Non-Traditional Machining (NTM)

Limitations in conventional machining:

- The tool needs to be harder than the job/workpiece. In that case how do you machine very hard materials ?

- Intricate dimensional and accuracy requirements.

- Difficult to achieve higher production rates.

Non-Traditional Machining can overcome these limitations

Non-Traditional Machining

Some non-traditional machining techniques:

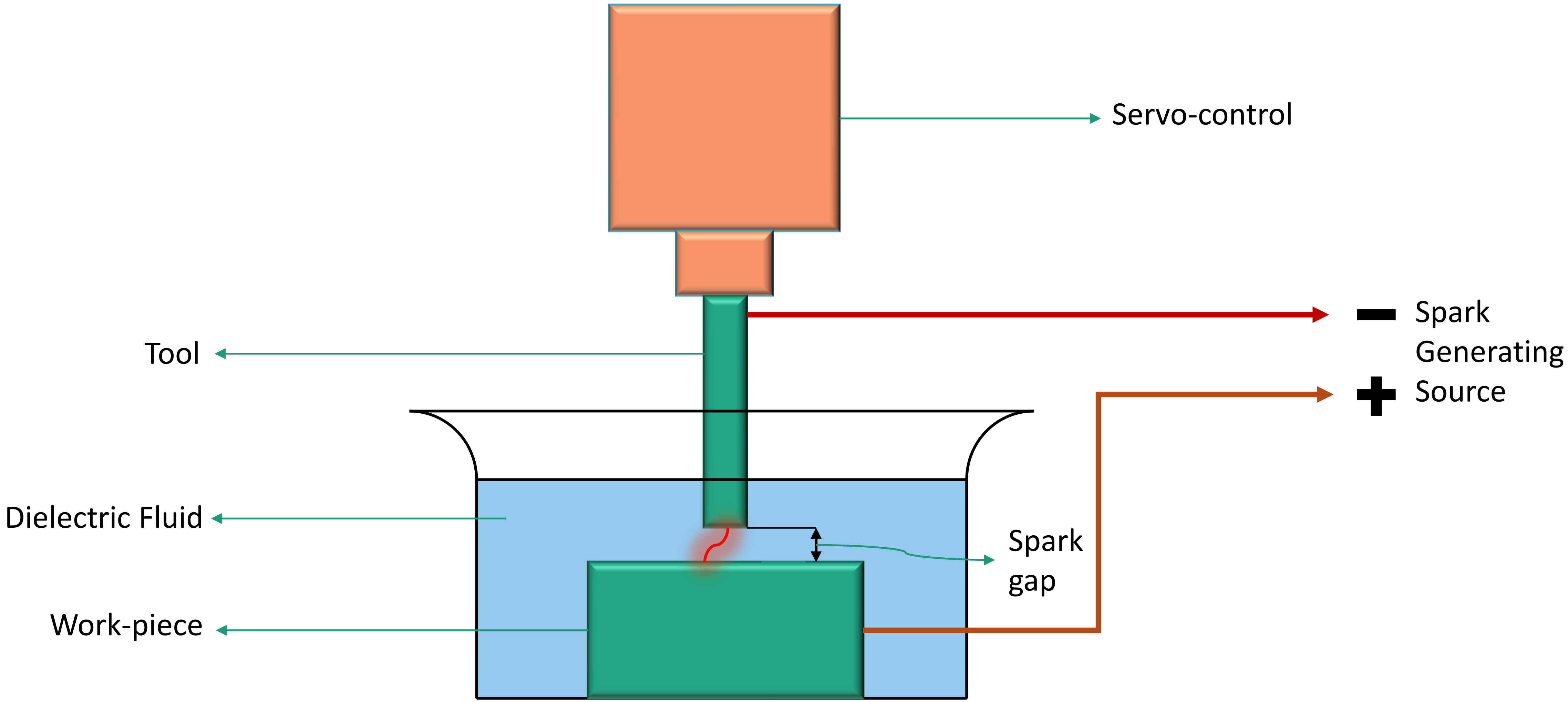
- Electric Discharge Machining (EDM)
- Electrochemical Machining (ECM)
- Abrasive Jet Machining (AJM)
- Laser Beam Machining (LBM)

Electric Discharge Machining (EDM)

Definition-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.**

Why EDM? 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. Work material to be machined by EDM has to be electrically conductive.

Electric Discharge Machining (EDM)



Schematic of EDM

Mechanics of EDM

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. 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. The tool is connected to the negative terminal of the generator and the workpiece to positive terminal. As the electric field is established between the tool and the job, the free electrons on the tool are subjected to electrostatic forces. When these forces overcome the work function or the bonding energy of the electrons, the electrons would be emitted from the tool (Cathode). 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.

Mechanics of EDM (Contd..)

As they gain velocity and energy, and start moving towards the job, there would be collisions between the electrons and dielectric molecules. Such collision results in ionisation of the dielectric molecule depending upon the work function of the dielectric molecule and the kinetic energy of the incident electron. As the electrons get accelerated, more positive ions and electrons would get generated due to collisions. This cyclic process would increase the concentration of electrons and ions in the dielectric medium between the tool and the job at the spark gap. The concentration would be so high that the matter existing in that channel could be characterized as “plasma”. A large number of electrons will flow from the tool to the job and ions from the job to the tool. This is called avalanche motion of electrons. 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.

Mechanics of EDM (Contd..)

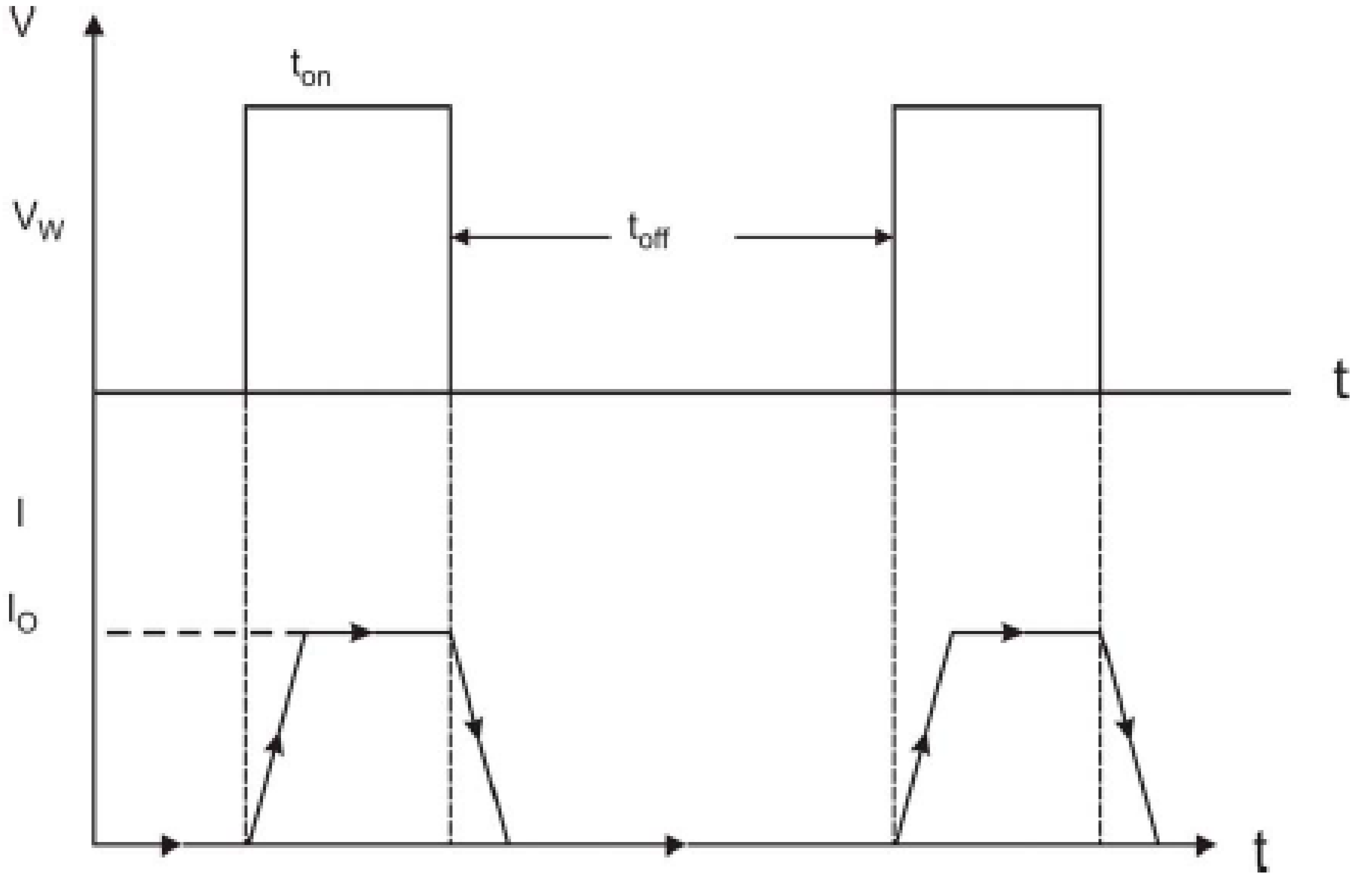
The high speed electrons then impinge on the job and ions on the tool. The kinetic energy of the electrons and ions on impact with the surface of the job and tool, respectively, and would be converted into thermal energy or heat. Such intense localized heating leads to extreme instantaneous confined rise in temperature which would be in excess of 10,000°C. Such localized extreme rise in temperature leads to instant vaporization of the material as well as melting. 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. 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 localized material removal at a particular point whereas sparks get distributed all over the tool surface leading to uniformly distributed material removal.

EDM-Process Parameters

The process parameters in EDM are mainly related to the waveform characteristics.

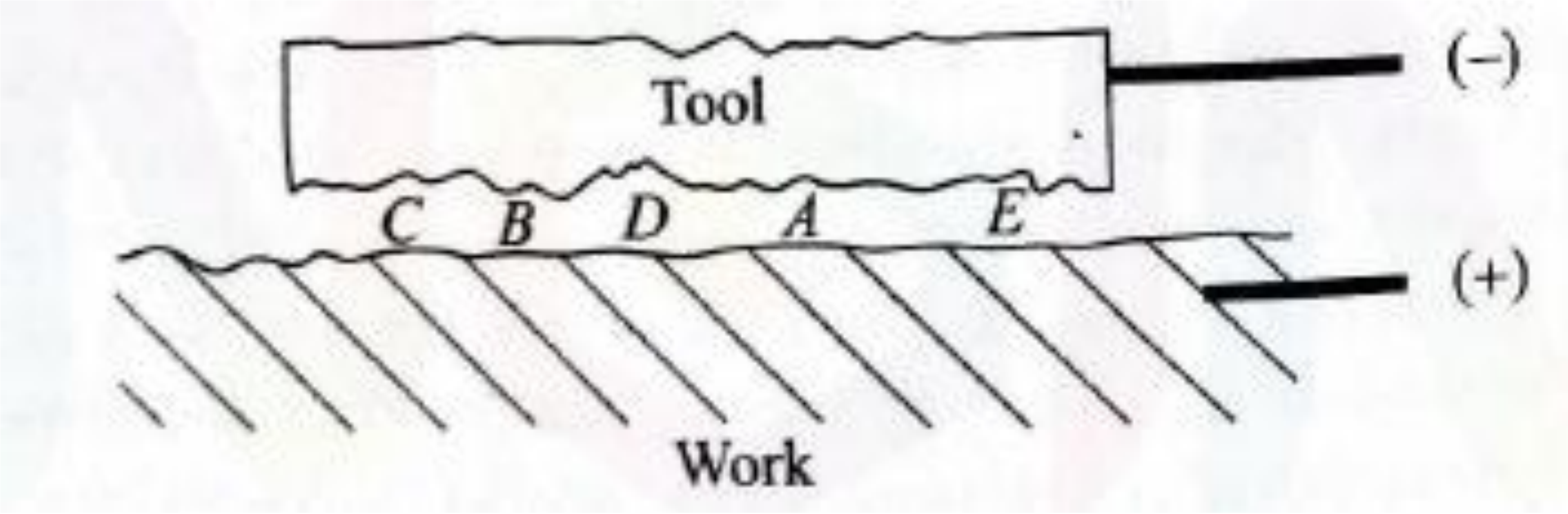
The waveform is characterized by

- The working voltage - V_w
- The maximum current - I_O
- The pulse on time – t_{on}
- The pulse off time - t_{off}
- The spark gap - δ
- The dielectric medium and its circulation through the spark gap.



Mechanics of EDM- Spark Propagation

The surface irregularities causes the local spark gap to vary. At the point of minimum gap (say at 'A') the spark first occurs. As soon as this happens, the gap between the electrodes at A increases, the next location of the shortest gap is somewhere else (say at 'B'). In this way, the spark wanders all over the electrode and, ultimately, the process results in a uniform gap. So, depending on the negative electrode shape, an impression is created on the other electrode.



EDM- Role of Servodrive

If the tool is stationary relative to the workpiece, the gap increases as the material removal progresses, necessitating an increased voltage to initiate the sparks. To avoid this problem, the tool is fed with the help of a servodrive, which senses the magnitude of the average gap and keeps it constant.

Characteristics of EDM

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

b) Material removal depends on mainly thermal properties of the work material rather than its strength, hardness, and toughness.

c) There is a physical tool and geometry of the tool is the replica of the impression of the geometric feature machined.

d) Though the local temperature rise is 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. However, the heat affected zone (HAZ) is formed.

e) Taper and overcut are the defects produced in EDM

EDM-Role of Dielectric

Material removal occurs due to intense heating, resulting in vaporization and melting of workpiece. This needs to be executed in absence of oxygen so that oxidation is avoided. Oxidation often leads to poor surface conductivity (electrical) of the workpiece hindering further machining. **Dielectric fluid should provide an oxygen free machining environment**. Dielectric medium is generally flushed around the spark zone to achieve efficient removal of molten material.

<u>Basic requirements of an ideal dielectric fluid:</u>

1. Low viscosity
2. Absence of toxic vapors
3. Chemical neutrality
4. Readily available /low cost

Kerosene, Parrafin Oil, Deionised water are used as dielectric fluids in EDM

EDM- Choice of Tool materials

Basic requirements of the Tool material:

1. It should not undergo much wear when impinged by positive ions.

2. Also, it should be easily machinable, that is, it should have high machinability. This feature allows us to machine complicated shapes using conventional machining processes.

Therefore, the Tool material should exhibit:

1. High electrical conductivity – electrons are cold emitted more easily and there is less bulk electrical heating.

2. 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 therefore, less tool wear.

EDM- Choice of Tool materials

3. Higher density – for the same tool wear by weight there would be less volume removal or tool wear and thus less dimensional inaccuracy.

4. High melting point – high melting point leads to less tool wear due to less tool material melting for the same heat load.

5. Low cost and readily available.

   Brass, Oxygen-free Copper, Tellurium-Copper, Graphite are commonly used.

6. High machinability.

EDM-Process Summary

Mechanics of Material Removal	Melting and Evaporation aided by cavitation
Medium	Dielectric Fluid
Tool Materials	Cu, brass, graphite, Cu-W alloy
$\frac{Material\ Removal\ Rate(MRR)}{Tool\ wear\ rate}$	0.1-10
Spark Gap	10-125 μm
Maximum MRR	5 X 10^3 mm^3/min
Specific Power Consumption (typical)	1.8 $W/mm^3/min$
Critical Parameters	Voltage, Capacitance, spark gap, Dielectric Circulation, Melting Temperature
Materials application	All conducting materials and alloys
Shape application	Blind Complex cavities, micro-holes for nozzles, narrow slots.
Limitations	About 50 times high specific power consumption compared to conventional machining. Only for conducting materials and alloys.

Electro Chemical Machining

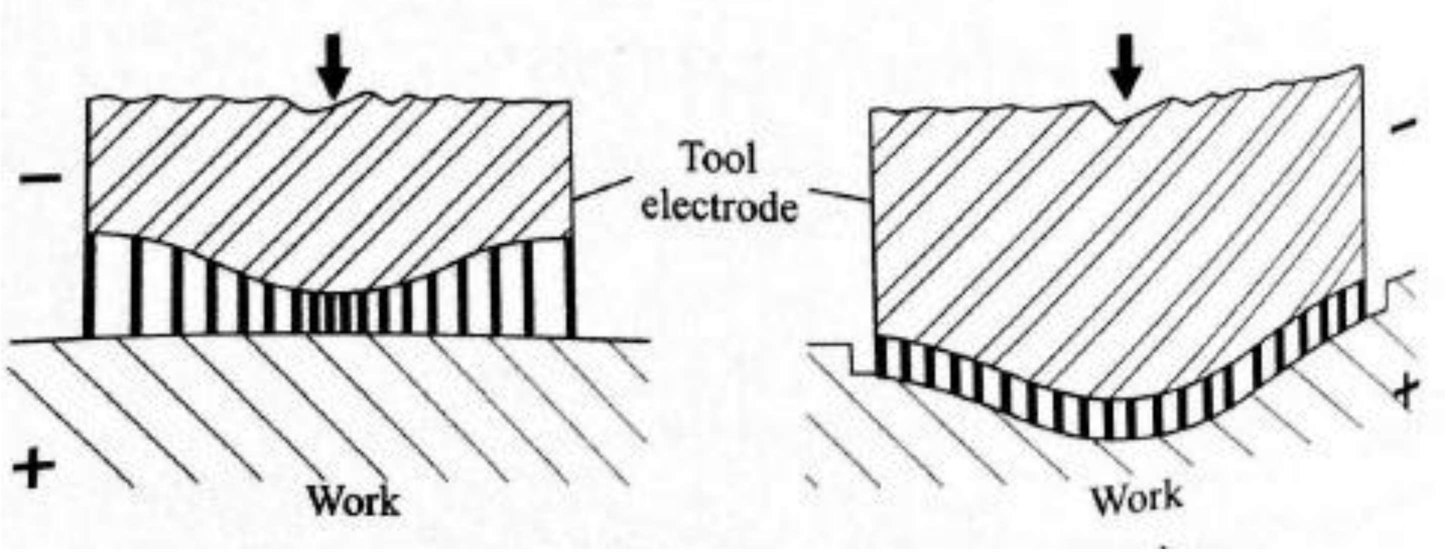
- Electrochemical Machining (ECM) is a non-traditional machining (NTM) process based on the principles of electrolysis.

- ECM is opposite of electrochemical deposition process/electroplating.

- In ECM, objective is to remove metal. The workpiece (electrode) is generally connected to the positive terminal (anode). When current is passed, a controlled anodic dissolution the work piece occurs with almost no deposition or dissolution of the cathode (tool). This is possible due to suitable choices of the electrodes and the electrolyte.

Electrochemical Machining (ECM)-Mechanism

- The gap between the suitably-shaped tool and the workpiece is filled by electrolyte.
- The rate of anodic dissolution is inversely proportional to this gap.
- When tool is given downward motion, the work surface tends to take the same shape as that of the tool.
- At steady state the gap is uniform, and the shape of the tool is reproduced in the job.



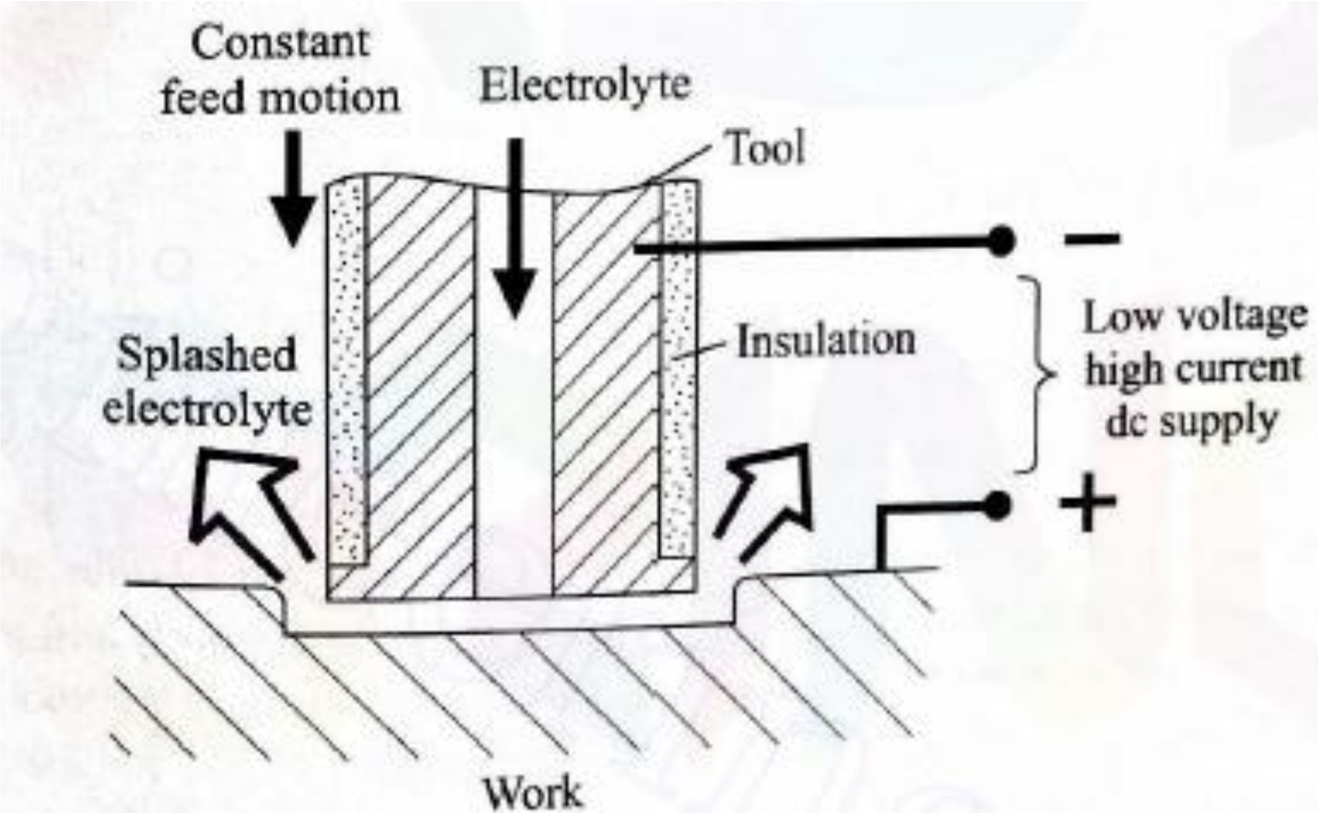
Initial State Steady State

ECM- Schematic of the Setup

- In ECM, tool is provided with a constant feed motion.

- The electrolyte is pumped at a high pressure through the tool.

- The electrolyte is so chosen that such the anode is dissolved but no deposition takes place at cathode (tool).



ECM-Electrochemistry of the process

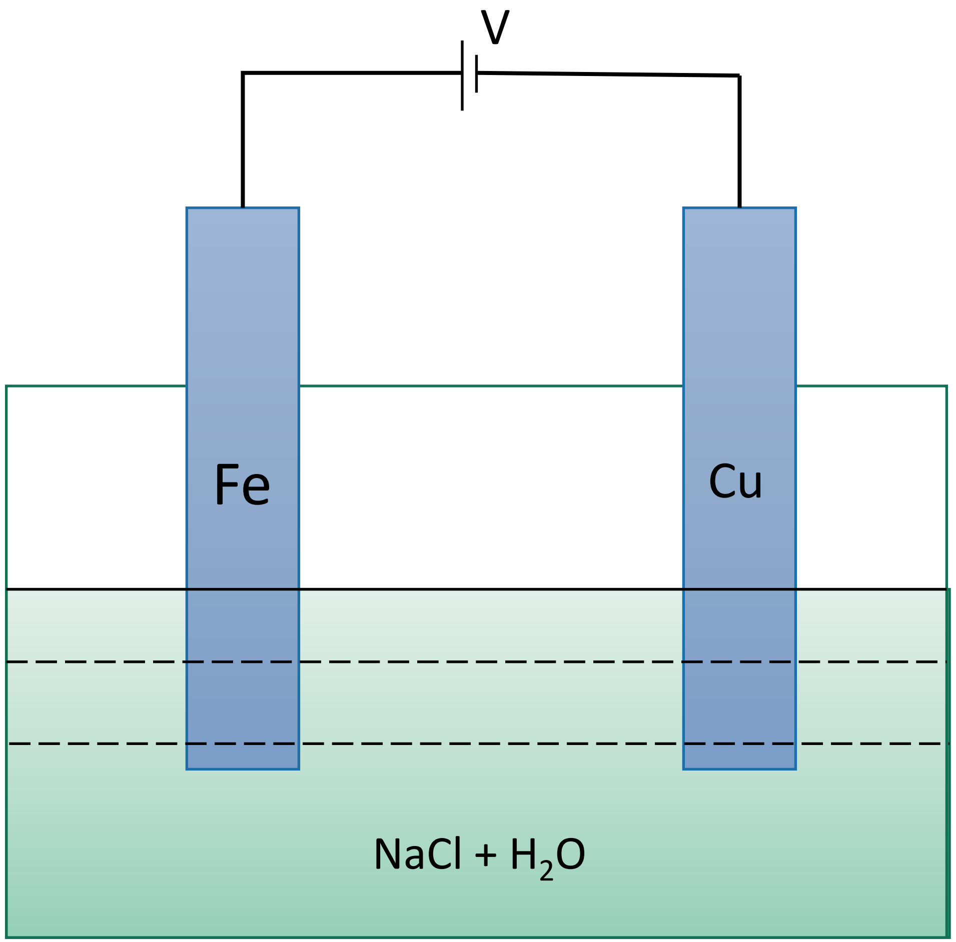
- Consider Iron (Fe) and Copper (Cu) electrodes immersed in aqueous solution of sodium chloride (NaCl).

Reaction at Anode:

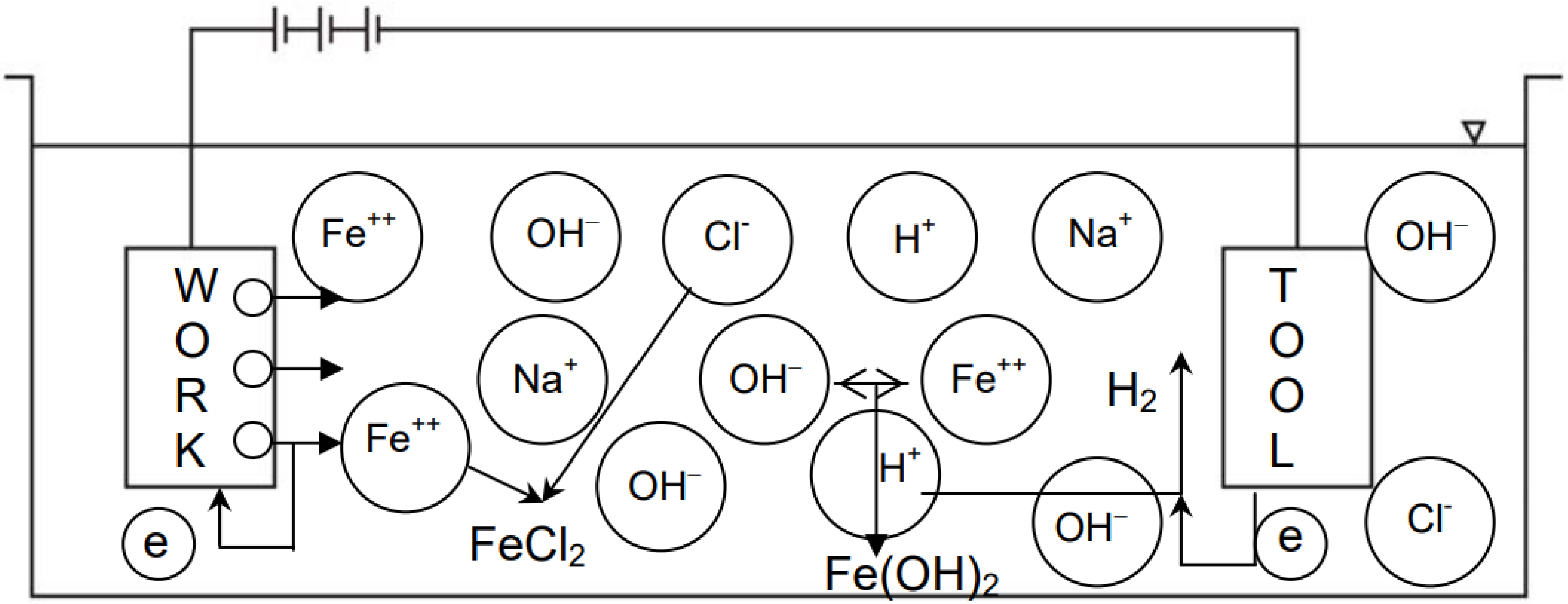
$$Fe \longrightarrow Fe^{++} + 2e$$

Reaction at Cathode:

$$2H_2O \longrightarrow H_2\uparrow + 2(OH^-)$$

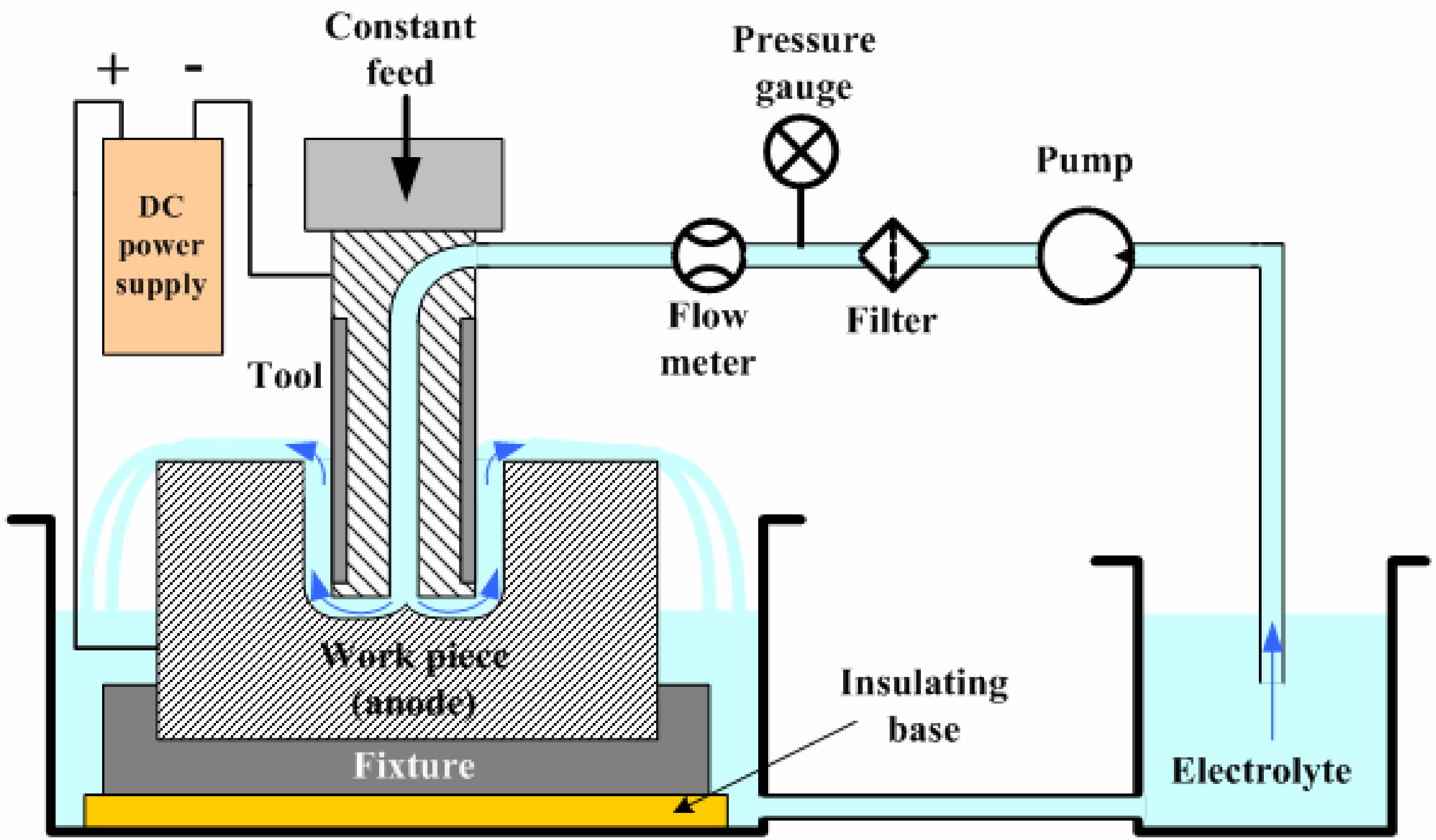


Schematic representation of electro-chemical reactions



- Ferrous Chloride and Ferrous Hydroxide are deposited at the bottom of the chamber.

Electrochemical Machining (ECM)



ECM- Characteristics

- Tool and work material need to conductive.
- Atomic level dissolution. Controlled Anodic Dissolution
- Surface finish is excellent.
- No thermal damage, or formation HAZ.
- Stress-free machined surface.

Electrochemistry of ECM-Modelling of Material Removal Rate

- Material Removal Rate (MRR) is an important characteristic of any machining process.

- In ECM, material removal takes place due to electrolytic dissolution of work material.

- This dissolution is governed by Faraday's laws.

Faraday's Laws:

1. The amount of any material dissolved or deposited is proportional to the quantity of charge passed.
2. The amounts of different substances dissolved or deposited by the same quantity of electricity is proportional to their chemical equivalent weights.

In the quantitative form, the two laws state:

$$m \propto It\varepsilon$$

Where, m is the mass of material deposited/dissolved (in grams), I is the current (amperes), t is the time (in seconds) and ε is gram equivalent weight of the material.

Faraday's Laws for a metal

$$m \propto It\varepsilon$$

$$m = \frac{It\varepsilon}{F}$$

F is the constant of proportionality, called Faraday. 1 F=96500 coulombs. Using the numerical value of F, we obtain $m = \frac{It\varepsilon}{26.8}$.

Note that the t is in hours, I is in amperes, in this expression.

<u>To obtain MRR, denoted as Q, the expression is modified as:</u>

$$Q = \frac{AI}{\rho ZF}$$

A is the gram atomic weight, ρ is the density in g/cc and Z is the valency of the anode/workpiece.

Faraday's Laws as applied to an alloy

- When anode is made of alloy instead of pure metal, the removal rate can found out by considering the charge required to remove a unit volume of each element.

- Let atomic weights and the valencies be A_1 , A_2 ,…and Z_1 , Z_2 ,…,respectively and composition of the alloy by mass is x_1 %, x_2 %,…, then a v cm^3 of the alloy contains $v\rho x_i$ / 100 gram of the ith element, where ρ is the overall density of the alloy in g/cc.
- The charge required to remove all ith element in volume v is given by $\frac{v\rho x_i}{100}\left(\frac{Z_i F}{A_i}\right)$
- Thus, volume of alloy removed per unit charge is Q = $\frac{100}{\rho F}\left(\frac{1}{\sum\frac{x_i Z_i}{A_i}}\right)$

Problem 1

- In electrochemical machining of pure iron a material removal rate of 5 cm^3/min is required. Estimate current requirement.

Problem 2

The composition by % weight of the Nimonic 75 alloy is given as:

Ni 72.5, Cr 19.5, Fe 5.0, Ti 0.4, S 1.0, Mn 1.0, Cu 0.6. Calculate the removal rate in cc/min when 1000 A current is passed. Use the lowest valency of each element

Metal	Gram atomic weight	Valency of dissolution	Density (g/cm^3)
Aluminium	26.97	3	2.67
Chromium	51.99	2/3/6	7.19
Cobalt	58.93	2/3	8.85
Copper	63.57	1/2	8.96
Iron	55.85	2/3	7.86
Nickel	58.71	2/3	8.90
Tin	118.69	2/4	7.30
Titanium	47.9	3/4	4.51
Tungsten	183.85	6/8	19.3
Zinc	65.37	2	7.13
Silicon	28.09	4	2.33
Manganese	54.94	2/4/6/7	7.43

Solution to Problem 1

The gram atomic weight, valence at which dissolution takes place, and density of iron are 56g, 2, and 7.8 g/cm^3 , respectively. Now, using equation for MRR :

$$Q = \frac{AI}{\rho ZF}$$

$$\frac{5}{60} = \frac{56 * I}{7.8 * 2 * 96500}$$

$$I = \frac{5 * 7.8 * 2 * 96500}{60 * 56} = 2240\ amp$$

Solution to Problem 2

ECM-Process Summary

Mechanics of Material Removal	Electrolysis
Medium	Conducting Electrolyte
Tool Materials	Cu, brass, steel
$\frac{Material\ Removal\ Rate(MRR)}{Tool\ wear\ rate}$	Infinity
Gap	50-300 μm
Maximum MRR	15 X 10^3 mm^3/min
Specific Power Consumption (typical)	7 W/mm^3/min
Critical Parameters	Voltage, Current, feed rate, electrolyte
Materials application	All conducting materials and alloys
Shape application	Blind Complex cavities, curved surfaces, narrow slots.
Limitations	150 times higher specific power consumption compared to conventional machining. Very Expensive machine

Thank You !