Advanced Manufacturing Processes (AMPs)

Electrochemical Machining

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Chapter Description

- Aims
  - To provide and insight on advanced manufacturing processes
  - To provide details on why we need AMP and its characteristics

- Expected Outcomes
  - Learner will be able to know about AMPs
  - Learner will be able to identify role of AMPs in todays sceneries

- Other related Information
  - Student must have some basic idea of conventional manufacturing and machining
  - Student must have some fundamentals on materials

- References

Neelesh Kumar Jain, **Sunil Pathak** (2016), “Chapter 30028: “Electrochemical Processing and Surface Finish” in **Comprehensive Materials Finishing** Vol. 3 (Volume Editor: Bakir Sami Yilbas; Editor-in-Chief: S. Hashmi) Elsevier Inc. Oxford (UK). (DOI: 10.1016/B978-0-12-803581-8.09182-7; online since 29 April 2016). (ISBN: 978-0-12-803581-8)

1. INTRODUCTION

- Initially developed to machine hard and tough materials for aircraft and rocket industry.
- Among electrical machining processes, ECM involves highest material removal.
- As in electroplating, ECM employs electrolytic principles to dissolve work material.
- Work materials must be electrical conductors.
- ECM is the reverse of electroplating.

In electroplating, metal is deposited on workpiece, While in ECM, metal is removed from workpiece.

2. ELECTROLYSIS

- Electroplating and ECM are based on Faraday's Laws of Electrolysis:

  Amount of material produced in electrolysis is directly proportional to:

  a) *Current flowing through* - $m \propto I$
  b) *Duration of electrolysis* - $m \propto t$

  $\Big\} m \propto It$

  c) *Equivalent weight of deposited material* - $m \propto G$

- Process depends on existence of ions in electrolysis liquid solution (electrolyte).

➢ Ions are electrically charged atoms. They facilitate electrical flow through electrolyte.

➢ Ions can be positively charged (eg metal ions) or negatively charged (eg sulphate and chloride ions).

2. ELECTROLYSIS (cotd)

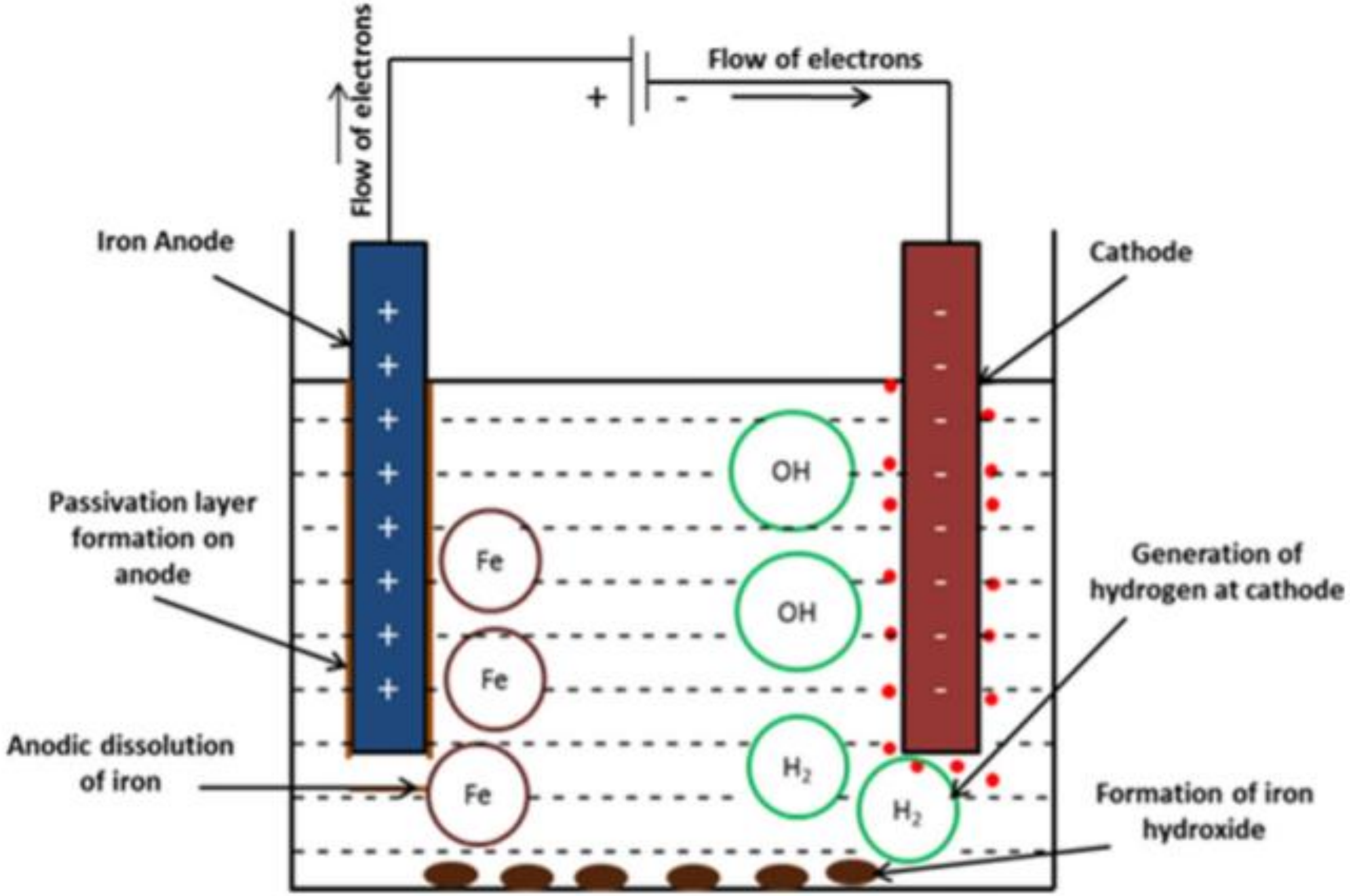

Figure: Schematic of a simple electrolysis process.

3. COPPER PLATING

- Object to be plated, say steel, is made the negative electrode (cathode).
- The positive electrode (anode) is made of copper.
- Electrolyte solution is copper sulphate solution ($CuSO_4$).
- When electricity is connected to both electrodes, electrical potential between plates dissolves $CuSO_4$ to become positive copper ions and negative SO_4 ions.
- Copper ions are attracted to cathode and deposited as metal (anode metal is transferred to cathode).
- SO_4 ions are attracted to anode and attack copper to form $CuSO_4$ (replacing $CuSO_4$ removed from solution by electrolysis).

3. COPPER PLATING (cotd)

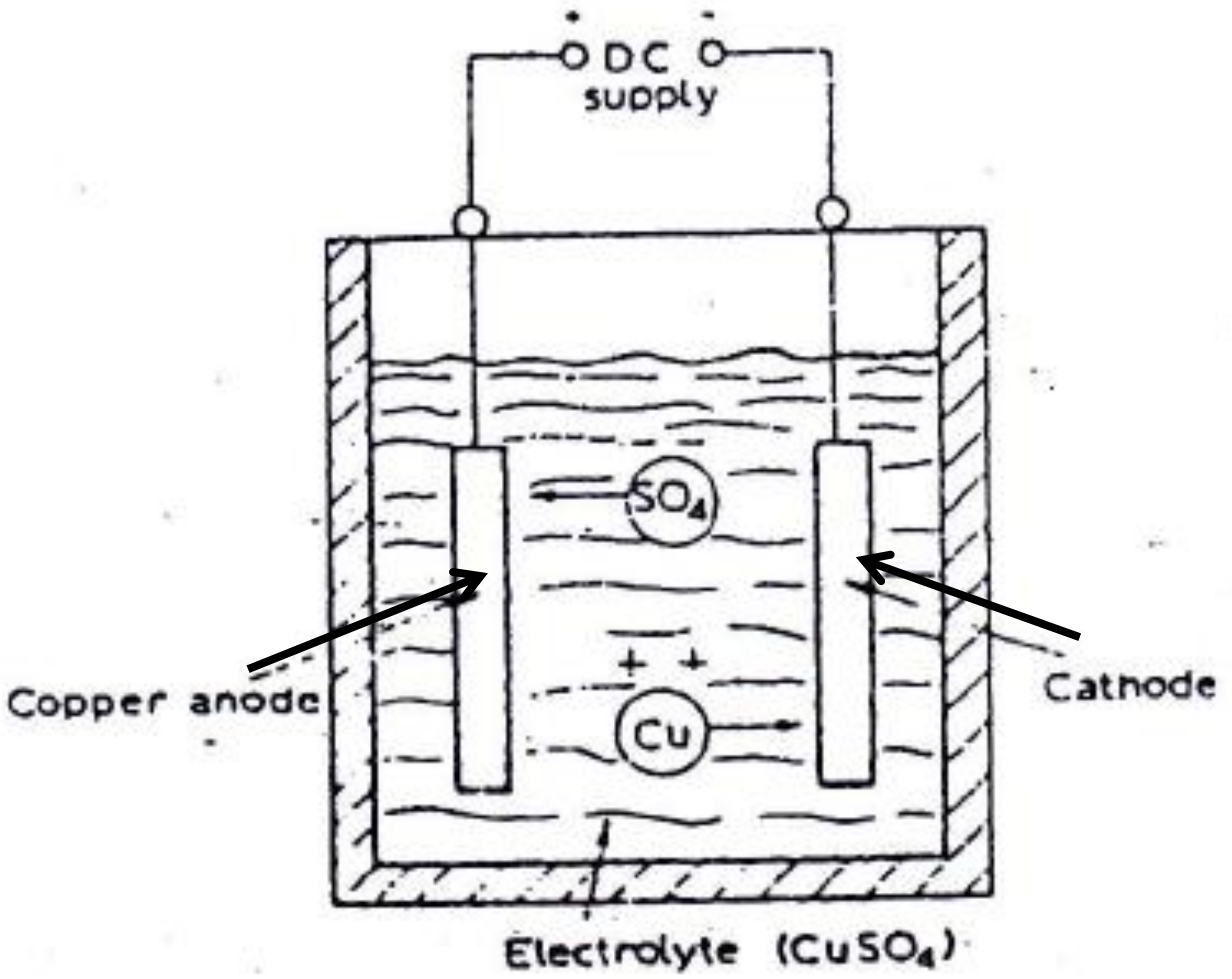

Fig. 1 - Electroplating Process.

4. PRINCIPLES OF ECM (general description)

- In ECM, the reverse of electroplating happens.
  - Workpiece is anode, tool is cathode.

- What matters is not deposition of metal to cathode but metal removal from anode.

- Workpiece material is removed (machined), but before it is deposited on the tool, the dissolved metal is carried away by electrolyte to another place.

- In ECM, all material removal is by electrolytic action.

NOTE: difference between EDM and ECM:

in EDM an arc is used to heat metal, in ECM
the metal dissolves chemically

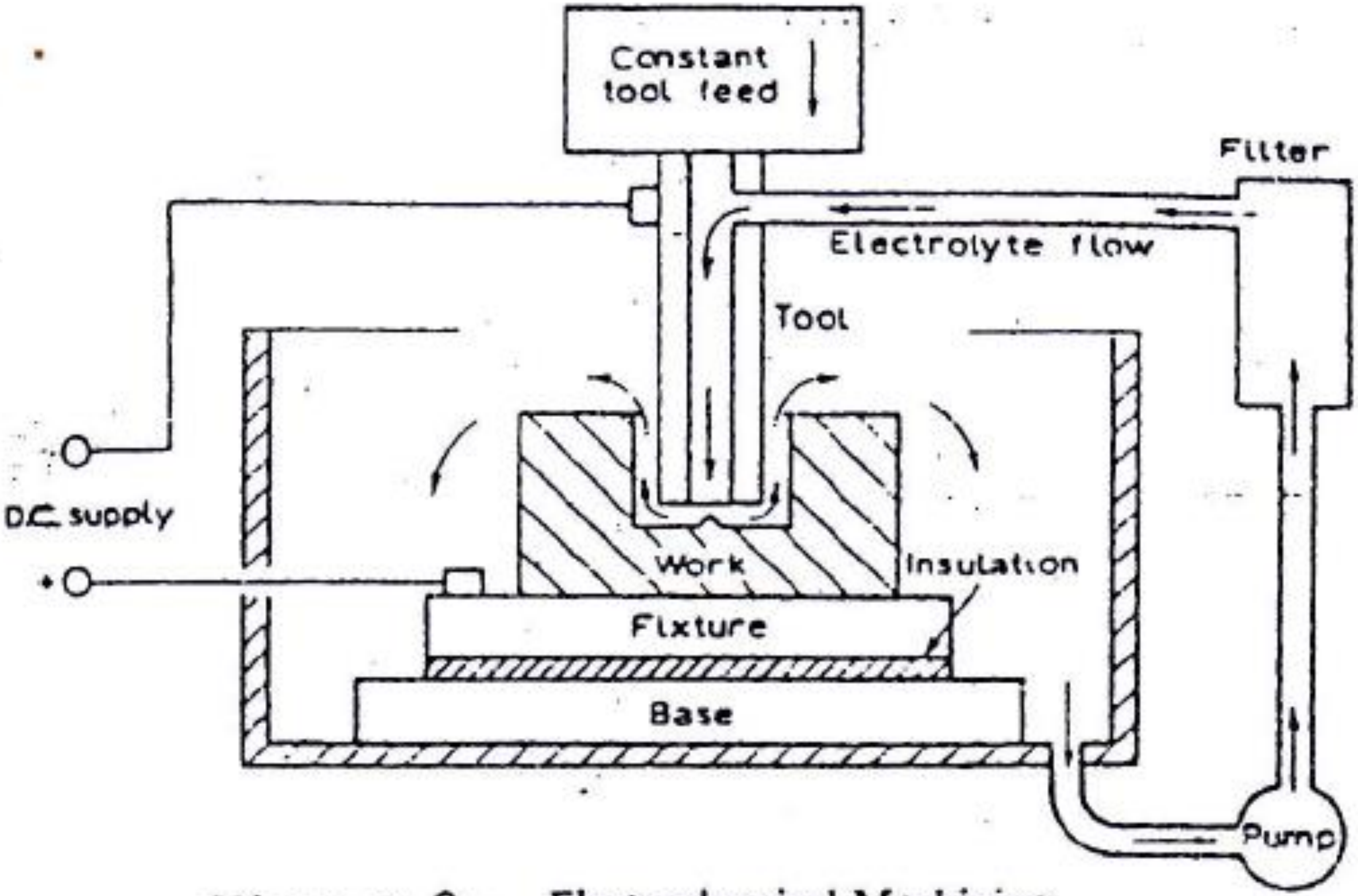

Figure 2 - Electrochemical Machining

4. PRINCIPLES OF ECM (cont…)

Shape of workpiece is determined by:

- shape of tool
- relative motion of tool and workpiece

In ECM operation, cathode tool is positioned close to material to be machined.

Thus, resistance is low and more current can flow
(Ohm's Law: I = V/R)

Gap is between 0.1 and 0.5 mm and is flooded with a conducting electrolyte under pressure.

4. PRINCIPLES OF ECM (cont…)

- Adequate electrolyte flow is necessary to prevent overheating and selective removal.
- Potential of 5 to 30 V is applied between workpiece and tool.
- High current flows causing metal to dissociate from work surface.
- Current density is between 50 and 800 A/cm^2.
- Lower current densities cause selective machining and poor finish.
- Higher current densities cause overheating of electrolyte and excessive hydrogen generation leading to sparking.

4. PRINCIPLES OF ECM (cont…..)

Metal removal rate depends on conductivity of electrolyte.
Assuming constant voltage, control of conductivity is necessary for accurate machining.

Gap between tool and workpiece depends on:
✓rate at which tool is advanced towards workpiece
✓rate at which metal is removed from workpiece.

The smaller the gap:
✓the greater the accuracy of reproduction of tool contour on workpiece surface
✓the higher the current density, hence increasing metal removal rate.

CONDUCTIVITY and RESISTIVITY

Conductivity of electrolyte is affected by:

a) electrolyte temperature

b) amount of hydrogen evolved at cathode

c) chemical concentration of salt solution

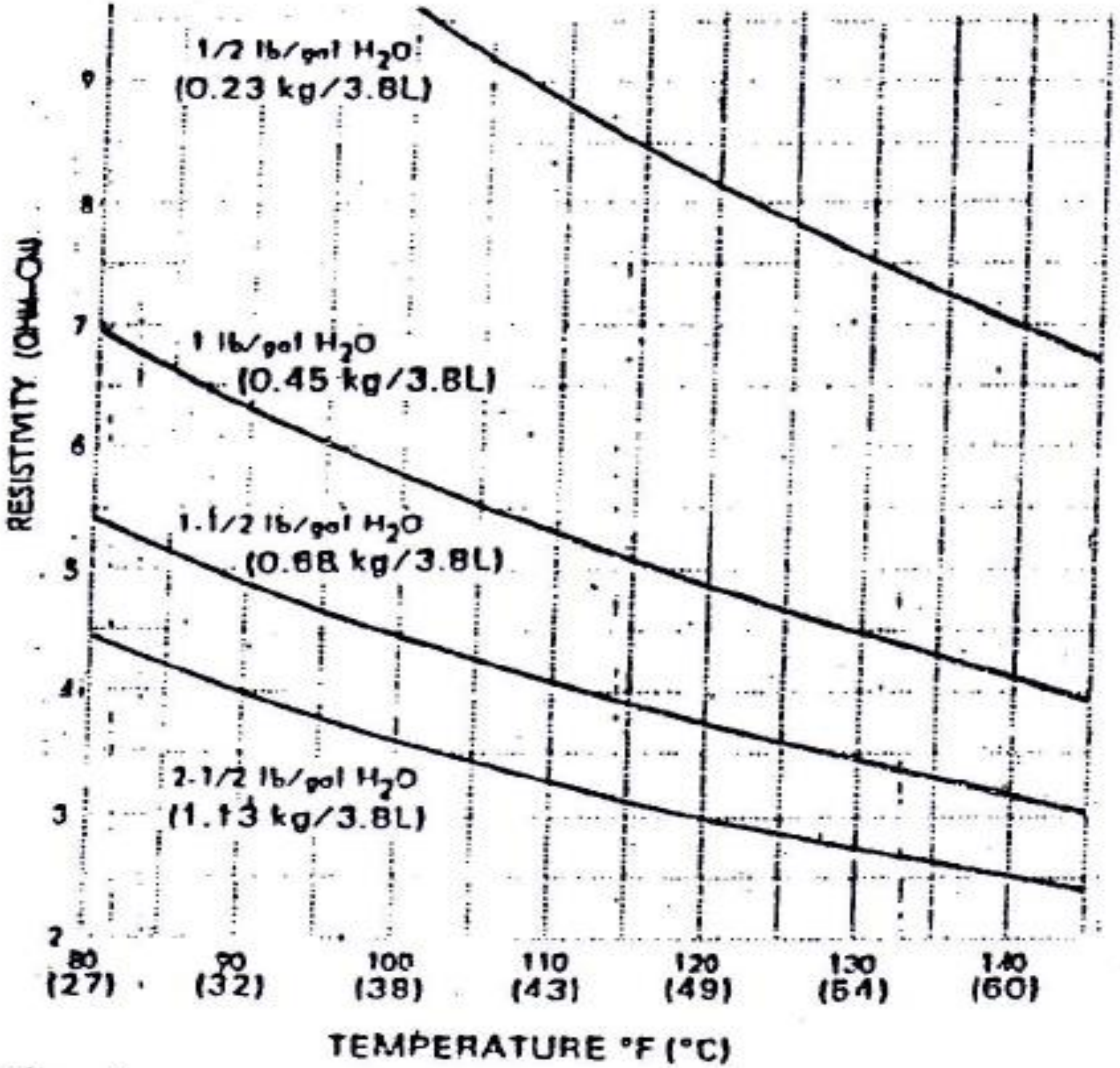

Fig. 4 . Resistivity of sodium chloride solution vs. temperature and concentration.

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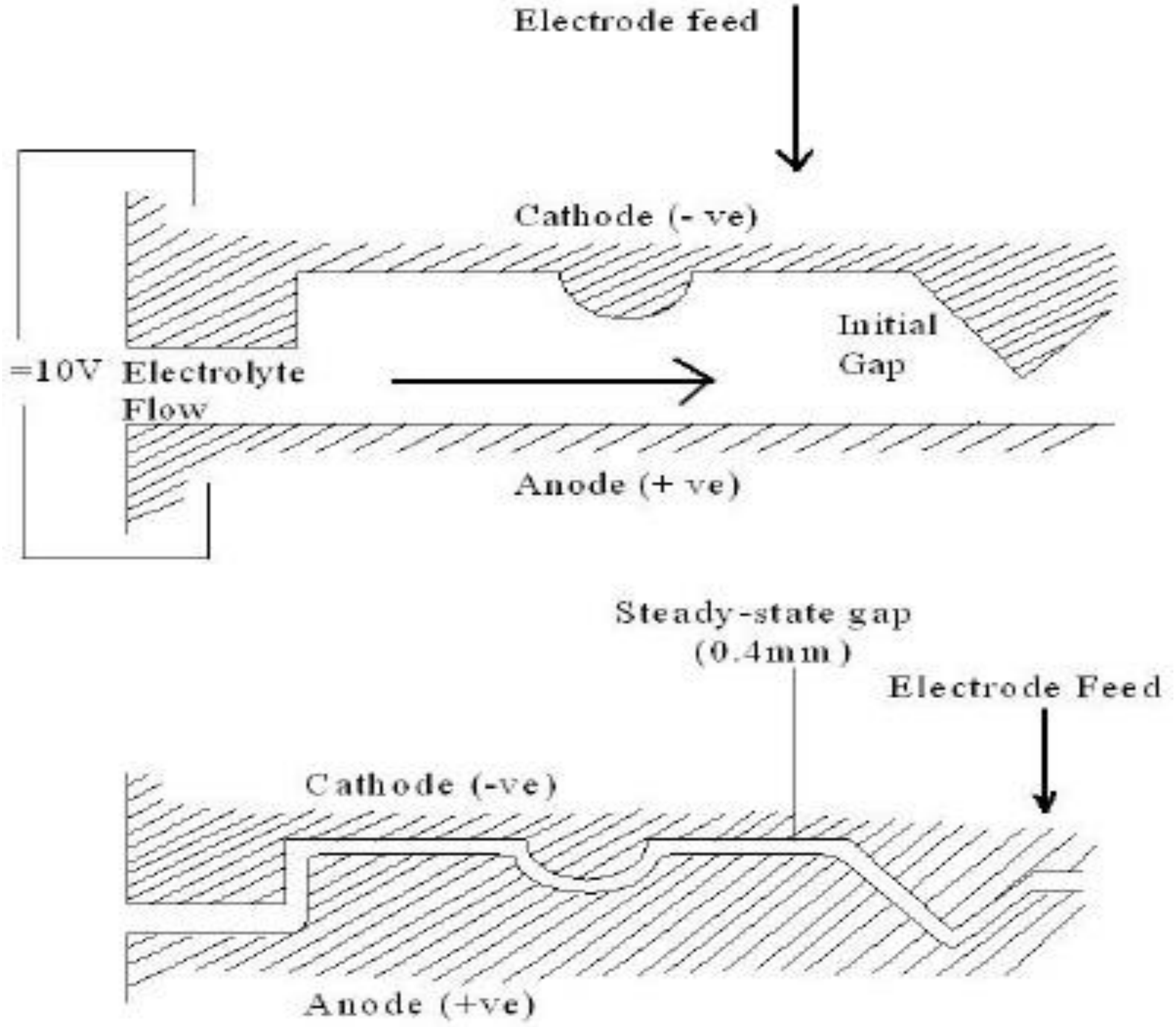


Figure: Working principles of ECM

5.BASIC ELECTROCHEMICAL REACTIONS

Electrolytes consist of acids, alkalis, salts;
chemical reactions being different in each case.

In the case of **salts**, salt crystals split into small particles (positive and negative ions) and move freely in solution. Example, by dissociation:

$$\mathbf{NaCl \rightarrow Na^{+} + Cl^{-}\ ; \qquad H_2O \rightarrow H^{+} + OH^{-}}$$

If iron/steel electrode (anode) and a cathode are immersed, and electrical potential applied between electrodes, ions will migrate (this represents a current flow).

High voltage gradient between positive ions and adjacent cathode causes electrolysis of water:

$\mathbf{2\,H_2O + 2e = H_2 + 2(OH)^{-}}$;hydrogen is evolved as gas.

Negatively charged hydroxyl ions OH^{-} are attracted to the positive anode, reacting with the positive ions of the anode:

$$\mathbf{Fe^{++} + 2\,(OH)^{-1} = Fe(OH)_2}.$$

This is a simplified statement of the theory. But ECM is a complex process.

5. BASIC ELECTROCHEMICAL REACTIONS (cont….)

A number of chemical reactions can take place at cathode, anode, and in electrolyte.

Which of the possible reactions will actually take place is determined by oxidation-reduction potential of the reactions.

The conditions at the two electrodes are different:

At **cathode** (or tool): reaction having lowest oxidation potential will take place.

At **anode** (or workpiece): reaction having highest oxidation potential will take place.

Oxidation potentials are dependent upon the electrochemical conditions:

- ✓ electrode material
- ✓ electrolyte material
- ✓ electrolyte temperature
- ✓ current density on electrode surface
- ✓ concentration of metal ions.

5. BASIC ELECTROCHEMICAL REACTIONS (cont)

At **CATHODE**, 2 possible reactions:

1. **Metal plating** on cathode: $\mathbf{M^+ + e^- \rightarrow M}$ (M= any metal),

positively charged ions of anode are attracted to negatively charged cathode and lose their charge upon deposition.

This effect is undesireble since tool will loose accuracy.
In many cases, 'plating out' can be reduced or eliminated by choice of correct conditions.

Example, in machining iron, plating out will occur with acid electrolyte at low current density, not with neutral electrolyte at high current density.

2. **Hydrogen evolution**: $\mathbf{2\,H^+ + 2\,e^- \rightarrow H_2}$ (H = hydrogen).

For electrolyte, halide salts are frequently used, they have simple electrolyte reactions. Most commonly used is sodium chloride (NaCl).

5. BASIC ELECTROCHEMICAL REACTIONS (cont…)

At **ANODE**, 3 possible reactions:

1. **Metal dissolution**: $\mathbf{M \rightarrow M^+ + e^-}$

2. **Oxygen evolution**: $\mathbf{2\,H_2O \rightarrow O_2 + 4H^+ + 4e^-}$

3. **Chlorine evolution**: $\mathbf{2\,Cl^- \rightarrow Cl_2 + 2\,e^-}$

Study of oxidation potentials shows: metal dissolution is most favourable.

Tests show: it accounts for at least 80% of current passed under correctly controlled conditions.

This represents machining efficiency. Optimum conditions have to be determined, if not η will be lower.

5. BASIC ELECTROCHEMICAL REACTIONS (cont)

When metal workpiece ions leave its surface, multitude of possible reactions can occur – electrochemistry can be very complex.

In the example of iron ECMed using NaCl:

As iron ion (Fe^{++}) leaves workpiece surface, it reacts with hydroxyl ions (OH^-) that have been attracted to the positively charged workpiece:

$\mathbf{Fe^{++} + 2\,(OH)^{-1} = Fe(OH)_2}$:

→ ferrous hydroxide (green-black precipitate, soluble in water)

On contact with oxygen in air and in solution, ferrous hydroxide oxidises to ferric hydroxide:

$\mathbf{Fe(OH)_2 + H_2O + O_2 = Fe(OH)_3}$:

→ ferric hydroxide (red brown sludge, insoluble in water).

5. BASIC ELECTROCHEMICAL REACTIONS (cont….)

The complete electrochemical process is thus:

$$2\ Fe + 4\ H_2O + O_2 = 2\ Fe(OH)_3 + H_2$$

[metal + water + air = sludge + hydrogen gas].

Note: neither sodium ions nor chlorine ions enter into ECM reactions; ions in electrolyte only serve as means of carrying electric current, sodium chloride electrolyte is thus not used up.

In ECM of steel, carbon is released, forming additional precipitate in electrolyte.

6. RATE OF METAL REMOVAL

Theoretical MRR can be derived based on Faraday's Law.

MRR α J, current density.

Current passing through gap is as defined by Ohm's Law:

$I = V/R$.

Since **$R \alpha l/A$**, where l = length of conductor,
$R = rh/A$ where r = specific resistivity, h = gap distance, being length of conductor in ECM.

$J = I/A$,
so **$J = V/rh$** or **$J = kV/h$**, where $k = 1/r$ = specific conductivity.

RELATIONSHIP BETWEEN V AND I

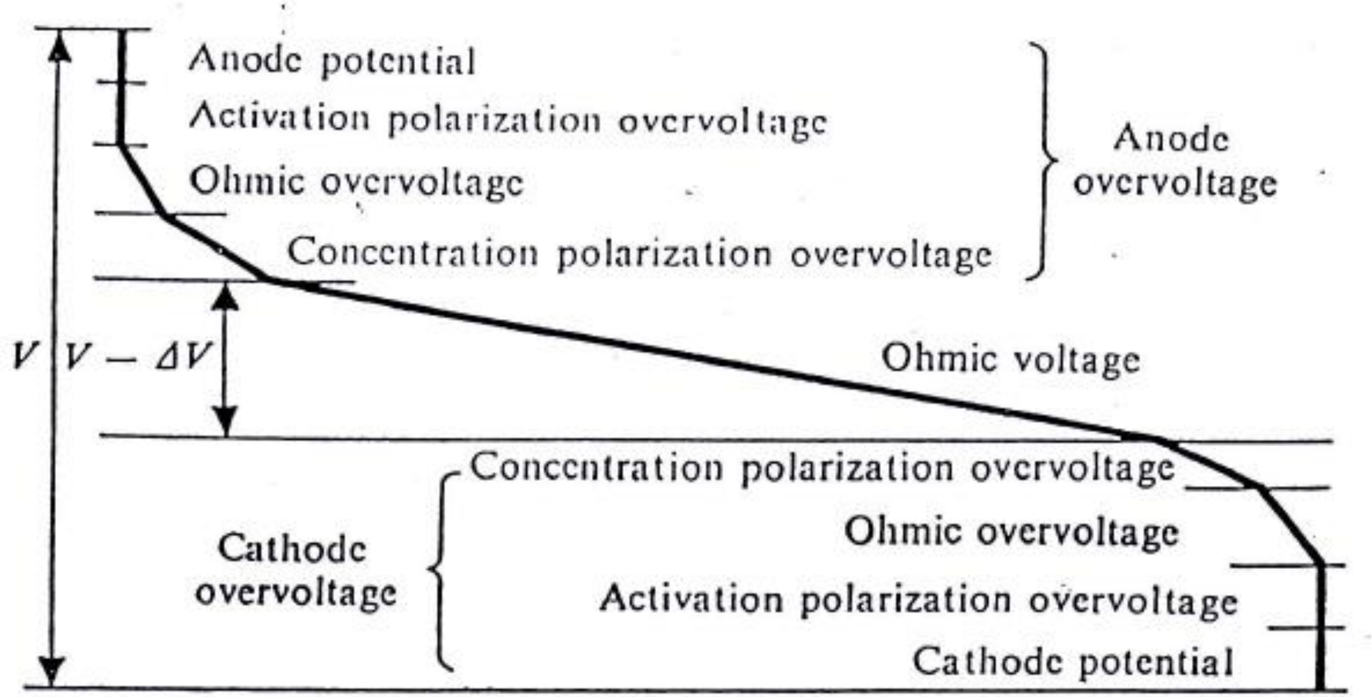


Fig. 6.30 Voltage drop in gap between electrodes.

If applied voltage is *V*, and if total overvoltage at anode and cathode is *ΔV*, then current I is given by:

$$I = \frac{V - \Delta V}{R},$$

Where *R* is the ohmic resistance of the electrolyte.

6. RATE OF METAL REMOVAL (cont…)

MRR for pure metals:

1. mass rate of material removal, $$\mathbf{m} = \frac{\mathbf{IW}}{\mathbf{Fz}} \quad (\text{kg/s})$$

where W = gram atomic weight,
z = valency of dissolution, and
F = Faraday's constant
= 96,500 coulomb = 96,500 amp.sec.

2. volumetric rate of material removal, $$\mathbf{v} = \frac{\mathbf{IW}}{\mathbf{Fz\rho}} \quad (\text{m}^3/\text{s})$$

where ρ = anode material density.

6. RATE OF METAL REMOVAL (cont….)

MRR for alloys:

MRR= QI

where Q = volume of alloy removed by a unit charge
(cm^3/amp.sec)

$$Q = \frac{100}{\rho F \sum (x_i z_i / W_i)}$$

where x_i = percentage by weight of each element in the alloy.

Overall density of alloy can be determined from density of each element in alloy, ρ_i,

$$\rho = \frac{100}{\sum (x_i / \rho_i)} .$$

6. RATE OF METAL REMOVAL (cont…..)

In practice, removal rates of 75 to 85 % of theoretical rates are achieved.

Possible reasons:

- ✓ incorrect assumption of valency
- ✓ existence of side reactions.

Maximum material removal rate is limited by:

- ✓ electrolyte **heating**, eventually boiling; changes resistance along gap length
- ✓ **swarf** production; changes resistance along gap length and leads to sparking
- ✓ **hydrogen** evolution; reduces conductivity of electrolyte and leads to sparking.

Under favourable conditions, **maximum current density** of 800 A/cm^2 has been attained.

Minimum material removal rate is limited by:
surface finish deteriorates at low current densities for most metals especially alloys; results in selective machining and leads to grain boundry etching.

Lowest practical current density in most cases is 80 A/cm^2.

Table : Metal machining rates

Metal	Atomic weight	Ionic charge	Density	Removal rate	
			10^3 kg/m^3	10^{-3} kg/s	10^{-6} m^3/s
Aluminum	26.97	3	2.67	0.093	0.035
Beryllium	9.0	2	1.85	0.047	0.025
Chromium	51.99	2	7.19	0.269	0.038
		3		0.180	0.025
		6		0.090	0.013
Cobalt	58.93	2	8.85	0.306	0.035
		3		0.204	0.023
Niobium (Columbium)	92.91	3	9.57	0.321	0.034
		4		0.241	0.025
		5		0.193	0.020
Copper	63.57	1	8.96	0.660	0.074
		2		0.329	0.037
Iron	55.85	2	7.86	0.289	0.037
		3		0.193	0.025
Magnesium	24.31	2	1.74	0.126	0.072
Manganese	54.94	2	7.43	0.285	0.038
		4		0.142	0.019
		6		0.095	0.013
		7		0.081	0.011

Table : Metal machining rates (cotd)

Metal	Atomic weight	Ionic charge	Density 10^3 kg/m^3	Removal rate 10^{-3} kg/s	10^{-6} m^3/s
Molybdenum	95.94	3	10.22	0.331	0.032
		4		0.248	0.024
		6		0.166	0.016
Nickel	58.71	2	8.90	0.304	0.034
		3		0.203	0.023
Silicon	28.09	4	2.33	0.073	0.031
Tin	118.69	2	7.30	0.615	0.084
		4		0.307	0.042
Titanium	47.9	3	4.51	0.165	0.037
		4		0.124	0.028
Tungsten	183.85	6	19.3	0.317	0.016
		8		0.238	0.012
Uranium	238.03	4	19.1	0.618	0.032
		6		0.412	0.022
Zinc	65.37	2	7.13	0.339	0.048

7. ELECTROLYTES

Functions of Electrolyte:

1) to allow electrolysis to take place by completing the circuit
2) transfer heat generated in machining zone due to high current density (coolant)
3) carry away metal particles from machining area so as to prevent deposition on tool.

Basic requirements:

1) start and maintain anode dissolution at high efficiency
2) reduce or stop cathode dissolution due to etching

7. ELECTROLYTES (cont.....)

Other requirements of electrolyte:

- ✓ high conductivity; to reduce power losses
- ✓ low viscosity; to reduce pumping power
- ✓ high specific heat; to reduce tendency to boil
- ✓ high thermal conductivity; to reduce tendency to boil
- ✓ high boiling point; to reduce tendency to boil
- ✓ stable towards reaction products; to reduce machining variation
- ✓ not toxic
- ✓ not corrosive
- ✓ cheap, easy to get
- ✓ ease of recycling
- ✓ ease of disposal
- ✓ by-products of reaction must be readily soluble in electrolyte.

7. ELECTROLYTES (cont….)

Suitability of some work material – electrolyte combinations:

Electrolytes / Work Material	Salts			Acids	Alkalis	Salt Acid combns.	Alkali Salt combns.
	Chlorides	Nitrates	Sulphates				
Alloy steels	+	+	+	+	-	+	-
Nickel alloys	+	+	+	+	-	+	-
Stainless steels	+	+	+	+	-	+	-
High speed steels	+	+	+	+	-	+	-
Die steels	+	+	+	+	-	+	-
Cobalt alloys	+	+	+	+	-	+	-
Cobalt cemented carbides	-	-	-	-	o	-	o
Tungsten	-	-	-	-	+	-	o
Titanium alloys	+	-	-	+	-	o	-
Zirconium	+	-	-	+	-	+	-
Beryllium	+	+	+	-	-	-	-

Key: [+] suitable, [-] unsuitable, [o] limited suitability

Commonly used electrolytes:

- ✓ sodium salts, particularly sodium chloride
- ✓ hydrochloric and sulphuric acids.

7. ELECTROLYTES (cont….)

- In general any sufficiently active (chemically) electrolyte in transporting metals during electrolysis can be used.
- Some electrolytes have high corrosivity such as acids.

- Some are flammable when dry, such as chlorate and nitrate.

- The most widely used electrolyte is **sodium chloride**.

- Many metals can be machined using sodium chloride either on its own or in combination with other chemicals.

➢ cheap
➢ easily available
➢ worst electrolyte as far as stray machining is concerned.

Example of sodium chloride mixing is with potassium dichromate (a little) and sodium nitrate (equal amount).

7. ELECTROLYTES (cont….)

- The second most widely used electrolyte is **sodium nitrate**.

- Compared with sodium chloride:
  - more expensive
  - produces less stray machining
  - less corrosive
  - has lower conductivity
  - surface finish is better when certain alloys are machined.

- Other electrolytes are **sodium chlorate** (the least stray machining ie for precise machining, but explosive), potassium chloride, sodium hydroxide, sodium fluoride, and sulphuric acid and hydrochloric acid.

8. ELECTROLYTE CIRCULATION

Electrolyte flow is important to avoid electrolyte over-heating.

To estimate minimum electrolyte speed, a simple method is based on Joule's heating.

Assuming all heat produced by current flow is retained in the electrolyte, increse in temperature, δT, for gap distance, δx, according to Joule's and Ohm's Laws:

$$\delta T = \frac{J^2 \, \delta x}{k_e \, \rho_e \, c_e \, U}$$

where J = current density

k_e = electrolyte conductivity

ρ_e = electrolyte density (concentration)

c_e = electrolyte specific heat

U = electrolyte speed

8. ELECTROLYTE CIRCULATION (conti…)

To simplify analysis, increase in conductivity due to increase in temperature is ignored.

Integration of the above equation yields:

$$\mathbf{U = \frac{J^2 L}{k_e \rho_e c_e \Delta T}}$$

where L = length of electrode
ΔT = temperature difference between electrolyte entry and exit points through gap

Example: If J = 50 A cm^{-2}, L = 100 mm, k_e = 0.2 Ω^{-1}cm^{-1}, ρ_e = 1.1 g cm^{-3}, c_e = 4.18 J g^{-1} °C^{-1}. Let say ΔT needs to be limited to 75 °C to avoid boiling and let say input temperature is 25 °C. So, elctrolyte speed to maintain favourable condition is U = 3.6 ms^{-1}.

In practice, the electrolyte is circulated between 3 to 30 m/s to ensure that the solution is supplied continuously, to avoid boiling and to avoid heat build-up affecting the current flow.

8. ELECTROLYTE CIRCULATION (cotd)

Machining produces small particles (approximately 1 micron) of usually metal oxides and hydroxides. They affect electrolyte composition.

Methods to handle:

- ✓ use the electrolyte until its composition is unsuitable for ECM
- ✓ centrifugal separation
- ✓ sedimentation.

The first method is widely employed and popular for small-scale operations. For larger operations, this method is inconvenient and uneconomical.

One strategy of recycling is by providing two electrolyte tanks. Electrolyte from machining is delivered to a receiving tank and pumped to a clean tank through a centifuge, which separates the sludge. The filtered electrolyte is pumped to the machining area.

9. TOOLING

- ❑ Usual tool material: copper or brass – high electrical and thermal conductivity, easily machined.
- ❑ Stainless steel - where high stiffness is required to withstand hydraulic and electric forces.
- ❑ Titanium – works well with acid electrolytes.
- ❑ In ECM, the tool does not wear.

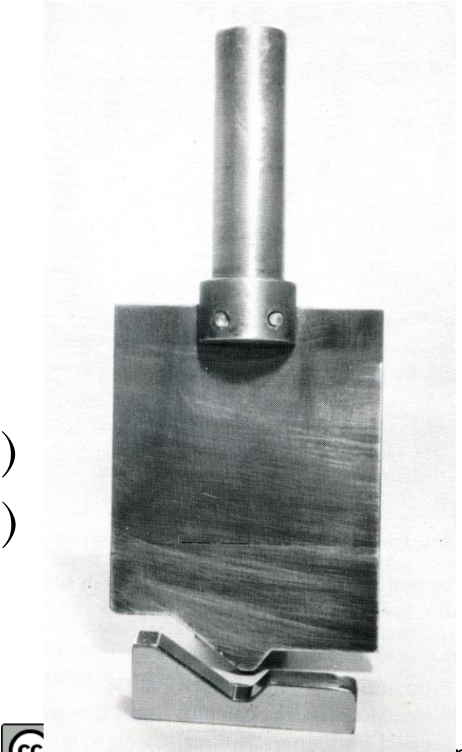


Figure: Example of cathode tool (above) and anode workpiece (below)

10.TOOL FEED

- Because tool does not wear in ECM, a servo control system is not required to maintain a certain gap distance.

- However, the tool needs to be fed at a constant rate, otherwise the gap distance will increase and this is undesirable in ECM.

- The feedrate depends on how fast it is required to remove material. This in turn depends on workpiece material and current density.

- The feedrate is very low but needs to be really smooth.

- The sliding movement of the tool can be controlled using a hydraulic cylinder, which allows an unlimited choice of feedrate.

- Tool feed rate (f) governs metal removal rate.

10. TOOL FEED (cont…)

- To obtain a relationship for change in gap distance, consider a tool fed towards a work material at a constant rate, f.

- Say a constant voltage V, is applied between two parallel electrodes (Fig. 6).

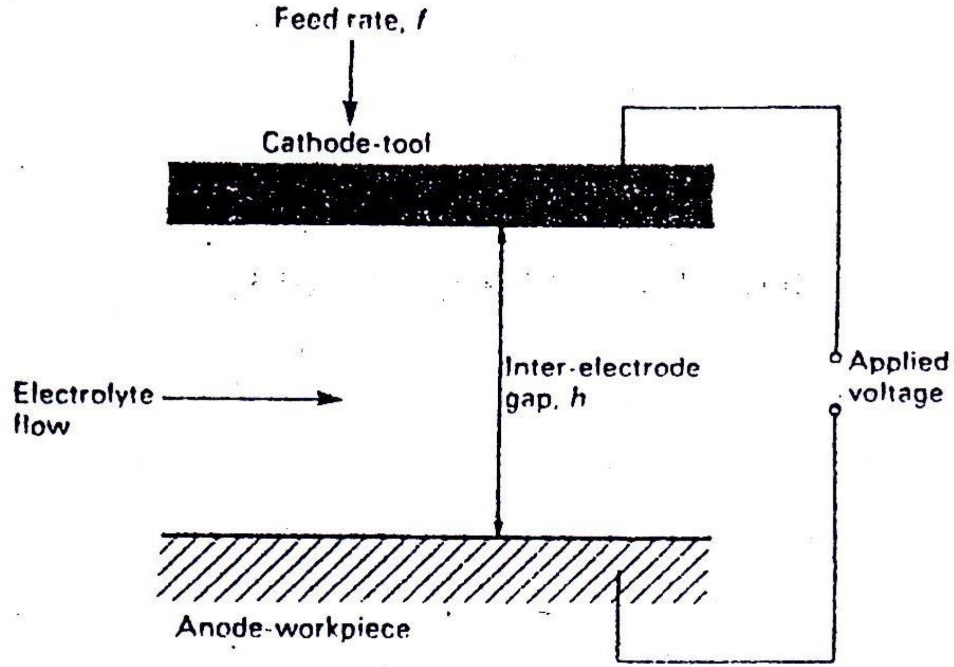


Fig. 6 Plane parallel electrodes in ECM.

10. TOOL FEED (cont….)

Assuming that specific conductivity of electrolyte, k, is unchanged and current efficiency is 100%, the rate of change of gap distance, h, relative to the tool surface is:

$$\frac{dh}{dt} = \frac{WJ}{z\rho F} - f \qquad \text{(eq 1)}$$

From Ohm’s Law, current density,

$$J = \frac{kV}{h} \qquad \text{(eq 2)}$$

Combining the two equations gives:

$$\frac{dh}{dt} = \frac{WkV}{z\rho Fh} - f \qquad \text{(eq 3)}$$

10. TOOL FEED (cont….)

CASE 1: If feedrate $f = 0$, ie tool does not move,
eq 3 yields the following solution for gap h(t) at time (t):

$$h^2(t) = h^2(0) + \frac{2WkVt}{z\rho F} \qquad \text{(eq 4)}$$

where h(0) is the initial gap.

This means, the gap distance increases at the square root of the machining time, t.

This condition is often used in **deburring** process using ECM. Burrs are removed in seconds without having to feed the tool.

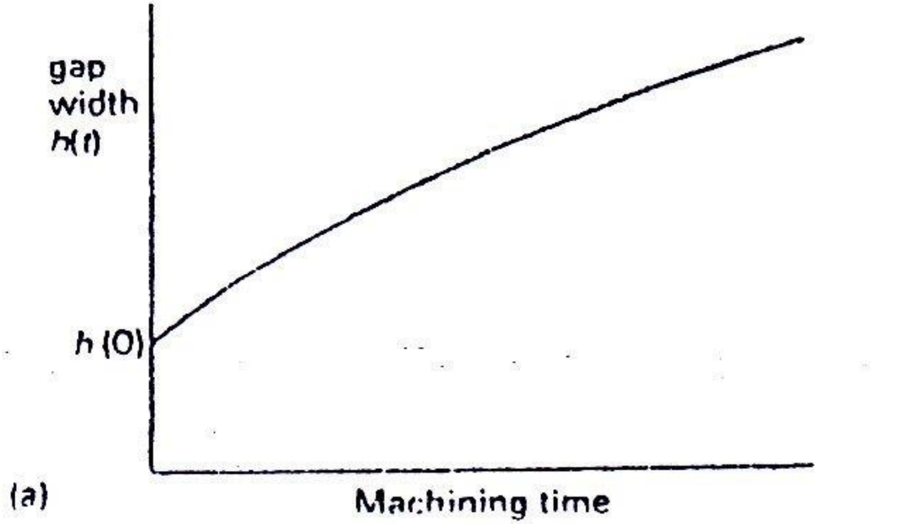


Figure: Variation of gap with machining time (electrode feedrate = 0)

10. TOOL FEED (cont…)

CASE 2: If a constant feedrate is used,

eq 3 yields the following solution:

$$t = \frac{1}{f}\, h(0) - h(t) + h_{eq} \ln_e \frac{h(0) - h_{eq}}{h(t) - h_{eq}} \quad \text{(eq 5)}$$

The figure shows gap distance approaching an equilibrium value, **h_{eq}**, given by:

$$h_{eq} = \frac{WkV}{z\rho Ff} \quad \text{(eq 6)}$$

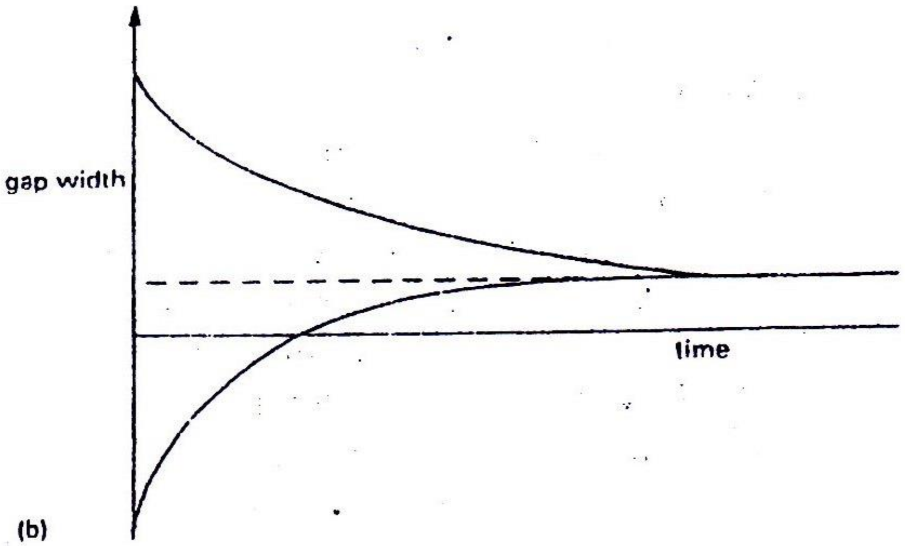


Figure: Variation of gap with machining time; gap attaining equilibrium value (constant electrode feedrate)

10. TOOL FEED (cont…..)

- The equilibrium gap is achieved when;

$$machining\ rate = tool\ feedrate$$

- It is a characteristic feature of ECM, where h α 1/f and h α applied voltage, V.
- If initially f is too low, large end gap exists between tool and workpiece. This gap reduces until metal removal rate is equal to f and gap becomes constant (equilibrium gap).
- Increase in f results in smaller equilibrium gap and proportionally higher current.
- If f is too high, the equilibrium gap obtained will be too small and this can cause sparking.

10. TOOL FEED (cont…..)

- Smaller gap means higher accuracy. Thus higher f results in greater accuracy.
- Increase in applied voltage results in large gap and lower accuracy.
- Supply voltage commonly used:
  - 20 V – rough machining
  - 5 V – fine machining.

Summary on feedrate (f), gap (h)and accuracy:

High f results in small equilibrium gap;

1) Small gap = higher current density = high MRR
2) Small gap = higher accuracy (workpiece copies tool better)

i.e., high MRR is also accompanied by high accuracy

This happens only in ECM

11. FACTORS AFFECTING ACCURACY

1. Stray current

Tool must be designed to the correct shape and inactive sections covered with an insulating material.

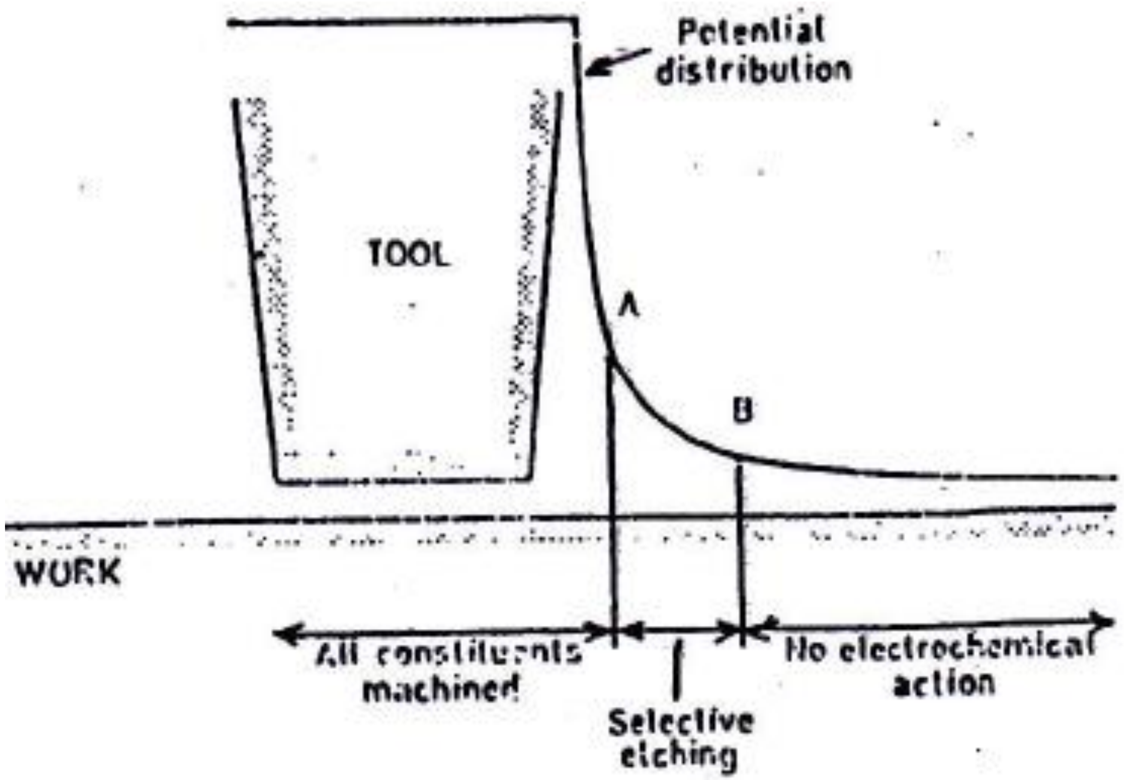


Figure: Effect of stray current

11. FACTORS AFFECTING ACCURACY(cont…)

2. Feed rate

Overcut will be produced in ECM, but variation in feed rate produces hole of varying diameter along its length.

3. Current

Variations in current produce effects similar to variations in feed rate. Instead of constant voltage supply, constant current supply is sometimes used.

4. Electrolyte

Variations in temperature, flow rate and chemical composition result in changes in electrical and thermal conductivity.

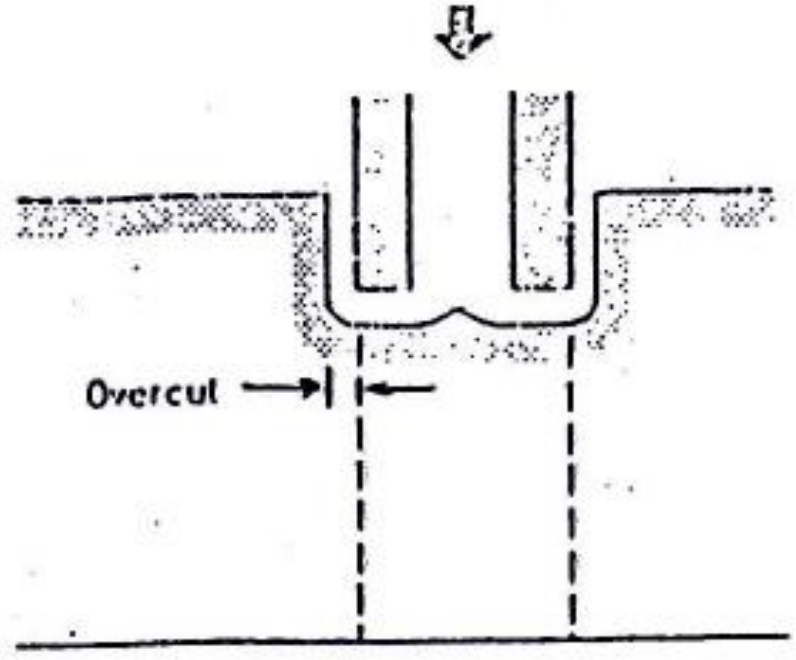


Figure: Overcutting in EC drilling

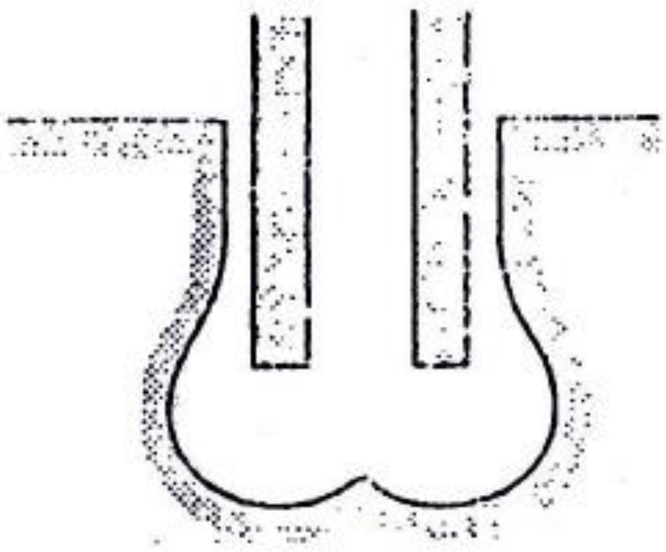


Figure: Effect of stopping tool feed

11. FACTORS AFFECTING ACCURACY(cont…)

5. **Machine stiffness**

Machine should be adequately stiff to withstand hydraulic and electric forces without undue deflection.

A large machine with workpiece surface area 0.5m x 0.25 m operating with electrolyte at 300 N/cm^2 *has to withstand a force of 200 kN in the direction tending to increase the gap;*

For a gap of 0.1 mm, there can be a transverse force of 100 N on both tool and workpiece due to viscous resistance to flow.

6. **Tool design**

Prediction of tool shape to produce a given workpiece shape can be a problem.

12. ACCURACY

Normal tolerance: ± 0.125 mm
0.0125 mm has been achieved

Stray current causes radiusing of corner
Minimum corner radius: 0.25 mm

Normal overcut value: 0.125 mm
Choice of electrolyte affects overcut and accuracy.

13. SURFACE FINISH

Depends on material machined and electrolyte used.

1. **Etched surface**
(uneven reflection of light due to non uniform dissolution of metal crystal).
Example: sodium chloride on steel and nickel alloy.
Surface finish: 1 μm Ra.

2. **Polished surface** (when high current density is used).
Mechanism of formation of polished surface not fully understood.

At times, presence of oxide layer is important.
Example: for nickel alloys, formation of nickel oxide layer is required in producing polished surface.
Surface finish for Nimonic using saturated sodium chloride: 0.2 μm Ra.

Surface finish for nickel-chromium steel using sodium chlorate: 0.1 μm Ra.

13. SURFACE FINISH (cont….)

3. **Rough surface**

Sometimes presence of oxide layer produces rough surface.
Example: titanium using chloride and nitrate solutions, because oxide produced is too passive.
When high voltage is used to break the oxide layer, result is not uniform due to deep grain boundary attack.

4. **Porous surface**

Surface with porous areas surrounded by polished areas. Porosity is due to evolution of gas at anode because gas bubbles break oxide layer and cause localised porosity.

14. ADVANTAGES OF ECM

- Can machine large area simultaneously (can produce whole 3D contour surface with single plunge operation)
- Highest MRR among electrical machining processes
- High MRR independent of hardness
  - > 400 Brinell: ECM is cheaper
  - < 400 Brinell: ECM can be cheaper
- No tool wear
- Stress free
- Bur free
- No thermal damage
- Complex shape easy to produce including deep holes
- With most metals, no effects on mechanical properties (yield strength, ultimate tesile strength)
- With tungsten and beryllium, conventional machining causes surface damage, not ECM
- Better wear, friction and corrosion resistance compared with conventional machining

16. DISADVANTAGES OF ECM

1) High capital cost
2) High maintenance cost
3) Exact control of process is difficult (tool design, lack of knowledge on electrochemistry, high current density etc)
4) Reduced fatigue characteristic
5) Requires special safety provision (gases, chemicals, high current)

17. ECM EQUIPMENT

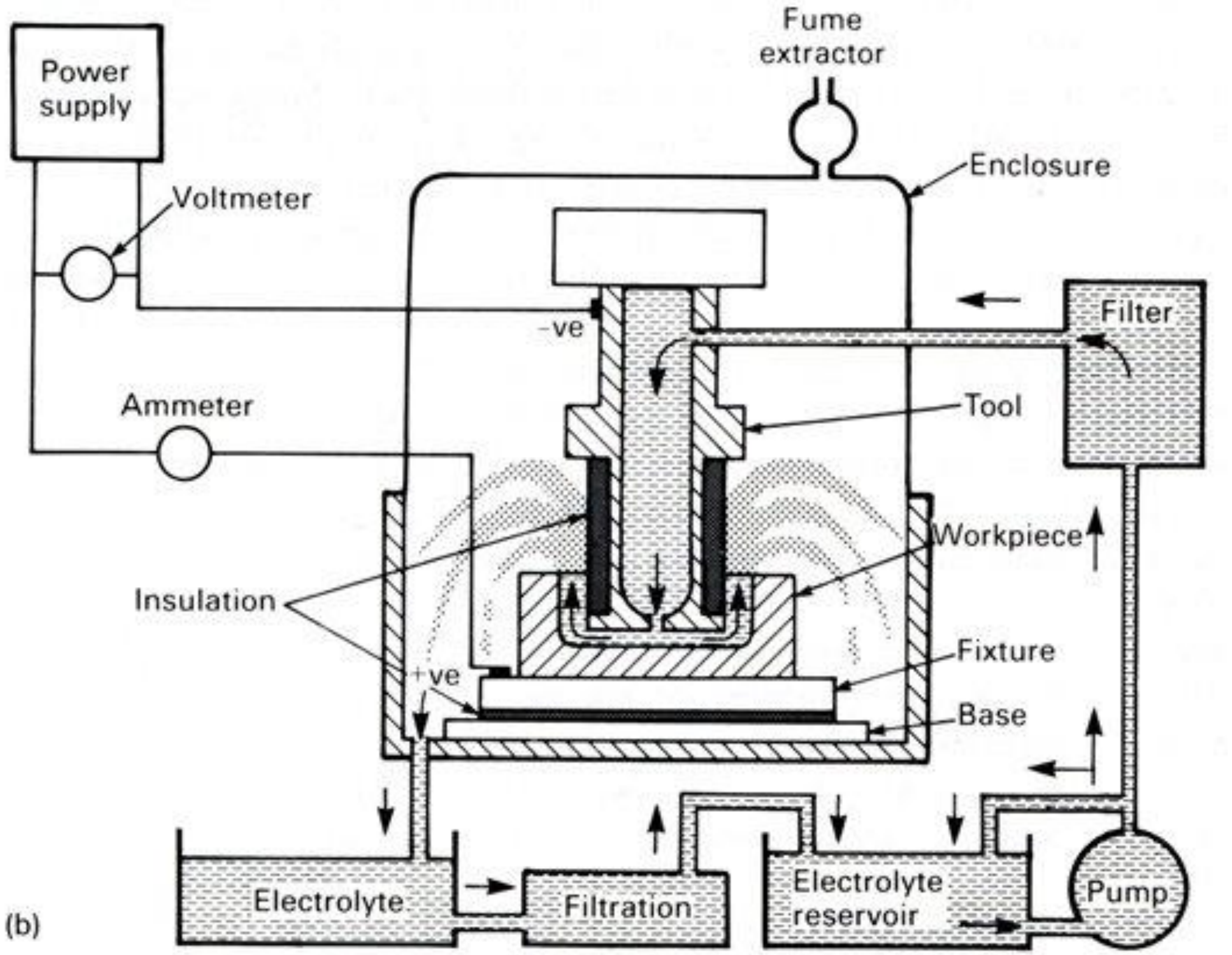


Figure: Industrial electrochemical machine

17. ECM EQUIPMENT (cotd)

- Equipment material must withstand corrosion by electrolyte.

Example: stainless steel, PVC coated concrete, graphite, organic coating (PU, nylon, epoxy).

Machine members must be strong/rigid to withstand hydrodynamic force.

- Spindle to be equipped with controlled linear movement (can control speed and can move rapidly).
- System for hydrogen gas extraction.
- System for circulation of electrolyte (pump, filter, heat exchanger).

Case study 1: Gas turbine

Method 1: individual airfoils are CNC milled, then anchored by nuts and bolts in a slotted central retainer.
Method 2: ECM of one-piece bladed disk (called a blisk). One blisk can replace up to 120 parts or more in an engine.

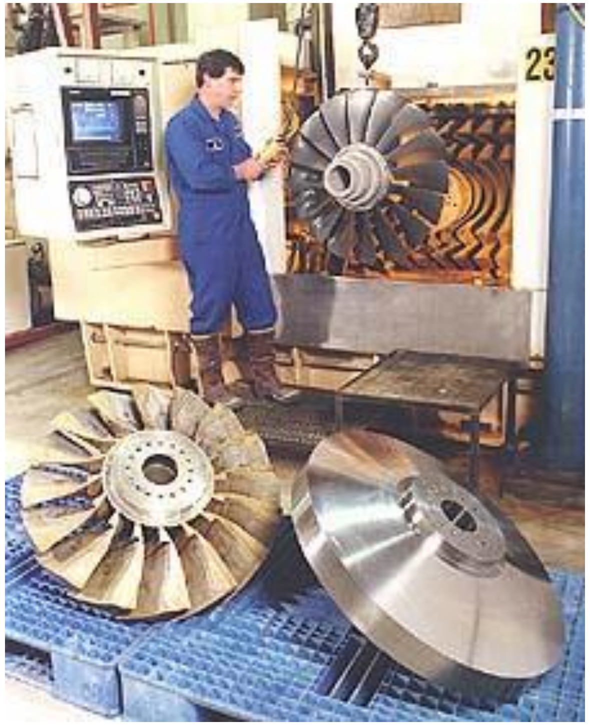


Figure: ECM of turbine blisk in 3 stages - forging (lower right), rough cut (lower left), and finish cut by ECM *[Sermatech Cincinnati, USA]*

Figure: Compressor blisk by ECM in F110 fighter engine feature both reduced mass and complexity compared to individually bladed rotors

Case study 1: **Gas turbine** (cont…)

Advantages of blisk using ECM:

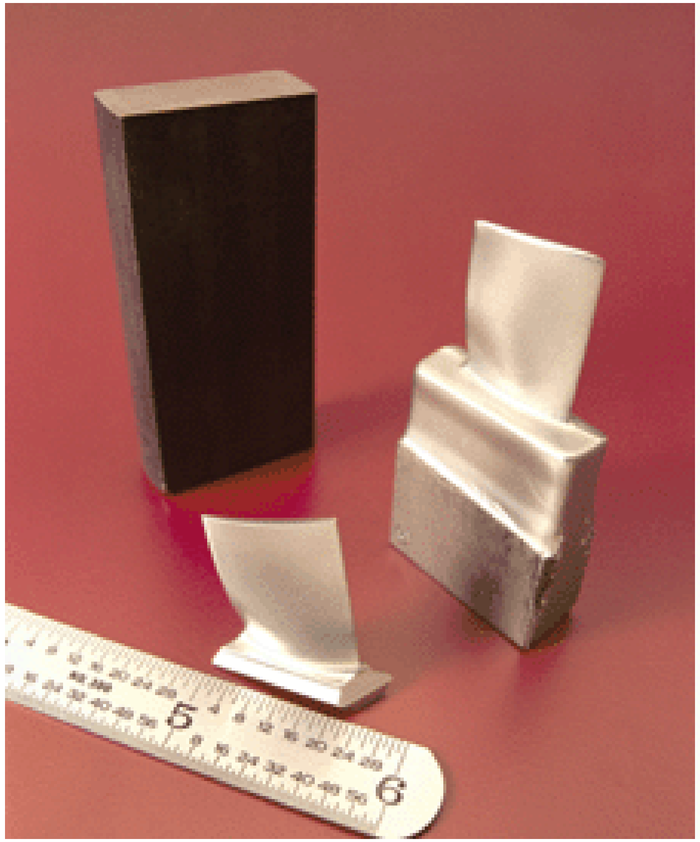
1) reduced aerodynamic losses, weight, and complexity of engine, 2) reduced dimensional deviations from 14 to 6%,

3) pitch, twist, and camber of airfoil shapes can be optimized by computer-aided design,

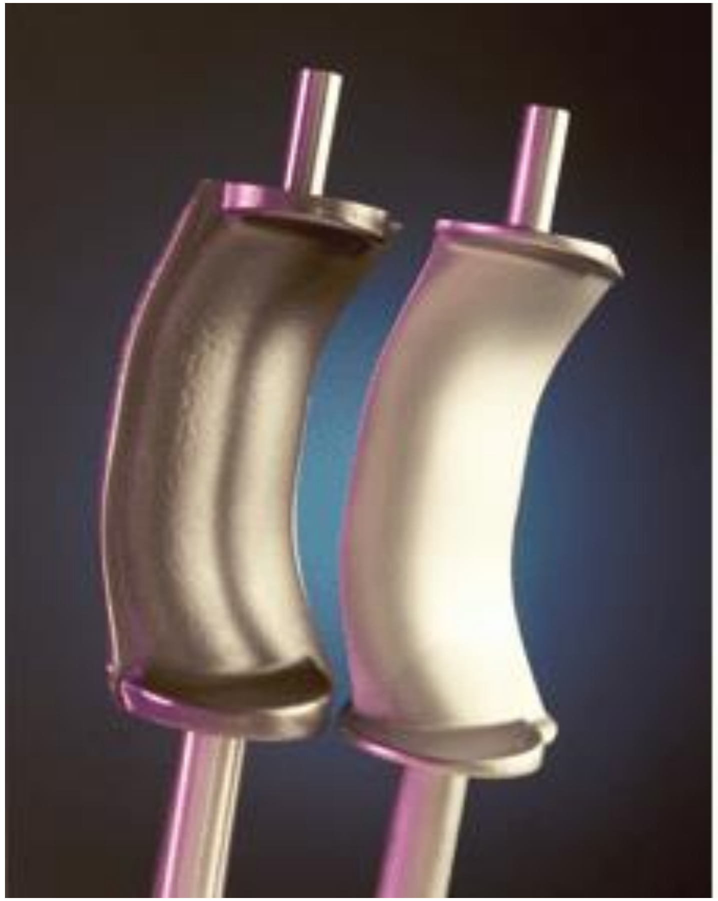
4) ECM can machine taller and thinner blades, compared with conventional milling,

5) airfoils on blisks can be spaced 10 to 15% closer than milled components,

6) ECM ensures smoother airfoils (better surface finish).



Compressor:
The platform and all edges of the airfoil (foreground) are machined from bar stock (back) by ECM in a single operation.



Spindle vane :
A rough cut of a part, is forged (left), then finished to specified tolerances by ECM (right).

SOME VARIATIONS OF ELECTROCHEMICAL MACHINING PROCESSES

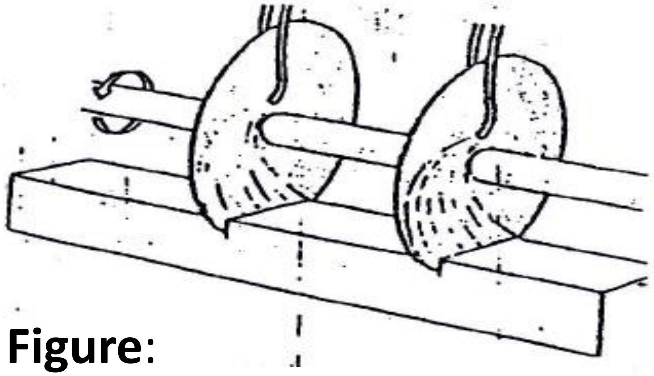


Figure:
Electrochemical Cutting-off

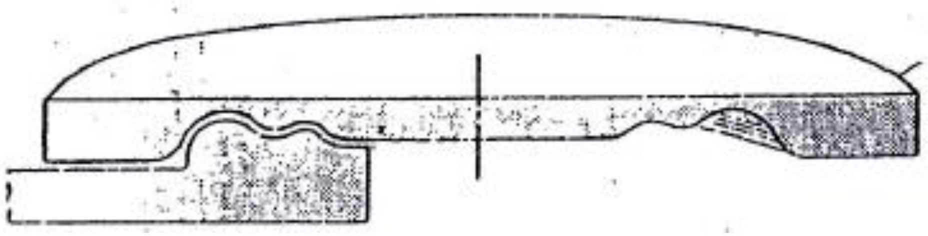
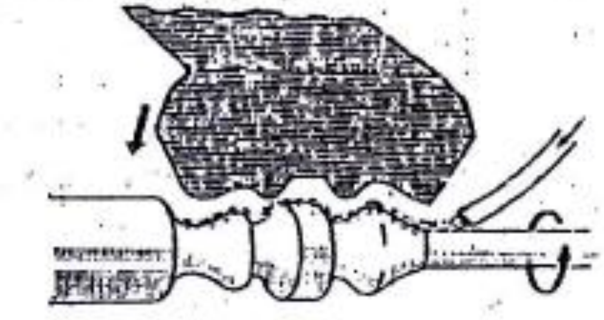


Figure: Electrochemical Turning of thin part



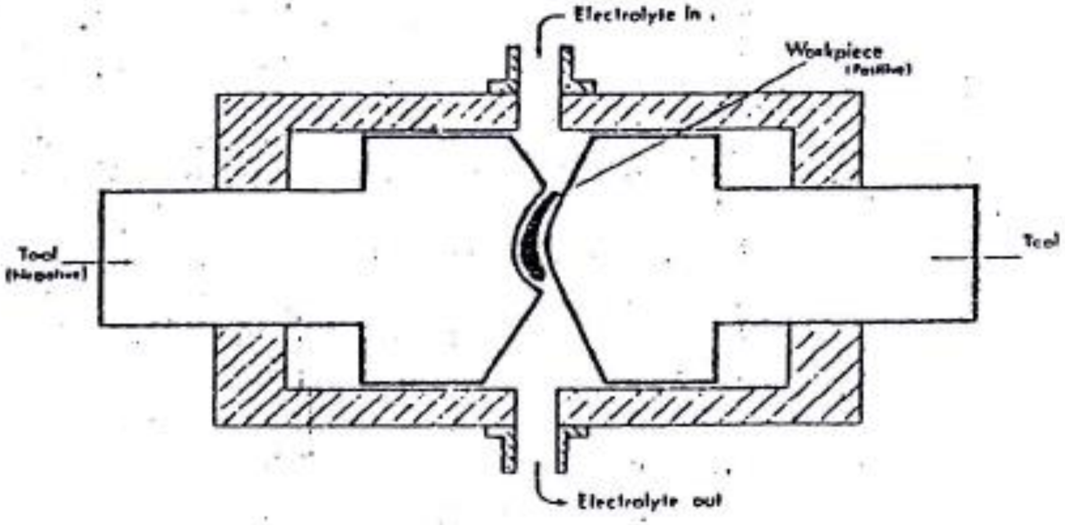


Figure: Electrochemical Turning

Figure: Electrochemical Shaping

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