ELECTROCHEMICAL MACHINING

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Instructional Objectives

- Identify electro-chemical machining (ECM) as a particular type of non-tradition processes
- Describe the basic working principle of ECM process
- Draw schematically the basics of ECM
- Draw the tool potential drop
- Describe material removal mechanism in ECM

Instructional Objective

- Identify the process parameters in ECM
- Develop models for material removal rate in ECM
- Analyse the dynamics of ECM process
- Identify different modules of ECM equipment
- List four application of ECM
- Draw schematics of four such ECM applications

CLASSIFICATIONS OF NTM PROCESSES

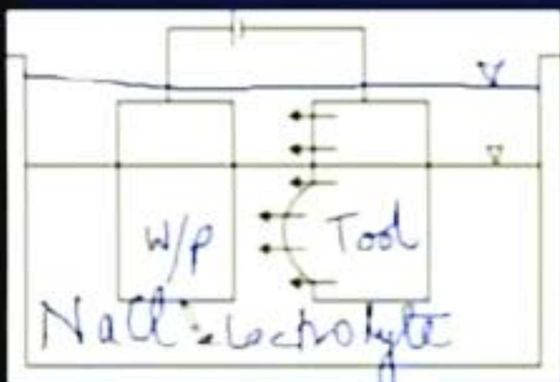
Mechanical Processes

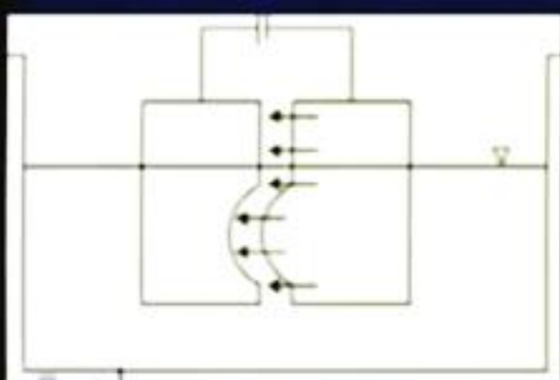
- Abrasive Jet Machining (AJM)
- Ultrasonic Machining (USM)
- Water Jet Machining (WJM)
- Abrasive Water Jet Machining (AWJM)

Electrochemical Processes

- Electrochemical Machining (ECM)
- Electro Chemical Grinding (ECG)
- Electro Jet Drilling (EJD)

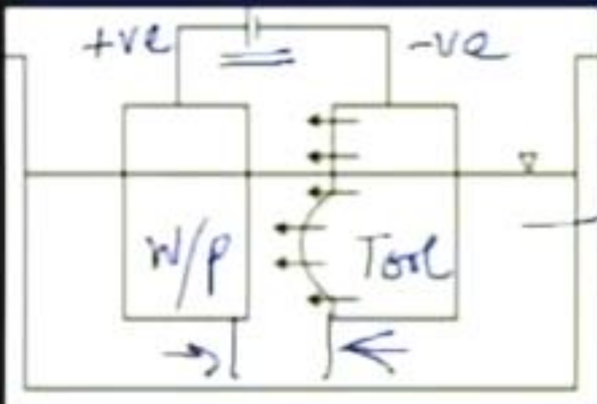
Electro Chemical Machining – Process

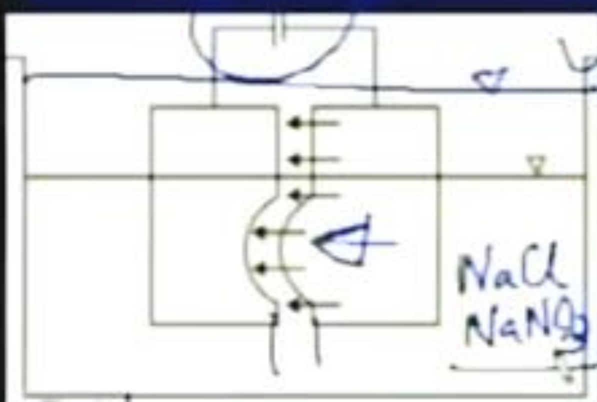




- Opposite of electro-chemical deposition
- Controlled anodic dissolution
- Tool and work piece – conductive
- Tool – cathode
- Work piece – anode
- Low potential
- High current
- Machining gap to maintained
- Electrolyte

Electro Chemical Machining – Process





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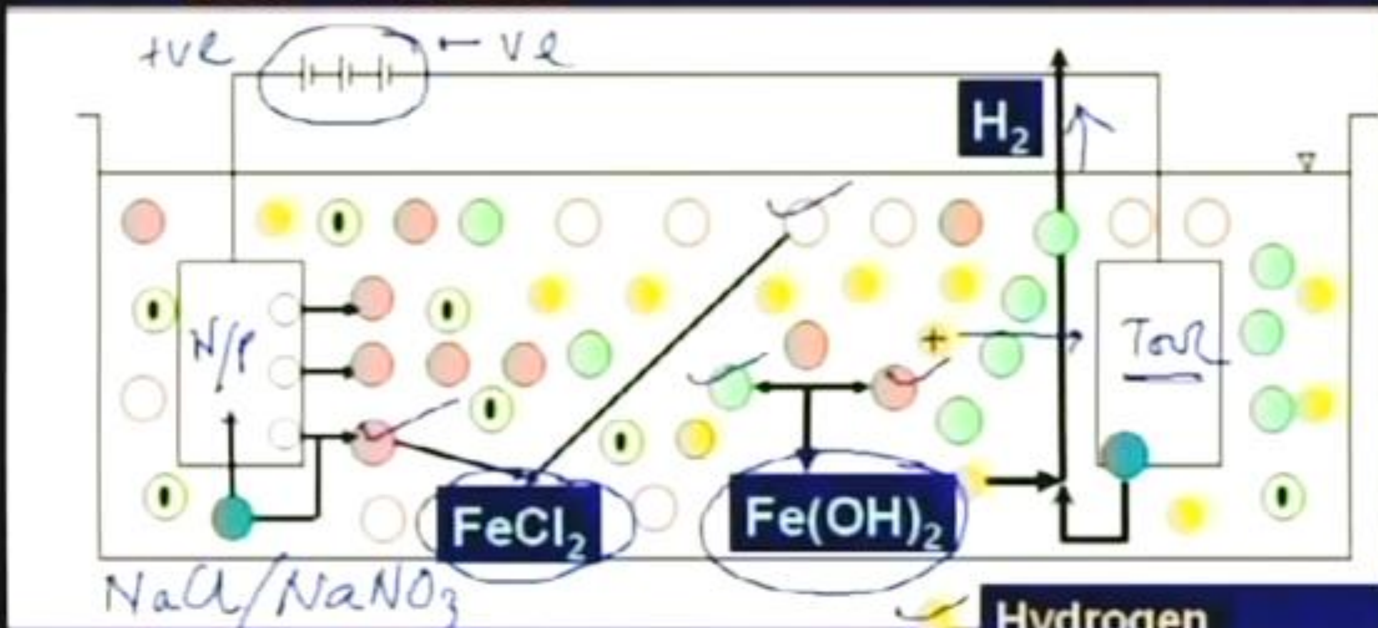
ECM – Process



- Hydrogen
- Hydroxyl ion
- Ferrous Ion
- Sodium Ion
- Chloride Ion

- Type direct current
- Voltage 2 to 35 V

Process Parameters

- Power Supply
  - Type — direct current
  - Voltage — 2 to 35 V
  - Current — 50 to 40,000 A
  - Current density — 0.1 A/mm^2 to 5 A/mm^2
- Working gap — 0.1 mm to 2 mm
- Overcut — 0.2 mm to 3 mm
- Feed rate — 0.5 to 15 mm/min
- Electrode material — Copper, brass, bronze
- Ra — 0.2 to 1.5 μm

Process Parameters

- Electrolyte

– Material	NaCl and $NaNO_3$
– Temperature	20°C – 50°C
– Flow rate	20 lpm per 100 A current
– Pressure	0.5 to 20 bar
– Dilution	100 g/l to 500 g/l

Characteristics of ECM

- Tool and Work Material – electrically conductive
- Atomic level dissolution
- Surface finish excellent
- Almost stress free machined surface
- No thermal damage.

Modelling of MRR in ECM

- Material removal due to atomic dissolution of work material
- Electrochemical dissolution is governed by Faraday's laws
- Amount of electrochemical dissolution or deposition proportional to amount of charge
- Amount of material deposited or dissolved depends on Electrochemical Equivalence (ECE)
  ECE – ratio of atomic weight and valency

ELECTRO CHEMICAL MACHINING - PROCESS

- Opposite of electro-chemical deposition
- Controlled anodic dissolution
- Tool and work piece – conductive
- Tool – Cathode
- Work piece – anode
- Low potential
- High current
- Machining gap to maintained
- electrolyte

PROCESS PARAMETERS

- Power Supply
  - Type Direct Current
  - Voltage 2 to 35 V
  - Current 50 to 40,000 A
  - Current density $0.1\ A/mm^2$
- Working gap 0.1 mm to 2 mm
- Overcut 0.2 mm to 3 mm
- Feed rate 0.5 mm to 15 mm/min
- Electrode material Copper, brass, bronze
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CHARACTERISTICS OF ECG

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MODELING OF MMR IN ECG

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ECE – ratio of atomic weight and valency

MODELING OF MMR IN ECM

m α Q m α ECE α $\frac{A}{v}$ m α $\frac{QA}{v}$ α $\frac{ItA}{v}$

m=$\frac{ItA}{Fv}$ F= Faraday's Law

= 96500 Coulomb

MRR= $\frac{m}{t\rho}$= $\frac{ItA}{Fvt\rho}$= $\frac{IA}{Fv\rho}$

Modelling of MRR for Alloys in ECM

Atomic Wt. – A_i Valency – v_i Wt fraction – α_i

For passing current of 'I' for time 't', Γ_a volume of alloy gets dissolved

$$m_i = \Gamma_a \rho \alpha_i \qquad m_i = \frac{Q_i A_i}{F v_i}$$

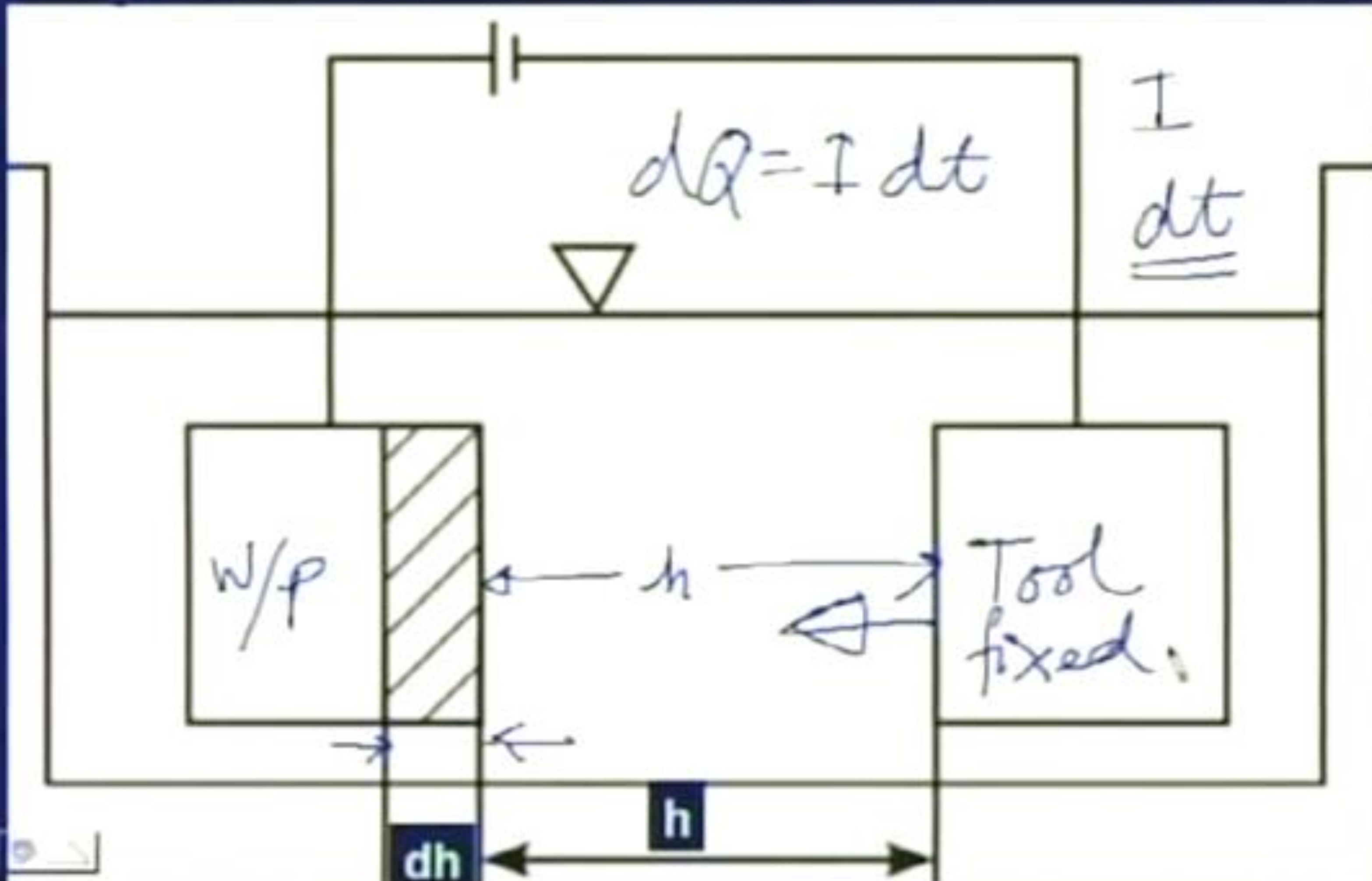
$$\Rightarrow Q_i = \frac{F m_i v_i}{A_i} = \frac{F(\Gamma_a \rho \alpha)_i v_i}{A_i}$$

$$\boxed{MRR = \frac{m}{t\rho} = \frac{ItA}{Fvt\rho} = \frac{IA}{F\rho v}}$$

$$Q_T = It = \sum Q_i = F\Gamma_a \rho \sum\left(\frac{\alpha_i v_i}{A_i}\right)$$

$$\boxed{MRR = \frac{\Gamma_a}{t} = \frac{I}{F\rho} \cdot \frac{1}{\sum \frac{\alpha_i v_i}{A_i}}}$$

Dynamics of ECM – No Feed Condition



Dynamics of ECM – No Feed Condition

'I' is passed for time 'dt' & electrochemical dissolution of the material of amount 'dh' over an area of S takes place

$$I = \frac{V}{R} = \frac{V}{\frac{rh}{s}} = \frac{Vs}{rh}$$

$$\boxed{MRR = \frac{IA}{F\rho v} = \frac{dh}{dt}s}$$

$$\frac{dh}{dt} = \frac{A_x}{F\rho v_x}\left(\frac{Vs}{rh}\cdot\frac{1}{s}\right) = \frac{A_x}{F\rho v_x}\cdot\frac{V}{rh}$$

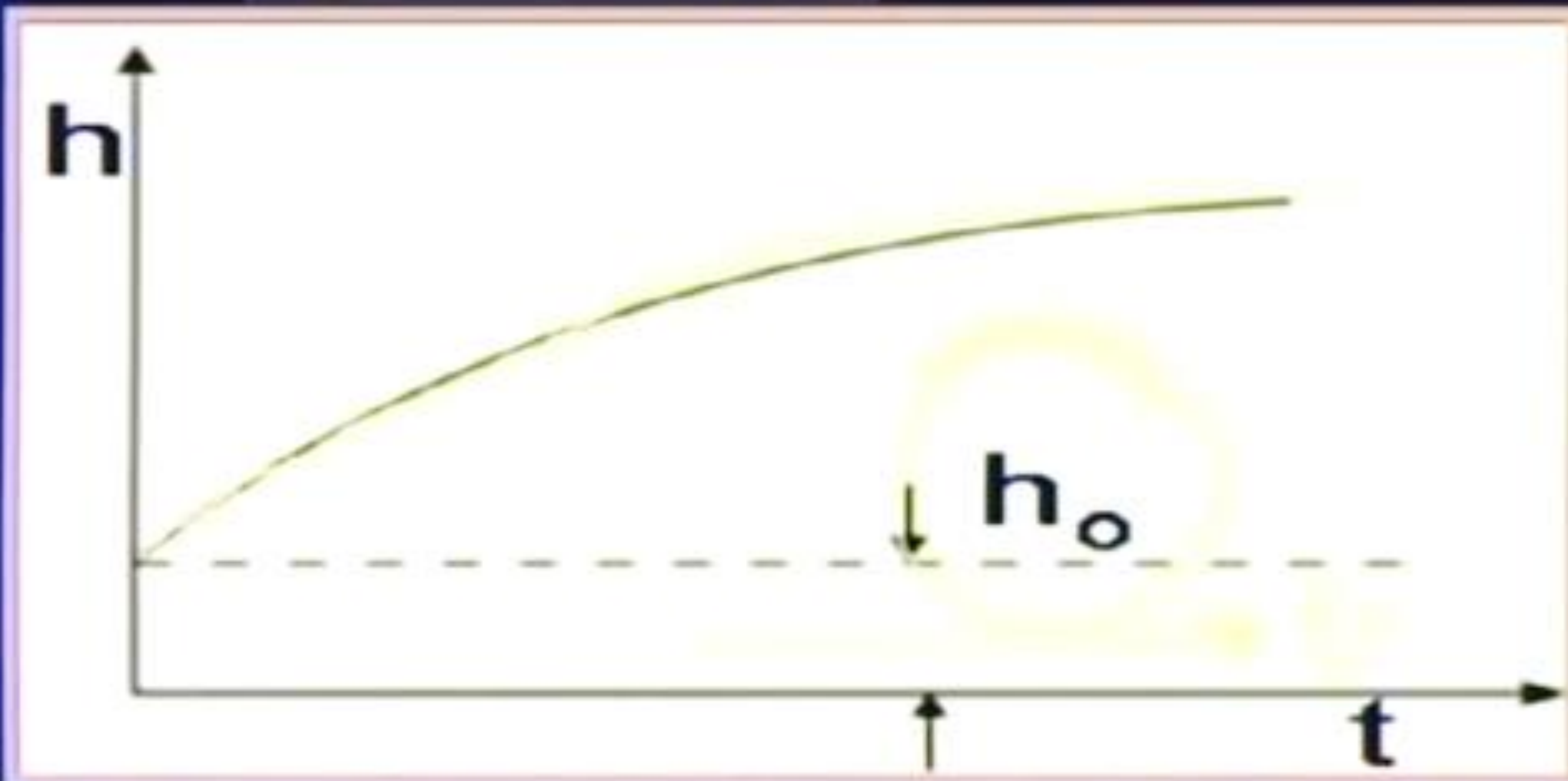
$$\frac{dh}{dt} = \frac{A_x V}{F\rho v_x r}\cdot\frac{1}{h} = \frac{c}{h}$$

$$C = \frac{A_x V}{F\rho v_x r}$$

$$c = \frac{V}{F\rho r\sum\frac{\alpha_i v_i}{A_i}}$$

Dynamics of ECM – No Feed Condition

$$\boxed{\frac{dh}{dt} = \frac{c}{h}} \qquad \int_{h_o}^{h_1} h\,dh = c\int_0^t dt \qquad \boxed{h_1^2 - h_o^2 = 2ct}$$



Dynamics of ECM – Feed Condition

Generally in ECM a feed (f) is given to the tool

$$\boxed{\frac{dh}{dt} = \frac{c}{h} - f}$$

Under steady state condition the gap is uniform i.e. the approach of the tool is compensated by dissolution of the work material.

$$\boxed{\frac{dh}{dt} = 0 = \frac{c}{h} = f} \qquad \boxed{f = \frac{c}{h}}$$

$$\boxed{h^{*} = \textit{steady state gap} = \frac{c}{f}}$$

Is it possible to $h_0 = h^*$?

$$\frac{dh}{dt} = \frac{c}{h} - f \qquad h' = \frac{h}{h^*} = \frac{hf}{c} \qquad t' = \frac{ft}{h^*} = \frac{f^2 t}{c}$$

$$\therefore \frac{dh'}{dt'} = \frac{f/c}{f^2/c} \cdot \frac{dh}{dt} = \frac{1}{f} \cdot \frac{dh}{dt} \qquad \frac{dh}{dt} = \frac{c}{h} - f$$

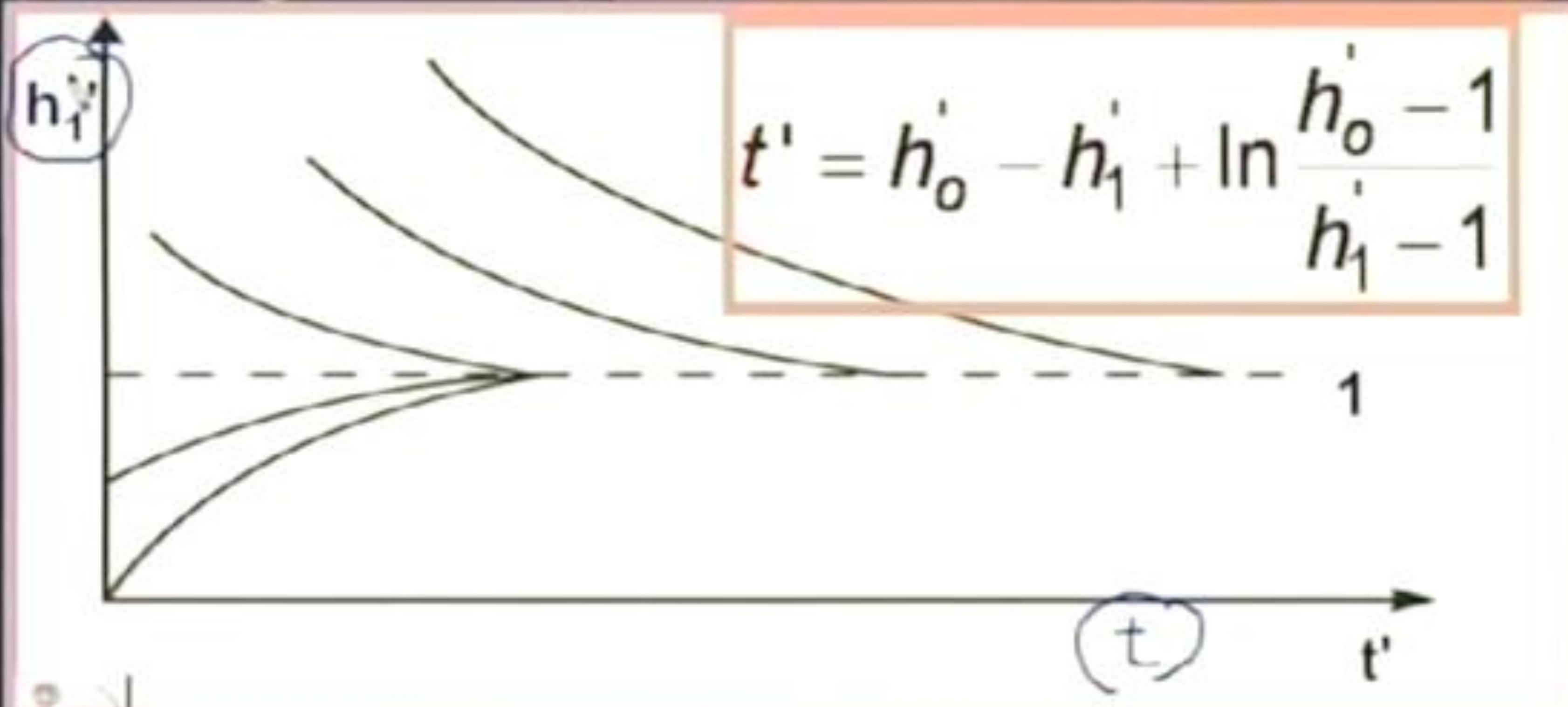
$$f\frac{dh'}{dt'} = \frac{c}{h'h^*} - f = \frac{cf}{h'c} - f \qquad f\frac{dh'}{dt'} = f\left(\frac{1-h'}{h'}\right)$$

$$\frac{dh'}{dt'} = \frac{1-h'}{h'} \qquad dt' = \frac{h'}{1-h'}dh'$$

Simulation for ho'= 0, 0.5, 1 – 5

$$\int_0^{t'} dt' = \int_{h_o'}^{h_1'} \frac{h'}{1-h'}\, dh'$$

$$t' = \int_{h_o'}^{h_1'} -\frac{d(1-h')}{(1-h')} + \int_{h_o'}^{h_1'} d(1-h')$$

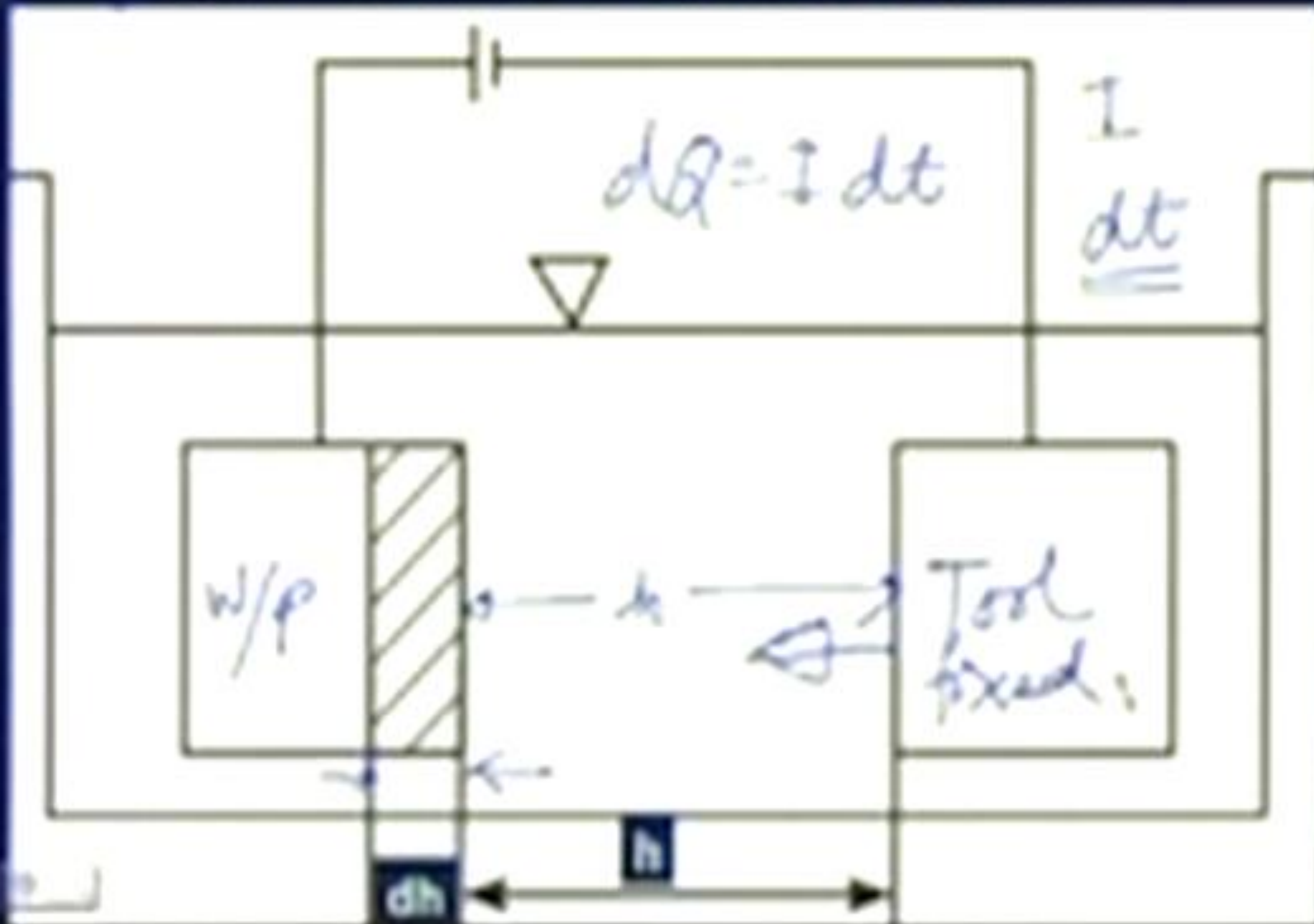


$$t' = h_o' - h_1' + \ln\frac{h_o' - 1}{h_1' - 1}$$

Thus irrespective of initial gap, h' = 1

$$\boxed{h' = \frac{h}{h^*} = \frac{hf}{c} = 1} \qquad \boxed{f = \frac{c}{h} = \frac{A_x V}{F \rho v_x r} \cdot \frac{1}{h}}$$

Dynamics of ECM – No Feed Condition



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$$h' = \frac{h}{h^*} = \frac{hf}{c} = 1$$

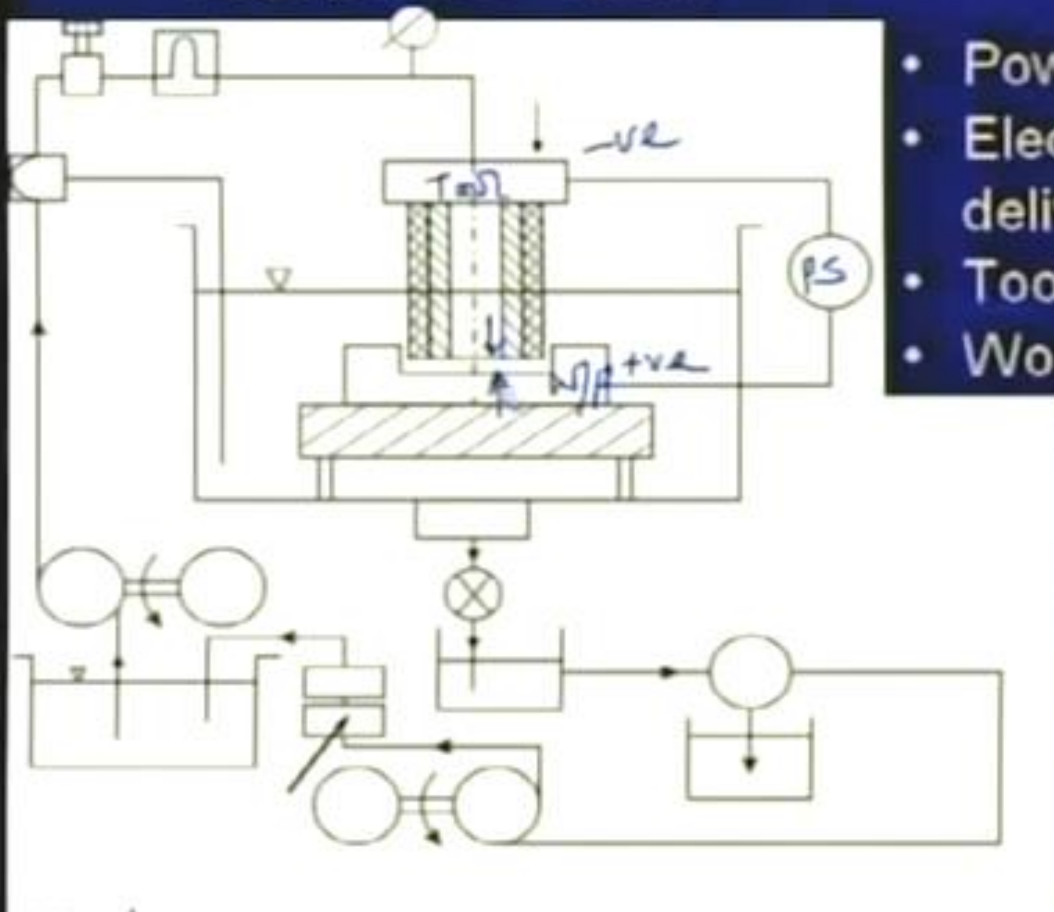
$$f = \frac{c}{h} = \frac{A_x V}{F \rho v_x r} \cdot \frac{1}{h}$$

$$f = \frac{A_x}{F \rho v_x} \cdot \frac{V}{rh} = \frac{A_x}{F \rho v_x} \cdot \frac{I}{s}$$

as $I = \frac{V}{R} = \frac{V}{\frac{rh}{s}} = \frac{Vs}{rh}$

$$f = \frac{A_x}{F \rho v_x} \cdot \frac{I}{\boxed{s}} = \text{MRR in mm/s}$$

Equipment – ECM



- Power supply
- Electrolyte filtration & delivery system
- Tool feed system
- Working tank

DYNAMICS of ECM – FEED CONDITION

- Generally in ECM a feed (f) is given to the fool
- $\frac{dh}{dt} = \frac{c}{h}$ = f
- Under steady state condition the gap is uniform i.e the approach of the tool is compensated by dissolution of the work material

$\frac{dh}{dt} = 0 = \frac{c}{h}$ = f

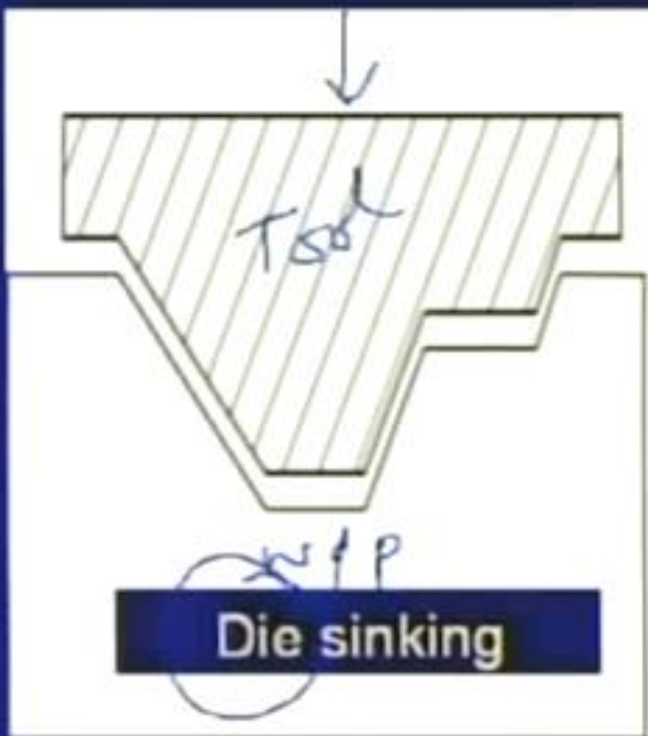
$f = \frac{c}{h}$

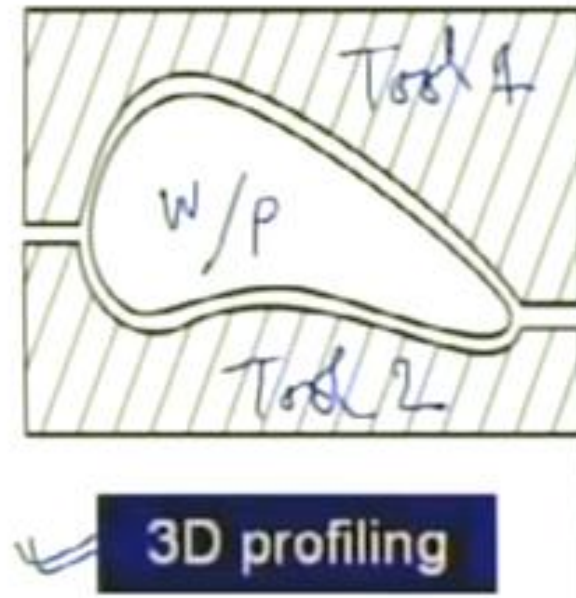
$$h^* = steady\ state\ gap = \frac{c}{h}$$

APPLICATIONS - ECM

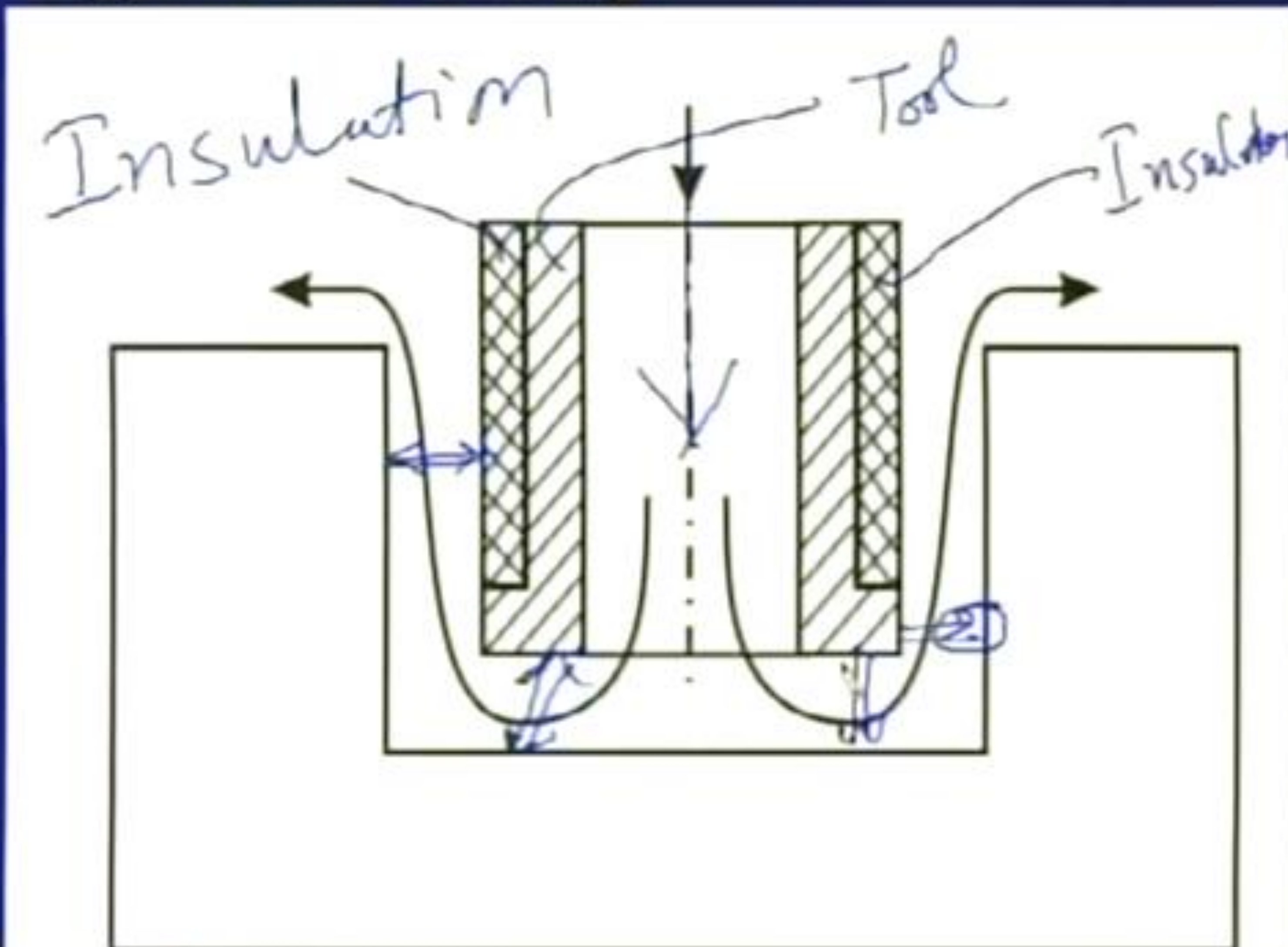
- Ore sinking
- Profiting and contouring
- Trepanning
- Grinding
- Drifting
- Micro-machining

Applications

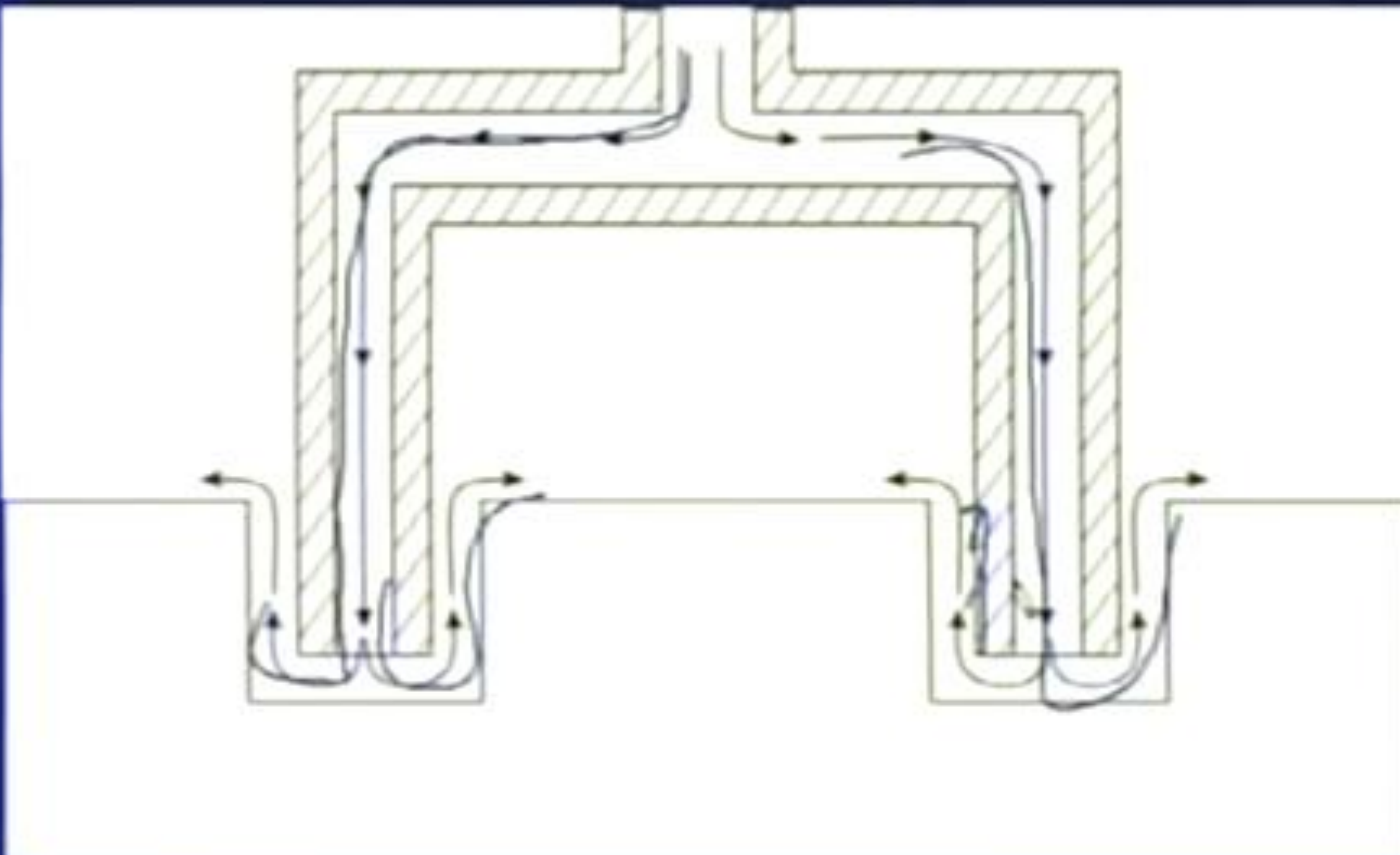




Application – Drilling



Application – Trepanning



QUIZ

1. For ECM of steel which is used as the electrolyte
   - Kerosene
   - **NaCl**
   - Deionised water
   - HNO_3
2. MRR in ECM depends on
   - Hardness
   - **Atomic weight**
   - Thermal conductivity
   - ductility

Quiz

3. ECM cannot be undertaken for
   - steel
   - Nickel based superalloy
   - Al_2O_3
   - Titanium alloy
4. Commercial ECM is carried out at a combination of
   - low voltage high current
   - low current low voltage
   - high current high voltage
   - low current low voltage

Solved Problem – 1

- In electrochemical machining of pure iron a material removal rate of 600 mm³/min is required. Estimate current requirement.

$$MRR = \dot{m} = \frac{m}{t} = \frac{AI}{F\nu}$$

$$MRR = \dot{\Gamma} = \frac{m}{\rho t} = \frac{AI}{F\rho\nu}$$

$$MRR = 600\ mm^3/min = 600/60\ mm^3/s$$
$$= 10\ mm^3/s = 10\times10^{-3} cc/s$$

$$10\times10^{-3} = \frac{56\times I}{96500\times7.8\times2}$$

Solved Problem – 1

- In electrochemical machining of pure iron a material removal rate of 600 mm³/min is required. Estimate current requirement.

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$$10\times10^{-3} = \frac{56\times I}{96500\times7.8\times2}$$

As $A_{Fe} = 56$

$v_{Fe} = 2$

$F = 96500$ coulomb

$\rho = 7.8$ gm/cc

$$I = \frac{96500\times10\times10^{-3}\times7.8\times2}{56}$$

$I = 268.8$ A

Answer

Solved Problem – 2

Composition of a Nickel superalloy is as follows: Ni = 70.0%, Cr = 20.0%, Fe = 5.0% and rest Ti. Calculate rate of dissolution if the area of the tool is 1500 mm^2 and a current of 1000 A is being passed through the cell. Assume dissolution to take place at lowest valency of the elements:

$A_{Ni} = 58.71$	$\rho^{Ni} = 8.9$	$\nu^{Ni} = 2$
$A_{Cr} = 51.99$	$\rho^{Cr} = 7.19$	$\nu^{Cr} = 2$
$A_{Fe} = 55.85$	$\rho^{Fe} = 7.86$	$\nu^{Fe} = 2$
$A_{Ti} = 47.9$	$\rho^{Ti} = 4.51$	$\nu^{Ti} = 3$

Ni 70.0%, Cr 20.0%, Fe 5.0% & rest Ti

Ni	58.71	ρ	8.9	ν	2
Cr	51.99	ρ	7.19	ν	2
Fe	55.85	ρ	7.86	ν	2
Ti	47.9	ρ	4.51	ν	3

$$\rho_{alloy} = \frac{1}{\sum \frac{\alpha_i}{\rho_i}} = \frac{1}{\frac{\alpha_{Ni}}{\rho_{Ni}} + \frac{\alpha_{Cr}}{\rho_{Cr}} + \frac{\alpha_{Fe}}{\rho_{Fe}} + \frac{\alpha_{Ti}}{\rho_{Ti}}} = \frac{1}{\frac{0.7}{8.9} + \frac{0.2}{7.19} + \frac{0.05}{7.86} + \frac{0.05}{4.51}} = 8.07 \text{ gm/cc}$$

$$MRR = \frac{m}{\rho t} = \frac{I}{F\rho \sum \frac{\alpha_i \nu_i}{A_i}}$$

$$= \frac{1000}{96500 \times 8.07 \times \left\{\frac{0.75 \times 2}{58.71} + \frac{0.2 \times 2}{51.99} + \frac{0.05 \times 2}{55.85} + \frac{0.05 \times 3}{47.9}\right\}}$$

$= 0.0356$ cc/sec

$= 2.14$ cc/min

$= 2140$ mm^3/min

Solve Problem – 3

In ECM operation of pure iron an equilibrium gap of 2 mm is to be kept. Determine supply voltage, if the total over-voltage is 2.5 V. The resistivity of the electrolyte is 50 Ω-mm and the set feed rate is 0.25 mm/min.

$$h^* = \frac{c}{f}$$

$$c = \frac{VA_{Fe}}{F\rho_{Fe}r\,v_{Fe}}$$

$$c = \frac{(V-2.5)\times 55.85}{96500\times 7.8\times 10^{-3}\times 50\times 2}$$

$$= \frac{(V-2.5)}{1347.7}$$

$$h^* = 2 = \frac{c}{f} = \frac{(V-2.5)}{1347\times\frac{0.25}{60}}$$

$$2 = \frac{V-2.5}{5.615}$$

$$V = 8.73\ \text{Volt}$$

Answer