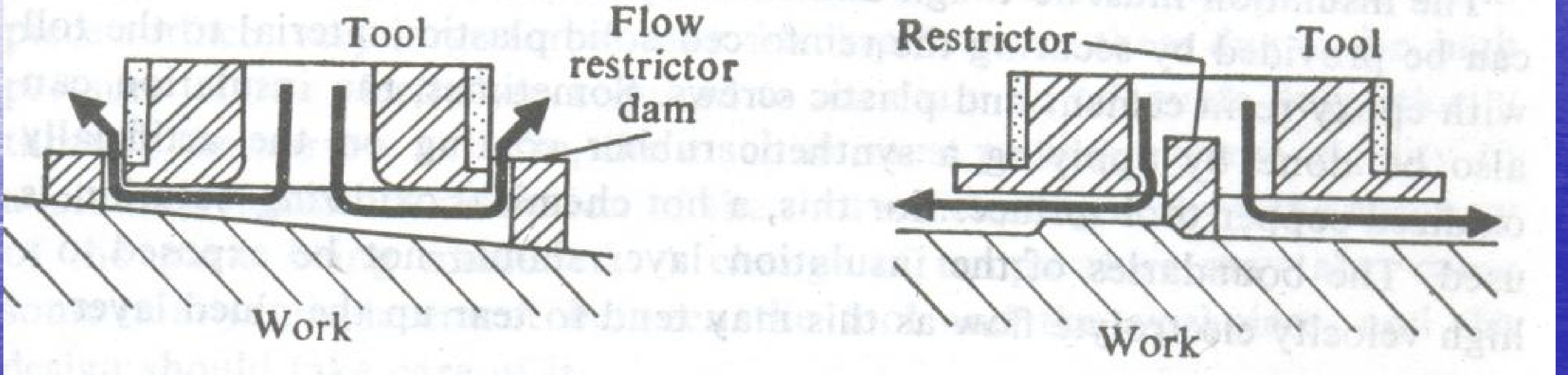


Fig. 6.46 Control of electrolyte flow by restrictor dams.

In many situations, when the initial work conforms to the tool shape, the machining process itself causes the formation of boss and ridge in the workpiece, which helps in the proper distribution of the electrolyte flow

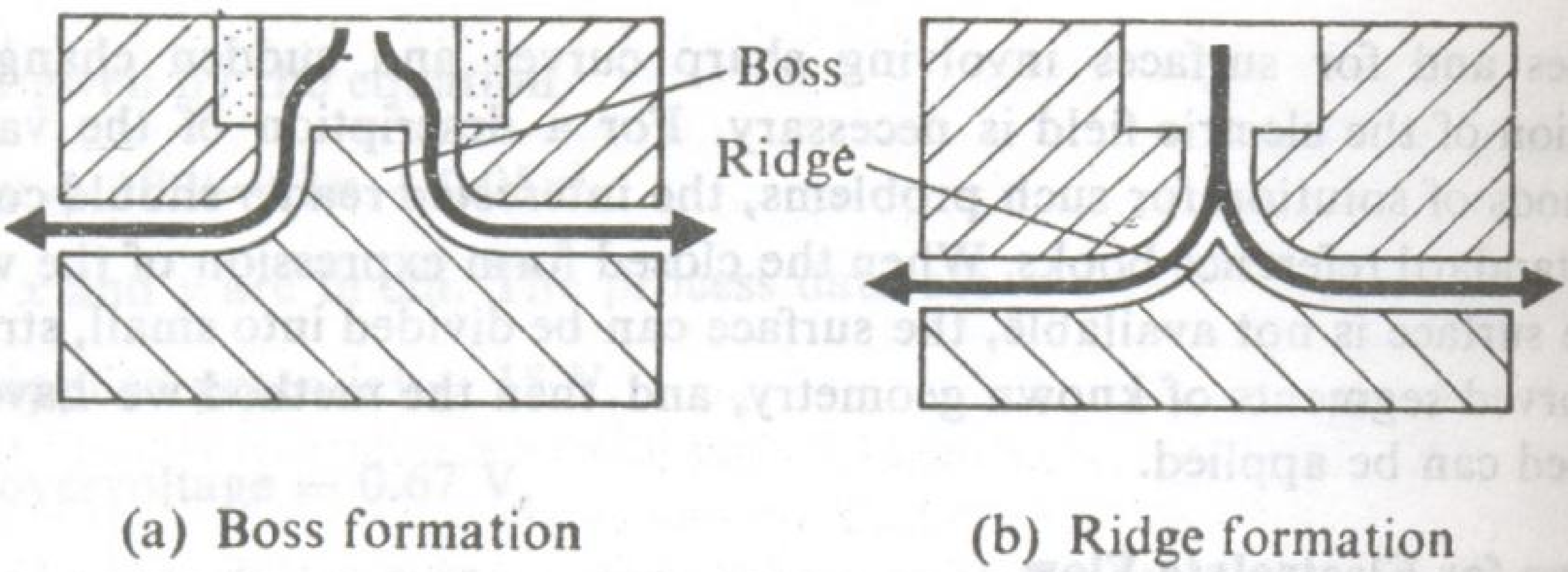


Fig. 6.42 Formation of boss and ridge on machined surface.

Tool with an electrolyte supply slot is simple to manufacture, but such a slot leaves small ridges on the work. However, the ridges can be made very small by making the slot sufficiently narrow

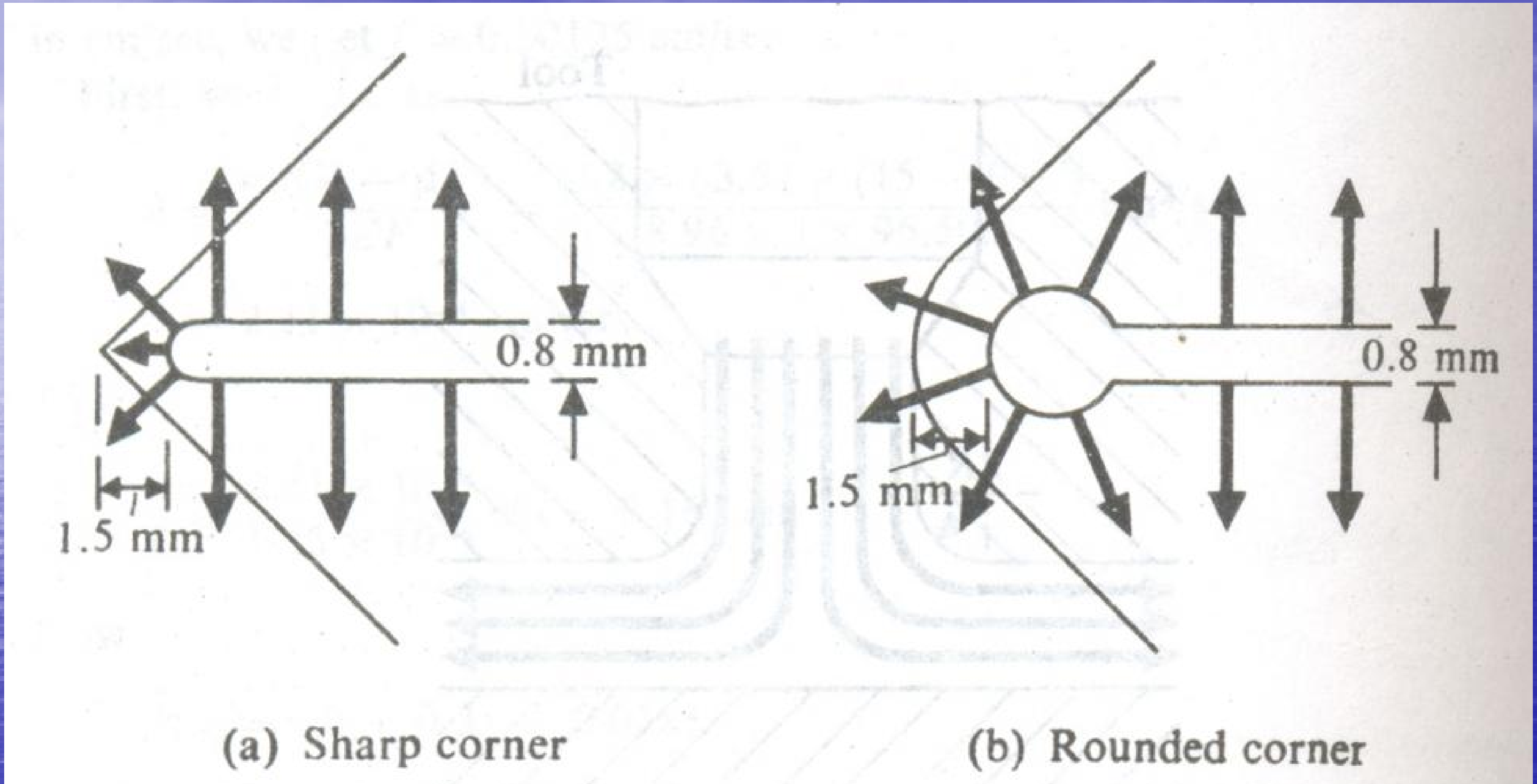
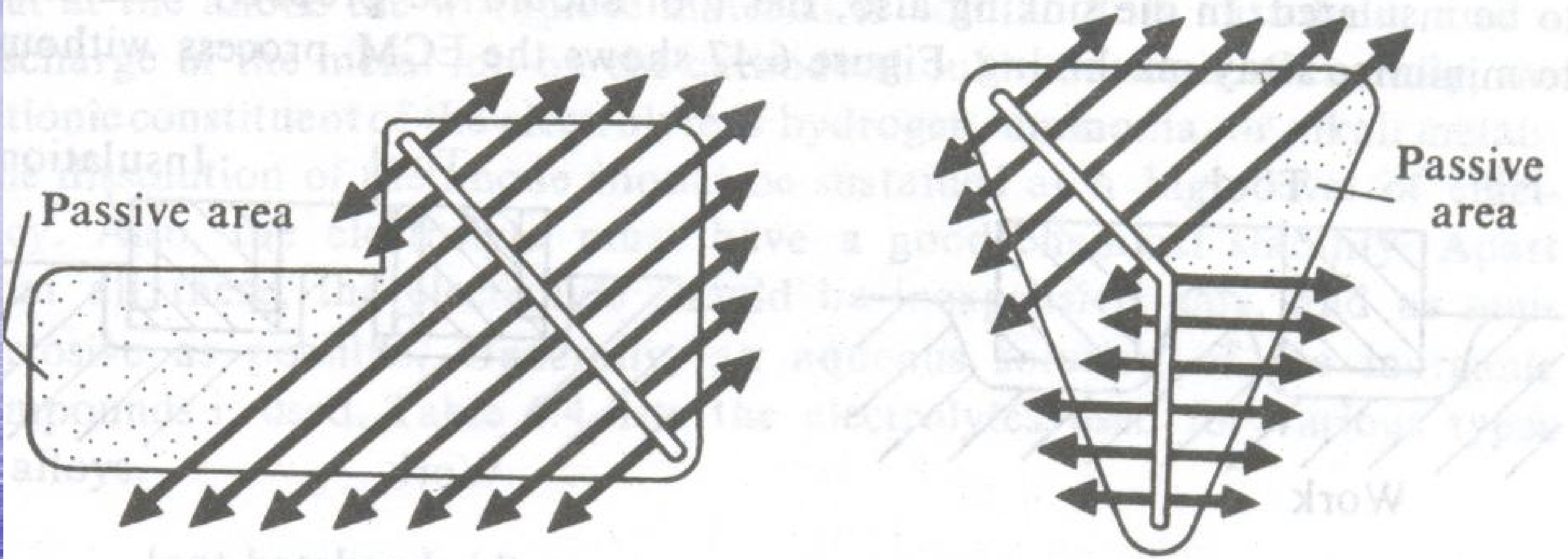


Fig. 6.43 Slot in tool face with sharp and rounded corners.

The flow from a slot takes place in a direction perpendicular to the slot and the flow at the end is poor – therefore the slot is terminated near the corners of the w/p surface

The shape and location of the slot should be such that every portion of the surface is supplied with electrolyte flow and no passive area exists



(a) Passivation due to flow interruption

(b) Passivation due to sharp bend in slot

Fig. 6.44 Development of passive area due to improper slot design.

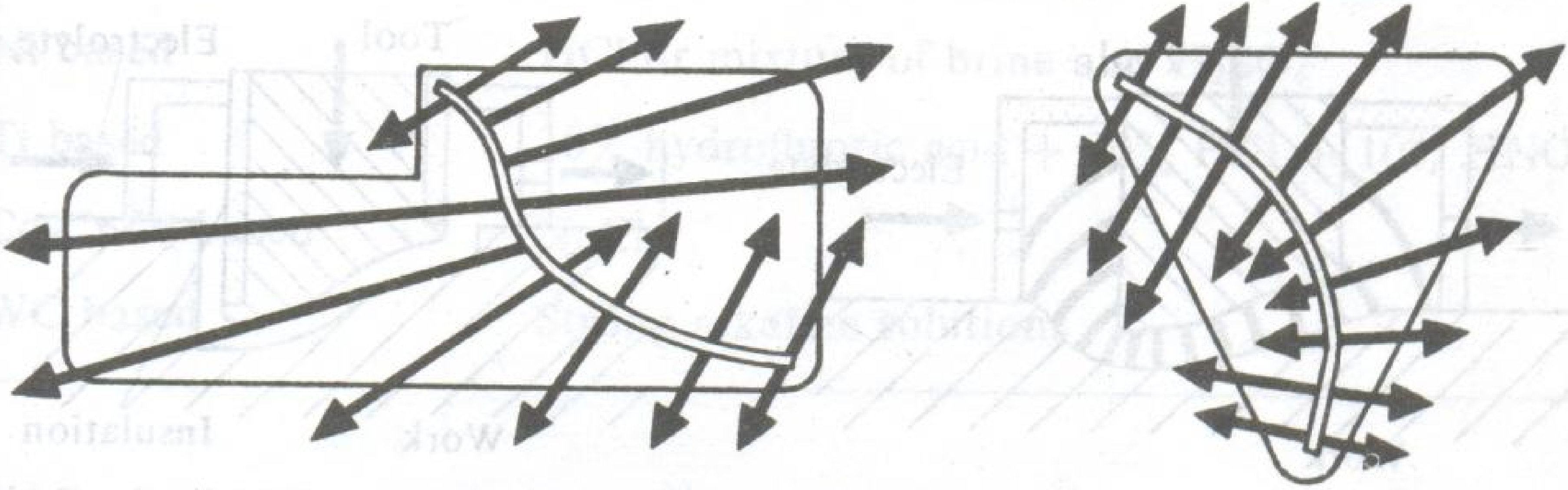


Fig. 6.45 Slot design to avoid development of passive area.

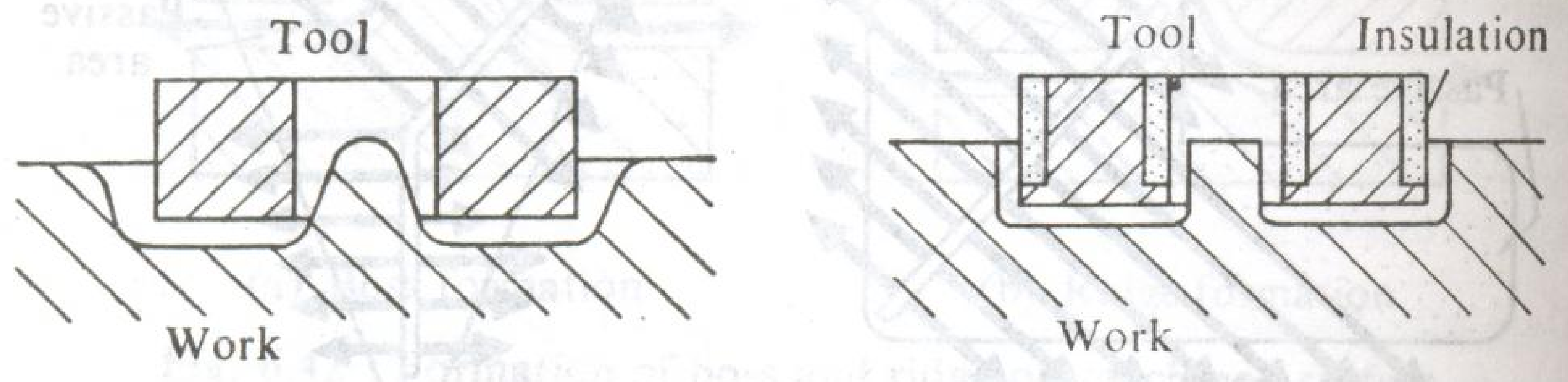
Insulation

- Insulation is important in the control of the electrical current
- Desirable qualities of insulation:

1. Adhesion to the tool: preformed insulation can be held to the tool by shrinkfitting, adhesives or fasteners
2. Sealing without pores or leaks that could cause stray machining by current leakage
3. Adequate thickness
4. Smoothness to avoid disturbing the flow of electrolyte
5. Resistance to heat for continuous service at 200°C without breakdown
6. Durability to resist wear in guides and fixtures
7. Chemical resistance to the electrolyte
8. High electrical resistivity
9. Uniform application to minimize disturbance of the flow of electrolyte and to prevent interference
10. Low water absorption

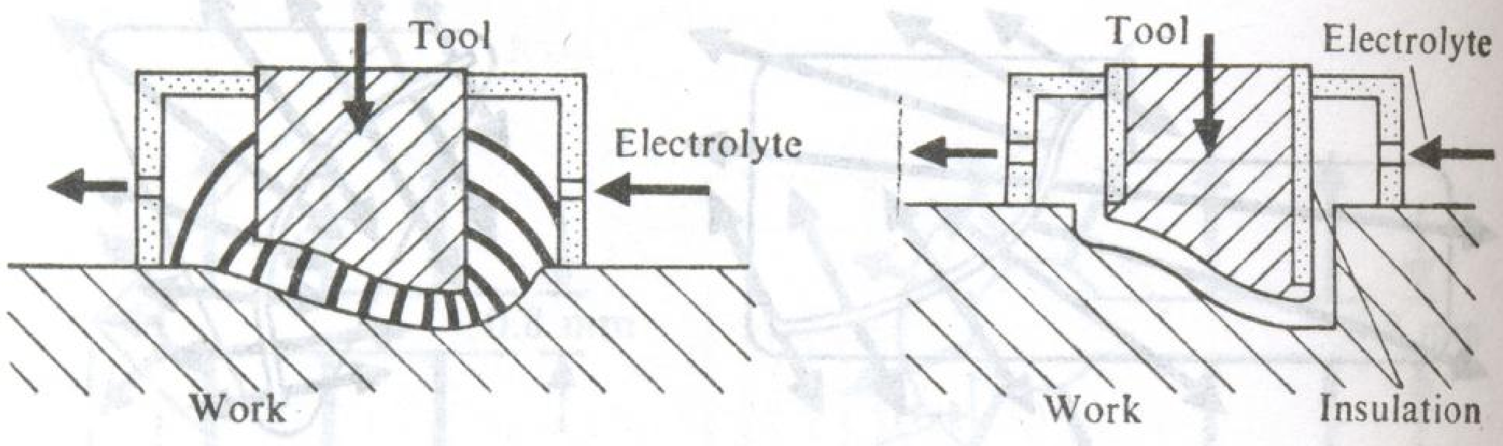
- Generally the simplest method of applying insulation is by spraying or dipping
- Teflon, urethane, phenolic, expoxy, powder coating and other materials are commonly used for insulation
- Sprayed or dipped coatings of epoxy resins are among the most effective insulating materials
- For optimum effectiveness, these coatings should be used with a protective lip on the tool to protect the edge of the insulation from the flow force of the electrolyte

ECM process without and with a proper insulation



(a) Tool without insulation (b) Insulated tool

Die sinking without and with a proper insulation



(a) Tool without insulation (b) Insulated tool

Process parameters

- MRR with ECM are sufficiently large and comparable with that of the conventional methods
- The rate of material removal in ECM is governed by Faraday's law and is a function of current density.
- Current density is not only controlled by the amount of current that the power supply is delivering, but also by the size of the IEG
- A small IEG results in the highest current density. However, when its very small, there is a danger of sludge particles bridging the gap and causing a short circuit
- When the gap is too large, current density is reduced, resulting in a poor surface finish and decreased MRR
- Other variables that affect the current density and the MRR are:

1. Voltage
2. Feed rate
3. Electrolyte conductivity
4. Electrolyte composition
5. Electrolyte flow
6. Workpiece material

Voltage

- Voltage across the cutting gap influences the current and the MRR and is controlled in most ECM operations
- Low voltage decreases the equilbrium-machining gap and results in a better surface finish and finer tolerance control
- Increased current leads to electrolyte heating – low temperature of the electrolyte is conducive for a better surface finish and tolerances

Feed rate

- Feed rate determines the current passed between the tool and the work
- As the tool approaches the work, the length of the conductive path decreases and the magnitude of the current increases
- High feed rate results in higher MRR
- High feed rates also decreases the equilibrium machining gap resulting in improvements of the surface finish and tolerance control
- Most rapid feed possible is not only highly productive but also produces the best quality of surface finish
- At slower feed rates, the MRR decreases as the gap increases resulting in the rise of resistance and drop in the current
- Limitations of feed rate are removal of hydrogen gas and products of machining;
- Also higher feed rate requires fine filtering

Electrolyte conductivity

- Affects the resistance across the gap
- Increasing the concentration will cause conductivity to rise
- Temperature increases of the electrolyte also increases conductivity
- Low concentration and low temperature will results in lower MRR

Electrolyte composition

- Composition directly influences conductivity, MRR and surface characteristics
- Parameters used for a given application may not yield the same ECM results if a different type of electrolyte is used
- Normal development of an operation begins with the selection of the correct electrolyte. The other parameters and the cathode are adjusted to get the desired result

Electrolyte flow rate

- The velocity and the electrolyte flow through the gap is also an important parameter affecting the surface finish and MRR
- If the velocity is too low, the heat and by-products of the reaction build in the gap causing non-uniform material removal
- A velocity that is too high will cause cavitation, also promoting uneven material removal
- Increased electrolyte velocities require larger electrolyte pumps that add capital cost to the system
- Pressure control is the method of controlling the flow rate

Advantages

- Ability to machine complex 3D curved surfaces without feed marks
- Machines complicated shapes in single pass
- Capable of machining metals and alloys irrespective of their strength and hardness
- Since metal removal is by mettalic ion exchange, there are no cutting forces and the workpiece is left in a stress free state – very thin sections can be machined
- There is little or no tool wear – so large number of components can be machined without replacing the tool
- Not subjected to high temperatures
- Burr free
- Good surface finish
- Good accuracy and tolerance
- Low machining time
- Low scrap
- Automatic operation

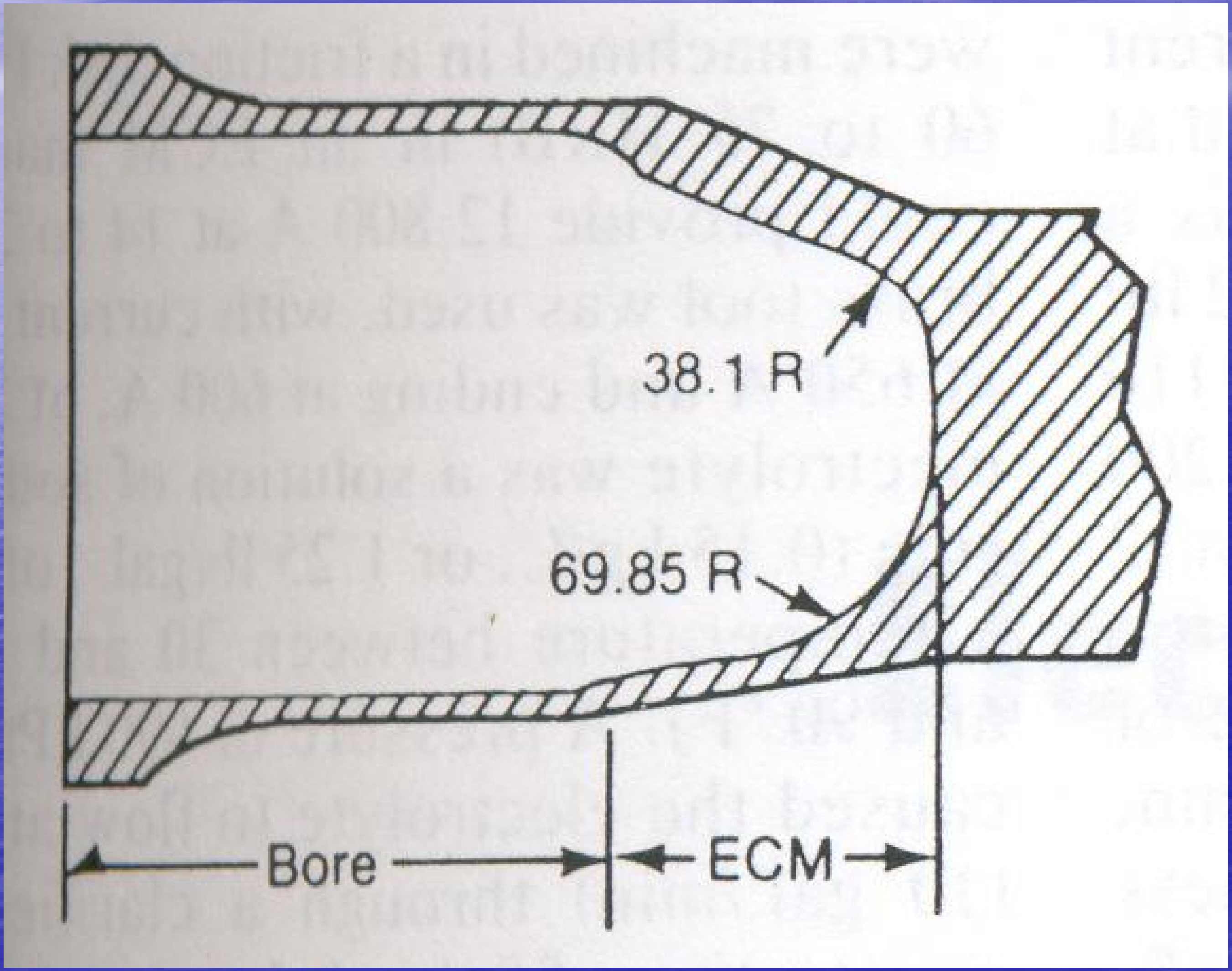
Limitations

- Work must be electrically conductive
- Inability to machine sharp interior edges and corners
- Large power consumption and related problems (heavy initial investment)
- Post machining cleaning is a must to reduce the corrosion of the workpiece and ECM machine
- Tool design is complicated and needs cut and try methods to achieve the final shape
- Although the parts produced by ECM are stress free, they are found to have fatigue strength or endurance limit lowered by approximately 10-25%. So may require post treatment (shot peening) to restore the strength especially for situations where fatigue strength is critical
- Additional problems related to machine tool requirements: power supply, electrolyte handling and tool feed servo system
- High maintenance
- Can cause intergranular attack (IGA)
- High tooling and set-up costs

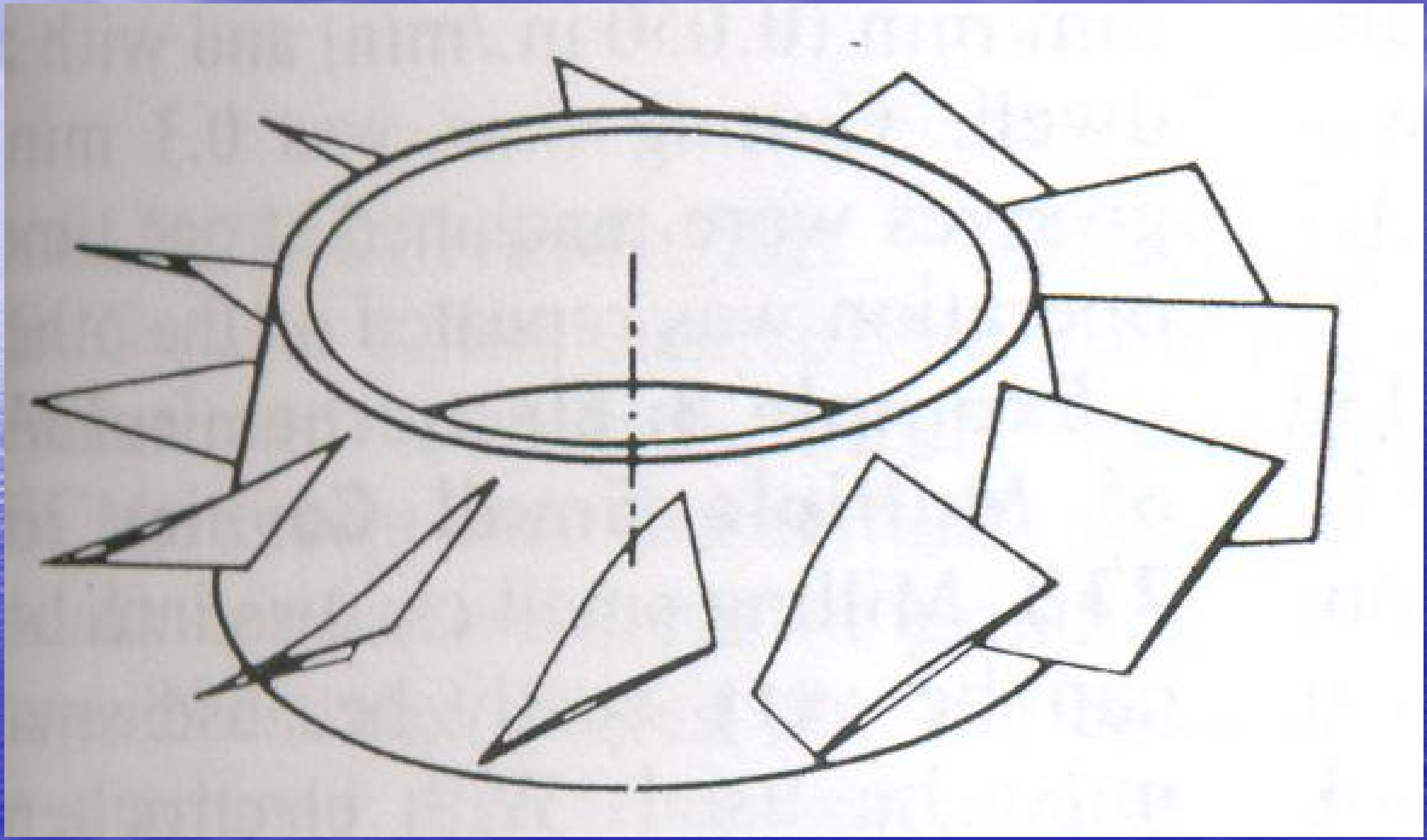
Applications

- Aerospace industries: machining gas turbine blades, airframe component fabrication, honey-comb aircraft panels, jet engine blade airfoils
- Manufacture of general machine parts: thin wall mechanical slotting, difficult to machine hollow shafts, chain pinions, internal profile of internal cams, driving joints, pump glands and impellers, connecting rod, hydraulic spools, gear wheels
- Facing and turning complex 3D surfaces
- Die sinking, particularly deep narrow slots and holes
- Profiling and any odd shape contouring
- Multiple hole drilling
- Trepanning
- Broaching
- Deburring
- Grinding
- Honing
- Cutting off

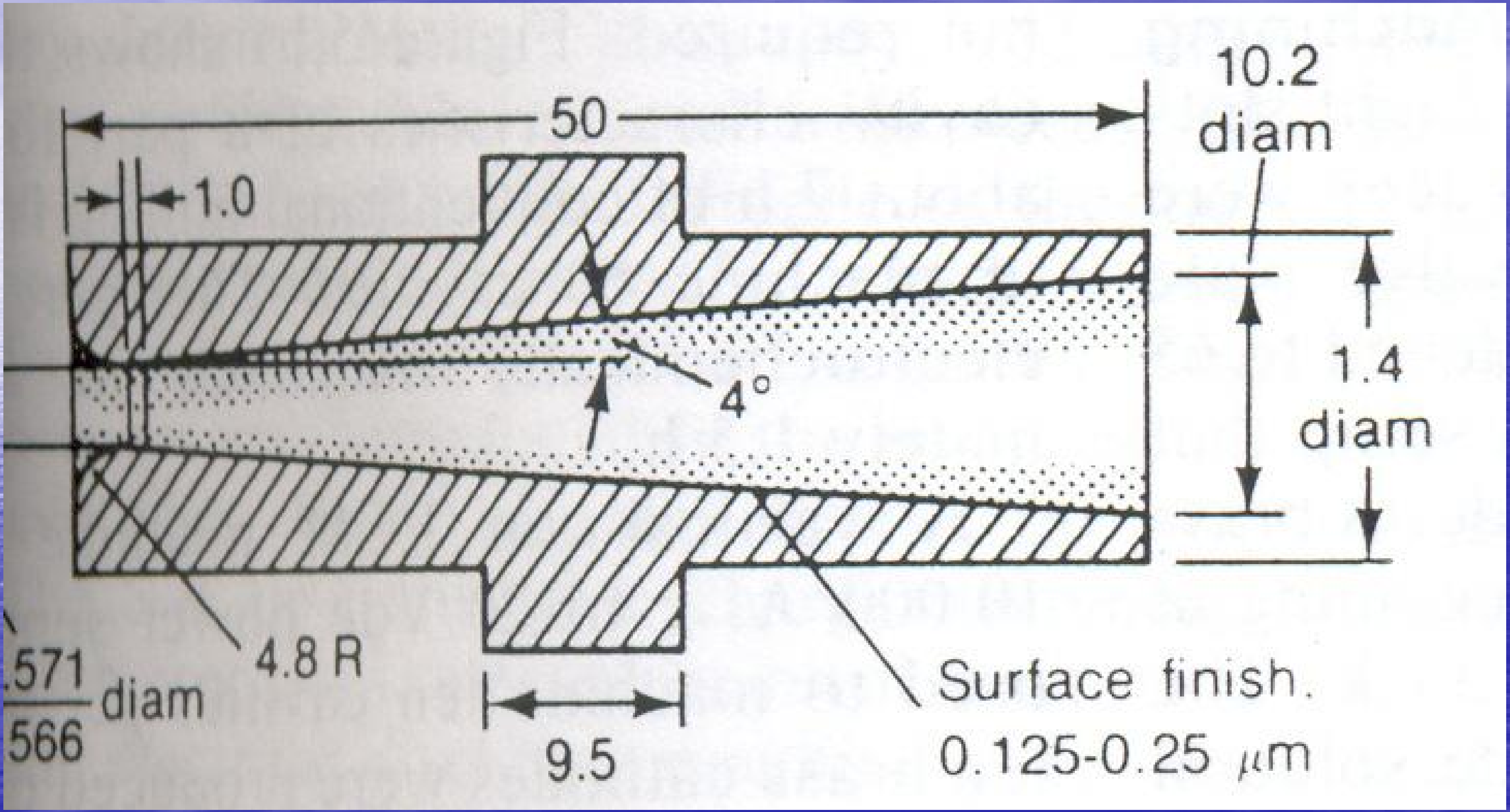
ECMed bottom contour of a deep hole



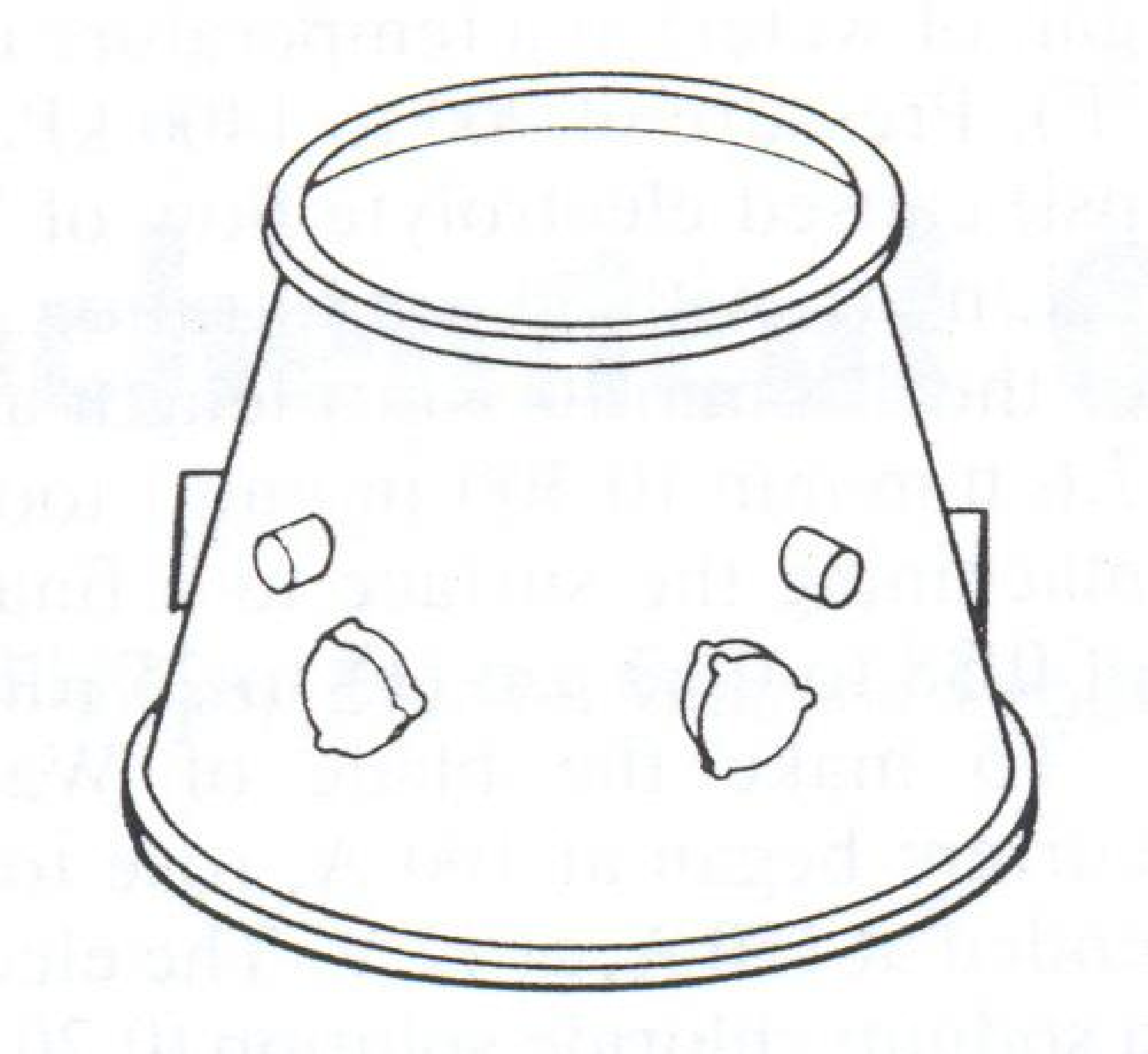
Airfoils machined directly on a compressor disk



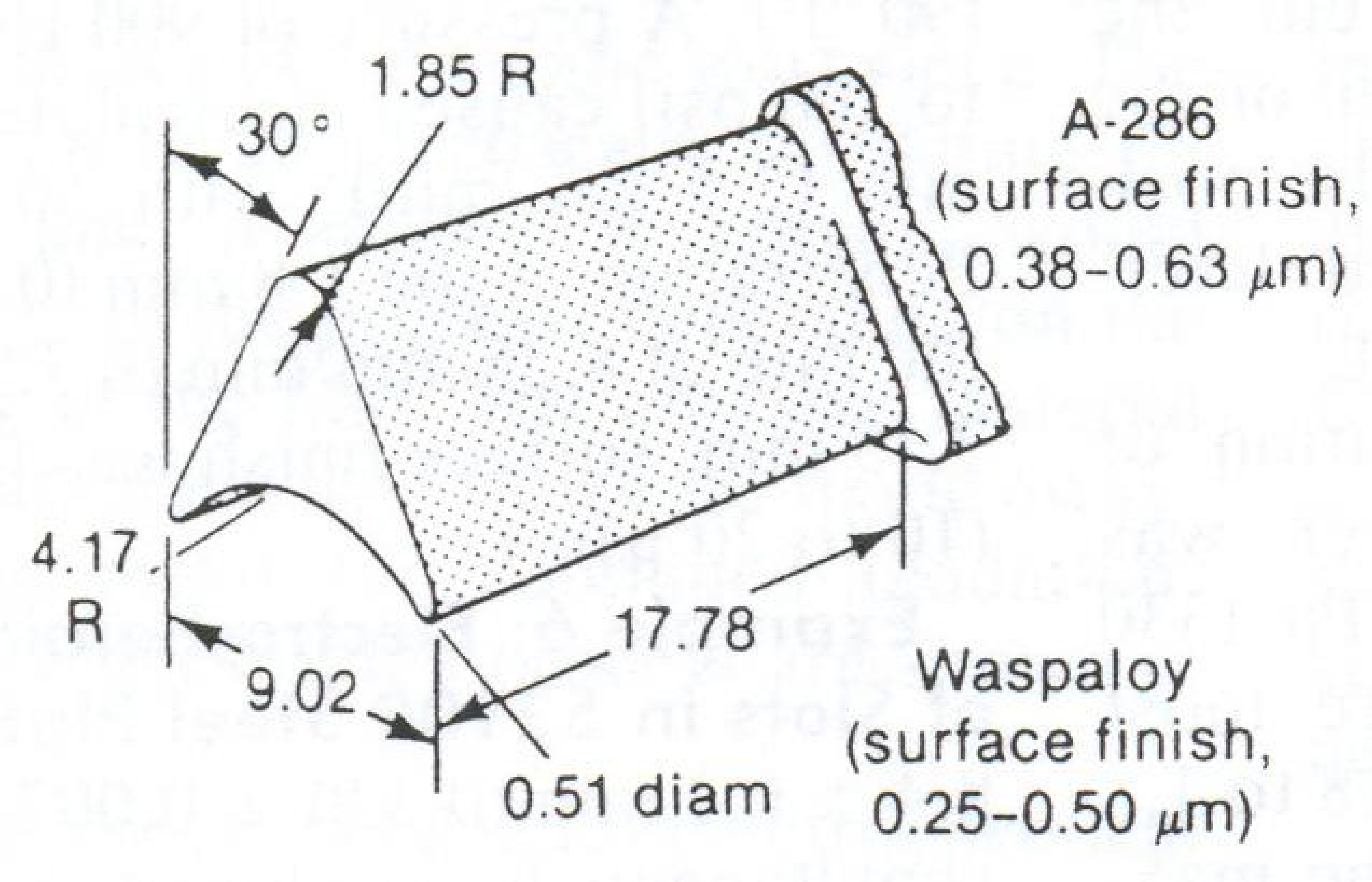
Finishing of a conical hole in a nozzle



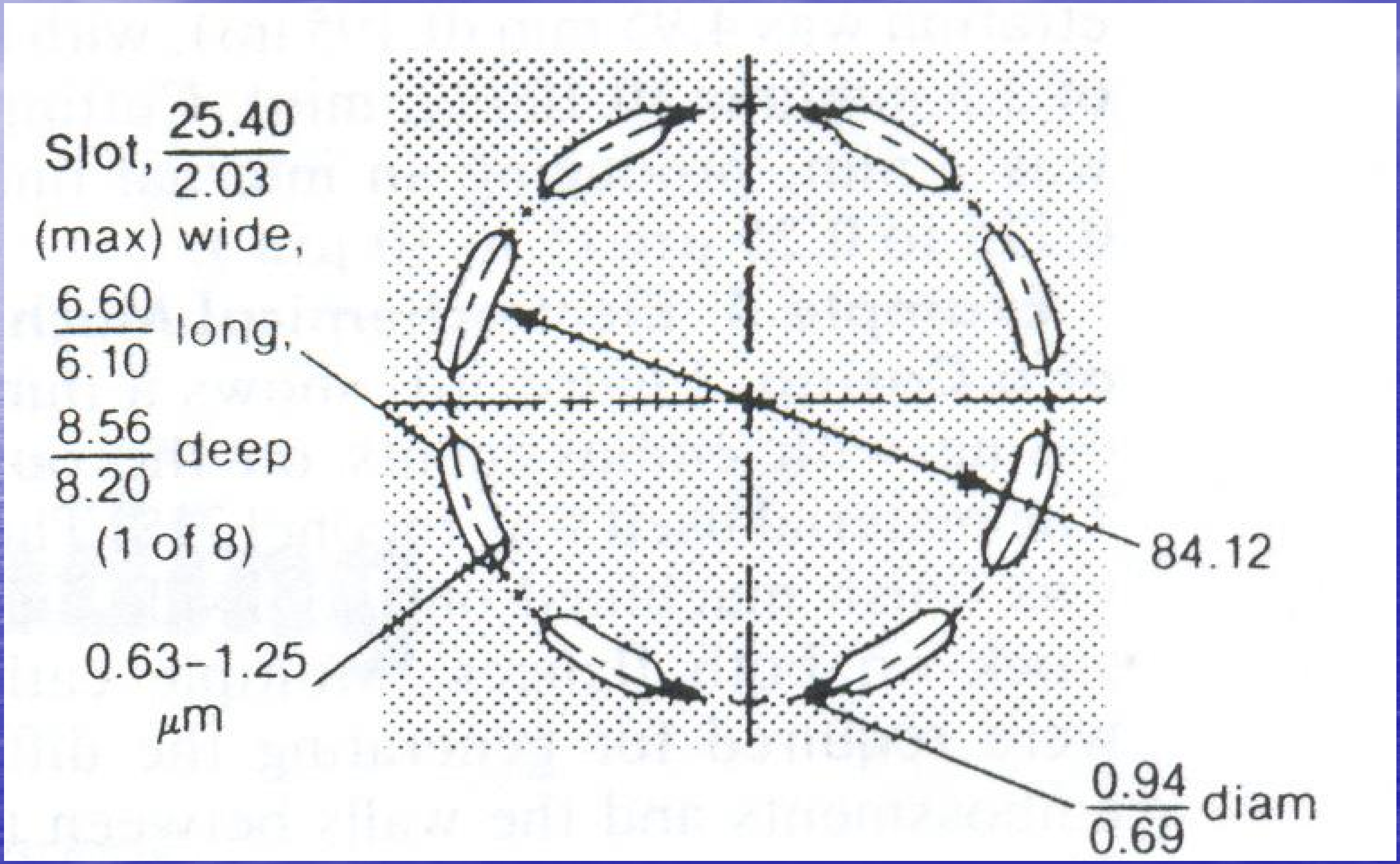
Machining a thin-wall casing with embossments



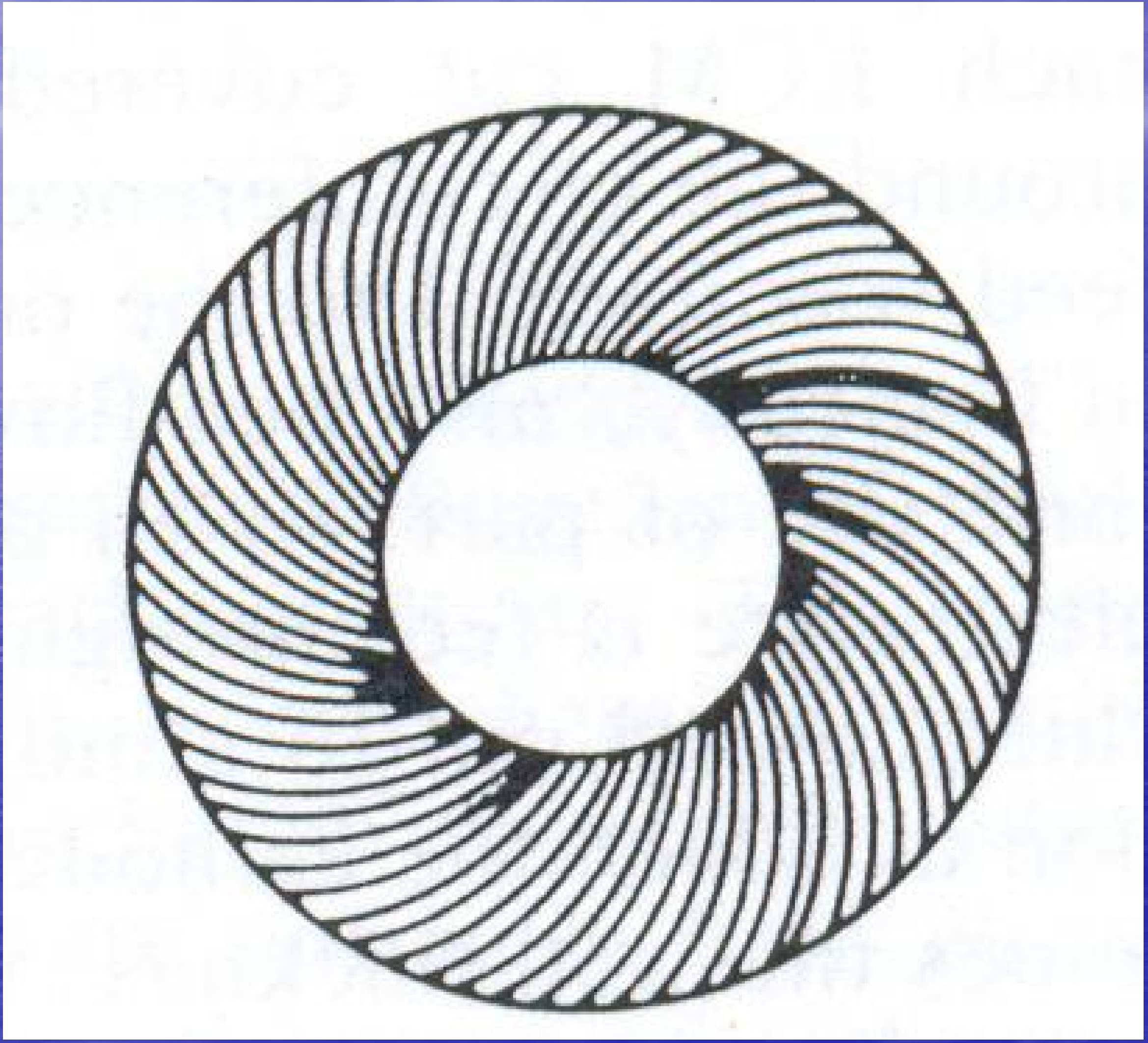
Contouring a turbine blade surface



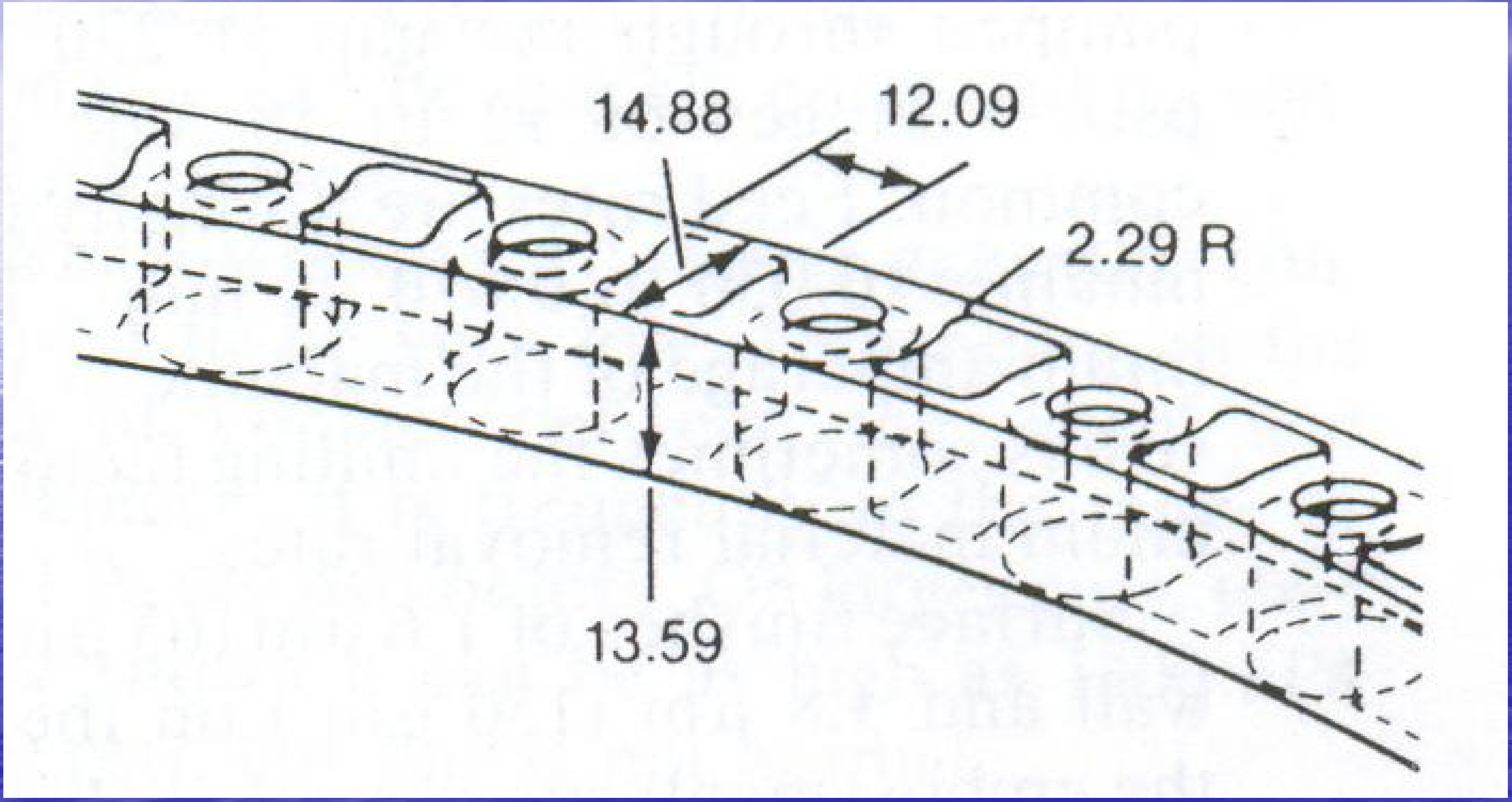
Cutting slots in a valve plate



Cutting spiral grooves in a friction plate



Cutting multiple small cavities in Inconel 718



Disc turned on ECM lathe

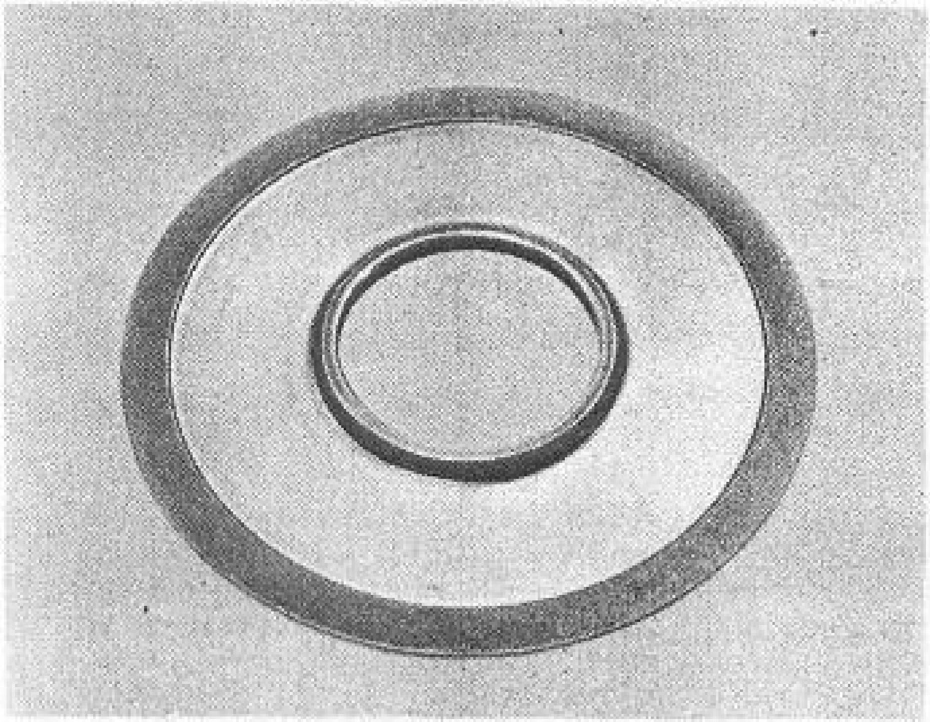


Fig. 3–6. Disc turned on ECM lathe to an accuracy of .0003 in. *(Courtesy, Anocut Engineering Company)*

Die sink impression for connecting rod die

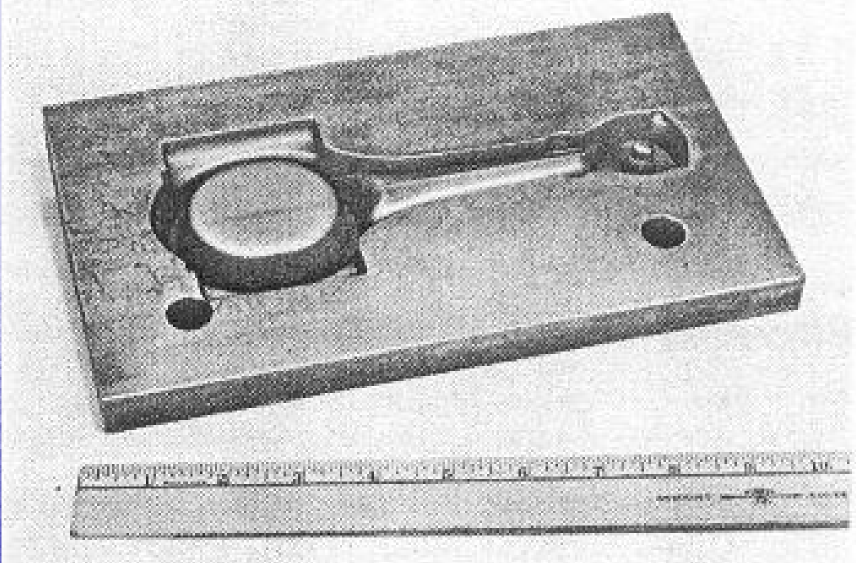


Fig. 3–7. Die sink impression for connecting rod die machined from a solid blank in 18 min. *(Courtesy, Anocut Engineering Company)*

Control cam profiled by ECM

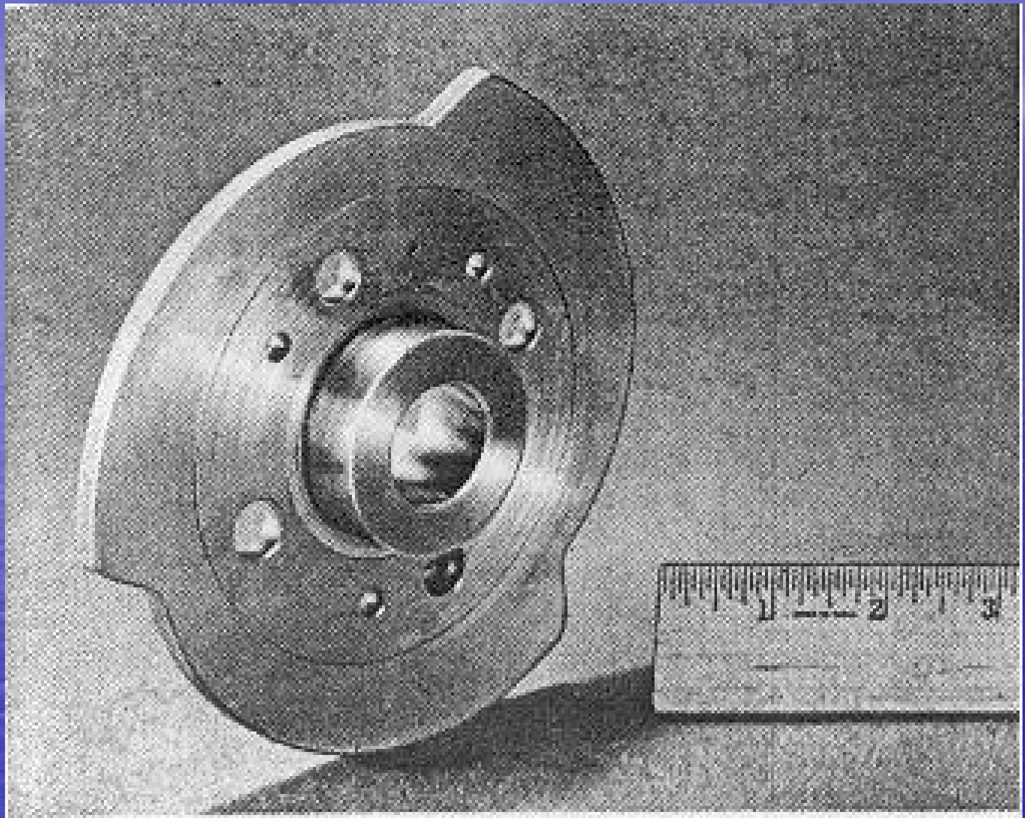


Fig. 3–8. Control cam profiled by ECM after hardening, with repeatable accuracy within .001 in. *(Courtesy, Anocut Engineering Company)*

Stainless steel parts (illustrates repeatability)

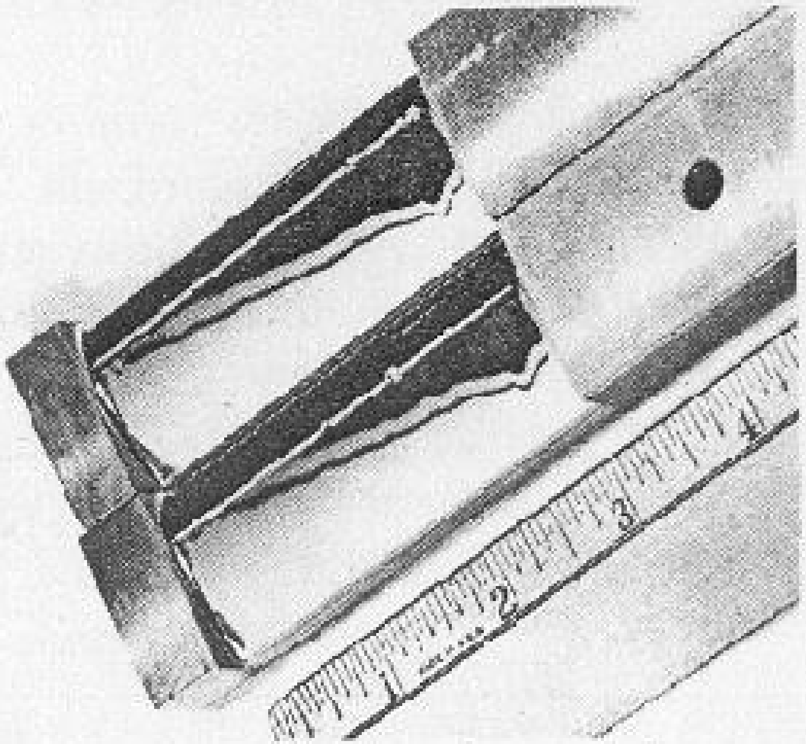


Fig. 3–9. Stainless steel parts electrochemically machined with same electrode (note identical reflected light patterns illustrating repeatability). *(Courtesy, Anocut Engineering Company)*

Multiple hole drilling in a SS burner plate

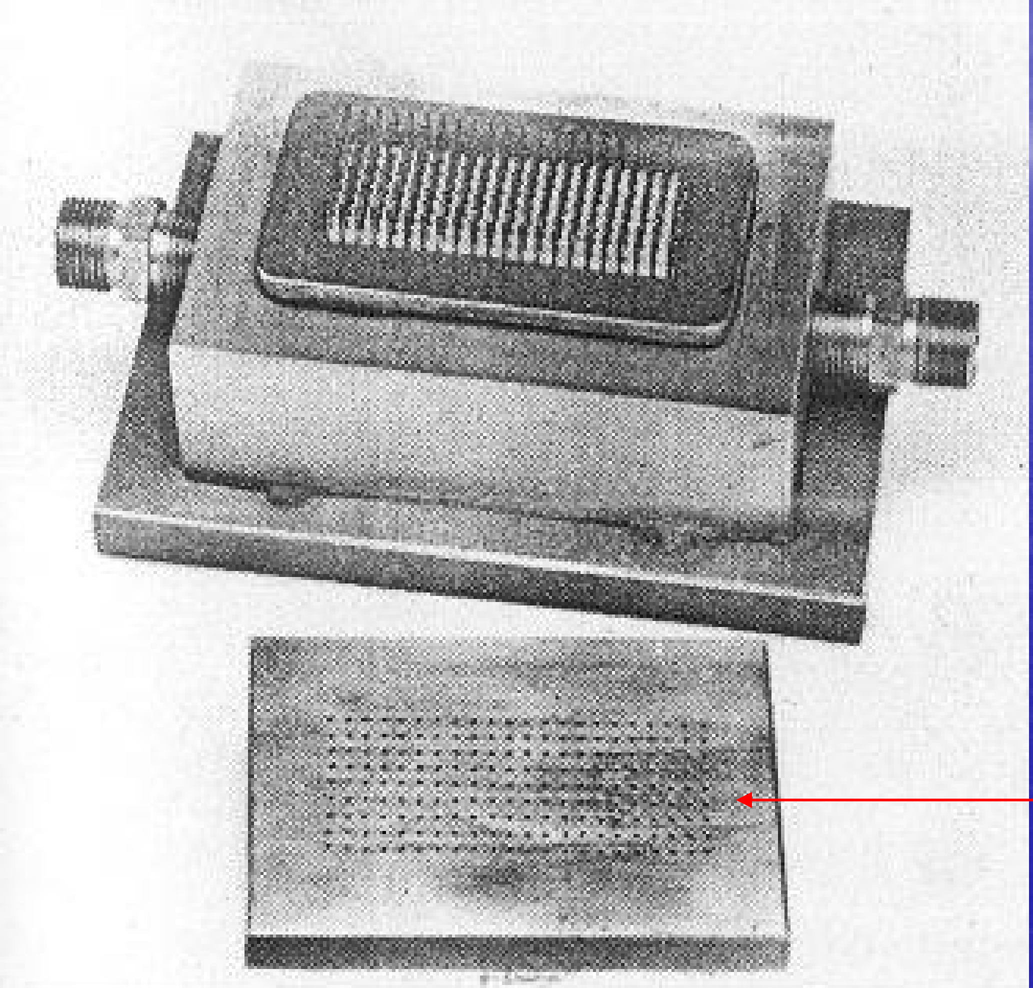
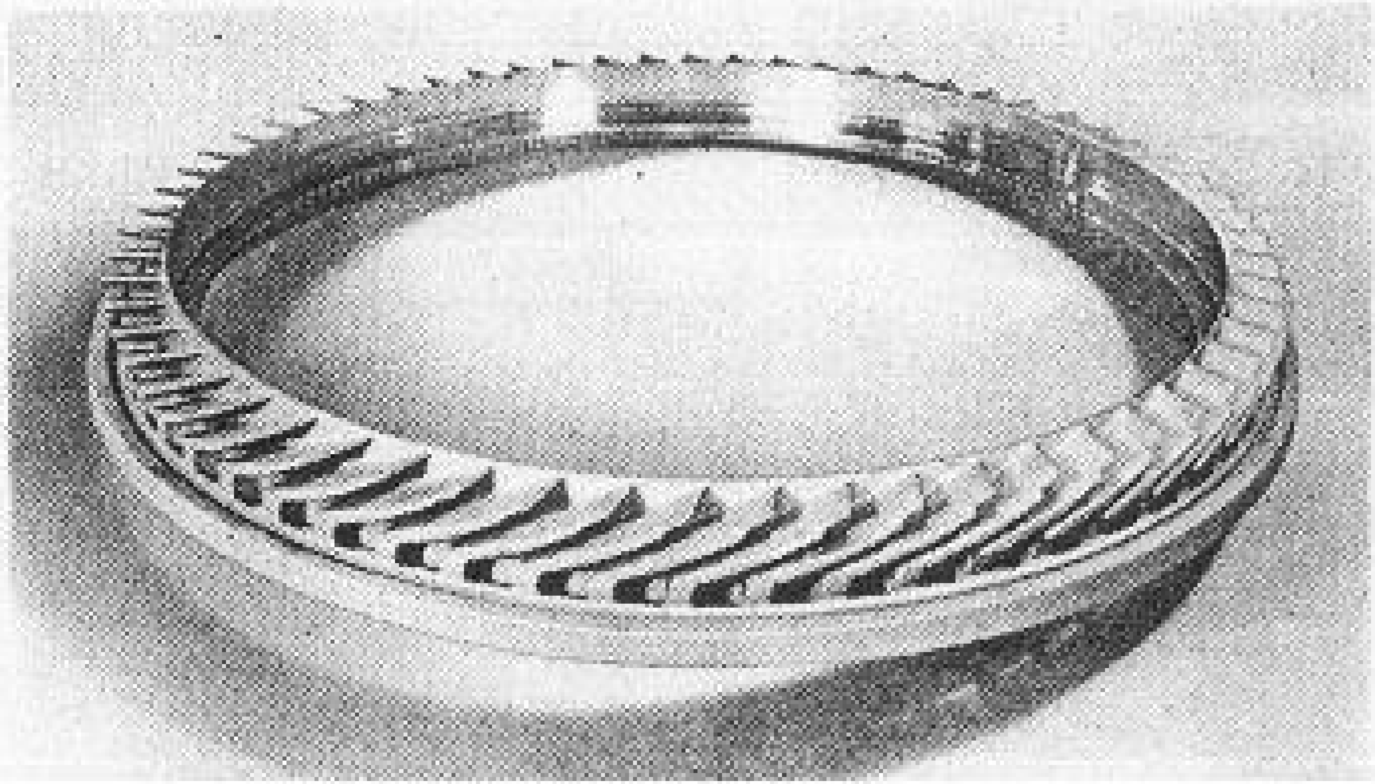


Fig. 3–10. Multiple hole drilling. *(Courtesy, The Ex-Cell-O Corporation)*

Part with 198 holes dia:1.25mm

Machining of integral valves

Fig. 3–11. Trepanning of nozzle valves.
(Courtesy, The Ex-Cell-O Corporation)



Production of burr-free slots in a tool steel part

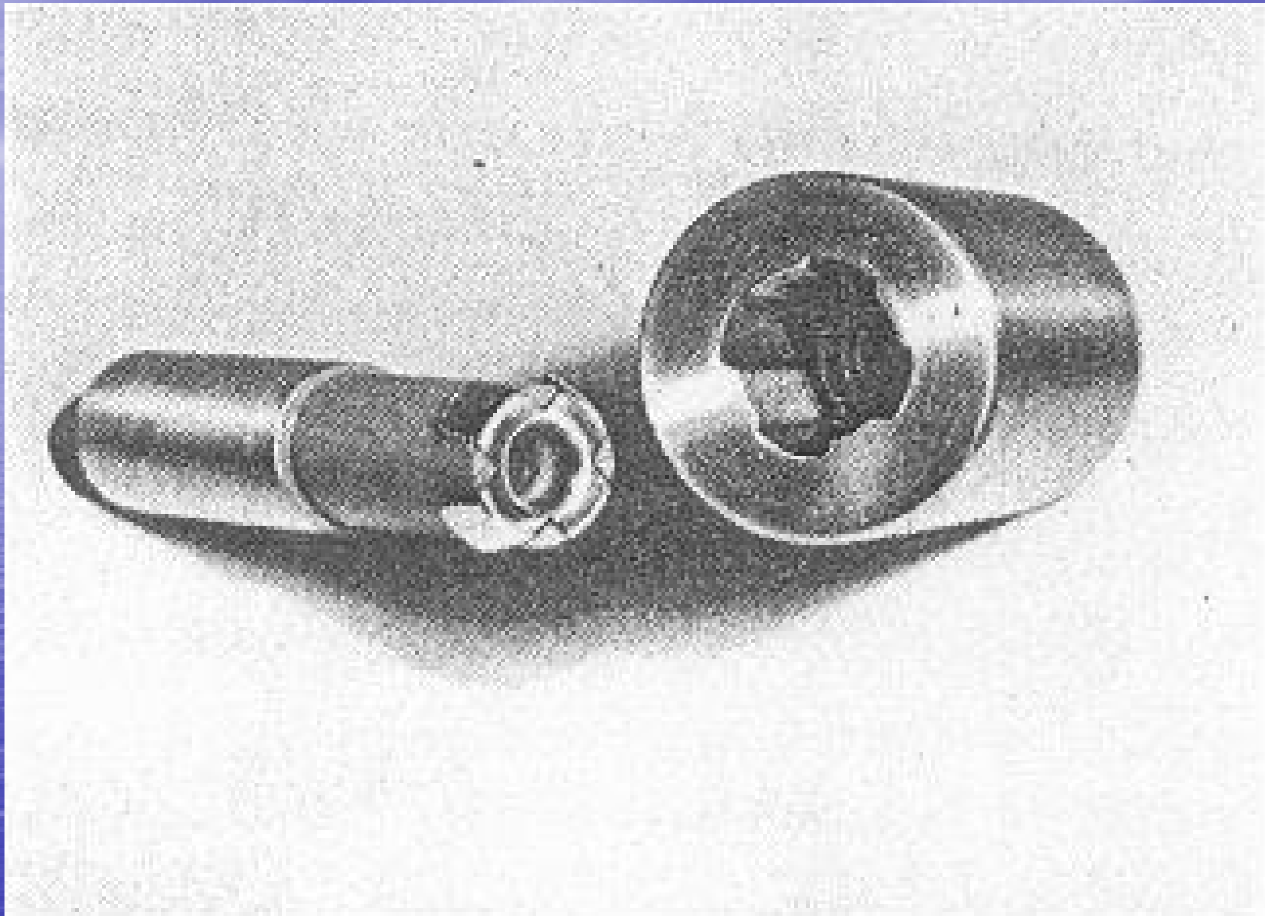


Fig. 3–12. Electro-broaching slots in a tool steel part. *(Courtesy, The Ex-Cell-O Corporation)*

Cutting slots in a valve plate

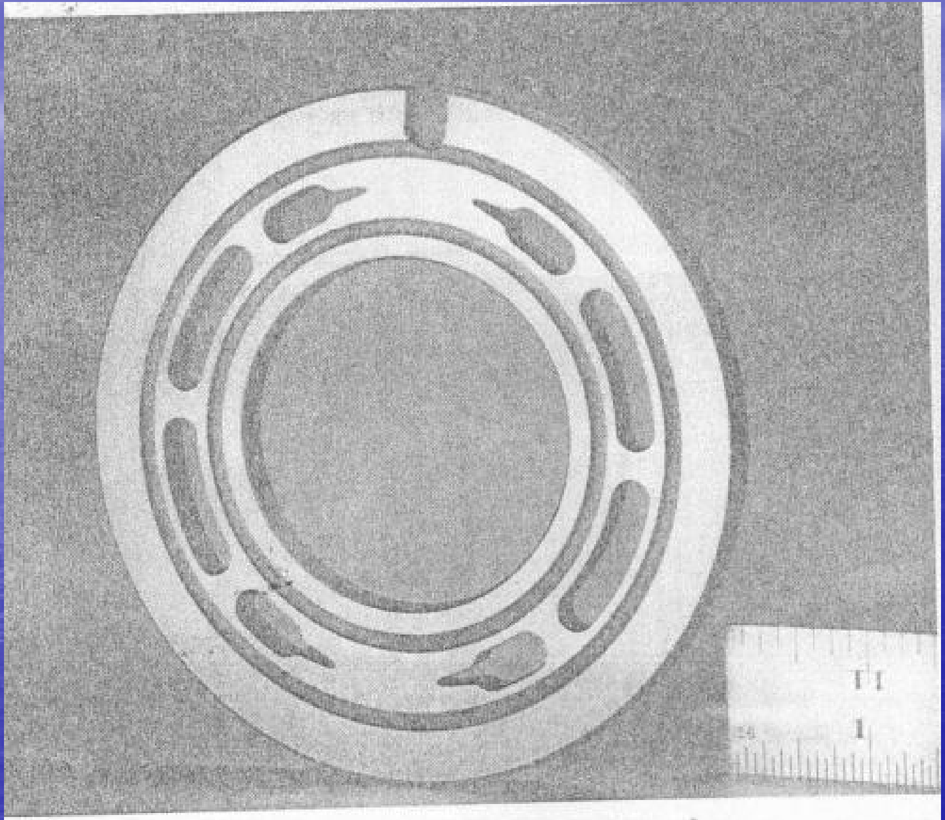


Figure 9.9 Electrochemically machined valve plate (*Source:* courtesy, Anocut, Inc., Elk Grove Village, Ill.).

8.4mm thick plate (hardened steel of 65HRC);
NaCl; 1800amps; 130sec/part

16 pockets in a cavity machined simultaneously

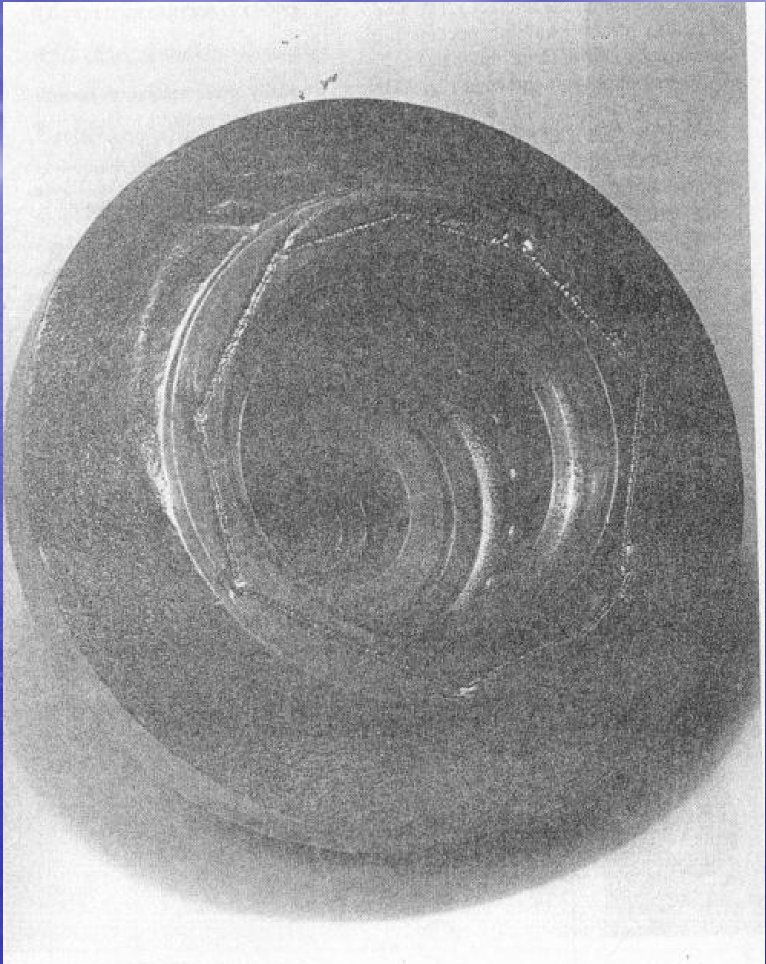


Figure 9.10 All 16 pockets in this cavity were simultaneously machined by ECM in less than 6 min (*Source:* courtesy, Chemform, Inc., Pompano Beach, Fla.).

Process time: less than 6 mins

Adjusting ring and sleeve profiled by ECM

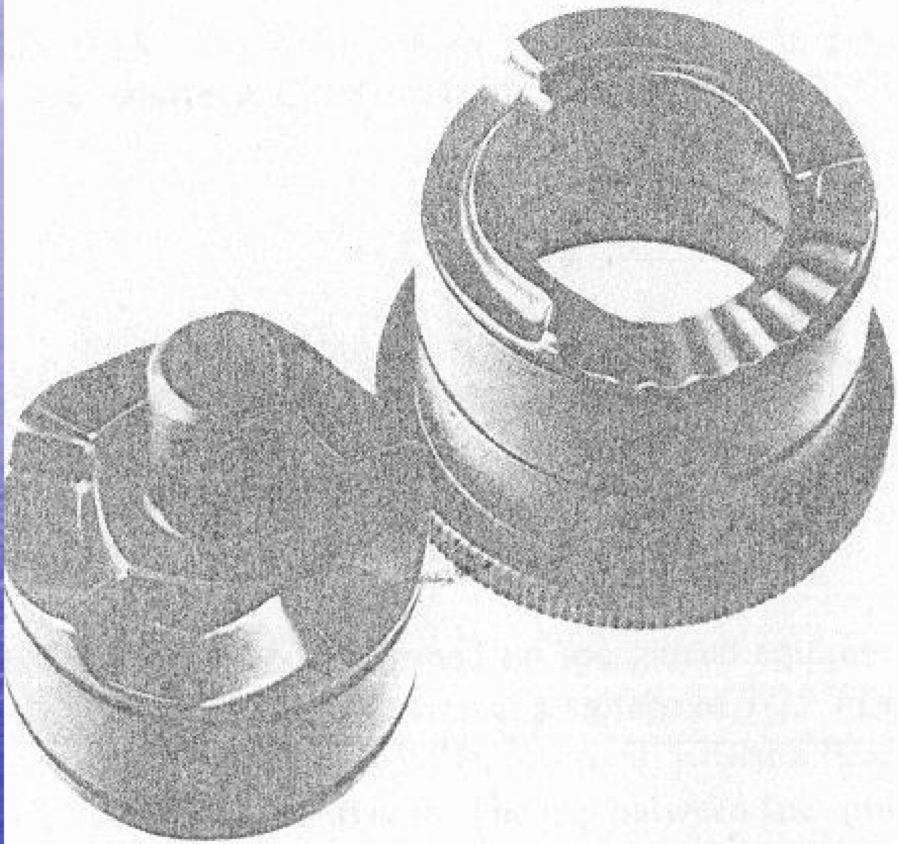


Figure 9.11 Adjusting ring and sleeve profiled by ECM (*Source:* courtesy, AEG-Elotherm GmbH., Remsheid, West Germany).

Parts made by Electrochemical Machining

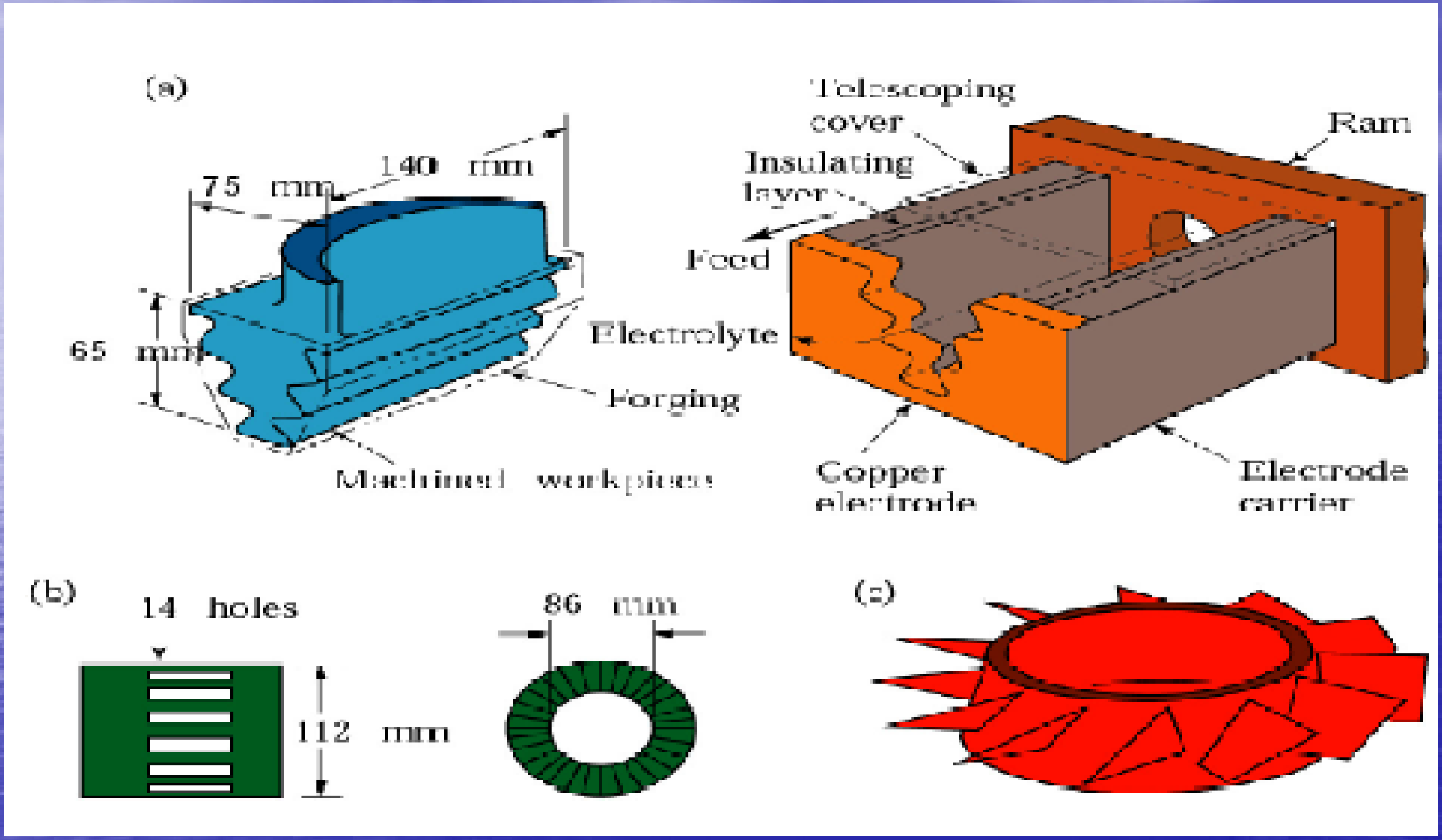


Fig : Typical parts made by electrochemical machining. (a) Turbine blade made of a nickel alloy, 360 HB; note the shape of the electrode on the right. (b) Thin slots on a 4340-steel roller-bearing cage. (c) Integral airfoils on a compressor disk.

Biomedical Implant

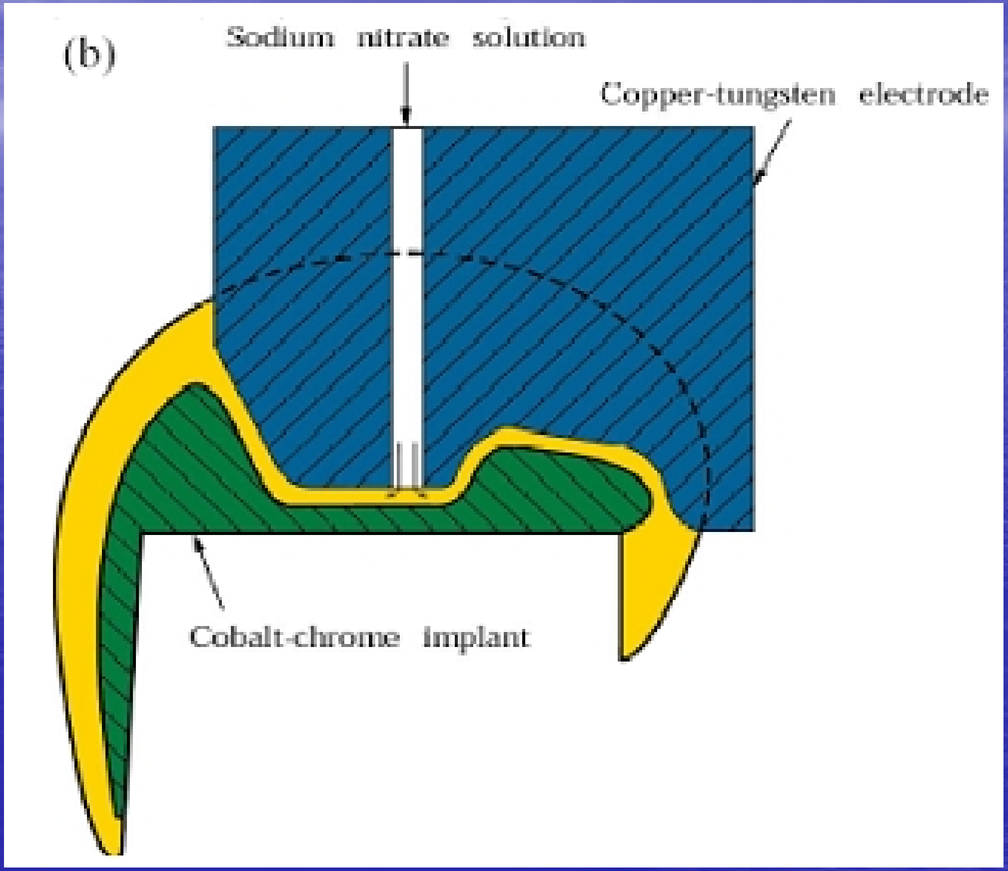


Fig : (a) Two total knee replacement systems showing metal implants (top pieces) with an ultrahigh molecular weight polyethylene insert (bottom pieces) (b) Cross-section of the ECM process as applied to the metal implant.

Design considerations for Electrochemical Machining

- Electrolyte erodes sharp surfaces and profiles so not suited for sharp edges
- Irregular cavities may not be produced to the desired shape with acceptable dimensional accuracy
- Designs should make provisions for small taper for holes and cavities to be machined

Pulsed electro chemical machining(PECM)

- Refinement of ECM
- Uses pulsed rather than direct
- Improves fatigue life, eliminates recast layer left on die and mold surfaces by electrical discharge machining
- Very high current densities, but the current is

Electrochemical Grinding (ECG)

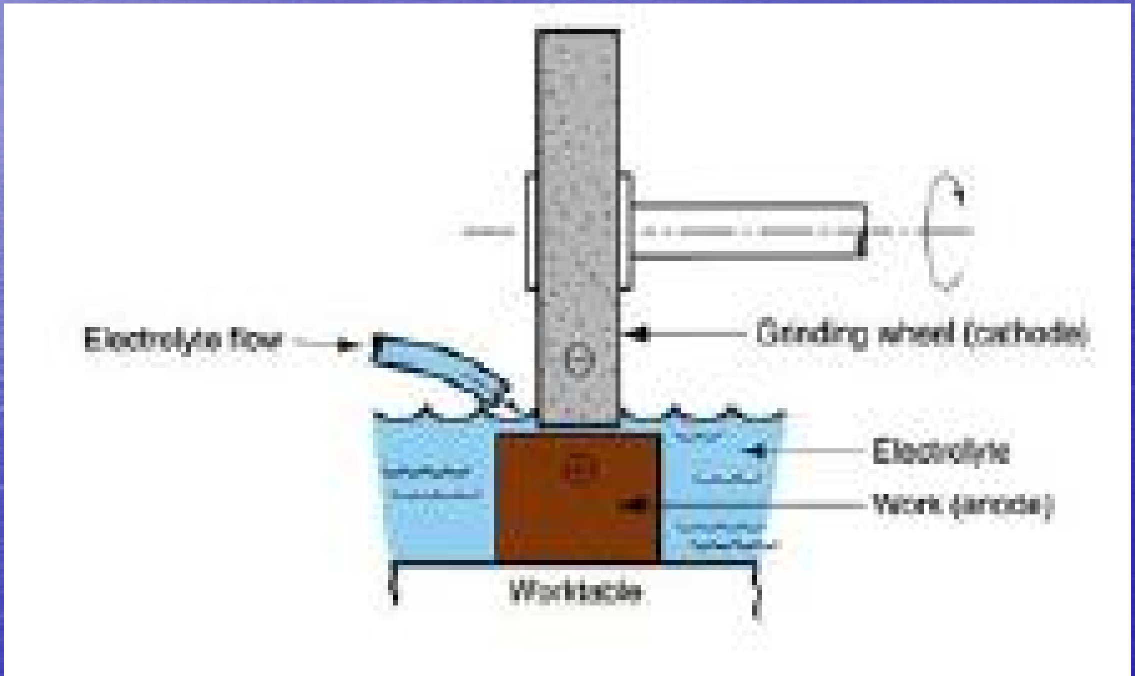
Synopsis

- Introduction
- Equipment
- Methods
- Process parameters
- Advantages
- Limitations
- Applications

Introduction

- ECG also called electrolytic grinding is similar to ECM, except that the cathode is an electrically conductive abrasive grinding wheel instead of a tool shaped like the contour to be machined
- Used primarily to machine difficult to cut alloys such as stainless steel, Hastelloy, Inconel, Monel, Waspally and tungsten carbide, heat treated workpeices, fragile or therm-sensitive parts, or parts for which stress-free and burr-free results are required
- Process introduced in the early 1950s evolving from developments in the USSR on EDM
- ECG removes metal by a combination of electrochemical (responsible for 90% of material removal) and grinding actions
- The grinding action removes the buildup of oxide film on the surface of the workpiece
- Less power is needed for ECG than for ECM since the machining area is smaller and the abrasive in the wheel is removing the oxide film – current ranges from 5 to 1000A are most common, with a voltage of 3 to 15V over an electrolyte gap of approximately 0.25mm or less and wheel speeds of 1100 to 1800m/min
- Many similarities between ECG and conventional grinding make this one of the easiest ECM based processes to both understand and implement – grinding wheel closely resemble their conventional counterparts with the exception that ECG wheels use an electrically conductive abrasive bonding agent; electrolyte is introduced to the work area in the same manner that coolant is introduced in conventional grinding

Special form of ECM in which a grinding wheel with conductive bond material is used to augment anodic dissolution of metal part surface



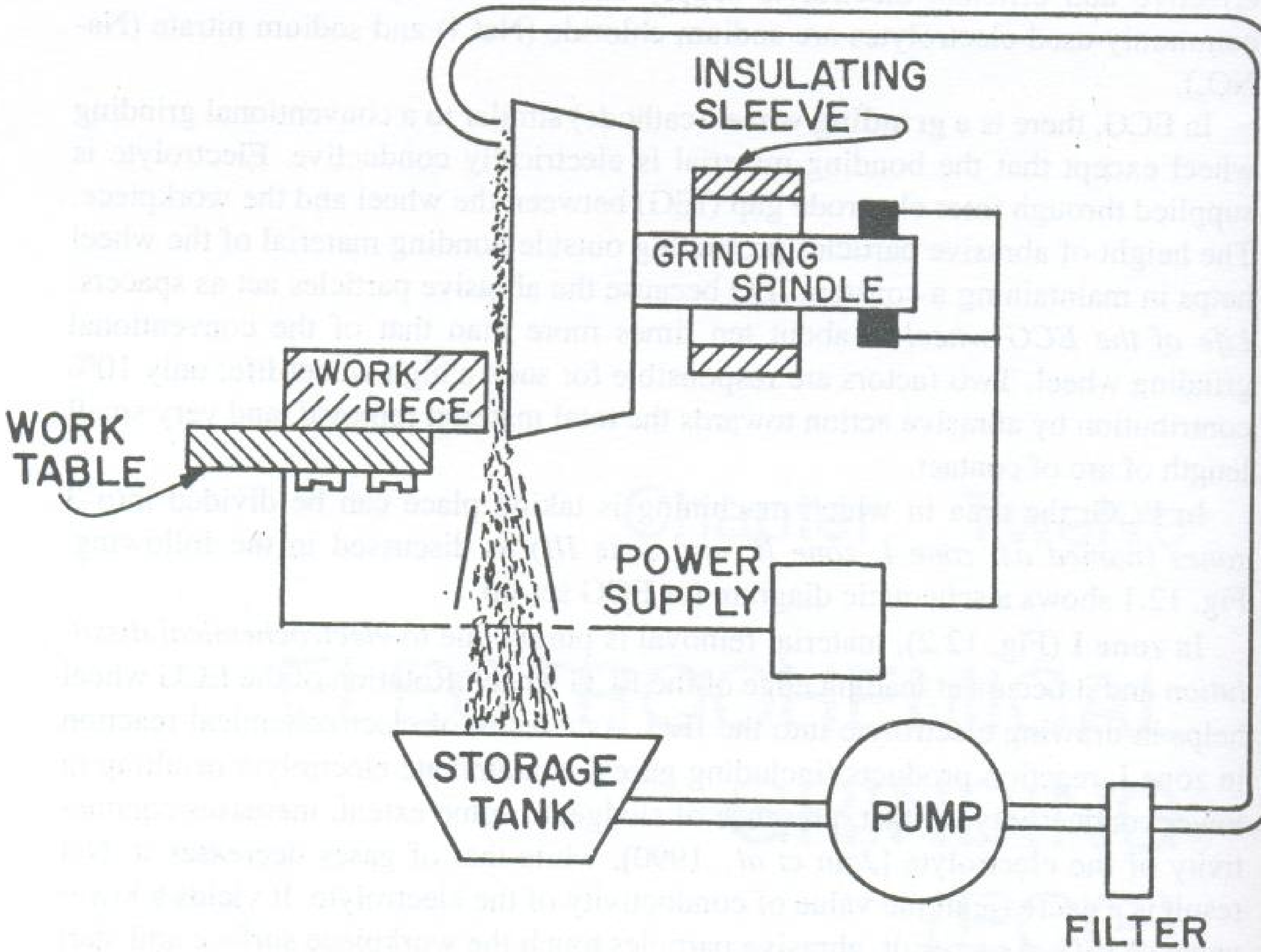
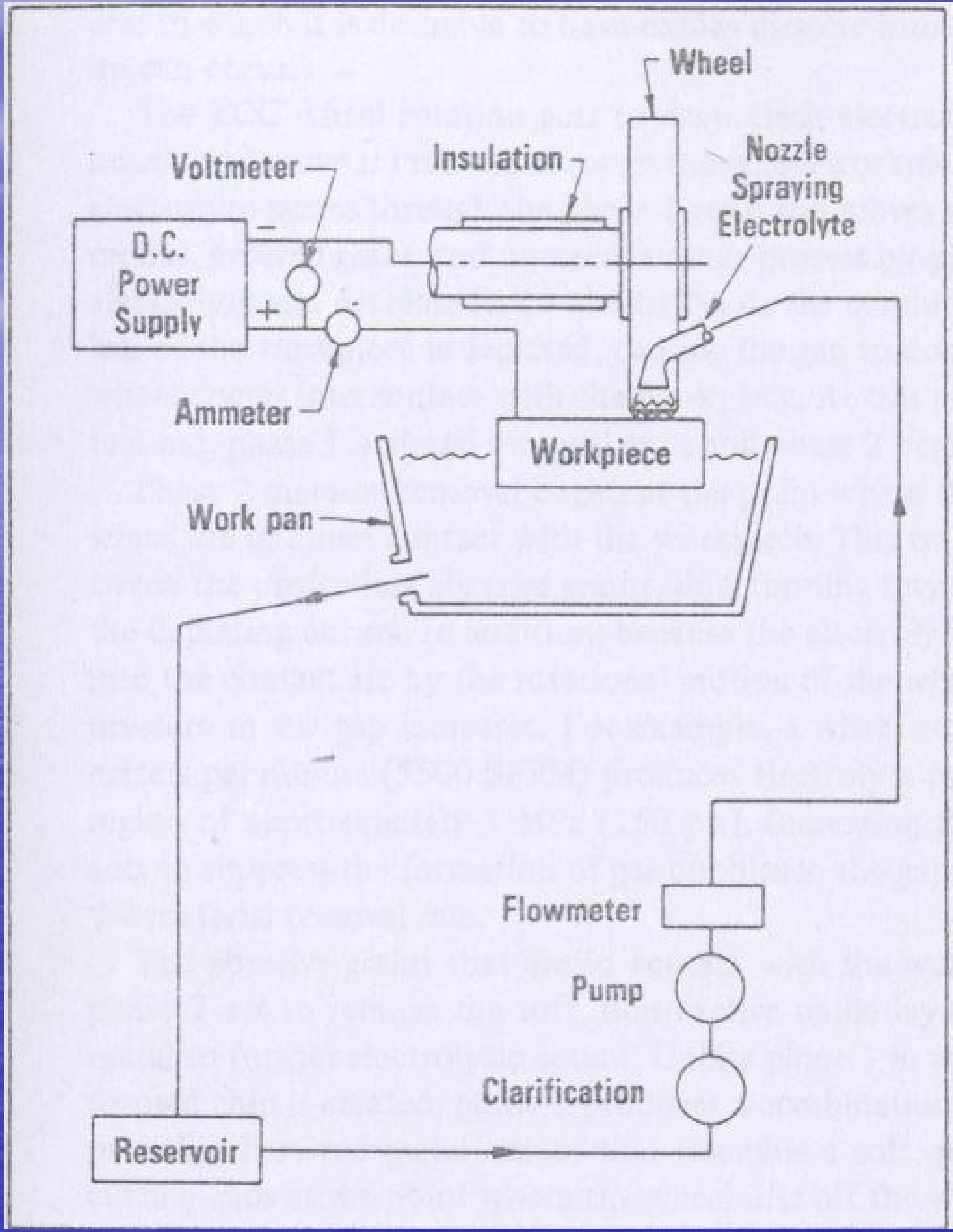


Fig. 12.1 Schematic diagram of electrochemical grinding set-up.


Wheel
Voltmeter
Insulation
Nozzle
Spraying
Electrolyte
D.C.
Power
Supply
Ammeter
Workpiece
Work pan
Flowmeter
Pump
Clarification
Reservoir

ECG - Combines electrochemical machining with conventional grinding

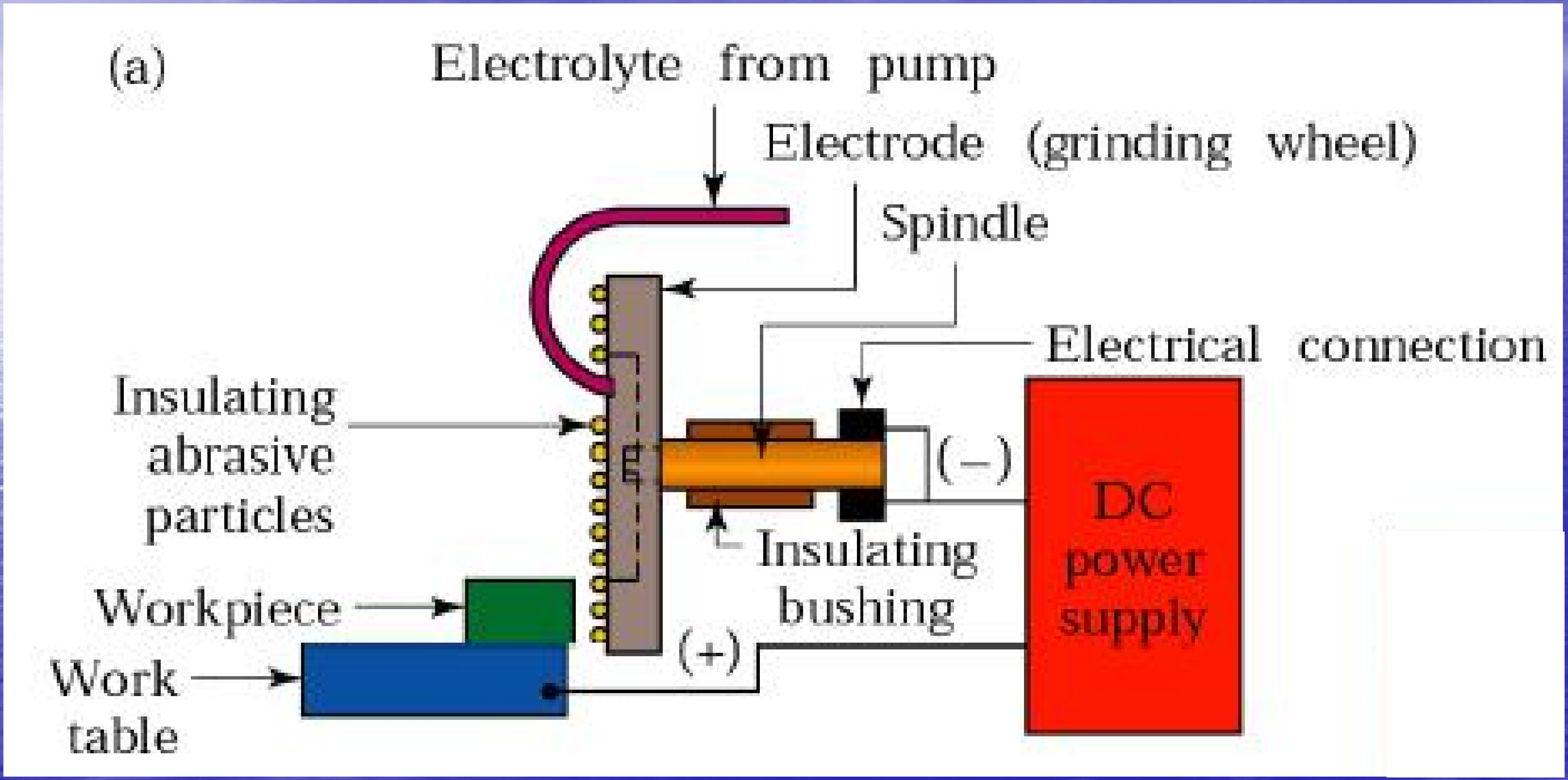


Fig : Schematic illustration of the electrochemical – grinding process

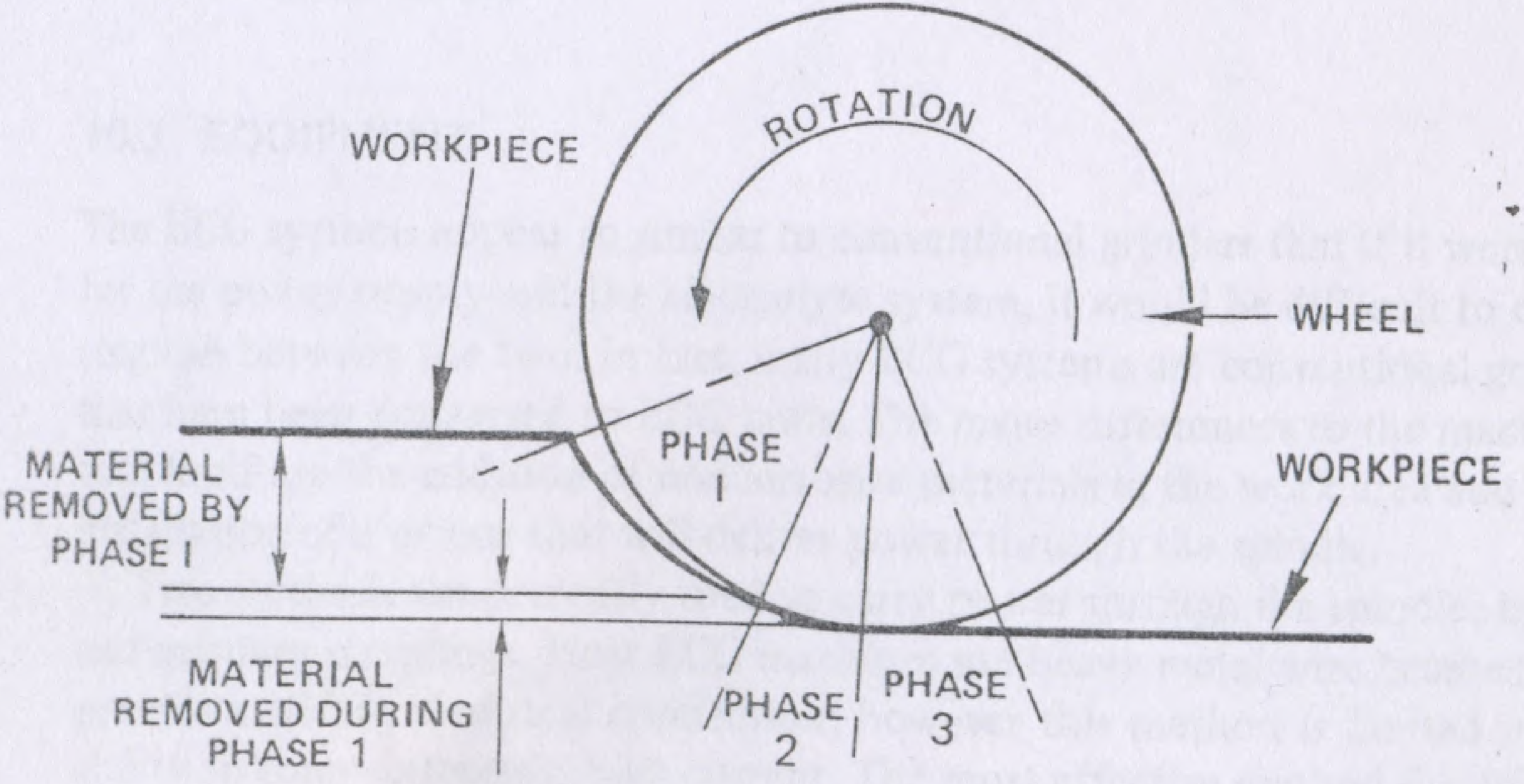


Figure 10.3 The three phases of ECG material removal.

Major components of the system

- Electrolyte delivery and circulating system
- Electrolyte
- DC power supply
- Grinding wheel
- Work piece

Electrolyte delivery and circulating system

- The electrodes are not totally immersed, yet there must be an ample supply of electrolyte
- Nozzles are used to ensure proper wetting action of the wheel
- Nozzle creates a partial vacuum and causes the electrolyte to be sucked up, filling the cavities around the grit – the rotation of the wheel then carries the electrolyte into the area of contact between the workpiece and the wheel

Electrolyte

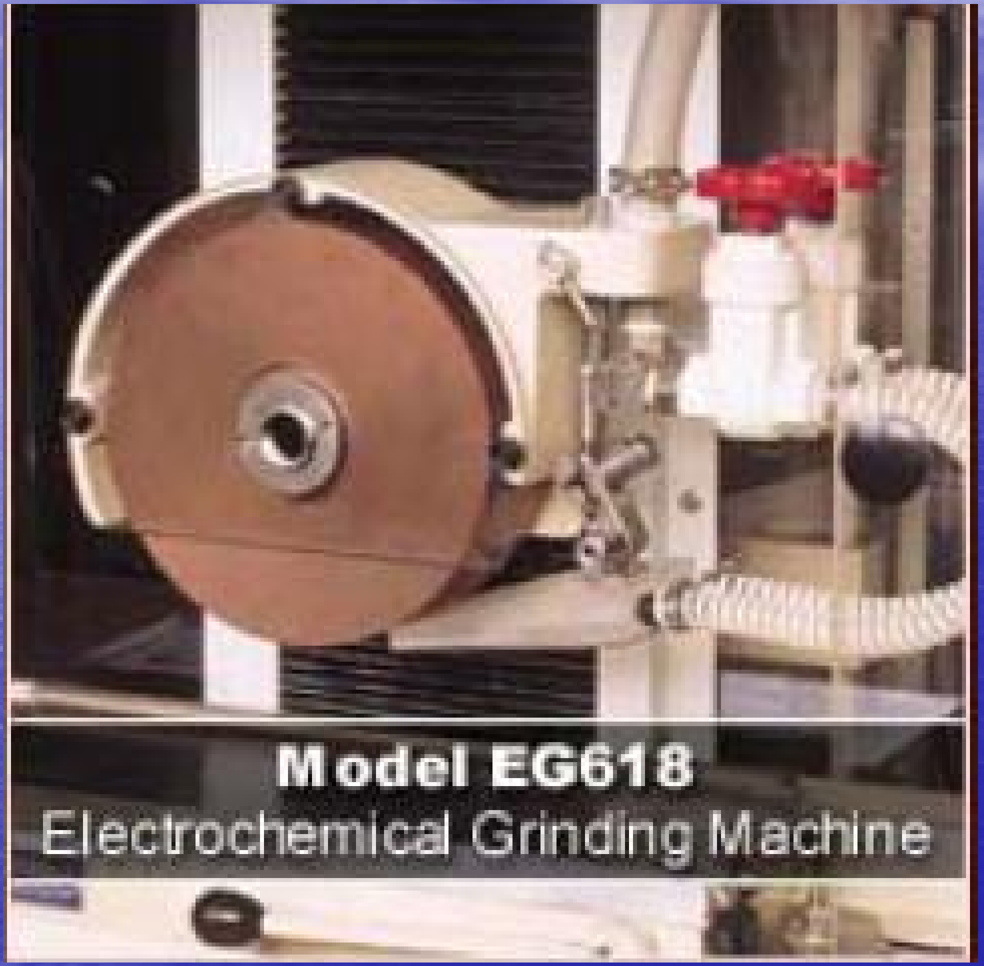
- Resemble those used for the ECM; however formulations for ECG are distinctly different – they are designed to enable faster formation of oxide films on the workpiece, whereas in ECM, the oxide must dissolve at once in the electrolyte
- Desirable electrolyte should provide: high conductivity, high stock removal efficiency, passivation to limit stray currents, good surface finishes and corrosion inhibition

Grinding wheel

- The abrasive grains on the ECG wheel serve three major purposes:

1. Act to wipe the oxide from the workpiece, exposing new metal and allowing the process to continue
2. Spacer to keep the conductive media in the wheel from making direct contact with the workpiece and generating a short circuit
3. The cavities between the grit are filled with electrolyte, and the grit acts as a carrier bringing the electrolyte to the work area between the workpiece and the wheel making the ECG process possible

- ECG wheels are made of an abrasive material, a bonding agent and a conductive medium
- Most ECG wheels have aluminium oxide as the abrasive and contain copper impregnated resins for conductivity
- Other abrasive materials used include silicon carbide and diamond and recently borazon


Model EG618
Electrochemical Grinding Machine

Methods

- Five different grinding methods can be performed with ECG equipment: face grinding, surface grinding, internal grinding, form grinding and cylindrical grinding

Process parameters

- ECG exhibits MRRs that are up to 10 times faster than conventional grinding on materials harder than 60HRC; although MRRs are high, ECG cannot obtain the tolerances achieved by conventional grinding
- The removal rate for ECG is governed by the current density, just as in ECM: as with ECM, the higher the current density, the faster the removal rate and the better the resulting surface finish
- Feed rates vary with different parameters, depending on the grinding method: if the feed rate is running too slowly for the application, a large overcut will be produced that will result in poor surface finishes and tolerances and if the feed rate is too fast, the abrasive particles will be prematurely forced into the workpiece, resulting in excessive wheel wear

Advantages

- No thermal damage to workpiece
- Elimination of grinding burn
- Absence of work hardening
- Long-lasting wheels – less truing
- Higher MRR;
- Single pass grinding - reduced cost of grinding;
- Absence of burrs on the finished surface;
- Improved surface finish with no grinding scratches;
- Reduced pressure of work against the wheel – no distortion;
- In ECG, the ECM action is efficient

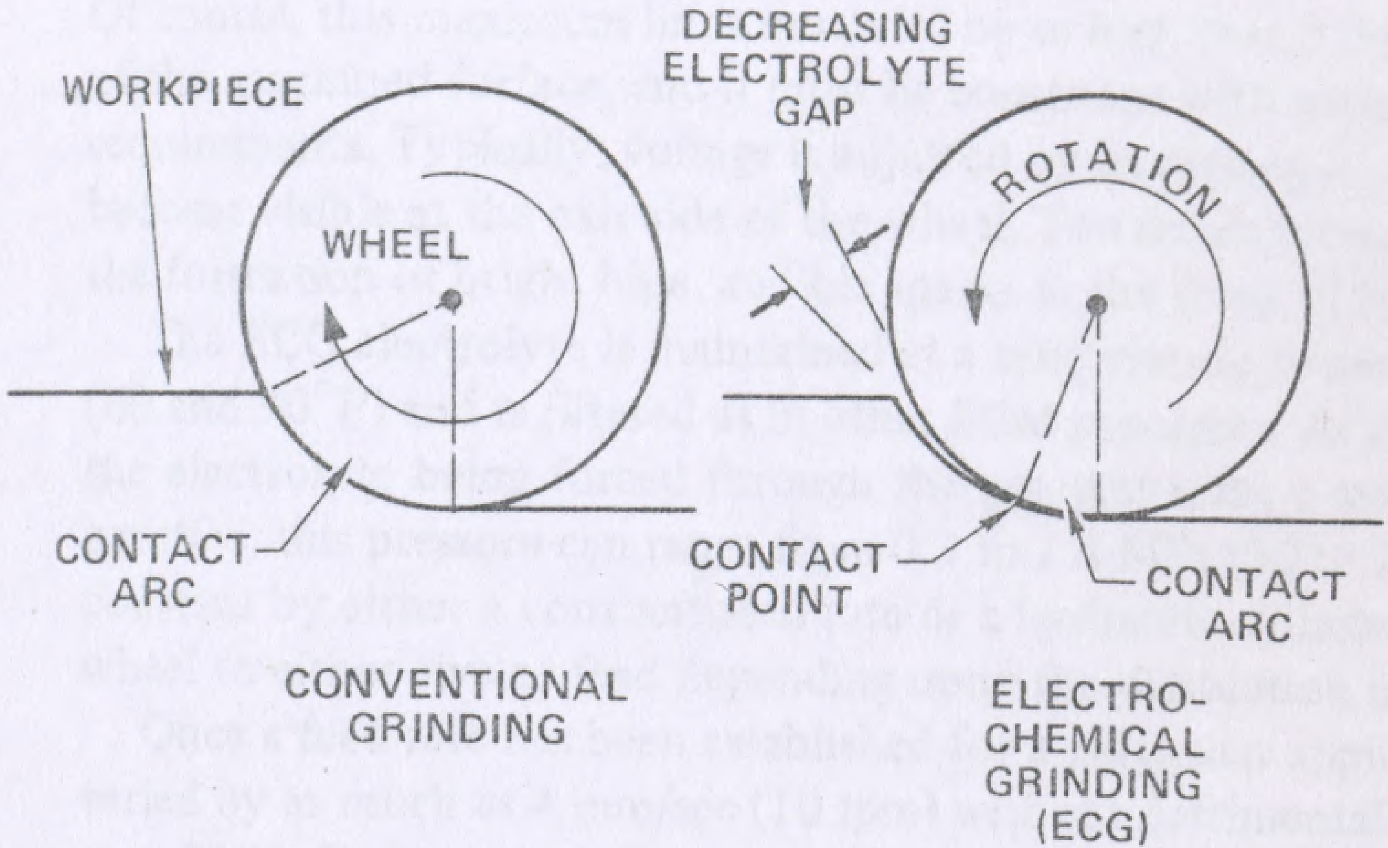


Figure 10.2 A small mechanical contact arc is partly responsible for the long wheel life experienced by ECG users.

Limitations

- High capital cost / Higher cost of grinding wheel;
- Corrosive environment
- High preventive maintenance cost
- Tolerance achieved are low;
- Difficult to optimize due to the complexity of the process;
- Non-conductive materials cannot be machined
- Not economical for soft materials – noncompetitive removal rates compared to conventional methods for readily machinable metals
- Requires disposal and filtering of electrolytes

Applications

- Single largest use for ECG is in the manufacturing and remanufacturing of turbine blades and vanes for aircraft turbine engines
- Grinding of tungsten carbide tool inserts
- Re-profiling worn locomotive traction motor gears
- Burr-free sharpening of hypodermic needles
- Grinding of surgical needles, other thin wall tubes, and fragile parts
- Machining of fragile or very hard and tough material – honey comb, thin walled tubes and skins
- High MRR's when grinding hard, tough, stringy, work-hardenable or heat sensitive materials

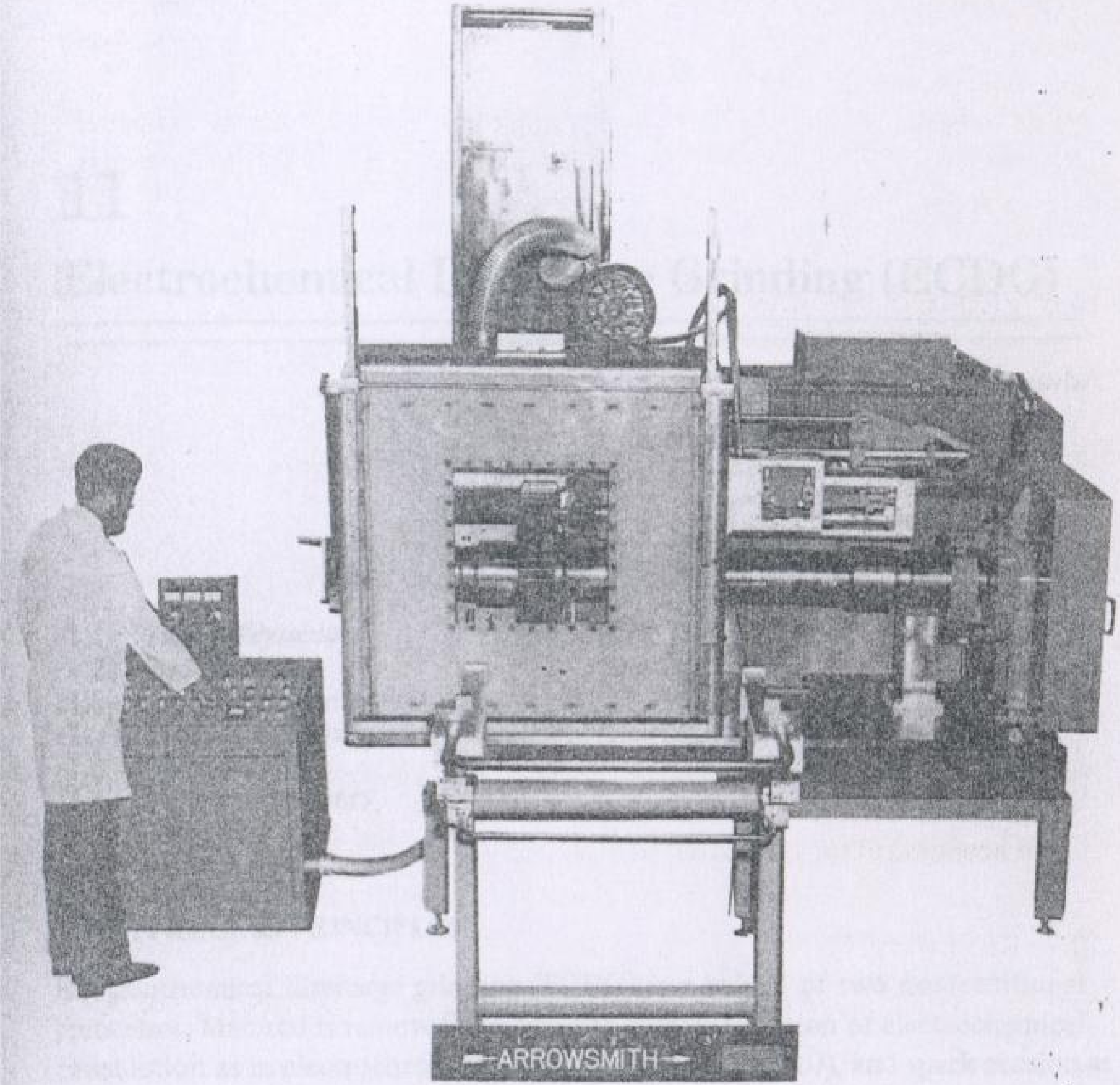


Figure 10.8 An ECG system used to reprofile locomotive traction motor gears (*Source:* courtesy, Arrowsmith Industries, Inc., Los Angeles, Calif).

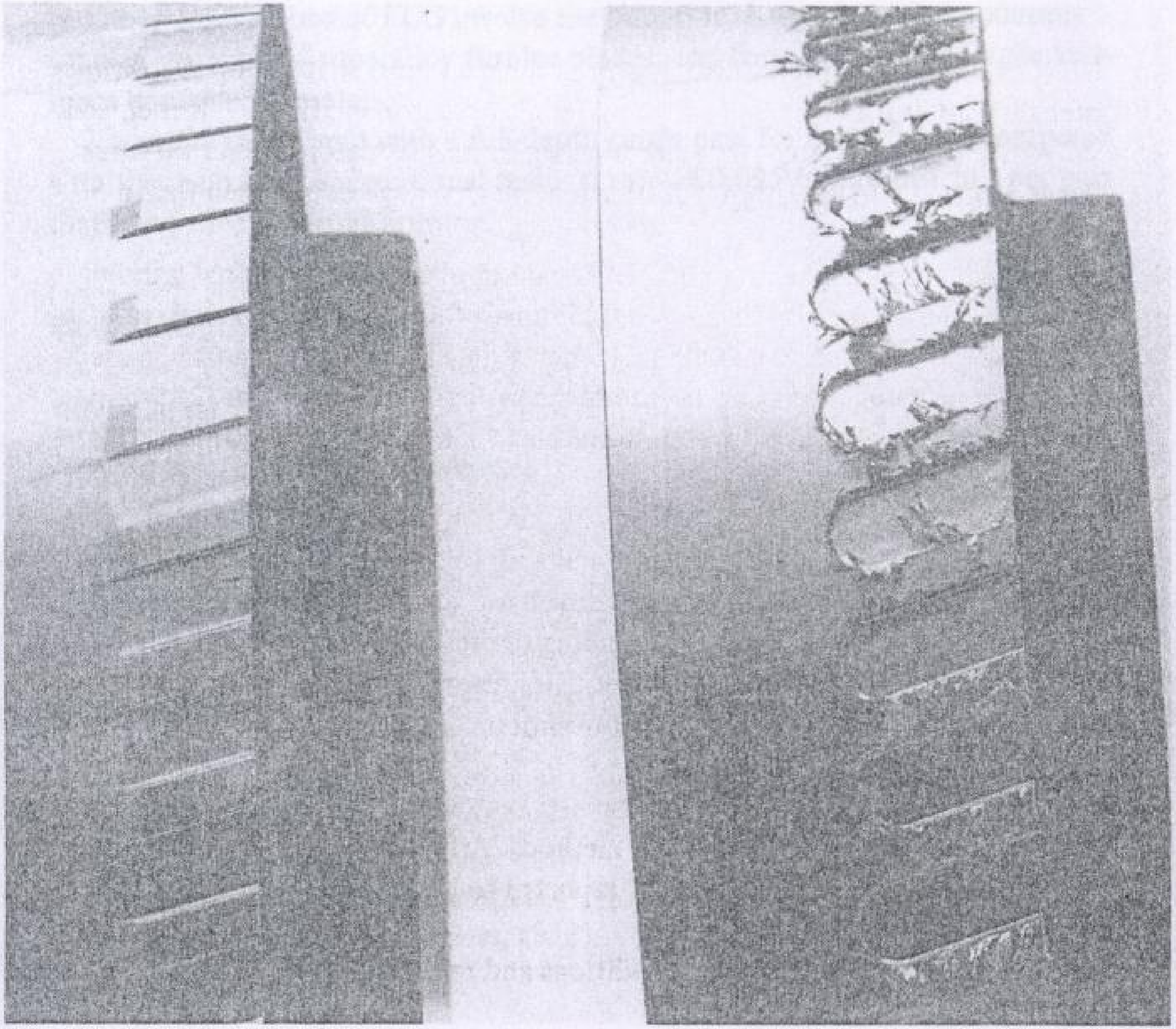


Figure 10.7 Two identical gas turbine components made from a tough super-alloy. The part on the left had the slots produced by ECG. The part on the right was produced by conventional milling. The slots produced by ECG require no postprocessing or cleanup operations (*Source:* courtesy, Garrett Turbine Engine Company, Phoenix, Ariz).

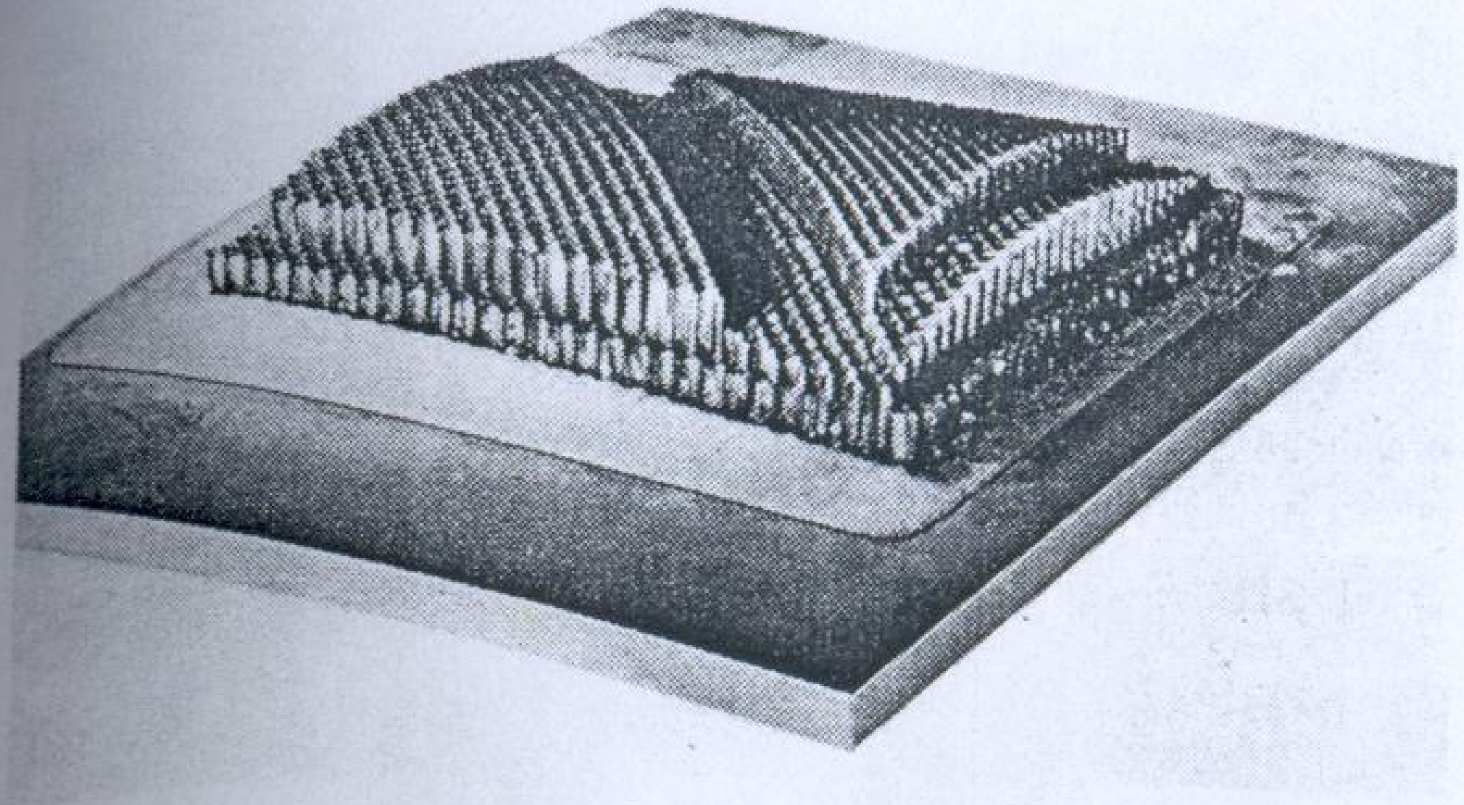


Fig. 3–14. Contoured stainless steel honeycomb, shaped by ECG. *(Courtesy, Anocut Engineering Company)*

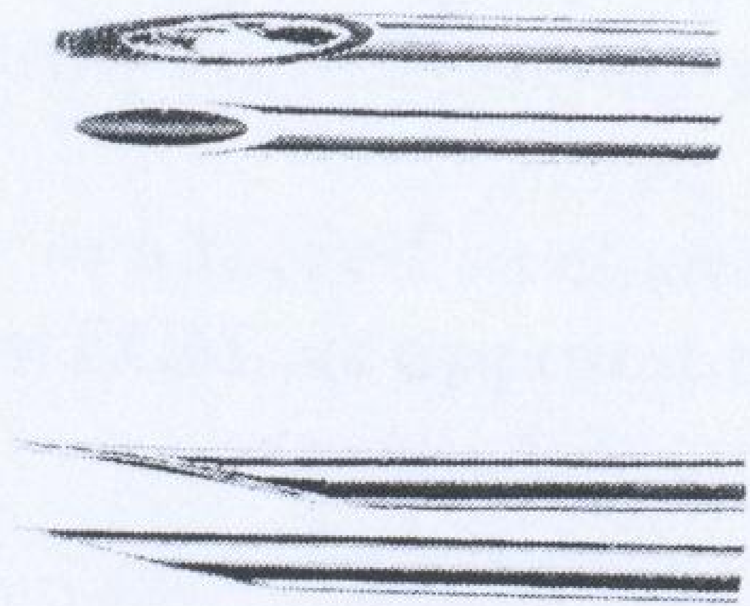


Fig. 3–15. Hypodermic needles (left) sharpened by ECG without burrs. Needles at right were conventionally ground at same speed (note burrs). *(Courtesy, Anocut Engineering Company)*

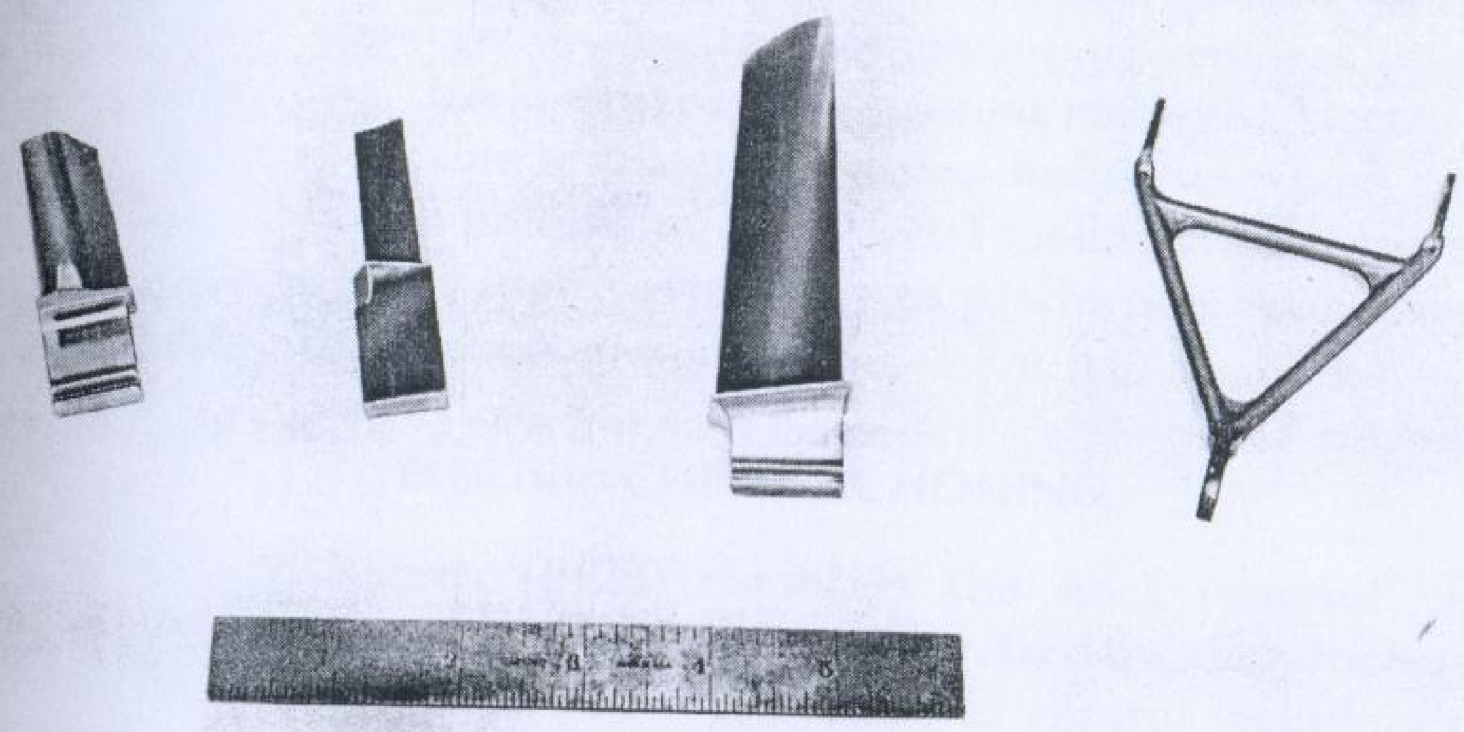
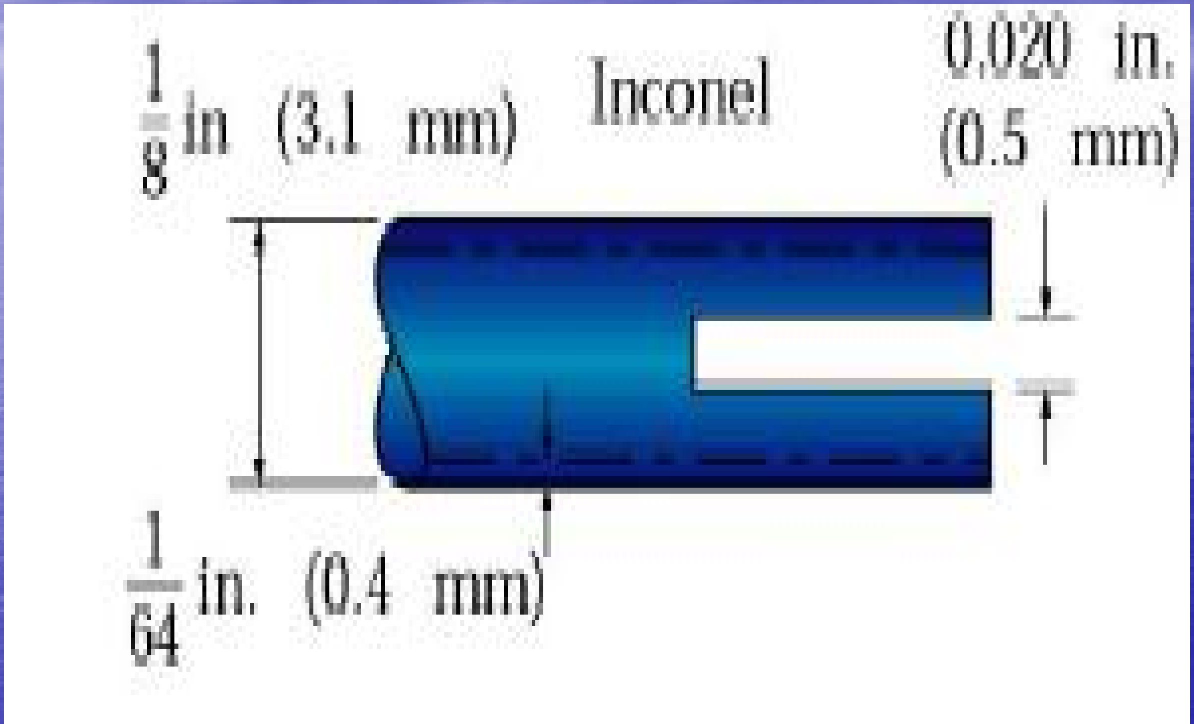


Fig. 3–16. Jet engine parts electro-chemically ground faster than conventional milling with virtually no tool cost. *(Courtesy, Anocut Engineering Company)*



<u>Fig</u> : Thin slot produced on a round nickel – alloy tube by this ECG

ECG parts

Electrochemical Honing (ECH)

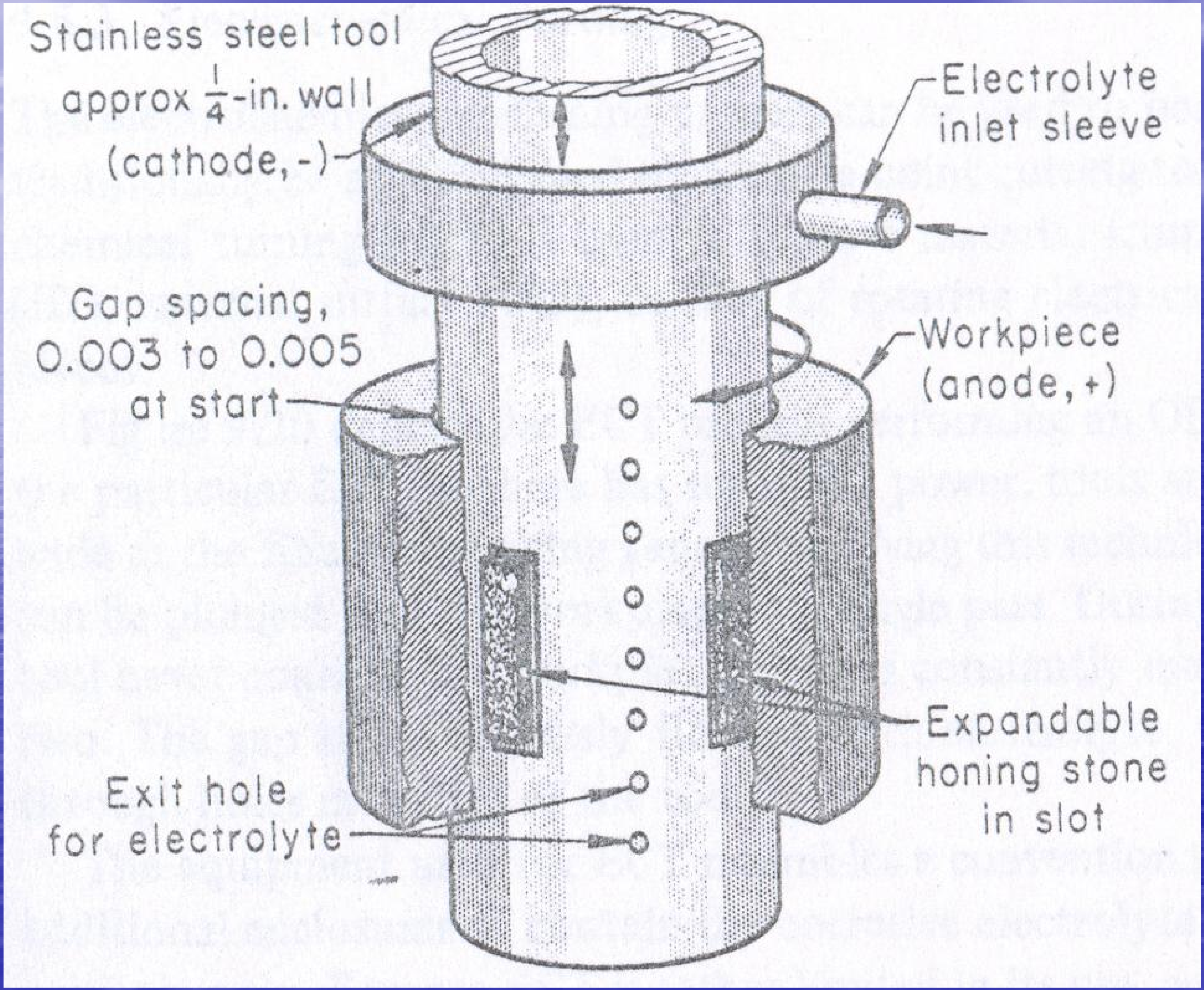
Synopsis

- Introduction
- Equipment
- Process parameters
- Advantages
- Limitations
- Applications

Introduction

- ECH is a process in which the metal removal capabilities of ECM are combined with the accuracy capabilities of honing. The process consists of a rotating and reciprocating tool inside a cylindrical component.
- Material is removed through anodic dissolution and mechanical abrasion – 8% or more, of the material removal occurs through electrolytic action
- As with conventional ECM, the workpiece is the anode and a stainless steel tool is the cathode

ECH tool construction



ECH tool construction

- Tool consists of a hollow stainless steel body that has expandable, nonconductive honing stones protruding from at least three locations around the circumference
- The honing stones are identical with those used in conventional honing operations, except that they must resist the corrosiveness of the electrolyte
- The honing stones are mounted on the tool body with a spring-loaded mechanism so that each of the stones exerts equal pressure against the workpiece
- The length of the stones is selected to be approximately one-half the length of the bore being processed

Working

- At the beginning of the ECH cycle, the stones protrude only 0.075-0.127mm from the stainless steel body, establishing the gap through which the electrolyte flows
- The electrolyte enters the tool body via a sliding inlet sleeve from which it exits into the tool-workpiece gap through small holes in the tool body
- After passing through the gap, the electrolyte flows from the workpiece through the gap at the top and bottom of the bore
- The mechanical action of the tool is the same as with conventional honing; the tool is rotated and reciprocated so that the stones abrade the entire length of the bore
- Electrolytes used in ECH are essentially the same as those used in ECM, although the control of pH, composition and sludge is less critical because the abrasive action of the stones tends to correct any resulting surface irregularities
- As in ECM, the electrolytes are recirculated and reused after passing through appropriate filtration, and the most commonly used electrolytes are sodium chloride and sodium nitrate

Process parameters

- Machines are available that deliver up to 6000 amp
- Current density at the workpiece can range from 12 to 47amp/cm2
- Working voltages are 6-30VDC
- The electrolyte is delivered to the work area at pressures of 0.5-1MPa
- ECH can remove materials at rates up to 100% faster than conventional honing, the gain being more pronounced as the material hardness increases
- Machine capacities are currently able to accommodate bore lengths up to 600mm and bore diameters from 9.5 to 150mm

Advantages

- Increased MRR particularly on hard materials
- Since most of the material is removed electrochemically, honing stone life is greatly extended
- Burr-free operation
- Unlike conventional honing, no micro-scratches are left on the work surface
- Less pressure required between stones and work
- Reduced noise and distortion when honing thin walled tubes
- Cooler action leading to increased accuracy with less material damage
- As with all ECM-based processes, ECH imparts no residual stresses in the workpiece
- Capable of achieving surface finishes of 0.05μ and dimensional accuracies of ±0.012mm
- By turning of the power to the tool before the end of the honing cycle, the stones can be used in the conventional manner to achieve tolerances of ±0.002mm and to impart a compressive residual stress in the work surface

Limitations

- High capital cost
- Corrosive environment
- High preventive maintenance cost
- Non-conductive materials cannot be machined
- Requires disposal and filtering of electrolytes

Applications

- Process is easily adaptable to cylindrical parts for trueing the inside surfaces
- Can duplicate over a number of components
- Example: 19mm dia bore of a carburized pinion gear made of 8620 steel and hardened to HRC 60-62 was hone by ECH; 0.05mm of material was removed from the bore in 4 sec with an accuracy of ±0.002mm; conventional honing required 18sec/part and consumed 300% more abrasive

UNIT -IV

ADVANCED NANO FINISHING PROCESSES

INTRODUCTION

- In order to substitute manual finishing process and to meet the functional properties such as wear resistance, power loss, due to friction on most of the engineering components, we go for advanced machining process.
- This finishing process is carried out at micro and nano level. This process is called as advanced nano finishing process.

NANO FINISHING PROCESSES

- Nano finishing is the only operation which can make rough surfaces in nanometers range. The ultimate precision through finishing will be where processed where there is a change in size of sub nanometer.

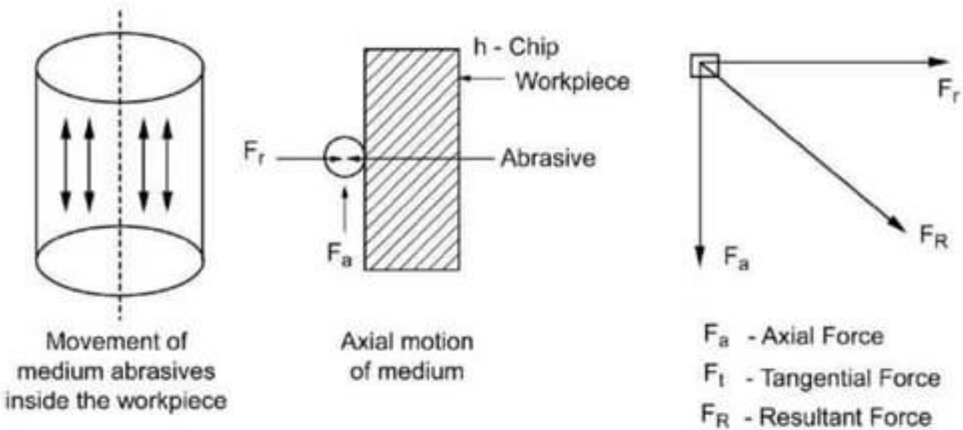
Nano finishing processes

1. Abrasive flow machining
2. Chemo mechanical polishing
3. Magnetic abrasive finishing
4. Magneto rheological finishing
5. Magneto rheological abrasive flow finishing

ABRASIVE FLOW MACHINING

- In abrasive flow machining process, the semisolid abrasive media acts as deformable grading wheel; which helps to remove small amount of materials.
- The abrasive media is given larger force or velocity by hydraulic or mechanical means to push the media into the areas in which conventional finishing process cannot be performed.

ABRASIVE FLOW MACHINING

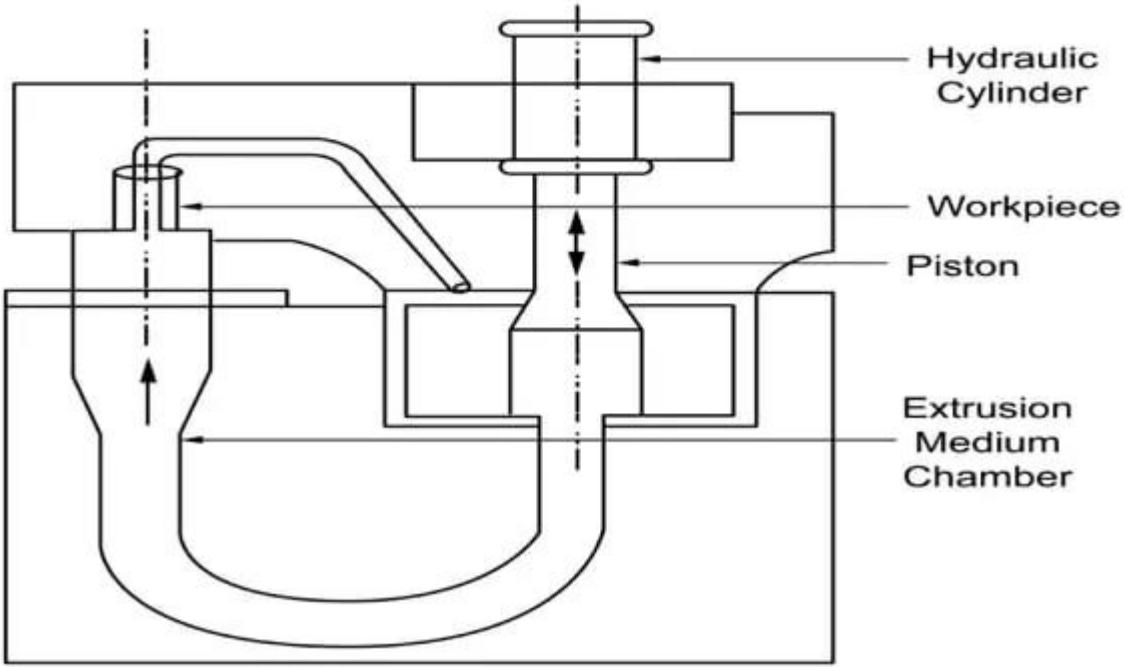


Force diagram of abrasive flow machining

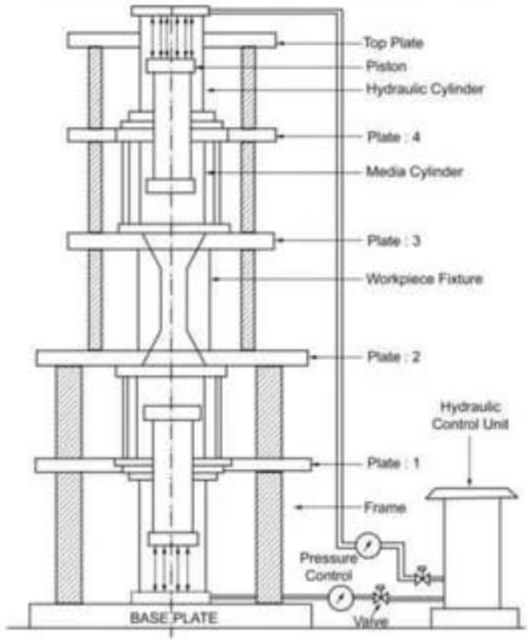
TYPES OF ABRASIVE FLOW MACHINING

1. One way abrasive flow machining
2. Two way abrasive flow machining
3. Orbital abrasive flow machining

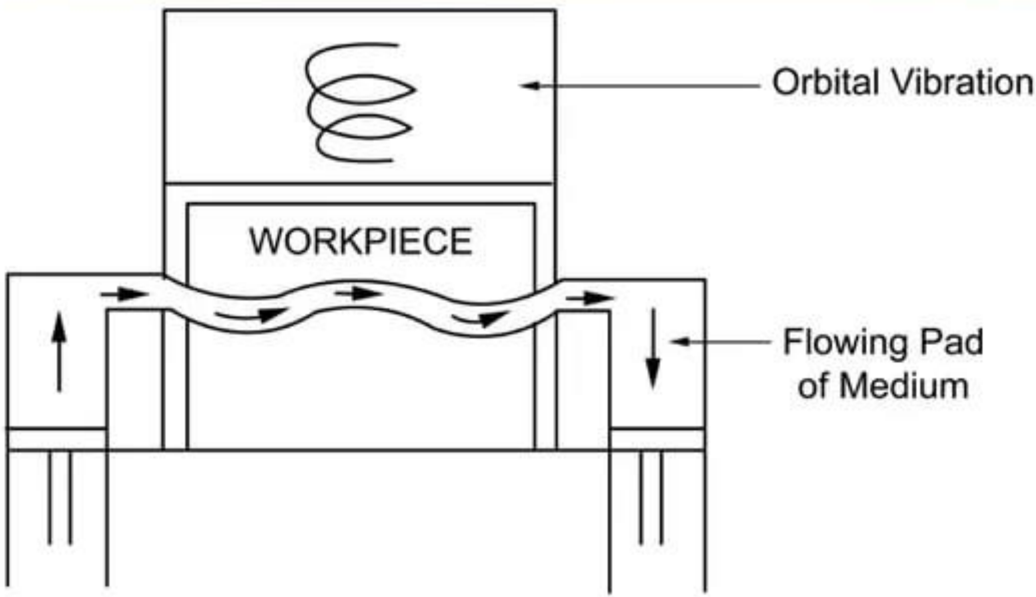
ONE WAY ABRASIVE FLOW MACHINING



TWO WAY ABRASIVE FLOW MACHINING



ORBITAL ABRASIVE FLOW MACHINING

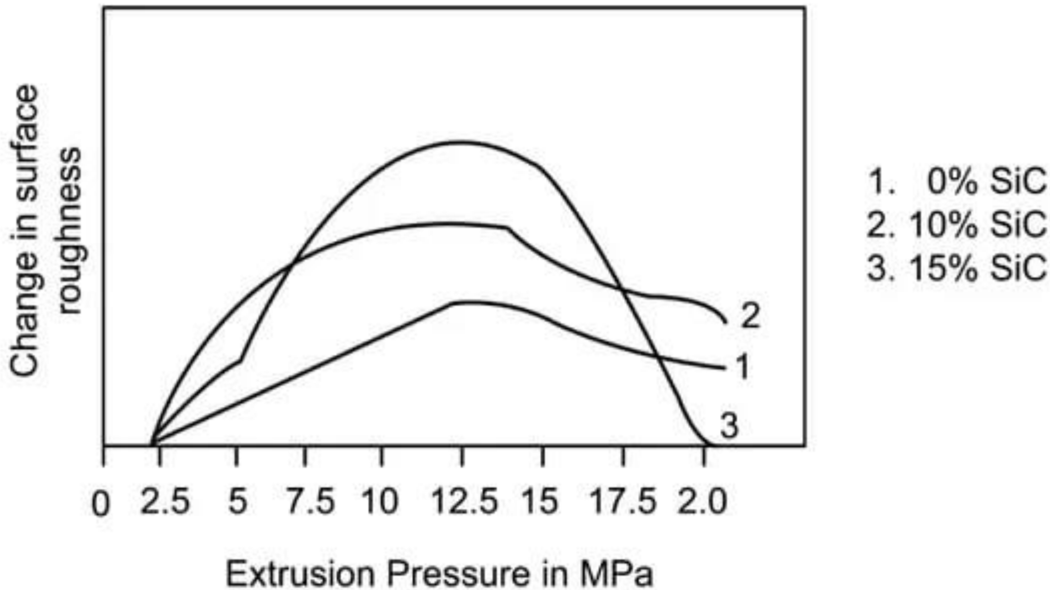


PROCESS PARAMETERS IN ABRASIVE FLOW MACHINING

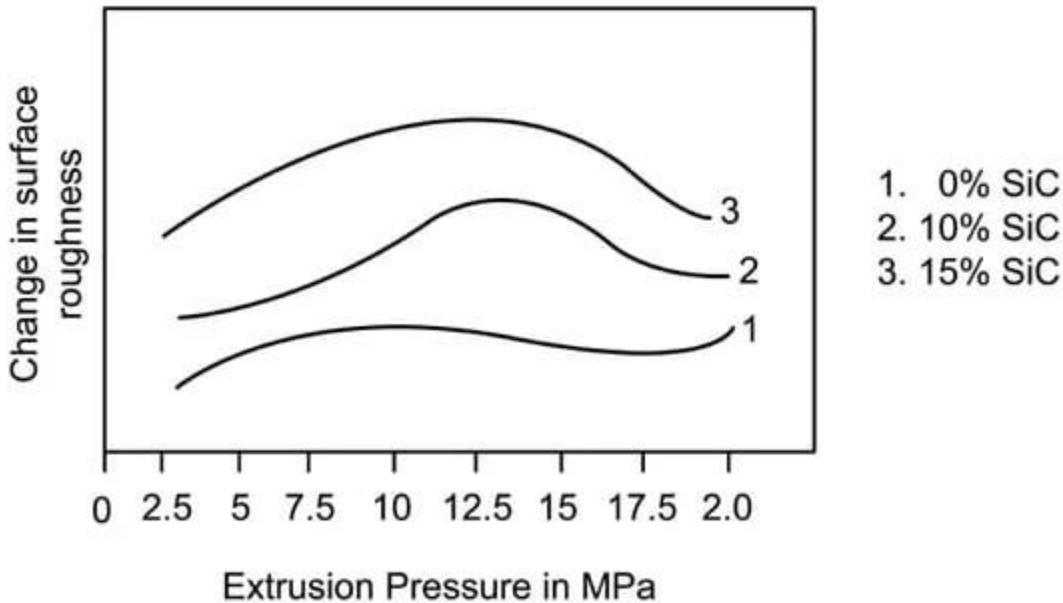
The metal removal rate depends upon the following parameters.

- 1. Addition of plasticizers
- 2. Extrusion pressure
- 3. Number of cycles

Plasticizer Vs Change in Surface Roughness



Extrusion Pressure Vs Change in Surface Roughness



Finishing Cycles Vs Change in Surface Roughness

- As the finishing cycles are increased from 100 to 400, the surface roughness also increased and good surface finish is obtained.
- The number of finishing cycles are controlled by mechanical counter

ADVANTAGES OF AFM

- Operations such as deburring polishing and radiusing can be done.
- This process is more suitable for batch production
- It is faster than manual finishing
- It can finish inaccessible areas in one single movement

LIMITATIONS OF AFM

- It has low finishing rate compared to other nano finishing process.
- The process involves high production time and high production cost.
- There should be repeated replacements of poly abrasive media that is used in AFM process.

APPLICATIONS OF AFM

- AFM is used in finishing of
- Extrusion dies
- Nozzle of flame cutting touch
- Air foil surfaces of impellors
- Accessory parts like fuel spray, nozzle, fuel control bodies.

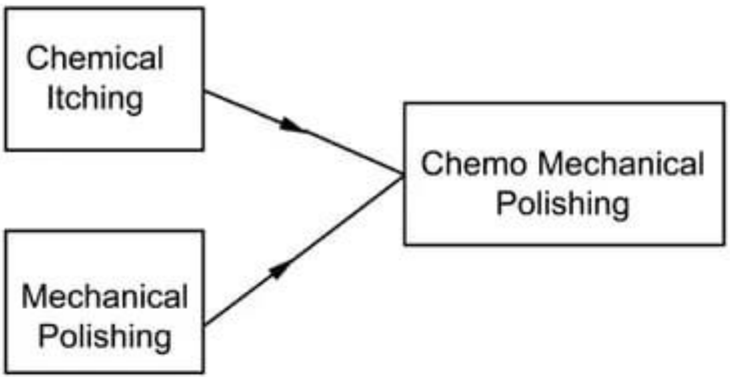
CHEMO MECHANICAL POLISHING

- Chemo mechanical polishing is a process of smoothing and planning surface with the combination of chemical etching and free abrasive polishing.
- CMP of silicon wafers is a basic processing technology for production of flat, defect free, highly reflective surface.
- This planarization method is a choice for < 0.5 micron technologies

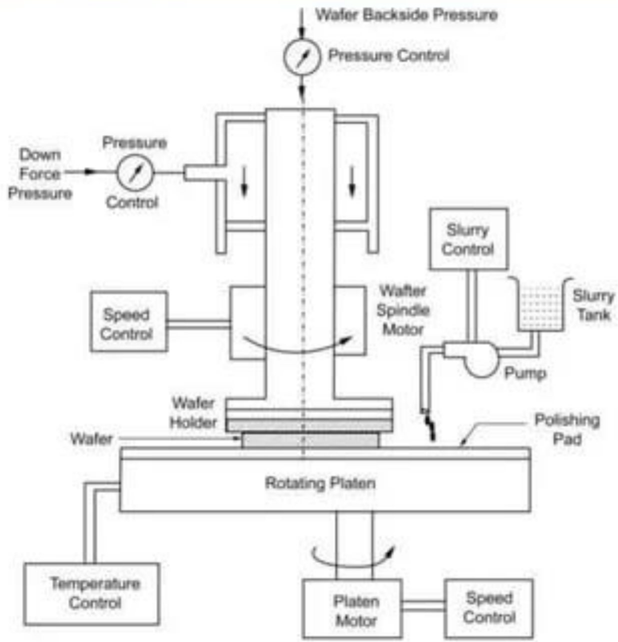
PRINCIPLE OF CMP

- In chemo mechanical polishing, a chemical reaction is used to soften the material and then mechanical polishing is done on the layer. The polishing action is partly mechanical and partly chemical

CMP


Chemical Itching
Mechanical Polishing
Chemo Mechanical Polishing

CONSTRUCTION AND WORKING OF CMP



POLISHING PAD

Types of Pad based on its Hardness

- The hardness is quantified by Youngs modulus value.
- 2GPa – hard pad – good global planarity
- 0.5 GPa – medium pad – good local planarity
- 0.1 GPa – soft pad – good llocal planarity

Pad Asperities

- Pores diameter – 30 – 50 µm
- Peak to peak – 200 – 300 µm

CMP

Abrasives in CMP Slurry

- Oxide slurry
- Metal slurry

The process condition are

- Flow rate - 50 to 100 m*l / min*
- Particle size - 180 to 280 nm

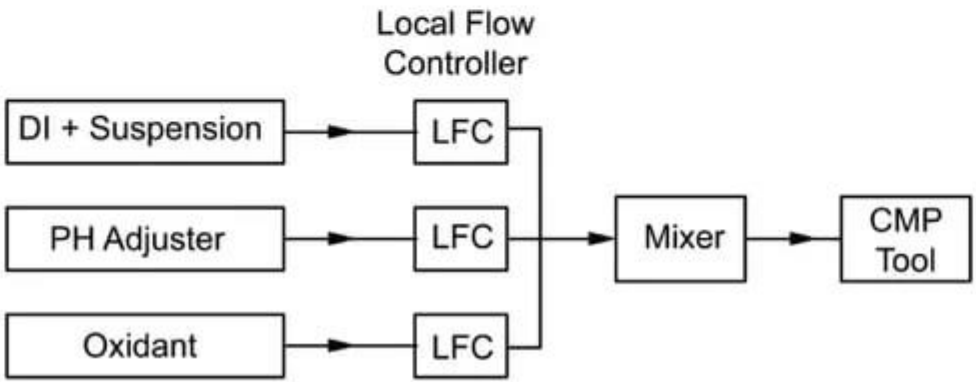
CMP

Metal Slurry

The various types of metal slurry used are

- Fe(NO3)2 – based
- H2O2 – based
- KJO3 – based
- H5IO6 based slurries having oxidizing ability

CMP Tool



Local Flow
Controller
DI + Suspension
PH Adjuster
Oxidant
LFC
LFC
LFC
Mixer
CMP
Tool

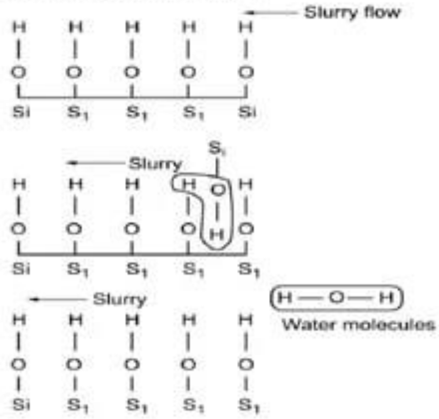
ASPECTS OF MATERIAL REMOVAL

The process is explained in two aspects

1. Chemical aspects of material removal
2. Mechanical aspects of material removal

Chemical Aspects of Material Removal

The process uses a chemical etching to soften the workpiece surface and the mechanical polishing off the layer takes place.



CHEMICAL ASPECT

And this Si_2O bonds breaks when the slurry particles move away. The reaction that occurs in polishing of metals are

In Si polishing it forms

$$Si + 2\,OH^- + H_2O \rightarrow SiO_2 + 2\,H_2$$

In copper

$$Cu \rightarrow Cu^{++} + 2\,e^-$$

$$2\,Cu^{++} + H_2O + 2\,e^- \rightarrow CuO + 2H^{++}$$

In tungsten

$$W + 6\,Fe\,(CN)_6^{3-} + 3\,H_2O \rightarrow WO_3 + 6\,Fe(CN)_6^{4-} + 6\,H^+$$

Mechanical Aspect of Material Removal

The six possible two way interaction are

- Fluid and workpiece
- Workpiece and pad
- Workpiece and abrasive particles
- Abrasive particles and pad
- Pad and fluid
- Fluid and abrasive particles.

Mechanical Aspect of Material Removal

Also four possible three way interaction are

- Workpiece, fluid and abrasives
- Work[piece, abrasives and pad
- Fluid, pad and abrasives.

PROCESS PARAMETER

- Process : 10 to 50 kPa
- Platen / carrier rpm: 10 to 100 rpm
- Velocity – 10 – 100 cm/s
- Slurry flow rate – 50 to 500 m/min

Typical material removal rate

- Oxide CMP – 2800 A ° / min
- Metal CMP – 3500 A° / min

PERSTON EQUATION

The mechanical material removal rate was given by person. This is called perston equation.

$$R = kp \times P \times \triangle V$$

The equation works good for the bulk film polishing processes

Where

P - is the polishing pressure

kp - perston coefficient

V - relative velocity

FACTORS AFFECTING PROCESS PARAMETERS

- Temperature in the polishing pad
- Conditioning of polishing pad.

ADVANTAGES AND DISADVANTAGES

ADVANTAGES OF CMP

- It is used to polish metal like Aluminium, Copper, Silver titanium etc.
- It can also polish insulators like SiO_2, Si_3N_4.
- Ceramics like SiC, TiN, TaN can also be polished.

LIMITATIONS OF CMP

- Cleaning of platen surface in a difficult process.
- Embedded particles, residual slurry are to be removed very carefully.
- Due to residues min scratches are also formed on the surface of the platen and the pad.
- Surface defects such riping out and dishing are formed on the surface.

APPLICATIONS OF CMP

- It is used in fabrication of semiconductor devices
- Oxides are deposited on the wafer in from of shape trenches
- Flat panel display
- Microelectronic mechanical system
- Magnetic recording head and CD writing

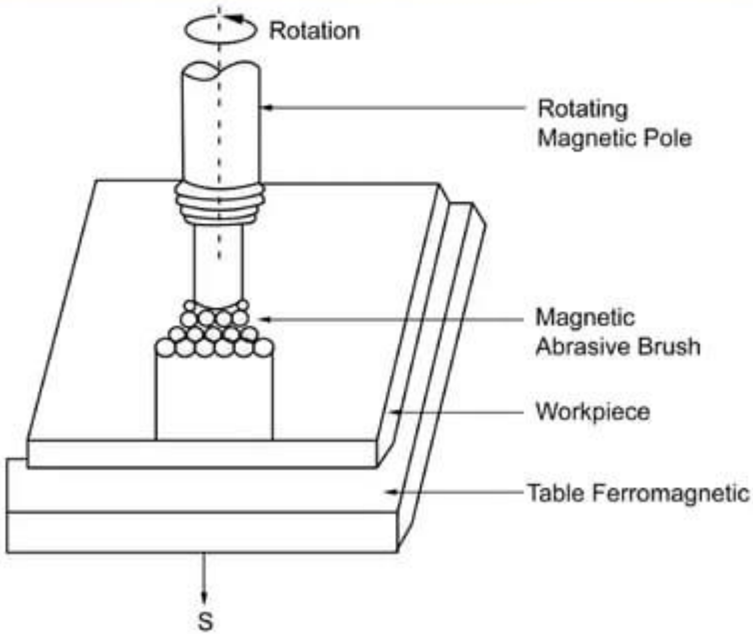
MAGNETIC ABRASIVE FINISHING

- Magnetic abrasive finishing process was developed in US, USSR, Bulgaria and Japan. This process is mainly used in finishing radiusing and deburring of various flat surfaces and cylindrical surfaces.

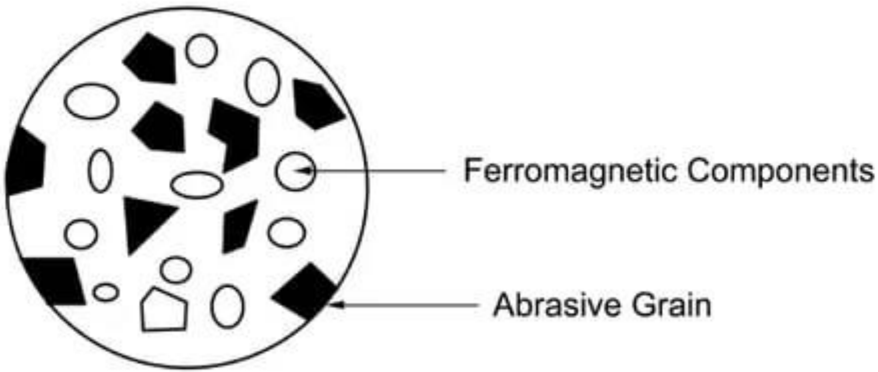
PRINCIPLE OF MAF

- In magnetic abrasive finishing process, the magnetic particles are joined to each other magnetically between magnetic poles along the lines of magnetic force forming a flexible abrasive brush.
- This magnetic abrasive brush is used to perform surface and edge finishing operation.

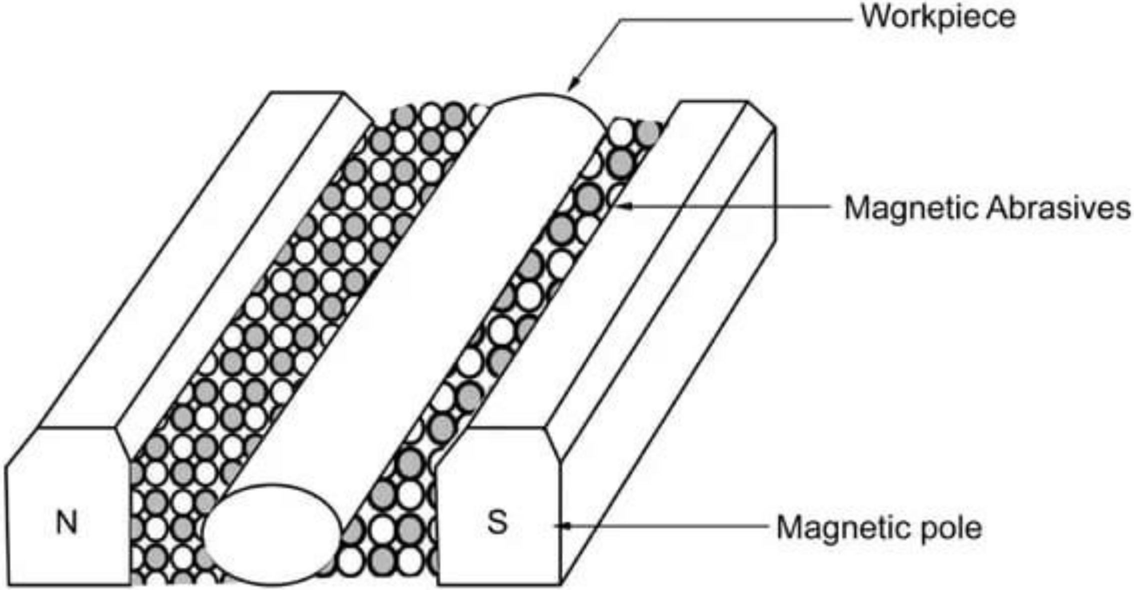
MAF


Rotation
Rotating
Magnetic Pole
Magnetic
Abrasive Brush
Workpiece
Table Ferromagnetic
S

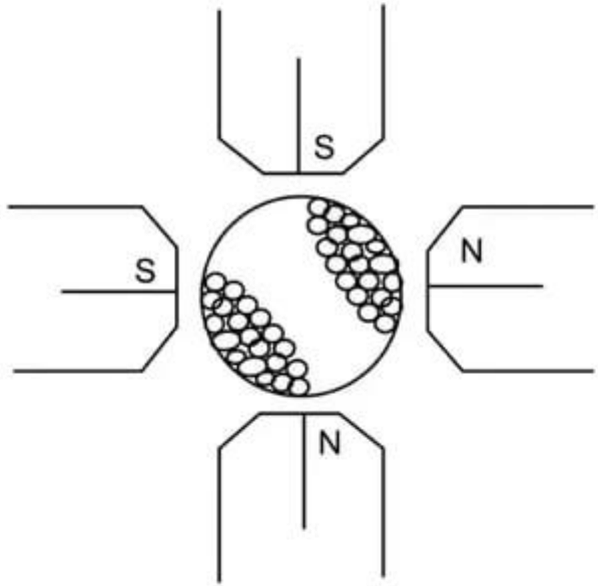
Magnetic Abrasive Particles



Magnetic abrasive finishing- cylindrical surface



Magnetic abrasive finishing – internal surface



NORMAL AND TENGENTIAL FORCE

The normal and tangential force are expressed as

$$F_y = \frac{\pi D^3}{6} kH\left(\frac{\partial H}{\partial y}\right)$$

$$F_x = \frac{\pi D^3}{6} kH\left(\frac{\partial H}{\partial x}\right)F_x$$

where D - diameter of abrasive particles

k - susceptibility of magnetic abrasive particle

H - magnetic field strength

The force required to remove material is

$$F_{req} = \tau_s A_p$$

where τ_s - shear strength of workpiece

A_p - projected area of penetration

$F_{req} = F_t \Rightarrow$ equilibrium condition

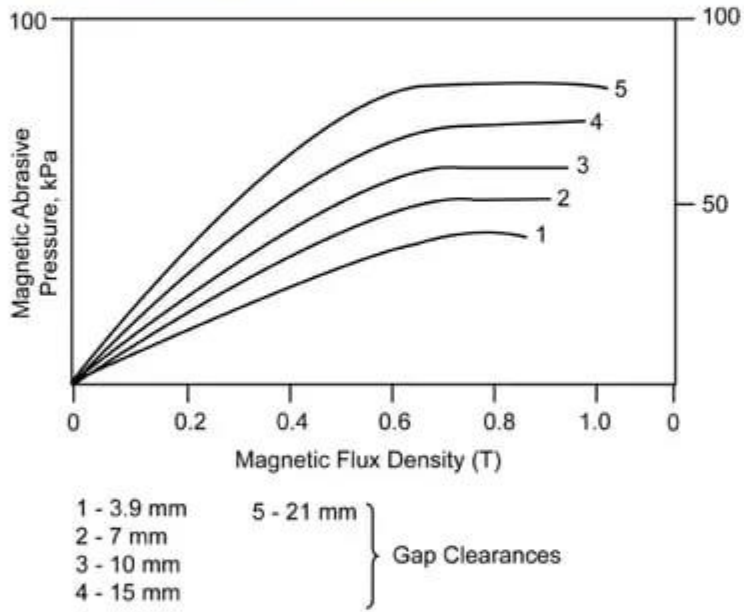
$F_{req} < F_t \Rightarrow$ material removal exchanging

$F_{req} > F_t \Rightarrow$ non cutting condition

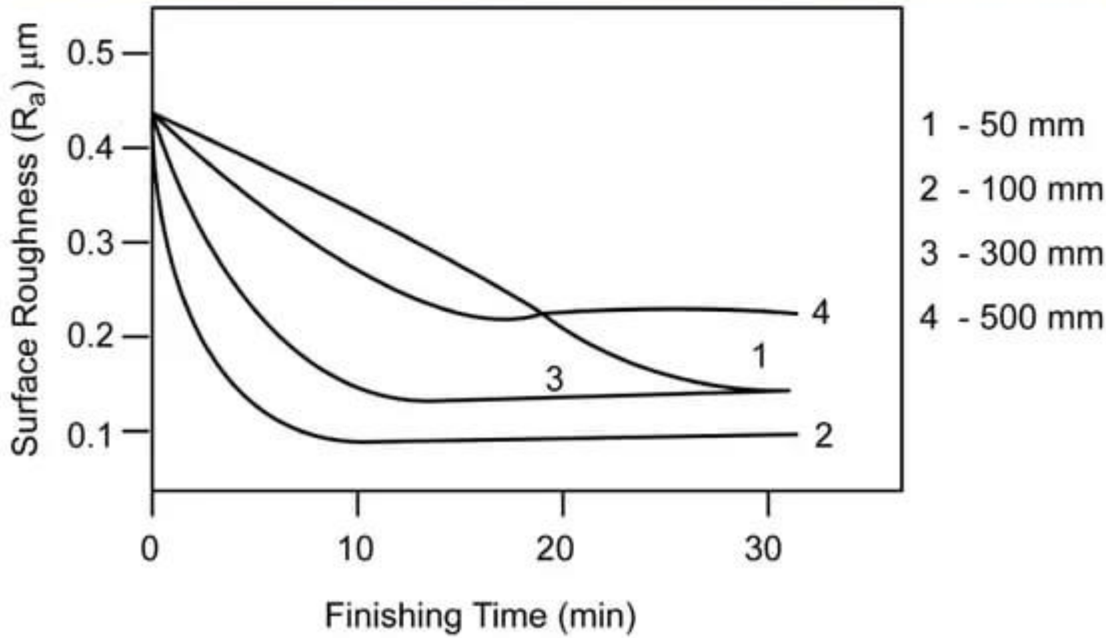
FACTORS AFFECTING PROCESS PARAMETERS

1. Pressure
2. Type and size of grains
3. Finishing efficiency
4. Bonded and unbounded magnetic abrasive
5. Magnetic flux density.

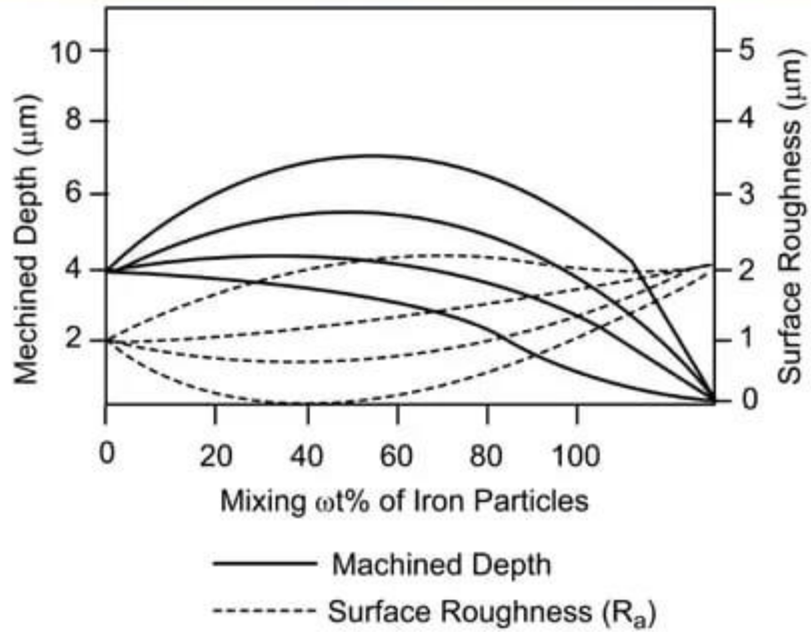
Pressure


100
100
50
Magnetic Abrasive Pressure, kPa
5
4
3
2
1
0
0.2
0.4
0.6
0.8
1.0
0
Magnetic Flux Density (T)
1 - 3.9 mm
2 - 7 mm
3 - 10 mm
4 - 15 mm
5 - 21 mm
Gap Clearances

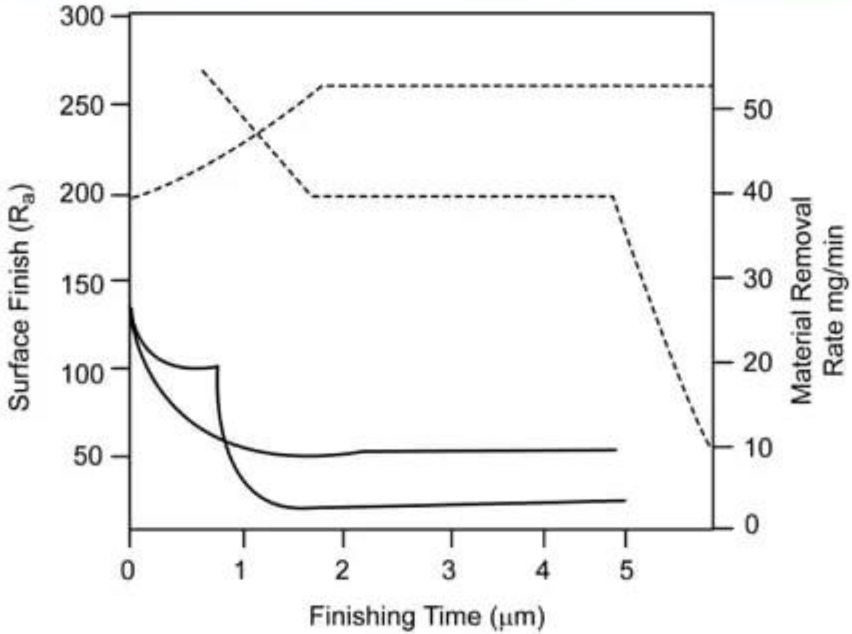
Type and size of grains



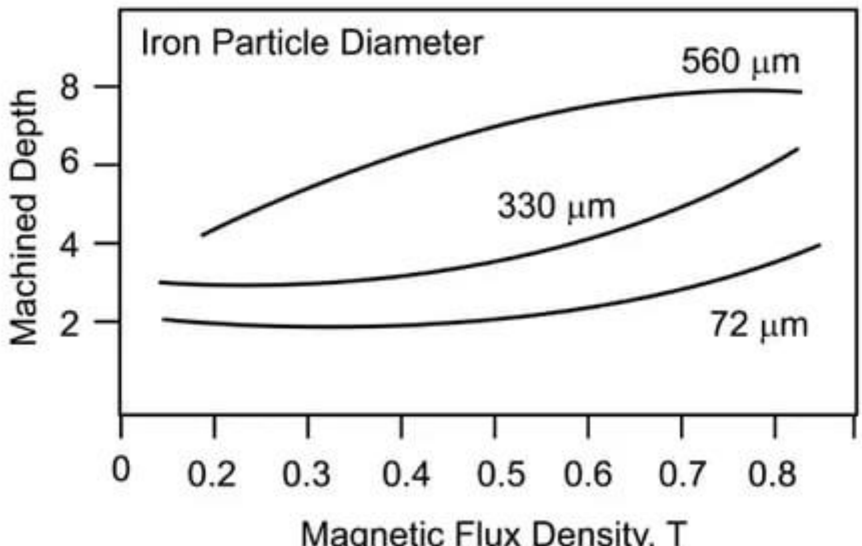
Finishing efficiency



Bonded and unbounded magnetic abrasive



Magnetic Flux Density



ADVANTAGES AND DISADVANTAGES OF MAF

ADVANTAGES OF MAF

- MAF have self adaptability and easy controllability
- Surface finish is in order of nanometer.
- The device can be easily mounted on other machine without the need of high capital investment.

DISADVANTAGES OF MAF

- It is difficult to implement MAF in mass production operation.
- It is a time consuming process.
- It is not applicable for some ordinary finishing task where conventional finishing technique can be easily implemented.

APPLICATIONS OF MAF

- It is used in finishing processes such as lapping, buffing, honing and burnishing operation in surface of tubes, bearing and automobile components.
- Precision deburring can be done on edges of the workpiece.
- It is used in medical field in areas of capillary tube, needles and biopsy needles etc.

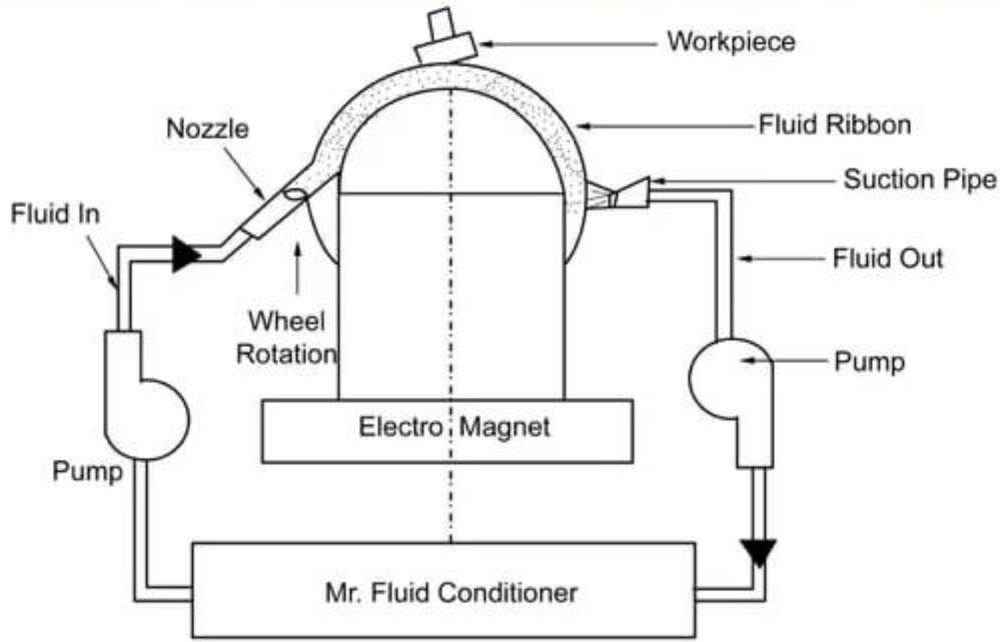
MAGNETO RHEOLOGICAL FINISHING

- A magneto rheological fluid is a layer of smart fluid in a carrier. It is a type of oil when subjected to a magnetic field, the fluid increases it apparent viscosity to the point that it becomes a viscoelastic solid.
- Rheology is a science of flow and deformation study of rheological properties of the medium. The performance of the medium. The performance of the medium is given by its rheological properties.

PRINCIPLE OF MRF

- In magneto rheological finishing process under the influence of magnetic field the MR fluid (Magneto rheological fluid) becomes a viscoelastic solid.
- This act as the cutting tool to remove the materials from the surface of the workpiece.

CONSTRUCTION AND WORKING OF MRF



Basic components in MR fluid

1. Magnetic dispersed phase- micron sized magnetizable particles (0.05 – 10μm)
2. Abrasive particles
3. Stabilizers
4. Carrier fluid

Abrasive particles

- The abrasives used are Aluminium oxide, silicon carbide, cerium oxide and diamond powder
- Polishing abrasives such as Alumina and diamond power is used in polishing optical materials.

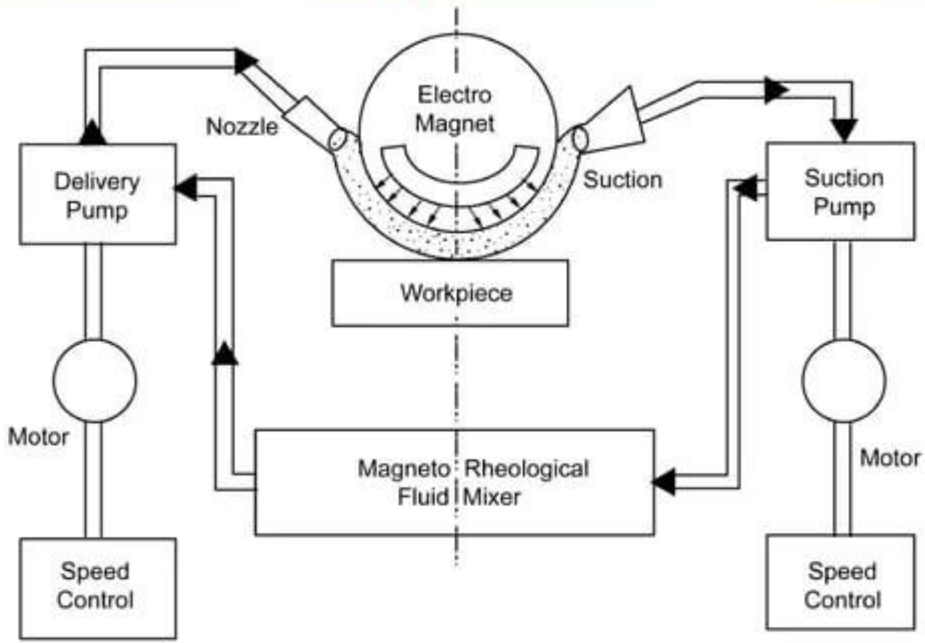
Characteristic of Base Carrier Fluid

- Optimum concentration of magnetic particles and abrasives
- High yield stress under magnetic field
- Low off state visciocity
- Resistance to corrosion
- High polishing efficiency

STABILIZERS

- The main function of stabilizers is used to disperse the magnetic particles and abrasives uniformly in suspension
- The main function of stabilizers is that it creates a coating on the particles so that MR fluid can easily re-disperse

Magneto rheological fluid circulation system



ADVANTAGES AND DISADVANTAGES OF MRF

ADVANTAGES

- High accuracy
- Enhances product quality and repeatability
- Increases production rate, productivity yield and cost effectiveness.
- Manufacture of precision optics.
- Optical glasses with roughness of less than 10 angstrom can be machined.
- Surface finish upto nanometer level is achieved without sub surface damage.

LIMITATIONS OF MRF

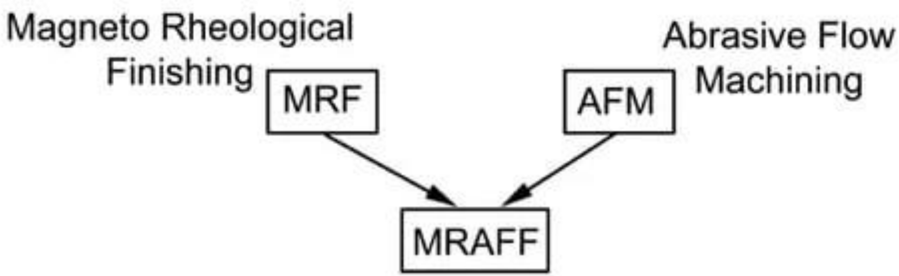
- High quality fluids are expensive.
- Fluids are subject to thickening after prolonged used and need replacement.
- Settling of ferromagnetic particles can be a problem for some application
- This process is not suitable for finishing of internal and external surface of cylindrical components.

APPLICATIONS OF MRF

- Use in lens manufacturing
- Optical glasses, single crystals, calcium fluorides silicon ceramic are machined.
- Square and rectangular aperture surface such as prism, cylinder and photo blank substrates are machined

MAGNETO RHEOLOGICAL ABRASIVE FLOW MACHINING

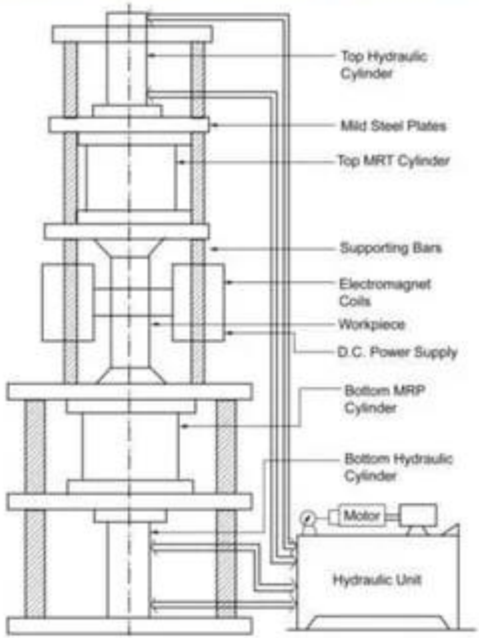
- This process is the combination of two finishing processes. They are abrasive flow machining and magneto rheological finishing. This process eliminates the limitations in AFM and MRF.



PRINCIPLE OF MRAFM

- Magneto rheological polishing fluid comprises of carbonyl iron powder and silicon carbide, abrasive dispersed in the viscoplastic base of grease and mineral oil.
- When external magnetic field is applied these fluid exhibit change in rheological behavior. These fluids behaves smartly and does the finishing operation precisely

Magneto rheological abrasuive flow finishing

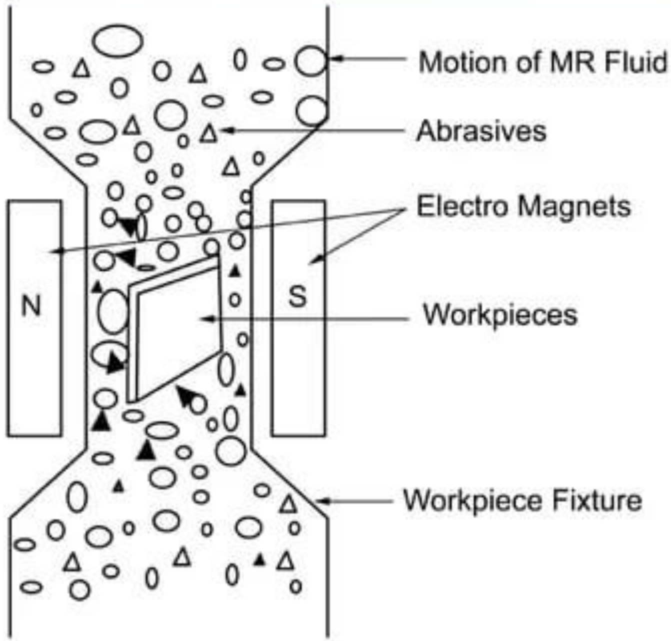


- **Electromagnets -** 2000 turns of 17 SWG copper wire.
- **Continuous Phase -**Organic fluids are used as continuous phase for MR fluids. The other type of fluids are silicone oils, kerosene, mineral oil and glycol.
- **Additives -**MR fluid is mixture of 26.6 vol% of electrolytes, 99.5% of Fe powder, 13.4 vol% of silicon carbide abrasive with 4.8% paraffin oil and 12% AP3 grease.

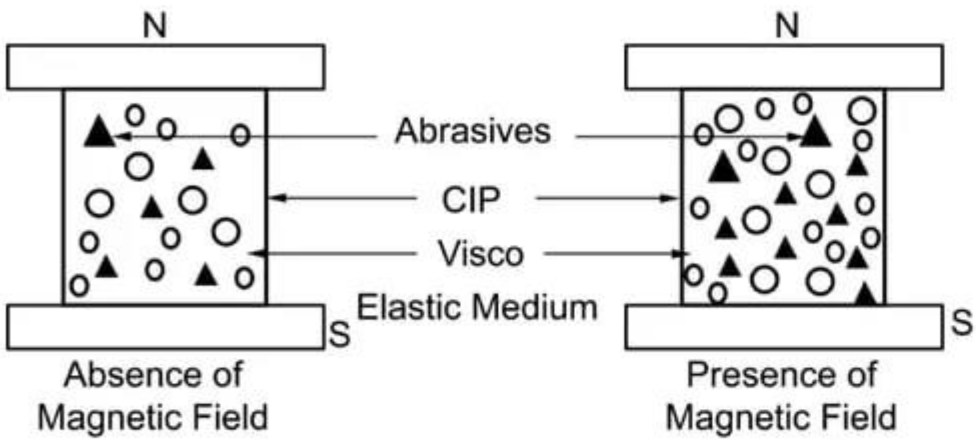
Characteristic of Magneto Rheological Fluids

- Faster response time
- High dynamic yield stress
- Low off- state viscosity
- Resistance to setting
- Easy remixing
- Excellent wear and abrasive resistance

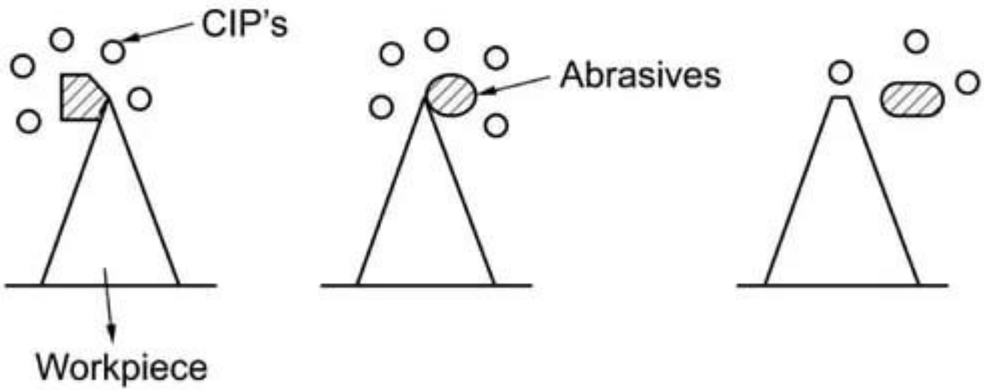
Mechanism of MRAFF



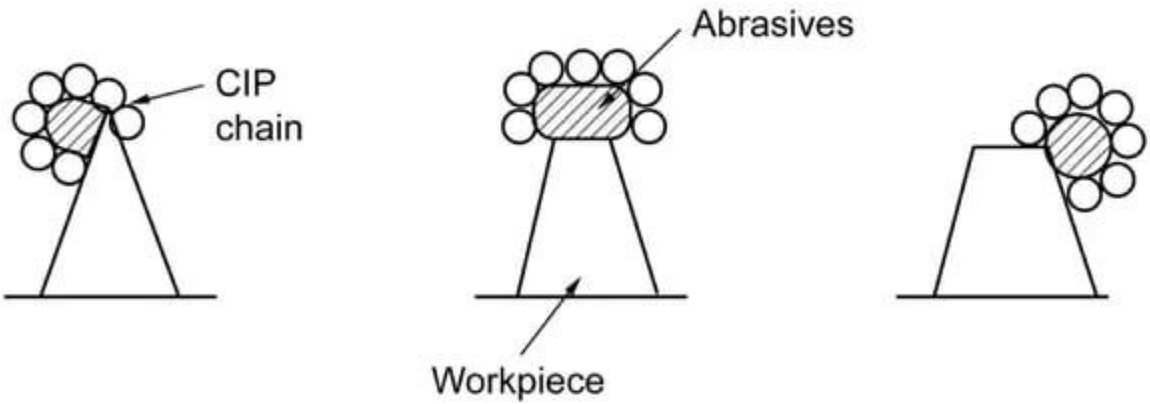
Microscopic image of MR fluid



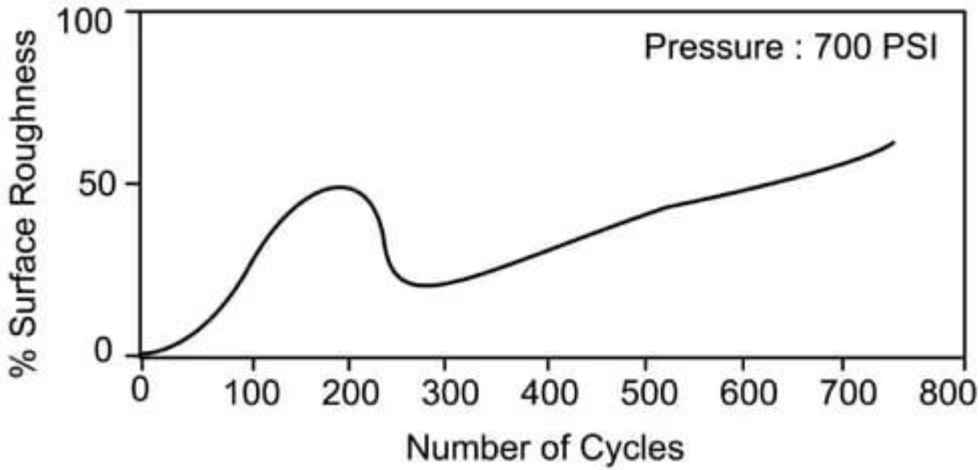
Absence of magnetic fluid



Presence of magnetic fluid



FACTOR AFFECTING PROCESS PARAMETER



When the number of cycles increases beyond 400, the finishing rate get increased

ADVANTAGES OF MRAFF

- Complex structures can be easily machined.
- Localized finishing is possible
- Thermal distortion is negligible
- High machining versatility.

LIMITATIONS OF MRAFF

- Low finishing rate
- Non uniform magnetic field produces non uniform surface finish
- Required a closed environment

APPLICATIONS OF MRAFF

- Used in investment cast milled parts, airfoil, cast aluminum automobile turbo components
- Complex piping for values, fittings, tubes and flow meter
- Finishing of automotive gears in a single pass, heart values, exhaust manifold and high pressure holes.
- Used in finishing of heart valves, exhaust manifold and high pressure holes.

UNIT -V

RECENT TRENDS IN NON-TRADITIONAL MACHINING PROCESSES

INTRODUCTION

- Recent developments in non traditional machining process is the hybrid process. This process was developed by combining the advantages of two non traditional machining processes and eliminating the limitations of those processes.

VARIOUS TYPES OF HYBRID PROCESS

1. Electric discharge diamond grinding (EDDG)
2. Electro chemical spark machining (ECSM)
3. Magneto rheological abrasive flow finishing (MRAFF)

MAIN PURPOSES OF IMPLEMENTING HYBRID PROCESS

- It enhances volumetric material removal rate.
- Computer controls of the processes have good results and better performance.
- Awareness of capabilities will resolve many problems in machining.
- Application of adaptive control machining becomes easier.

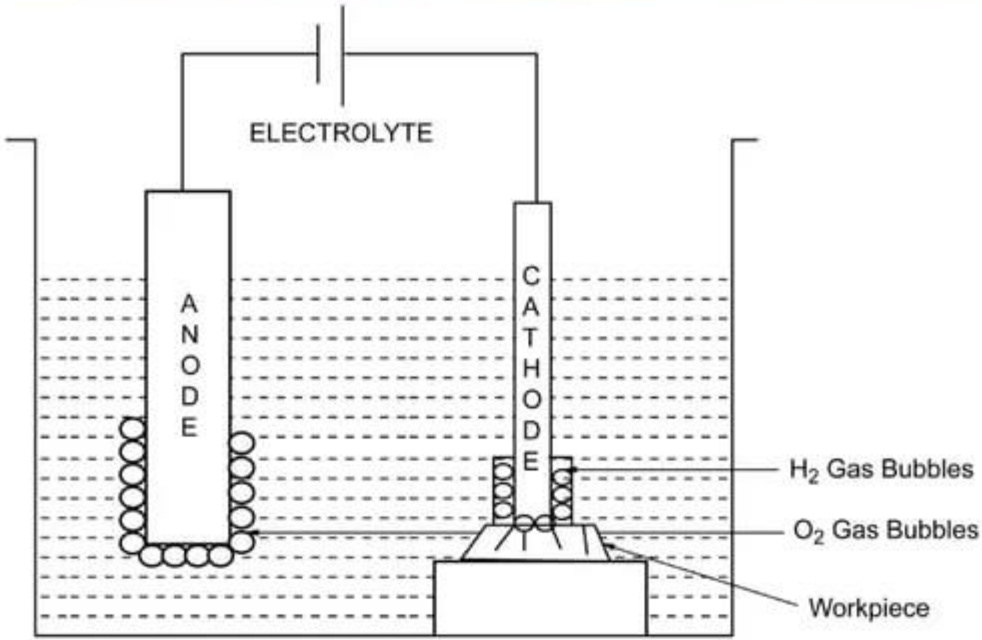
Electro chemical spark machining (ECSM)

- Electro chemical spark machining is a hybrid process of electro chemical machining and electric discharge machining. This process is Unique because it is suitable for both conducting and non conducting material.
- It is used for selective deposition, microwelding and machining of special non conductive material

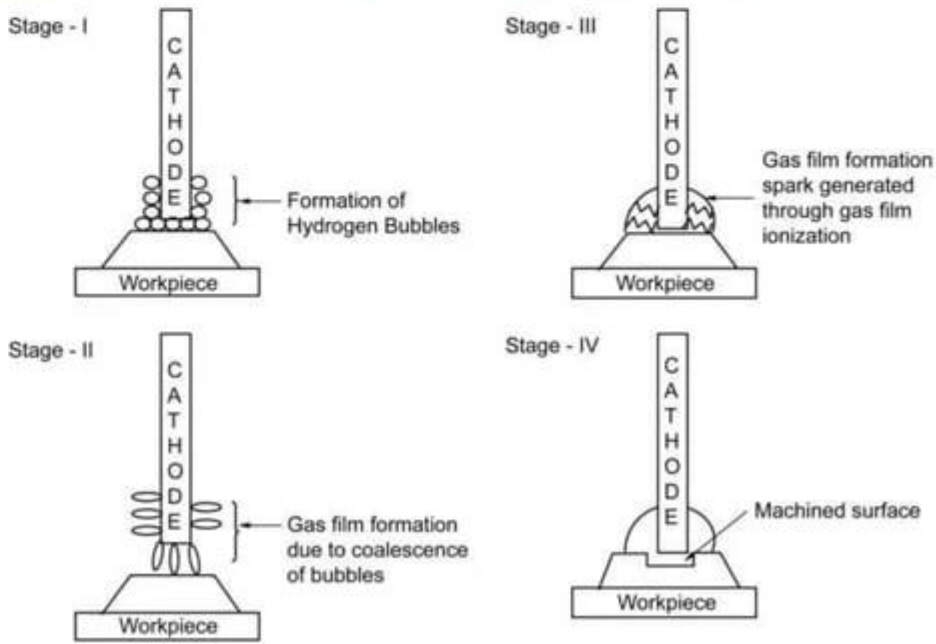
PRINCIPLE OF (ECSM)

- The anode and the cathode are immersed inside the electrolyte. Due to potential difference developed, hydrogen bubbles are generated and thus spark is created between the cathode and workpiece.
- This produces high energy that helps in material removal or vapourization of material take place as shown in figure

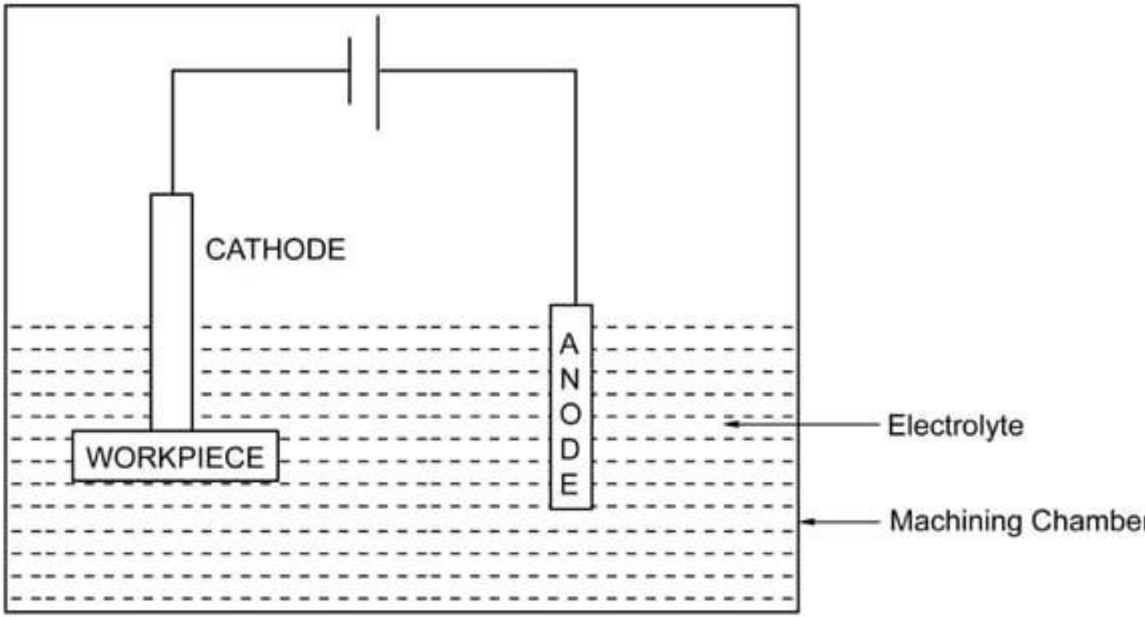
Electro chemical spark machining (ECSM)



ELECTRO CHEMICAL SPARK MACHINING (ECSM)



ELECTRO CHEMICAL SPARK MACHINING (ECSM)



MATERIAL REMOVAL IN ECSM

- Melting and vapourisation
- Chemical reaction when proper electrolyte is not selected.
- Cracks propagate through random thermal stresses.
- Due to mechanical shock and cavitations effect.

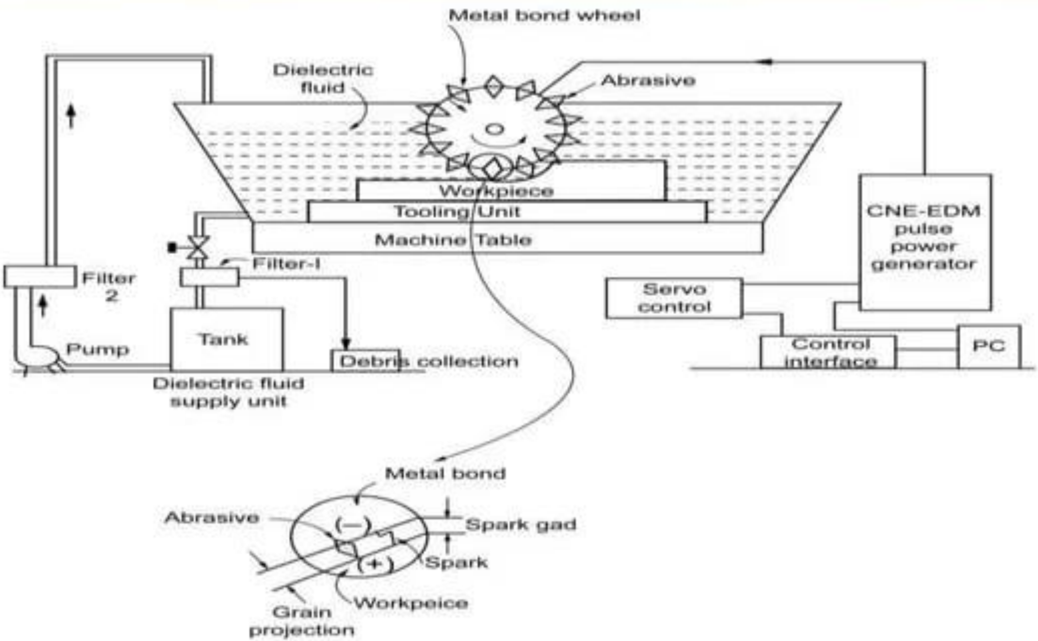
PROCESS PARAMETERS IN ECSM

- A supply voltage ranges between 35 – 50 V.
- Cutting tool has a wire diameter of 200 ⍰m.
- The workpiece used here is soda lime glass.
- The gap to be maintained between the cathode and workpiece is around 50 – 500 ⍰m depending on the type of application.
- The electrolyte solution is 14 – 20% of water and sodium chloride.
- The table speed is 4 rpm.

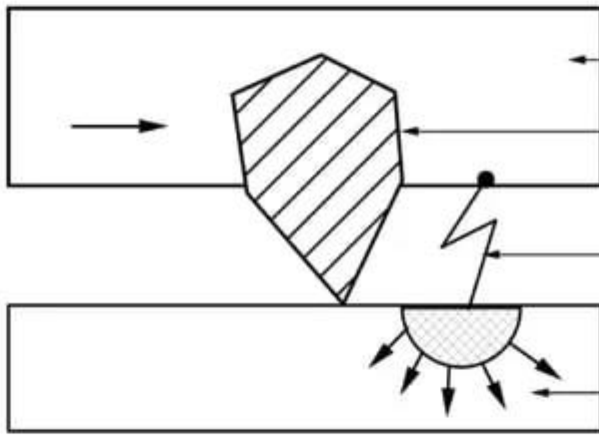
ELECTRICAL DISCHARGE DIAMOND GRINDING (EDDG)

- Electric discharge diamond grinding process is a spark erosion process used for precision grinding. Spark is produced between metal bonded grinding wheel and workpiece.
- Heat generated during sparking softens the workpieces surface and grinding process is easily abraded using diamond abrasive particles.

ELECTRICAL DISCHARGE DIAMOND GRINDING



Formation of Spark in an Abrasive

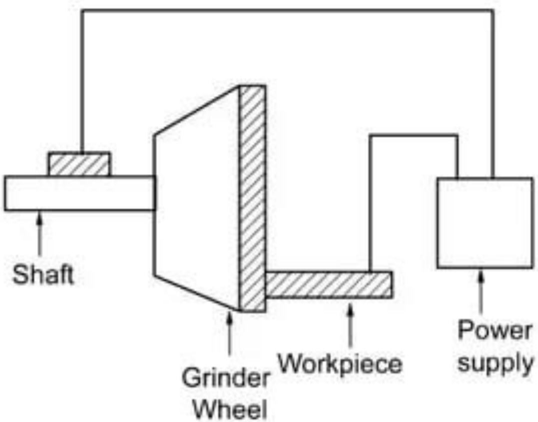


BASIC CONFIGURATION OF EDDG

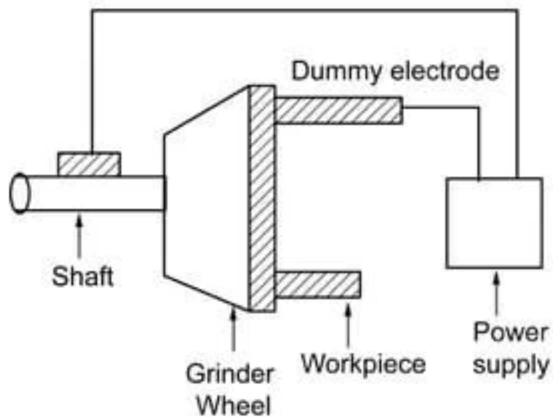
- When the workpieces is the electrically conductive material
- *When the workpiece is electrically nonconductive material.*

BASIC CONFIGURATION OF EDDG

Case (i)



Case (ii)



MAIN PARAMETERS USED IN EDDG

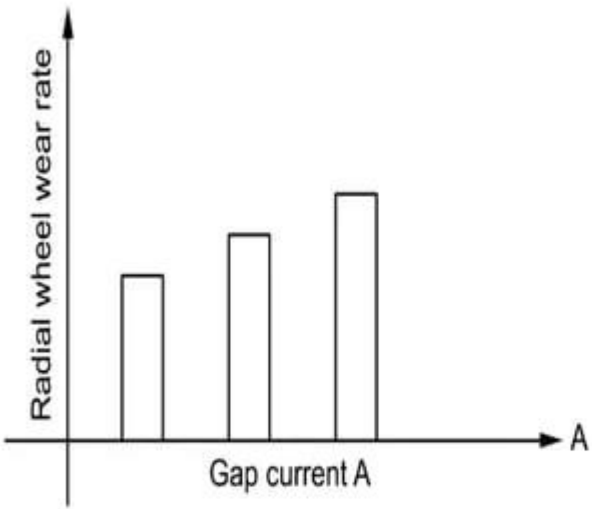
- Wheel speed
- Current
- Pulse on time
- Diamond particle size
- Bond material
- Dielectric material
- Voltage

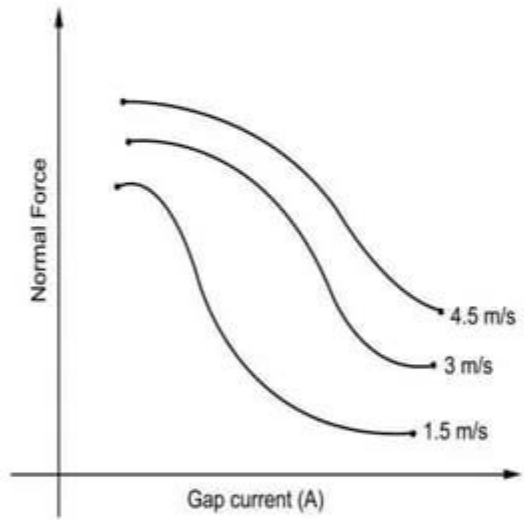
FACTORS AFFECTING PROCESS PARAMETERS OF EDDG

1. Wheel speed
2. Current
3. Pulse on time

Wheel speed

CURRENT


Radial wheel wear rate
A
Gap current A


Normal Force
4.5 m/s
3 m/s
1.5 m/s
Gap current (A)

ADVANTAGES OF EDDG

- It can grind any conductive and non conductive materials.
- Less corrosive effect is produced.
- This process involves continuous dressing and declogging of the abrasive wheel and thus increases the wheel life to 25%.
- Higher material removal rate than EDM
- Lower operating cost
- Produces higher accuracy

DISADVANTAGES OF EDDG

- Recast layer is formed after grinding
- Possibilities of oil fires
- Wheels are fragile

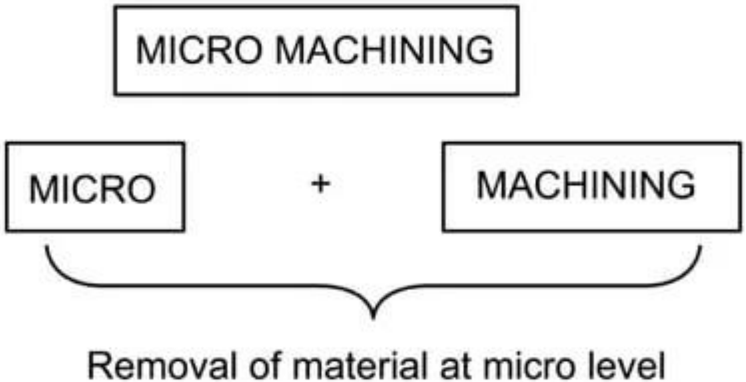
APPLICATION OF EDDG

- It is used in grinding of thin sections
- Grinding of high hardness materials such as cermates, super alloys and metal matrix composites.

MICROMACHINING

- Micromachining is machining of miniature components. It is also defined as removal of material in the form of chips or debris having the size in the range of micron with dimensions greater than or equal to one micro and smaller than or equal to 999 micron.

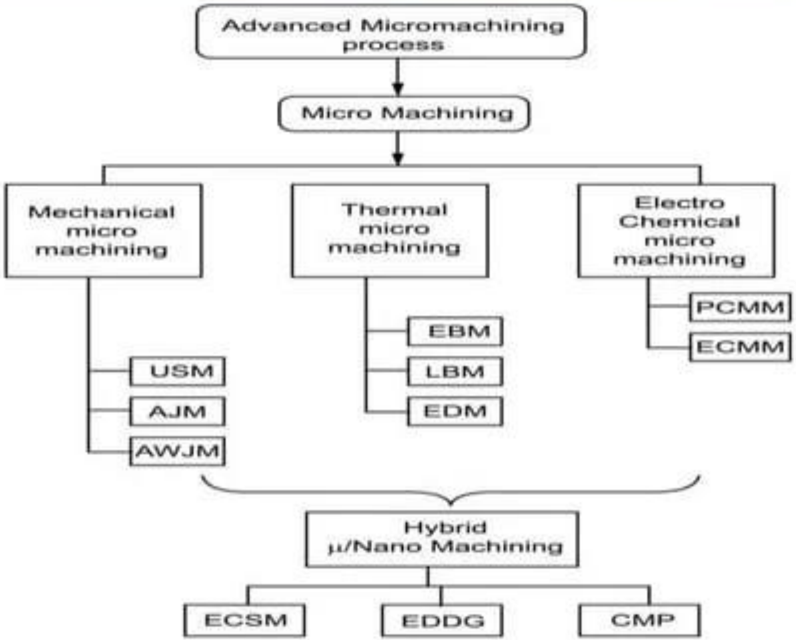
MICROMACHINING



FEATURES OF MICROMACHINING

- Minimising energy and material use
- Faster devices
- Increased selectively and sensitivity
- It has improved accuracy and reliability
- It is basically concern with machining of micro / nano components or material or material removal at micro / nano level.

Classification of Advanced Micro Machining Processes



ADVANCED MECHANICAL MICRO MACHINING PROCESSES

- The working principle of advanced mechanical type micro machining processes are fine abrasive particles with high kinetic energy bits the workpiece at an angle.

ADVANCED MECHANICAL MICRO MACHINING PROCESSES

- Abrasive jet micromachining
- Abrasive waterjet micromachining
- Ultrasonic micromachining

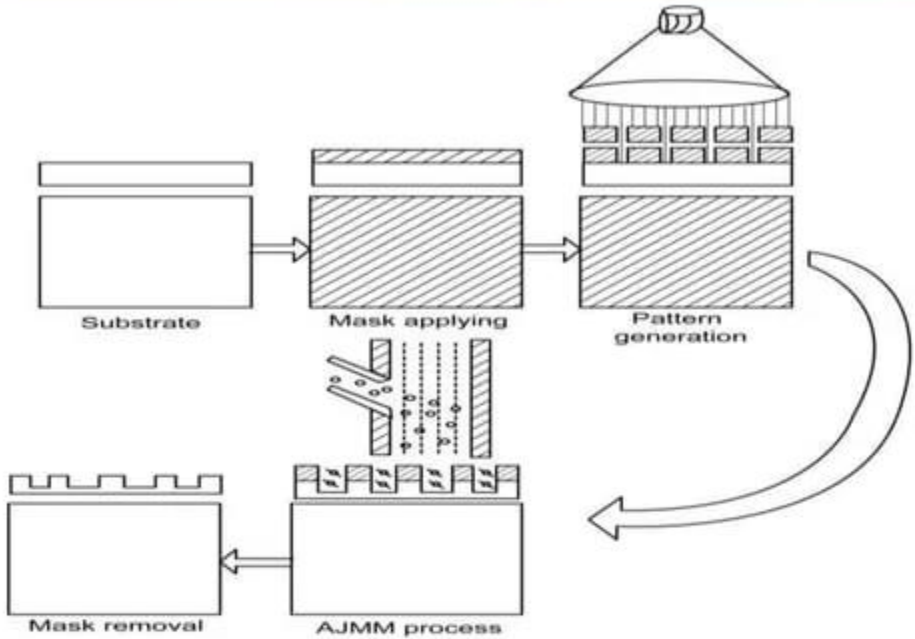
ABRASIVE JET MICROMACHINING

- Abrasive jet micromachining works in the same principle of abrasive jet machining (AJM)
- A high speed stream of mixture of fluid (air or gas) with abrasive particle is injected through the nozzle on the workpiece to be machined.

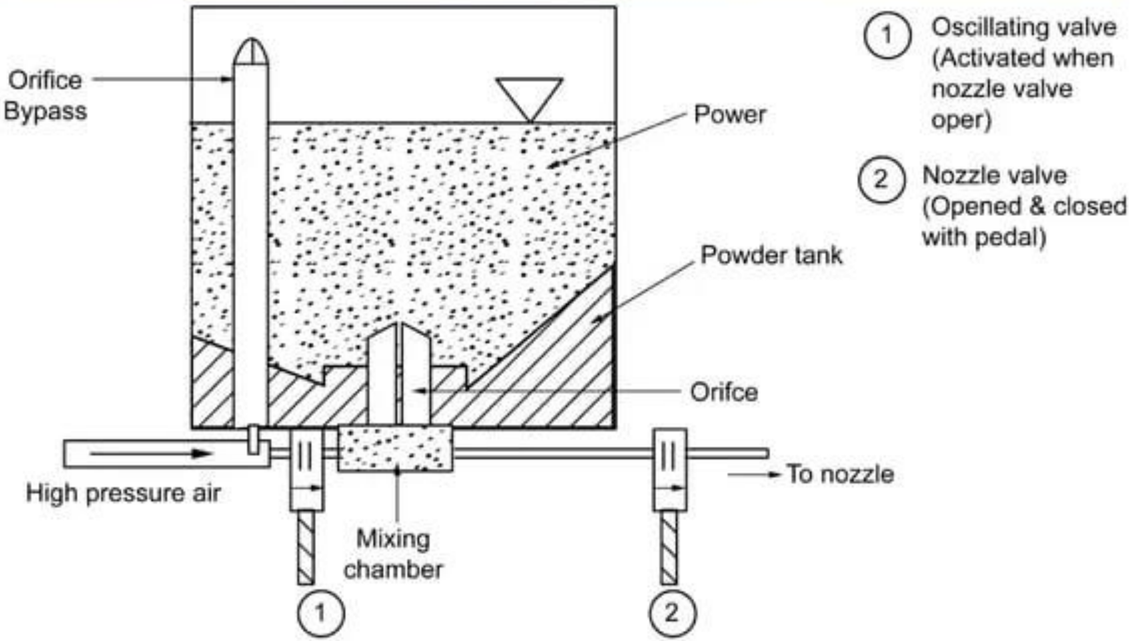
Powder flowability and compactability depends on

- Particle size
- Size distribution
- Moisture content and
- Surface texture

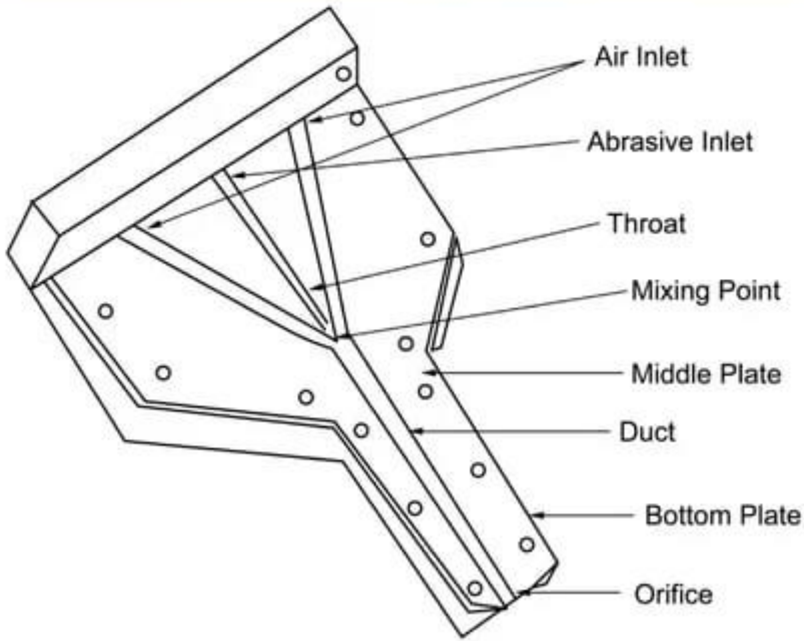
Steps involved in abrasive jet micro machining



Pressurized powder feed system



Laval nozzle – Inner view



MASS LOSS

$$\text{mass loss} = \frac{k\,l}{H} \times \frac{1}{2}\,mv^2$$

k	-	dimensionless factor
m & v	-	amount and velocity of particles
ρ & H	-	density and hardness of the eroded material

EFFECT OF PROCESS PARAMETER IN AJMM

- Powder compaction
- Powder stratification
- Powder humidity

ADVANTAGES AND DISADVANTAGES OF AJMM

ADVANTAGES

- Shallow holes can be accurately machined.
- Machining of grooves with the use of mask pattern or target material can be done.

DISADVANTAGES OF AJMM

- Low erosion rate
- Minimum thickness of the substrate should be 0.3 mm or otherwise buckling of the plate occurs.
- Constant powder feeding is affected due to compaction, stratification and humidity.

APPLICATIONS OF AJMM

- Micro accelerometer beam
- Matrix of micro E-cores
- Capillary electro phores is chips
- 3D suspended microstructures
- 3D passive glass micro mixer.

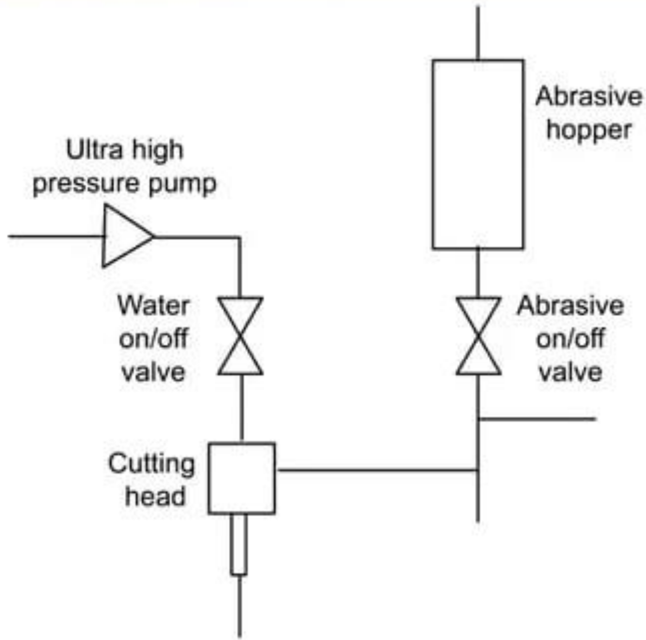
ABRASIVE WATERJET MICROMACHINING

- Abrasive waterjet micromachining works in the same principle of abrasive waterjet machining.
- Abrasive waterjet cut by erosion. A million of such particles impact on a workpiece per second travelling with 2 times the speed of sound for machining the work surface.

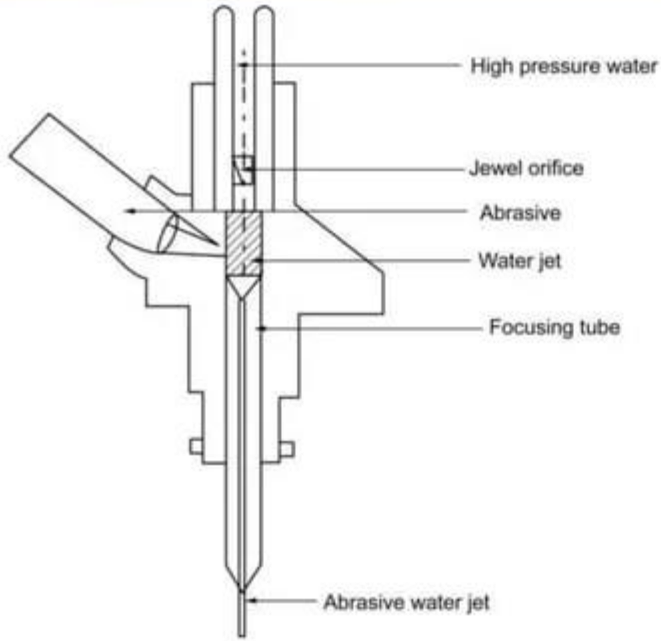
COMPONENTS OF AWJMM

- Abrasive water jet generation
- Abrasive waterjet subsystem
- Abrasive waterjet machining centers.

generating abrasive waterjets



Cutting head of abrasive waterjet



ABRASIVE WATERJET

- ultra high pressure water at 3000 to 6000 bar
- water speed is 750 m/s

ABRASIVE WATER JET SUBSYSTEM

- Ultra high pressure water feed system
- The cutting head
- Abrasive feed system

Abrasive Water Jet Micro Machining Centre

- Motion system - ball screw and linear motors.
- Machine structure
- Workpiece holding
- Human machine interface and control system

ADVANTAGES AND DISADVANTAGES OF AWJMM

ADVANTAGES OF AWJMM

- Alloy steel and all grades of stainless steel can be machined.
- Machining of layered materials such as rubber or polymer bonded to metal can be cut.
- It can cur thicker material than a laser.

DISADVANTAGES OF AWJMM

- Difficult to machine metals like armour plating, titanium and copper base alloys.
- High residual stresses are produced in thin and toughened glass during machining.

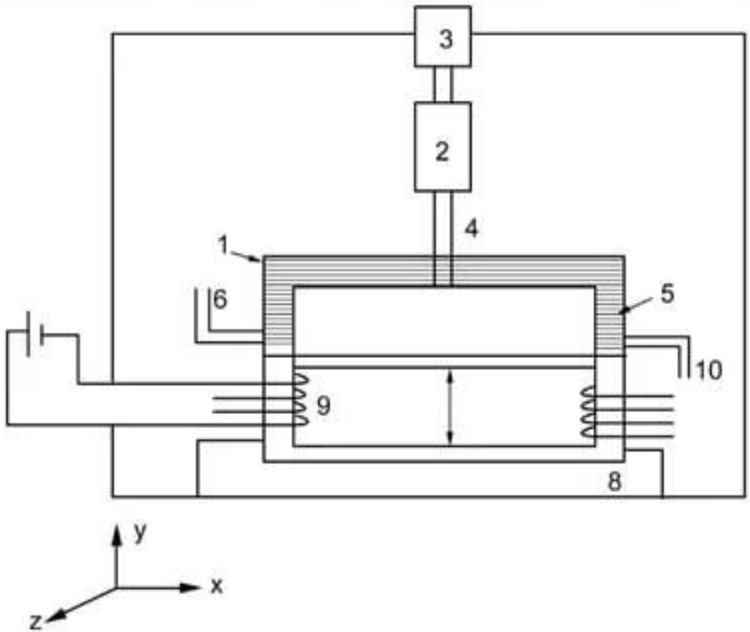
APPLICATIONS OF AWJMM

- Used in jewellery and craft markets
- Used in precision cleaning, peening to remove and dismantle nuclear plants
- Used in cutting precision pocket milling, turning and drilling.

ULTRASONIC MICROMACHINING PROCESS

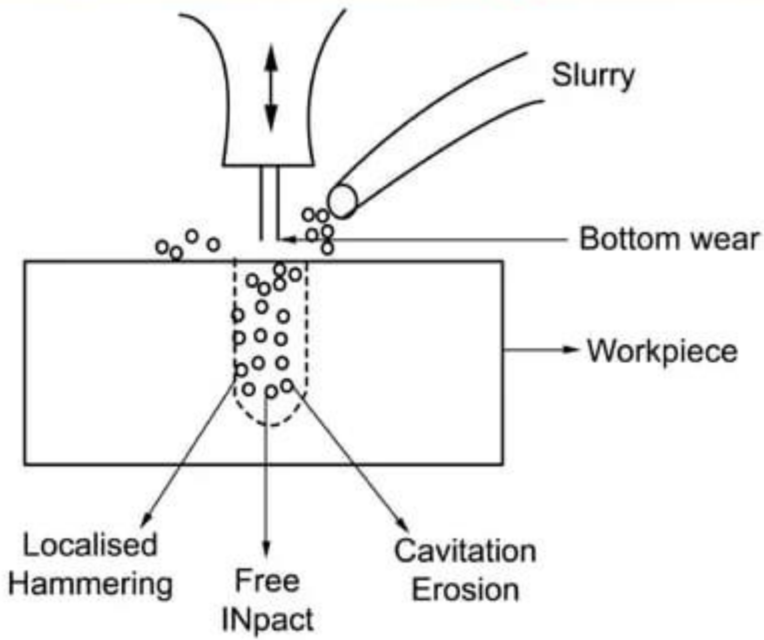
- Ultrasonic micromachining process works in the same principle of ultrasonic machining process.
- Ultrasonic micromachining produces ultrasonic vibration, when combined with a abrasive slurry to create a accurate cavity of any shape through the impact of fine grains. Ultrasonic micromachining is a mechanical process that it produces high quality surface.

Schematic arrangement of ultrasonic micromachining



1. Abrasive slurry
2. Spindle
3. AC motor
4. Micro tool
5. Workpiece
6. Inlet
7. Power source
8. Clamp
9. Pie zoelectric transducer
10. Outlet

Material removal in ultrasonic micro machining



ULTRASONIC MICROMACHINING HAS 7 BASIC COMPONENTS

- High frequency oscillating current generator
- The acoustic head
- Tool spindle mechanism
- Controlled axes
- The micro tool
- Abrasive slurry
- Workpiece

- The range of output produced is 5 to 15 kW and controlled range of 19-22 kHz. The main function of this generator is to convert low frequency 50 Hz electrical power to high frequency 220 Hz.
- It has 2 parts *(i) Transducer (ii) horn.*

Microtool

- High wear resistance
- Good elasticity and fatigue strength
- Optimum toughness and hardness
- Cemented carbide tools are used for its hardness toughness and thermal conductivity that is used to cut glass.

Abrasive Tools

- The slurry consists of small abrasives particles mixed with water or oil and abrasive concentration 30 to 60% by weight
- Alumina is best for cutting glass, germanium and ceramics
- Diamond powder for cutting diamond rubies
- The size of the abrasives range between 300 to 2000 grit
- Coarse grades are used for roughing operation

FACTORS AFFECTING PROCESS PARAMETER

- machining rate
- surface finish
- machining accuracy
- toolwear

PROCESS VARIABLES OF USMM

1. Amplitude of vibration = 5 µm
2. Workpiece material = silicon
3. Tool material = Tungsten
4. Tool size = 50, 100,150 µm
5. Abrasive grain type = polycrystalline diamond powder
6. size = 1 – 3 µm
7. Total tool feed = 515 µm

EFFECT OF PROCESS PARAMETERS ON QUALITY CHARACTERISTICS OF USMM

- Effect of process parameters on material removal rate
- Effect of process parameter on tool wear
- Effect of process parameter on surface finish
- Effect of process parameter on accuracy

EFFECT OF PROCESS PARAMETERS ON MATERIAL REMOVAL RATE

Material removal rate (MRR) depends upon

- Machining parameters
- Abrasive slurry
- Work material properties
- Tool material properties and tool geometry

The machining parameters that affect the material removal rate are

- amplitude of vibration
- frequency of vibration
- static load

EFFECT OF PROCESS PARAMETERS ON TOOL WEAR

The factors that influences tool wear are

- Static load
- Work material
- Tool size
- Tool material
- Type of abrasives and its grain size
- Machining time
- Depth of machining

Effect of Machining Parameter on Surface Finish

- By using fine grains
- Driven by smaller vibrations and amplitude.
- Smaller static force at smaller depth of cut and larger lateral feed.
- Larger grain size of 2 to 120 ?m is used for roughing operation.
- Smaller grain size of 0.2 to 10 ?m is used for finishing operations

Effect of Process Parameter on Accuracy

The factors affecting accuracy in USMM are

- accuracy of feed motion
- accuracy of fixtures used
- quality of assembly element
- abrasive grit size
- tool wear
- transverse vibration effect
- depth of cut

ADVANTAGES AND DISADVANTAGES OF USMM

- Machining of any materials regardless of their conductivity
- Machining of semiconductor as silicon germanium
- Suitable for machining precise brittle materials
- Can drill circular or non circular holes in hard materials
- Less stress is produced because of its non thermal characteristics

DISADVANTAGES

- Low material removal rate
- Tool wear is faster in USMM
- Machining area and depth is restrained in USMM.

APPLICATIONS OF USMM

- Used for making press tool dies
- Drilling small holes in helicopter power transmission shaft
- Drilling of diamond dies, machining of aluminium oxides Al_2O_3
- Producing hollow cubes
- Used in surgical tools manufacturer for better evacuation of chips
- Plague from the teeth are removed without any damage

THERMAL ADVANCED MICROMACHINING PROCESSESS

- In thermal advanced micromachining intense heat is produced and localized which increases the workpiece temperature in a zone or beam diameter equal to its melting and vapourization temperature.
- The material removal is at micro-nano level in form of debris.

Types of thermal advanced micromachining

(*i) Electric discharge micromachining*

(*ii) Electron beam micromachining*

(*iii) Laser beam micromachining*

Electric Discharge Micro Machining

- Electric discharge micromachining (EDMM) works in the same principle of electric discharge machining (EDM).
- EDM removes material by thermal erosive action of electrical discharge (spark) produced by a pulse DC power supply between anode and cathode. The tool acts as the cathode and the workpiece acts as the cathode and the workpiece acts as the anode.

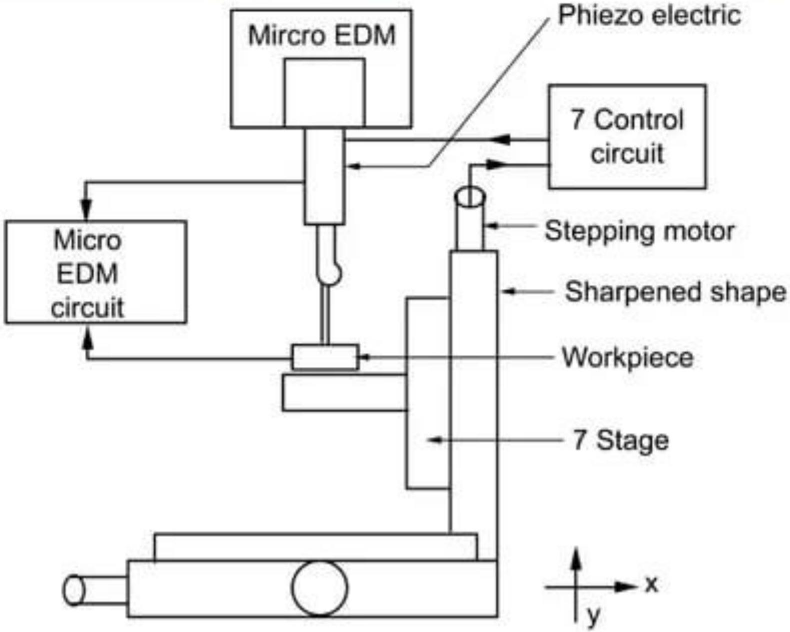
TYPES OF ELECTRODES AND THEIR MATERIALS

S.No	Electrode	Materials
1.	Metallic electrode	Cu, CuW, Br, Al, Alalloy W
2.	Non metallic electrode	Graphite
3.	Combined	Copper graphite
4.	Metallic coating on insulator	Copper on molded plaster and copper on ceramics
5.	Powder material	Powder-sintered or green compact

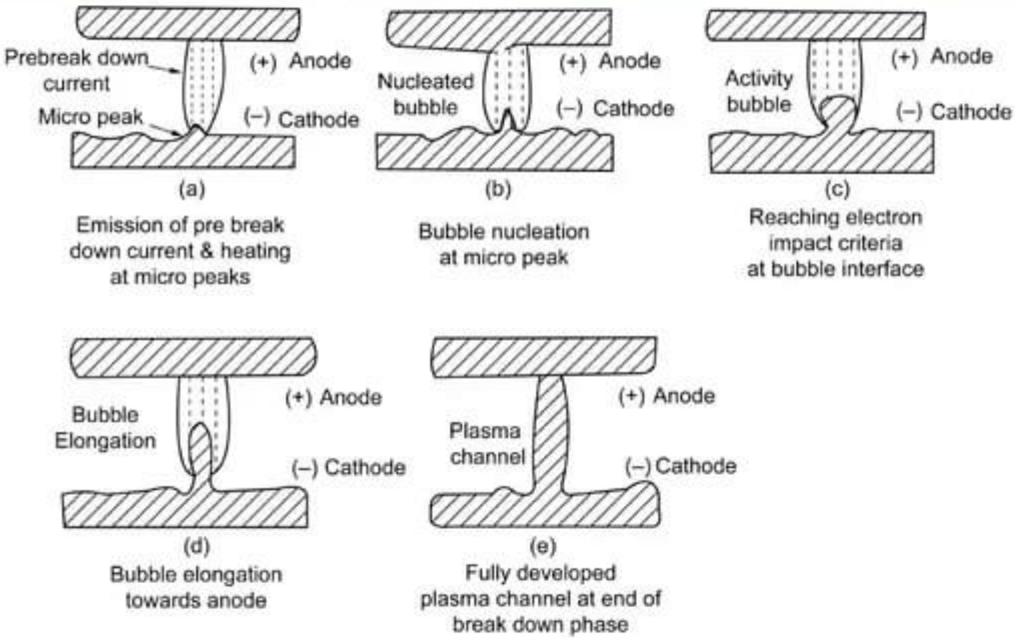
Types of dielectric fluids and its properties

S.No	Dielectric Fluid	Viscosity	Application
1.	Mineral oil	5-20 CST	applied for roughing process
2.	White oil or kerosene		For furnishing and super finishing operation and for machining tungsten carbide
3.	Water (deionized)	Nearly zero	Used for micromachining wire draw process
4.	Napaffic oil	specific gravity = 0.8 flash point = 105°C light: odour	High finishing accuracy and surface finish

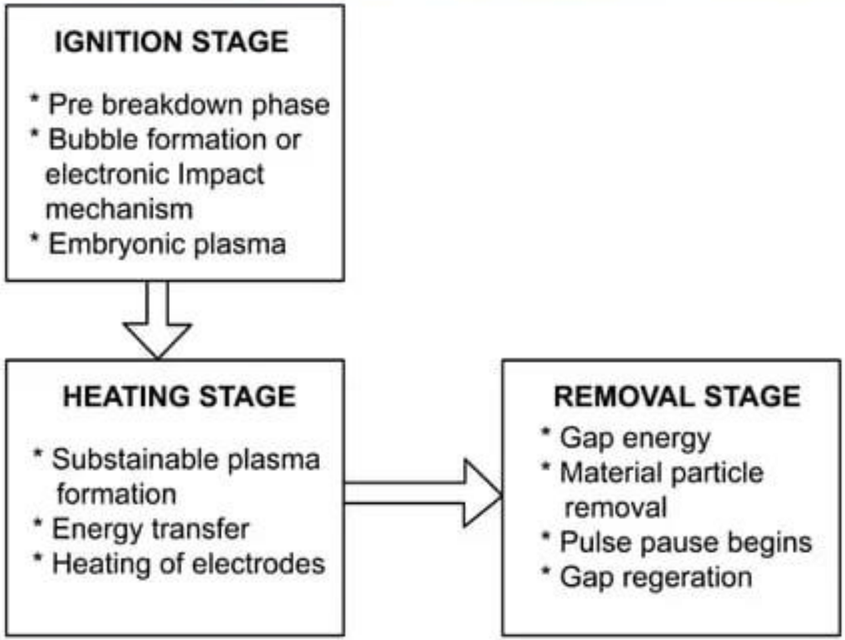
Schematic arrangement of electric discharge micromachining



Single Spark erosion in electric discharge micro machining



Three stages involved in formation of spark



IGNITION STAGE

- Prebreakdown phase – The initial stage of the ignition stage is prebreakdown phase.
- During this phase two phenomena occurs that breakdown of dielectric between electrodes take place.

(*i) Bubble formation*

(*ii) Electronic impact mechanism*

- The temperature of the embroyonic plasma increases and the energy balance equation is given by

$$\rho_{av} = \int_{T_n}^{T_p} C_p(T)\, d\,T = E_j\, \tau_{growth}$$

HEATING STAGE

- The power utilization is given by
- Work done during expansion of plasma channel
- Power flux utilized for vaporization and dissociation of dielectric media.
- Power flux dissipating towards anode and cathode.
- The power fraction utilized by the plasma

$$P_{circuit} = V(t) \times I(t)$$

Removal Stage

- In the removal stage, the heat generated during plasma formation and expansion is transferred to anode and cathode by two ways.

I)By radiation heat transfer

II) Ion or electron bombardment

- The power transfer due to particle bombardment and radiation flux is given by

$$\triangle P_{cathode} = \triangle P_{ions} + \triangle P_{electron} + \triangle P_{radiation}$$

PROCESS PARAMETERS OF EDMM

- Mechanism of material removal by melting and evaporisation.
- Material removal rate is between 0.6 to 6 mm3 /hr
- Dimensional accuracy is 2 ⍰m (sinking EDM) and 1 ⍰m (wire EDM).
- Surface finish is 0.4 to 0.5 ⍰m

EFFECT OF PROCESS PARAMETERS ON EDMM

- Dielectric - Water is used as dielectric which provides good discharge repetition rate.
- Tool - Electrode wear can be reduced by using diamond electrode.
- Workpiece

ADVANTAGES AND DISADVANTAGES OF EDMM

ADVANTAGE

- It is used for cutting complex or odd shape materials that are electrically conductive.
- It is used in machining hardened materials
- It has high machining rate
- It has good dimensional accuracy and surface integrity.

DISADVANTAGE

- It is not suitable for high aspect ratio holes and features.

APPLICATIONS OF EDMM

- Used in drilling 6.5 ⍰ holes in 50 ⍰m plate
- Used in making 1.2 ⍰ slots in 2.5 ⍰m wall.
- Used in shaping microfluids mixer and channel
- Used in machining microgears or internal gears.

COMPARISON OF EDM VS EDMM

S.No	Properties	EDM	EDMM
1.	Size range	greater than 1 mm	less than 1 mm
2.	Material Removal Rate (MRR)	Higher MRR	Lower MRR 0.6 to 6 mm^3/hr
3.	Spark gap	Higher near to 1 mm	gap is in few μm
4.	Power consumption	High as maximum current rating	Low power consumption
5.	Discharge voltage	Higher discharge voltage greater than 80 V	Relatively lower voltage 10-20 V
6.	Current	Very low frequency pulsating discharge current applied	very high frequency of pulsating discharge current applied 1 μs
7.	Material removal	In form of circular pits	Cracter size is very small

ELECTRON BEAM MICROMACHINING PROCESS

- EBMM works on the same principle of EBM. Electron beam micromachining uses a high velocity stream, of electron focused on the workpiece surface to remove material by melting and vapourization.

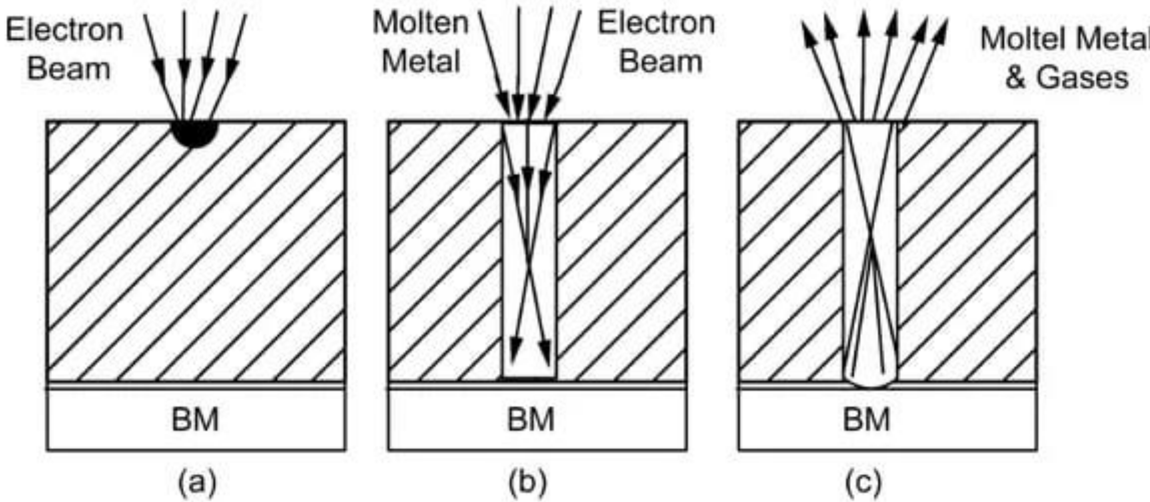
CONSTRUCTION AND WORKING

- The main components of EBMM are the electron gun, the anode, cathode, magnetic lens and deflection coils with a vacuum chamber.
- The anode applies a potential field that accelerates the electron with voltage of approx 50000 to 200000volts to create velocity over 200000 km/s.
- The power is defined by the accelerating voltage and the beam current which ranges from 100 μA to 1 Amps.

CONSTRUCTION AND WORKING

- An electromagnetic lens reduce the area of the beam to a diameter of 25 µm.
- This beam of fast moving electron gets focused to 10 to 200 µm area at density of 6500 GW/mm2
- The pulse duration ranges from 50 µs to 10 ms
- This process is limited to thin parts in the range of 0.2 to 6 mm thick.

Mechanism of material removal in drilling of electron beam micro machining



BM - Backing Material

PROCESS PARAMETERS OF EBMM

- The pulse time and beam current level of the pulse ensure high reproductability.
- Beam current varies from 100 μA to 1 A and governs the energy / pulse being supplied to workpiece.
- Pulse duration for EBMM ranges from 50 μs to 10 ms.
- The working distance and the focused beam diameter are determined by magnitude of current.
- The permissible minimum distance between 2 drilled holes is in order of 2 to 3 times the hole diameter.

EFFECT OF PROCESS PARAMETER ON EBMM

- Pulse beam time and operation
- Cutting speed
- Source disposal effect and power retention factor
- Conduction losses and temperature rises
- Heat affected zone
- Cross sectional area of beam

ADVANTAGES AND DISADVANTAGES OF EBMM

ADVANTAGES

- It is easy to modulate the electron beam parameters
- High precision stresses on the workpieces are relaxed due to rise in temperature of the material

DISADVANTAGES OF EBMM

- The process is conducted in vacuum
- Requirement of high energy
- The equipment is expensive

APPLICATIONS OF EBMM

- Used for drilling and cutting of metals, non metals, ceramics and composite
- Used to drill thousands of hole on the material both electrically conductive and non conductive material
- Used in making fine gas orifices in space nuclear reactors.
- Used in drilling holes in wire drawing dies
- Used in metering holes in injector nozzle of diesel engine.
- Employed for pattern generations for integrated circuit fabrication
- Used in drilling small diameter holes 250 µm
- Used in drill holes with very high depth to diameter ratio.

LASEB BEAM MICRO MACHINING PROCESS

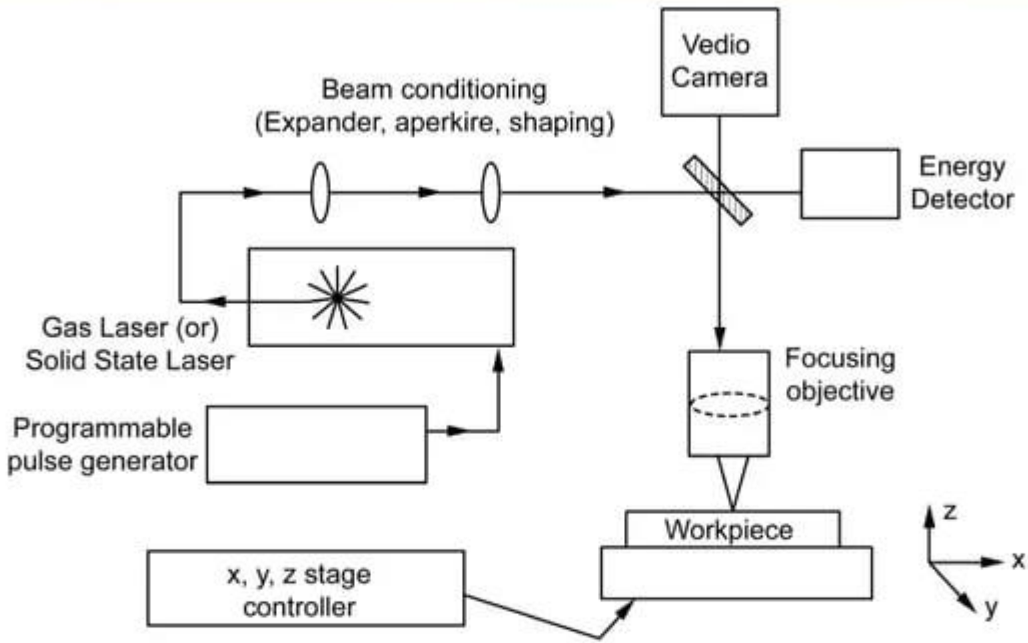
- Laser consists of an amplifying medium where stimulated emission and amplification of light is created.
- Mirrors are used as optical resonators and oscillation occurs because of amplifying medium. An optical resonator provides a feedback and a pump source to input energy in the amplifying medium. Laser is placed between suitable aligned mirrors.
- The types of lasers used for machining are CO2 laser, excimer laser yattrium, Aluminium, sapphire laser.

MECHANISM OF MATERIAL REMOVAL IN LBMM

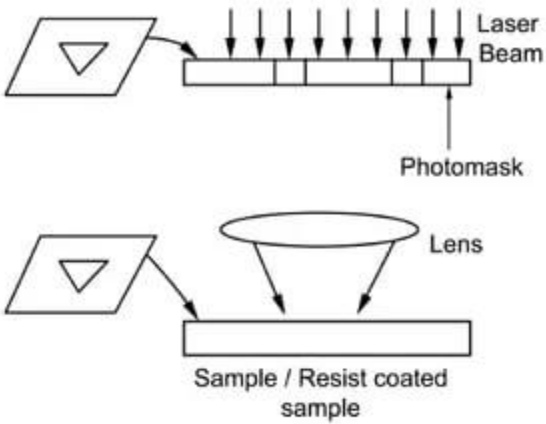
1. Direct writing
2. Mask projection
3. Interference technique

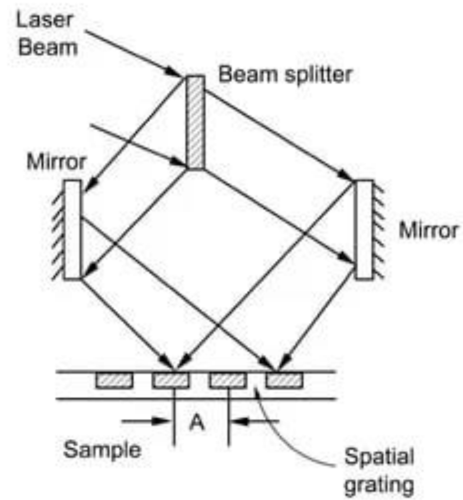
- specific power consumption - 1000 W/mm3/min
- MRR - 5 mm3/min

Laser direct writing technique

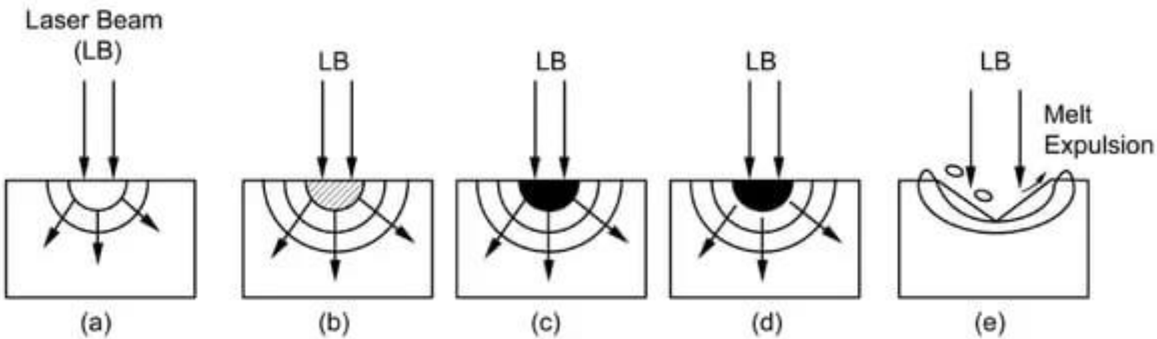


Mask Projection Technique and Laser Interference Technique





Laser and Material Interaction Process



LB - Laser Beam

(a) - Heating
(b) - Surface Melting
(c) - Surface Vaporization
(d) - Plasma Formation
(e) - Ablation

PROCESS PARAMETERS OF LBMM

- Mechanism of material removal by melting and vapourization
- Medium – normal atmosphere
- Tool – High power laser beam
- Maximum MRR – 5 mm3 /min
- Specific power consumption = 100 W/mm3 min
- Material – All material except material of high reflectivity (Aluminum and copper)
- Shape applications – drilling five holes
- Limitation – very high power consumption cannot machine materials with high heat conductivity and reflectivity

ADVANTAGES AND DISADVANTAGES OF LBMM

ADVANTAGES OF LBMM

- This process is forceless and contactless
- Minor heat affected zone
- machining is free from burr and bulging
- No additional tooling cost by wear
- Material removal rate is controllable.

DISADVANTAGES OF LBMM

- Very high power consumption
- It cannot machine materials of high
- High conductivity and reflectivity
- Not suitable for Aluminium and copper
- The equipment required for micromachining is very costly
- Need highly skilled operators to machine

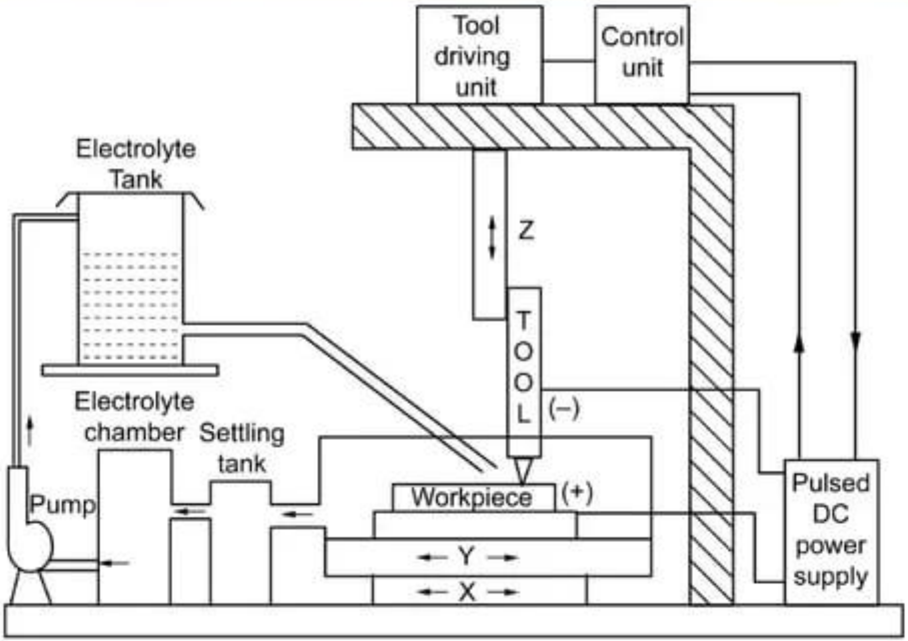
APPLICATIONS OF LBMM

- It is used in machining threads in a single poly fibre.
- Machining of microholes and microchannels on integrated chips.
- Micro cutting in tungsten pin using 511 nanometer using ND laser
- Micro fluidic devices in silicon showing laser drilled holes and connecting channels
- Micro machined letters on a single human hair
- Cutting of 1mm tube cutting, 100 μm wide V grooves

ELECTRO CHEMICAL MICROMACHINING PROCESS

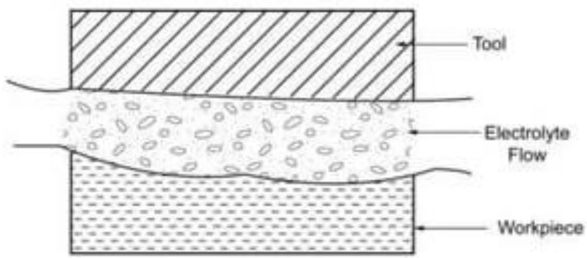
- Electro chemical micromachining works in the same principle of Electro chemical machining.
- Faraday's law of electrolysis states that the amount of substance deposited or dissolved in proportional to the quantity of electricity that is passed through the electrolyte.

Schematic Arrangement of ECMM



Electrolyte of ECMM

- Electrolyte are basically two types.
- Passive electrolyte containing oxidizing anions (sodium nitrate, sodium chloride)
- Non passive electrolyte containing aggressive anions (sodium chloride)



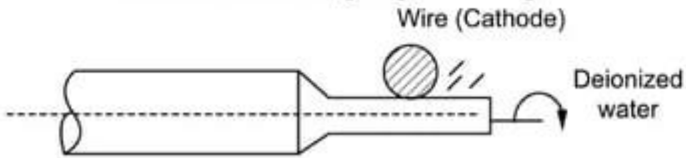
Inter Electrode Gap

IEG – Inter Electrode Gap

- In ECMM process, the IEG is kept in range of 6 -15µm.
- Methods of monitoring and measuring the IEG is during pulse of time of 0.1 to 5ms.
- Machining accuracy is directly proportional to the inter electrode gap size.

Micro Tool Design and Fabrication

- The computer based tool design for ECMM is feasible, economical and time saving one.
- Micro tools are fabricated using electro chemical etching and wire electro discharge grinding as shown in figure



Anodic Reaction and Current Efficiency

Anode: $Fe \rightarrow Fe^{++} + 2e^-$

Cathode: $2H_2O + 2e^- \rightarrow 2(OH)^- + H_2\uparrow$

At Electrolyte: $NaNO_3 \rightarrow Na^+ + (NO_3)^-$

$$Fe^{++} + 2(OH)^- \rightarrow Fe(OH)_2$$

$$4Fe(OH)_2 + 2H_2O + O_2 \rightarrow 4Fe(OH)_3 \downarrow \text{ sludge}$$

- ❖ The factors that influence the machining performance is
  - Dissolution rate
  - Shape control
  - Surface finish of the workpiece
- ❖ The current efficiency of metal dissolution

$$\eta = \frac{Q_{act}}{Q_{theo}} = \frac{Q_{act}\,FV}{I\,t_d}$$

Current Distribution and Shape Evolution

Through Mask ECMM – 3scales are considered

- Workpiece scale – geometry of the workpiece can be controlled by the current distributions
- Pattern scale – Current distribution depends upon the spacing of the features and their geometry
- Feature scale – shape is evaluated through the current distribution.

EFFECT OF PROCESS PARAMETERS ON ECMM

- Nature of power supply
- Inter electrode gap
- Concentration, temperature and electrolyte flow.
- Microtool feed rate

ADVANTAGES AND DISADVANTAGES OF ECMM

ADVANTAGES

- Precision manufacturing of miniature components
- Production of high accuracy holes.

DISADVANTAGES

- Material removal rate is very low
- The equipment used is of high cost

APPLICATIONS OF ECMM

- 3D micromachining of microstructure in copper sheet used in electronic circuit board
- Smooth surface and sharp borders are machined in titanium surfaces by using mask ECMM
- Manufacture of nozzle plate for inkjet printer heads.
- Use in aerospace, automobile and other heavy industries for shaping, sizing, deburring and finishing operation.

COMPARISION OF ECM VS ECMM

S.No.	Property	ECM	ECMM
1	Voltage	10 - 30V	< 10 V
2	Current	150 - 10000A	< 1 A
3	Current density	2 - 200A/cm^2	75 - 100A/cm^2
4	Power supply	Continuous / Pulsed	Pulsed
5	Frequency	Hz - KHz range	KHz - MHz - Range
6	Electrolyte flow	10 – 60 m/s	< 3 m/s
7	Electrolyte type	Salt solution	Natural salt and dilute acid
8	Electrolyte temperature	24 - 65°C	37 - 50°C