

ELECTRO CHEMICAL MACHINING

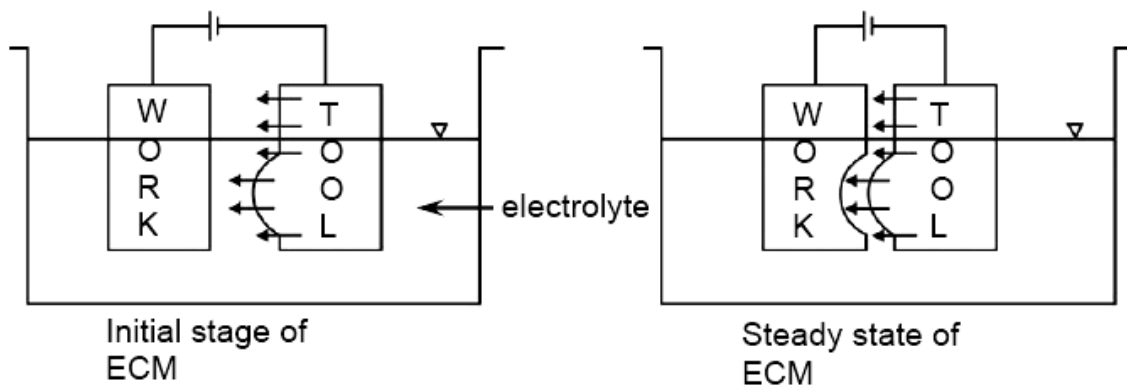
Introduction:

The process of metal removal by electro chemical dissolution was known as long back as 1780 AD but it is only over the last couple of decades that this method has been used to advantage. It is also known as contactless electrochemical forming process. The noteworthy feature of electrolysis is that electrical energy is used to produce a chemical reaction, therefore, the machining process based on this principle is known as Electrochemical machining (ECM). This process works on the principle of Faraday's laws of electrolysis.

Michael Faraday discovered that if the two electrodes are placed in a bath containing a conductive liquid and DC potential (5-25V) is applied across them, metal can be depleted from the anode and plated on the cathode. This principle was in use for long time. ECM is the reverse of the electroplating.

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

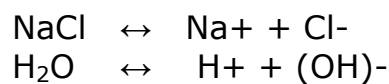
In ECM, Electrolyte is so chosen that there is no plating on tool and shape of tool remains unchanged. If the close gap (0.1 to 0.2mm) is maintained between tool and work, the machined surface takes the replica of tool shape.



Chemistry of Process.

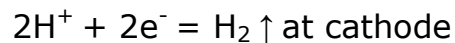
During ECM, there will be reactions occurring at the electrodes i.e. at the anode or work piece and at the cathode or the tool along with within the electrolyte.

Let us take an example of machining of low carbon steel which is primarily a ferrous alloy mainly containing iron. For electrochemical machining of steel, generally a neutral salt solution of sodium chloride (NaCl) is taken as the electrolyte. The electrolyte and water undergoes ionic dissociation as shown below as potential difference is applied

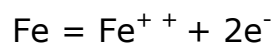


As the potential difference is applied between the work piece (anode) and the tool (cathode), the positive ions move towards the tool and negative ions move towards the work piece.

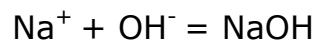
Thus the hydrogen ions will take away electrons from the cathode (tool) and form hydrogen gas as:



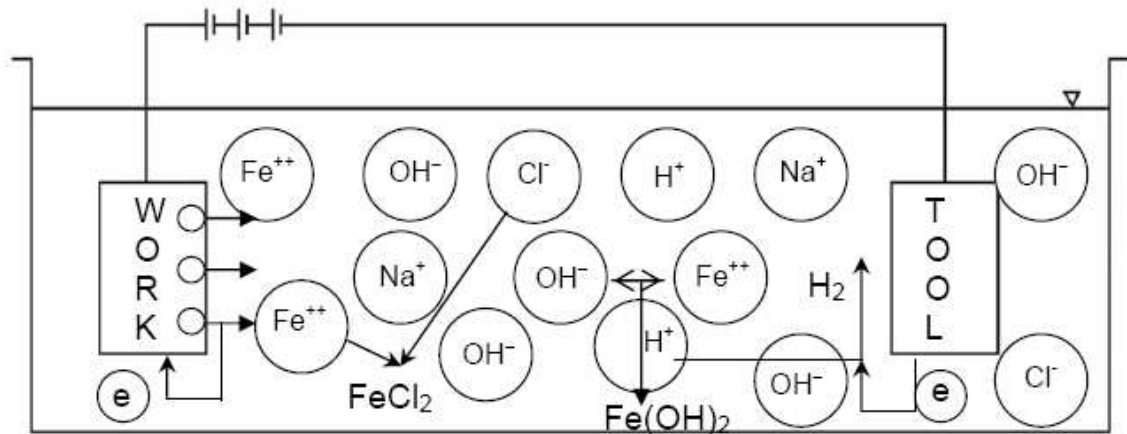
Similarly, the iron atoms will come out of the anode (work piece) as:



Within the electrolyte iron ions would combine with chloride ions to form iron chloride and similarly sodium ions would combine with hydroxyl ions to form sodium hydroxide

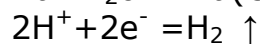
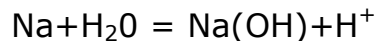
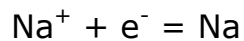


In practice FeCl_2 and $\text{Fe}(\text{OH})_2$ would form and get precipitated in the form of sludge. In this manner it can be noted that the work piece gets gradually machined and gets precipitated as the sludge. Moreover there is not coating on the tool, only hydrogen gas evolves at the tool or cathode. Fig. 2 depicts the electro-chemical reactions schematically. As the material removal takes place due to atomic level dissociation, the machined surface is of excellent surface finish and stress free.



Summary of cathode and anode reaction is given below

Cathode Reaction



It shows that there is no deposition on tool but only gas is formed, whereas, in cathode in machining an iron.

Anode Reaction



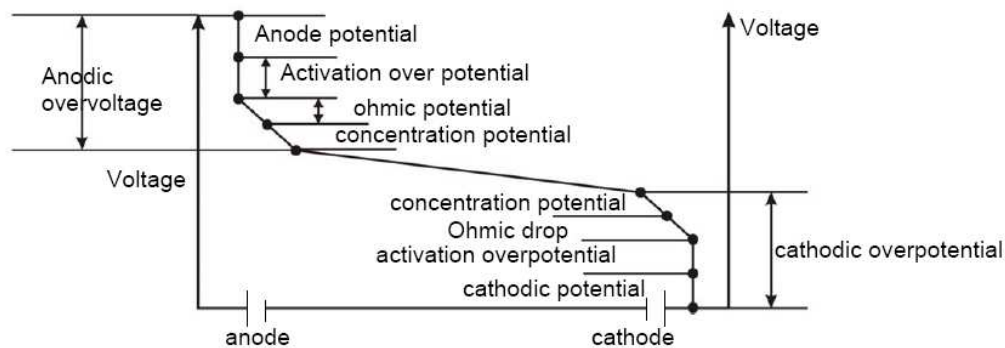
It shows that metal (work piece) i.e. Fe goes into solution and hence machined to produce reaction products as iron chloride and iron-hydroxide as a precipitate. Interesting part is that the removal is an atom by atom, resulting in higher surface finish with stress and crack free surface, and independent of the hardness of work material.

Smaller the interelectrode gap (IEG) the gap, greater will be the current flow because resistance decreases and higher will be rate of metal removal from the anode. Higher current density, in small spacing (usually about 0.5mm or less), promotes rapid generation of reaction products.

The voltage is required to be applied for the electrochemical reaction to proceed at a steady state. That voltage or potential difference is around 2 to 30 V. The applied potential difference, however, also overcomes the following resistances or potential drops. They are:

- The electrode potential
- The activation over potential
- Ohmic potential drop
- Concentration over potential
- Ohmic resistance of electrolyte

Fig. 3 shows the total potential drop in ECM cell.



Equipment

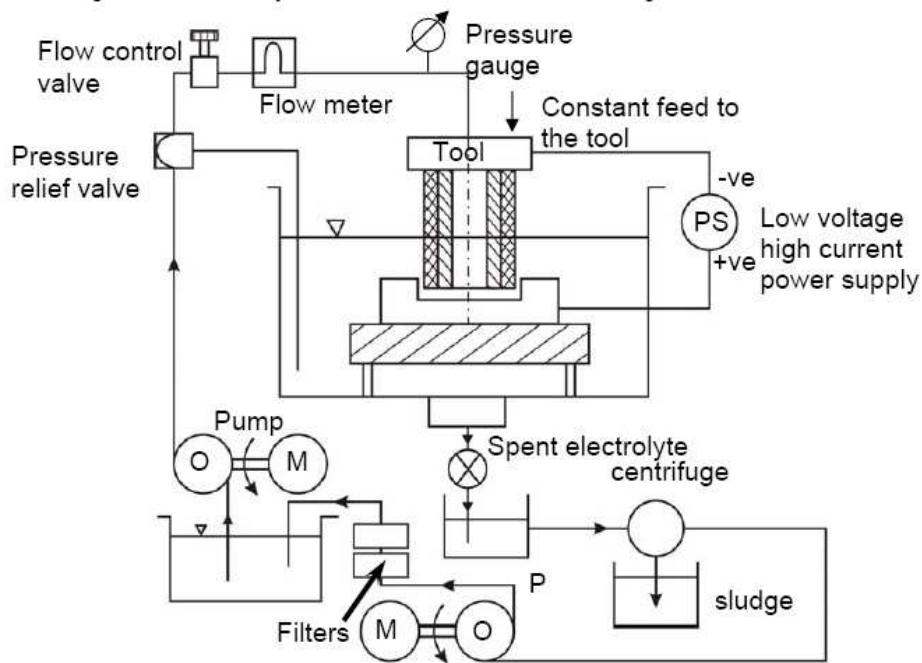
The electrochemical machining system has the following modules:

- Power supply
- Electrolyte supply and cleaning system
- Tool and tool feed system
- Work piece and Work holding system.

Fig. 4 schematically shows an electrochemical drilling unit.

Power supply: During ECM, a high value of direct current (may be as high as 40000 A) and a low value of electric potential (in range of 5-25 V) across IEG(Interelectrode gap) is desirable. The highest current density achieved so far is around $20,000 \text{ A/cm}^2$. Hence , with the help of a rectifier and a transformer, three phase AC is converted to a low voltage, high current DC. Silicon controlled rectifier (SCRs) are used both for rectification as well as for voltage regulation because of their rapid response to the changes in the process load and their compactness. Voltage regulation of $\pm 1\%$ is adequate

for most of the precision ECM works. However, lack of process control, equipment failure, operator's error, and similar other reasons may result in sparking between tool and work. The electrical circuitry detects these events and power is cut off (using the device like SCRs) within 10 micro seconds to prevent the severe damage to the tool and work. In case of precision works even a small damage to an electrode is not acceptable. It may be minimized by using a bank of SCRs placed across the DC input to ECM machine.



Electrolyte supply and Cleaning system : The electrolyte supply and cleaning system consisting of a pump, filter, pipings, control valves, heating or cooling coils, pressure gauges, and a storage tank (or reservoir). Electrolyte supply ports may be made in the tool, work or fixture, depending upon the requirement of the mode of electrolyte flow. Small inter electrode gap, usually smaller than 1mm, should be maintained for achieving High MRR and high accuracy. For this purpose, smooth flow of electrolyte should be maintained and any blockade of such a small gap by particles carried by electrolyte, should be avoided. Hence, electrolyte cleanliness is imperative. It is normally done with the help of filters made of SS steel, Monel or any other anticorrosive material.

It should be ensured that the piping system does not introduce any foreign material like corroded particles, scale or pieces of broken seal material. Piping system is therefore made of SS steel, Glass fibre reinforced plastic (GFRP), plastic lined MS or similar other anti corrosive material. The required

minimum capacity of electrolyte tank is 500 gallons for each 10000 A of current. ECM is supposed to machine different metals and alloys at optimum machining conditions and with varying requirements of accuracy, surface texture, etc. Under such situations, a single tank system is not recommended because of loss of time and wastage of electrolyte during drilling cleaning, mixing or filling of new electrolyte in the tank. It results in higher cost and poor accuracy of electro chemically machined surface and also poor control of operating conditions. More than one tank therefore, can be used and their number would depend upon the range of electrolytes needed to meet the work load.

Tool and Tool Feed system Use of anti corrosive material for tools and fixtures is important because they are required for a long period of time to operate in the corrosive environment of electrolyte. High thermal conductivity and high thermal conductivity are main requirements. Easy machining of tool material is equally important because dimensional accuracy and surface finish of the tool directly affect the work piece accuracy and surface finish. Aluminum, Brass, Bronze, copper, carbon, stainless steel and monel are a few of the material used for this purpose. Further, those areas on the tool where ECM action is not required, should be insulated. For example, lack of insulation on the sides of die sinking tool causes unwanted machining of work and results in a loss of accuracy of the machined work piece. Use of non – corrosive and electrically non conducting material for making fixtures is recommended. Also, the fixtures and tools should be rigid enough to avoid vibration or deflection under the high hydraulic forces to which they are subjected.

Work piece and work holding system: Only electrically conductive material can be machined by this process, The chemical properties of anode (work) material largely govern the material removal rate (MRR). Work holding devices are made of electrically non conductive materials having good thermal stability, and low moisture absorption properties, For Example, graphite fibres reinforced plastics, plastics, Perspex,etc., are the materials used for fabricating the work holding device.

Process Parameters

1. Power supply
 - Type – DC
 - Voltage – 30V
 - Current - 40000A
 - Current Density – 500 A/Cm²

2. Electrolyte

- Type – NaCl, NaNO₃, Proprietary mixtures.
 - Temperature – 26 to 50 deg.
 - Flow rate – 16 LPM to 20 LPM
 - Velocity – 1500 m/min to 3000 m/min
 - Inlet pressure – 2200 kPa.
 - Outlet Pressure- 300 kpa
3. Working Gap
 - 0.075 to 0.75mm
 4. Side over cut
 - 0.125 to 1mm
 5. Feed rate
 - 0.500 to 13 mm/min
 6. Electrode material
 - Copper , Brass, Bronze
 7. Tolerance
 - 0.025mm (2D) and 0.050mm(3D)
 8. Roughness
 - 1.5 microns

Applications

1. ECM can be used to make disc for turbine rotor blades made up of HSTR alloys
2. ECM can be used for slotting very thin walled collets
3. ECM can be used for copying of internal and external surfaces, cutting of curvilinear slots, machining of intricate patterns, production of long curved profiles, machining of gears and chain sprockets, production of integrally bladed nozzle for use in diesel locomotives, production of satellite rings and connecting rods, machining of thin large diameter diaphragms.
4. ECM principle has be employed for performing a number of machining operations namely, turning, treplaning, broaching, grinding, fine hole drilling, die sinking, piercing, deburring,plunge cutting etc.
5. ECM can also be used to generate internal profile of internal cams.

Advantages

ECM offers impressive and long lasting advantages.

1. ECM can machine highly complicated and curved surfaces in a single pass.
2. A single tool can be used to machine a large number of pieces without any loss in its shape and size. Theoretically tool life is high
3. Machinability of the work material is independent of its physical and mechanical properties. The process is capable of machining metals and alloys irrespective of their strength and hardness.

4. Machined surfaces are stress and burr free having good surface finish
5. It yields low scrap, almost automatic operation, low overall machining time, and reduced inventory expenses.
6. There is no thermal damage and burr free surface can be produced.

Disadvantages

1. High capital cost of equipment
2. Design and tooling system is complex
3. Hydrogen liberation at the tool surface may cause hydrogen embrittlement of the surface.
4. Spark damage may become sometimes problematic
5. Fatigue properties of the machined surface may reduce as compared to conventional techniques (by 20%)
6. Non conductive material cannot be machined.
7. Blind holes cannot be machined in solid block in one stage
8. Corrosion and rust of ECM machine can be hazard
9. Space and floor area requirement are also higher than for conventional machining methods. Some additional problems related to machine tool requirements such as power supply, electrolyte handling and tool feed servo systems.

Theoretical Analysis of ECM

Metal removal rate calculations

During ECM, metal from the anode (or work piece) is removed atom by atom by removing negative electrical charges that bind the surface atoms to their neighbors. The ionized atoms are then positively charged and can be attracted away from the work piece by an electric field. In an electrolytic cell (ECM cell) material removal rate is governed by Faraday's law of electrolysis.

- The amount of chemical change produced by an electric current (or the amount of substance deposited or dissolved) is proportional to the quantity of electric charges passed through electrolyte.

$$W \propto Q$$

- The amount of different substances deposited or dissolved by the same quantity of electricity are proportional to their Electro chemical equivalent weights.(ECE)

$$W \propto ECE;$$

$$ECE = M/v$$

Where M is the atomic weight and v is the valency.

These laws can be expressed in mathematical form as follows:

MRR

$$W = 1/F(ECE) \cdot Q$$

$$MRR = \frac{(ECE)It}{F\rho}$$

$$MRR = 1/F(M/v)I t$$

Where F is the faraday's constant=96500 coulombs =26.8amp-hr, Q is the charge (0coulomb), I the current (ampere) and t is the dissolution period.

This equation is based on number of simplified assumption and does not account for the effect of some of significant process variables, namely, changes in valency of electrochemical EC dissolution during the operation, gas evolution and bubble formation, electrolyte electrical conductivity and temperature variation along the electrolyte flow path, over potential in presence of passivation film etc. Passivity arises as a result of chemical and electro chemical behavior of metals which results in the formation of protective film on their surfaces. Further, dissolution of iron in NaCl solution, depending upon the machining conditions, may be either in the form of ferrous hydroxide or ferric hydroxide. Mode of dissolution during machining of alloys, is still more difficult to know. The preferential valency mode of dissolution has been found to depend upon the electrolyte flow rate, IEG and length of electrolyte flow path.

Electrochemical Equivalent of alloys.

The evaluation of MRR becomes difficult when the anode is made up of an alloy because the value of electrochemical equivalent of an alloy.

An alloy consists of different elements to give required properties. To find the rate of dissolution of an alloy, one must consider each element separately and combine them for the whole alloy.

Let

1,2,3,... n = number of elements in alloy

$m_1, m_2, m_3, \dots, m_n$ = atomic weight of individual element in alloy

$v_1, v_2, v_3, \dots, v_n$ = valency of the respective elements

$x_1, x_2, x_3, \dots, x_n$ = percentage of element present in the alloy

p = density of alloy

V_a = volume goes into solution in a given time t

$w_1, w_2, w_3 \dots w_n$ = weight of element in alloy.

Weight of first element

$$W_1 = \frac{V_a \rho X_1}{100}$$

Similarly

$$W_2 = \frac{V_a \rho X_2}{100}$$

$$W_n = \frac{V_a \rho X_n}{100} \quad \text{and so on}$$

The charge (Q_1 - Q_n) taken by each element present in the alloy can be the given by the eq as

$$Q_1 = \frac{W_1 F v_1}{M_1} = \frac{V_a \rho F v_1 X_1}{100 M_1}$$

Similarly

$$Q_2 = \frac{W_2 F v_2}{M_2} = \frac{V_a \rho F v_2 X_2}{100 M_2}$$

$$Q_n = \frac{W_n F v_n}{M_n} = \frac{V_a \rho F v_n X_n}{100 M_n}$$

Now the total charge require for removing all the elements from the alloy will be

$$Q_{\text{total}} = Q_1 + Q_2 + \dots + Q_n;$$

$$Q_{\text{total}} = \frac{V_a \rho F}{100} \left[\frac{v_1 X_1}{M_1} + \frac{v_2 X_2}{M_2} + \dots + \frac{v_n X_n}{M_n} \right]$$

Hence volumetric material removal rate V_m per unit charge is given by

$$V_m = \frac{V_a}{Q_{\text{total}}} = \frac{100}{\rho F \sum_{i=1}^n \frac{X_i v_i}{M_i}}$$

If current I flows for time t sec, then from equation,

$$Q_{total} = It = \frac{V_a \rho F}{100} \sum_{i=1}^{i=n} \frac{X_i V_i}{M_i}$$

$$MRR = \frac{V_a}{t} = \frac{100}{\rho F} \frac{1}{\sum_{i=1}^{i=n} \frac{X_i V_i}{M_i}}$$

Mechanical properties of parts produced by ECM process

It is important to know the effect of ECM on the mechanical properties of electrochemically machined parts. This will greatly affect the acceptability of the process in different industries. Hardly any evidence is available about the hydrogen embrittlement of the ECM components. The basic reason being that hydrogen is evolved at cathode while metal removal is taking place due to anodic dissolution at the anode. It has been reported that there is no effect of ECM on ductility, yield strength, ultimate strength, and micro hardness of the machined component.

Surface layers damaged during conventional machining or by some other processes, may be removed by ECM and this may result in improvement in the properties of the work material. However, such removal of layers from the work surface reduces fatigue strength of a conventionally machined components. The conventionally machined surfaces have compressive residual stresses responsible for higher fatigue strength. This fact has been verified experimentally. However, the required fatigue strength can be restored by further appropriate post mechanical finishing treatment . These subsequent mechanical treatment impart compressive stresses to the surface, so that the resulting work piece can exhibit fatigue properties comparable to or better that those of mechanically finished parts.

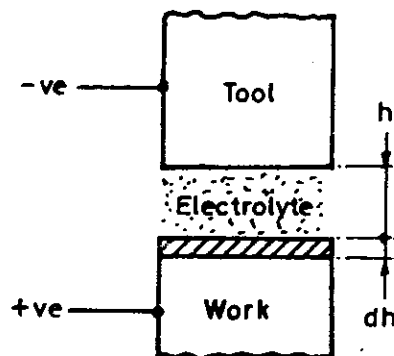
The surface finish produced by ECM may also be source of reduction in fatigue properties. The surface produced by ECM generally has better wear friction and corrosion resistance properties than those produced by mechanical means. Following Table gives effect of type of finish on fatigue strength.

Surface finish	Fatigue life x 10 ⁵ cycles.
Electrochemically polished	4.9
Etched	4.4
Intergranular attack	4.25
Hemispherical pits	3.3

Micro examination of specimen has revealed that fatigue cracks usually originate from pits. Due to flowing electrolyte, these defects are more severe than those found in electro polishing. However, reduction in fatigue life is low and depth of inter granular attack measured is about hundredth of a millimeter or even less. Removal of compressive stress layer seems to be the main reason, and inter granular attack and other defects induced during ECM appears to be secondary reasons for reduction in fatigue strength. Improper combination of work and electrolyte or inappropriate selection of operating conditions may result in non uniform dissolution of metals and alloys. It would lead to selective etching, intergranular attack or pitting. But such defects can be minimized by employing proper heat treatment procedure and also by developing an appropriate electrolyte and selecting proper operating conditions.

Dynamics of ECM Process

In last section, we have derived an expression for MRR in ECM. Now the question arises whether one should allow machining without any feed or give a feed. To solve this, let us consider an electrolyte flowing through a parallel gap "h" between tool and work piece. If the constant voltage (V) is applied across the gap, one should find out how gap changes take place.



Zero feed rate

Now if dh is the change in gap in a given time dt area of cross section of tool (reaction area) is A and density of material ρ then the weight dissolved

$$dw = \rho A dh = \frac{1}{F} \frac{M_x}{v_x} I dt$$

$$\frac{dh}{dt} = \frac{1 M_x I}{F \rho v_x A}$$

the rate of change of gap is proportional to current density (I/A).

now, if V is the applied D.C voltage, R is the resistance of electrolyte and r the specific resistance of the electrolyte, then

$$I = \frac{V}{R_s} = \frac{V}{\frac{rh}{A}} = \frac{VA}{rh}$$

On substituting the value of I from equation, we can rewrite

$$\frac{dh}{dt} = \frac{1 M_x V}{F \rho v_x rh}$$

and for a constant voltage source

$$\frac{dh}{dt} = \frac{C}{h}$$

Where

$$C = \frac{1 M_x V}{F \rho v_x r}$$

$$C = \frac{100}{r F \rho} \frac{1}{\sum_{i=1}^n \frac{X_i v_i}{M_i}}$$

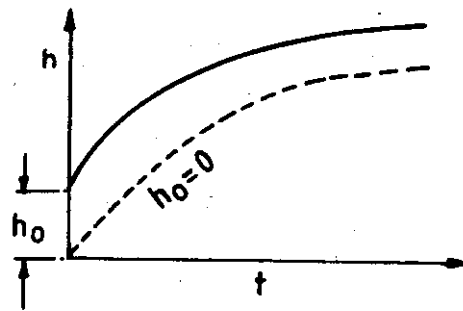


Fig. 6.9 Variation of Gap Length with Time

For an alloy which shows that the rate of change of gap is inversely proportional to gap length i.e. with time the rate of change of gap or the dissolution rate falls.

Now let us examine if no feed is given under zero feed arte condition how the gap varies with time.

We know

$$\frac{dh}{dt} = \frac{C}{h} \quad \text{integrating this with in the limits}$$

$$(h^2_1 - h^2_0) = Ct$$

Which gives the parabolic variation of gap shown in fig it shows that if we do not give any feed to the tool, the dissolution rate falls. Hence *it is necessary to give a feed to the tool*

Dynamics under given feed conditions

If feed S is given to the tool , then eq is modified to

$$\frac{dh}{dt} = \frac{C}{h} - S$$

It is necessary to establish the feed rate because if S is high compared to rate of change of gap, then the short circuit will result in stoppage of electro chemical reaction. Hence to establish a reaction for feed a steady state condition of electro-chemical reaction is to be established under this steady state condition

$$\frac{dh}{dt} = 0$$

hence $\frac{C}{h} = S$

The gap under steady state condition h_e is

$$\frac{C}{h} = h_e$$

In steady state or equilibrium condition with a constant feed, the gap remains constant.

Now it is necessary to know how and when the equilibrium condition is reached. To establish this one must find out the behavior of eq with respect to feed. The approach to the equilibrium gap can be found out by method of substitution of the equation, by reducing the variable to ECM units since they are not dimensionally balanced.

In ECM units we can assume the equilibrium gap h_e to an unit for conversion of gap and time units.

$$\text{Gap, } h' = \frac{h}{h_e} = \frac{Sh}{C} \quad \text{and time} \quad t' = \frac{St}{h_e} = \frac{S^2h}{C}$$

Hence

$$\frac{dh'}{dt'} = \frac{C}{S} \frac{dh}{S^2 dt} = \frac{1}{S} \frac{dh}{dt}$$

$$\text{Hence} \quad \frac{dh}{dt} = S \frac{dh'}{dt'}$$

Therefore, the above equation is converted and expressed as

$$\frac{dh'}{dt'} S = \frac{S}{h'} - S \quad \text{or}$$

$$dt' = \frac{h'}{1-h'} dh' \quad \text{on integration} \quad \int_0^{t'} dt' = \int_{h_0}^{h_1} \frac{h}{1-h^2} dh' \quad \text{or}$$

$$t' = \left[(1-h') - \log(1-h') \right]_{h_0}^{h_1}$$

$$\text{Or} \quad t' = \left[(h_0' - h_1') + \log \frac{h_0' - 1}{h_1' - 1} \right]$$

The plot of above equation is shown in above Figure.

This shows that whatever the initial gap is given, it tends to a unit gap, equilibrium is reached, since approaches the gap asymptotically.

$$\text{Hence } h'=1 \quad \text{or} \quad \frac{Sh}{C} = 1$$

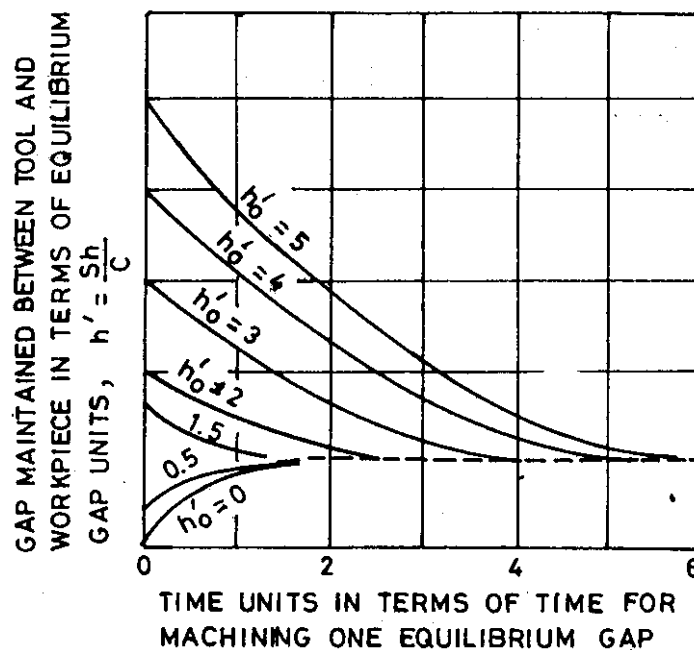
$$\text{From which,} \quad S = \frac{C}{h} = \frac{M_x V}{v_x Fpr h}$$

$$\text{Where } C = \frac{M_x V}{v_x Fpr} \quad \text{or}$$

$$S = \frac{M_x V}{v_x F_p r h} = \frac{M_x I}{\rho F v_x A}$$

Therefore

$$S = \frac{M_x I}{\rho F v_x A} = MRR$$



It is seen that, in a constant feed rate ECM system, the machining process is inherently self-regulated since the MRR tend to approach the feed rate. Another interesting phenomena is that a highest feed condition(for a limiting value of current) the equilibrium gap is minimum and produces a closer tolerance between the tool and the work surface, i.e as production rate is increased the accuracy is maintained is higher in ECM operation. Hence it can be considered as one of high production system.

HYDRODYNAMICS OF ECM PROCESS

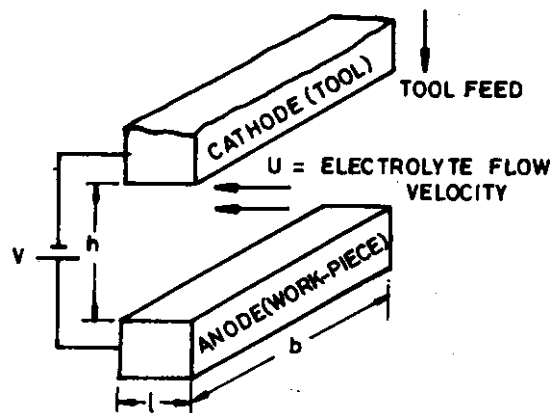
It is clear that the material removal rate increases with the current and the machine can be operated at the highest feed rate condition, The increased current will produce more heat in electrolyte (Joule Heating) that might reach a boiling condition and prevent the electrolytic reactions further. So it is necessary to allow sufficient flow of electrolyte through the gap schematically shown in the figure for a pair of parallel electrodes.

Now the heat produced in the electrolyte due to the current I flowing through it

$$H = I^2 R_e = \frac{I^2 r h_e}{A}$$

If C_{pe} is the average specific heat of the electrolyte and specific resistance r is assumed to be constant

$$I^2 R_e = 4.187 q \rho_e C_{pe} (\theta_0 - \theta_i)$$



Flow through a pair of parallel electrodes

Where q is the flow rate of the electrolyte, ρ_e the density of the electrolyte, θ_0 is the outlet temperature of the electrolyte and θ_i the inlet temperature of the electrolyte.

It is also preferred that θ_0 should be as close to boiling temperature θ_b but never in excess for accelerated reaction.

Hence

$$I^2 R_e = 4.187 q \rho_e C_{pe} (\theta_0 - \theta_i)$$

Now if we consider the current density in the gap, J_c is given by

$$J_c = \frac{I}{A}$$

Where A is the area of the tool then,

$$(J_c^2 A^2) \frac{r h_e}{A} = 4.187 q \rho_e C_{pe} (\theta_0 - \theta_i)$$

Or

$$J_c^2 = \frac{4.187 q \rho_e C_{pe} (\theta_0 - \theta_i)}{h_e A}$$

From which the flow rate of electrolyte to prevent boiling

$$q = \frac{I^2 r h_e}{4.187 q \rho_e C_{pe} (\theta_0 - \theta_i)}$$

In the case of a rectangular electrode if the velocities of the electrolyte flow is U then

$$q = U b h_e$$

hence

$$U = \frac{I^2 r}{4.187 A \rho_e (\theta_0 - \theta_i) b}$$

Again , if V is the applied voltage

$$I = \frac{V}{R_e} = \frac{VA}{r h_e}$$

Since $A = b l$, therefore

$$U = \frac{V^2 l}{4.187 r h_e^2 \rho_e C_{pe} (\theta_0 - \theta_i)}$$

ECONOMICS OF ECM PROCESS

Fixed costs of ECM installations are quite high compared to its operating costs. Overhead costs are same as for other conventional machining methods. Some costs are quite unique, such as those of high power, electrode tooling and electrolyte.

ECM needs power of high current capacity. In localities where power is sufficiently cheap, this factor can be overlooked.

Electrode or tooling cost is a fixed cost because there is a little wear of the ECM tool. There occurs, however, a negligible abrasion wear of electrode due to electrolyte flow across the gap, with regard to actual tooling cost, it is not very different from conventional machine tooling.

Electrolyte is not as costly as one might think it to be. The most widely used electrolyte is Sodium chloride (salt) and it is quite cheap. The normal price of salt seldom exceeds Rs 10 per kg, when purchased in large quantities.

Cost of the work piece fixtures are not very high. The cost per piece will however depends on work piece material and number of component. On the shop floor, ECM installation need not be operated by very skilled engineers and operation of machinery can be learnt easily.

The economic success of ECM, in fact depends largely on choice of applications, if an operation is simple or if the material can be easily machined by other methods, high cost of ECM plant cannot be justified.

Problem

Turbine section of HAL wishes to produce complex die for making a part for aircraft application. 250 numbers of parts are required to be produced. Part is made up of hard nickel- based alloy. The profile can be generated on a copy milling machine or an ECM plant. Presuming that two machines are fully utilized. Using BEA, Suggest which manufacturing method is economical to produce 250 parts. The following data are provided:

	Copy milling	ECM
Capital cost	Rs 1500000	3750000
Amortization period	10 years	5 years
Labour cost /hour	Rs 100	Rs 100
Fixture and tooling cost	Rs 225000	Rs 1125000
Electric power consumption per hour	Rs 8	Rs 80
Production time/Component	40 hours	1 hour

Assume 2500 Working hours in a year,

Solution:

Machine cost/hour = Capital cost/ (Amortization period x 2500)

Machine cost/hour (for ECM) = $3750000/5 \times 2500 = \text{Rs } 300 \text{ /hour}$

Machine cost/hour (for Copy milling) = $1500000/10 \times 2500 = \text{Rs } 60 \text{ /hour}$

Let x be number of components , Cost of which on the two machines are equal.

Solution:

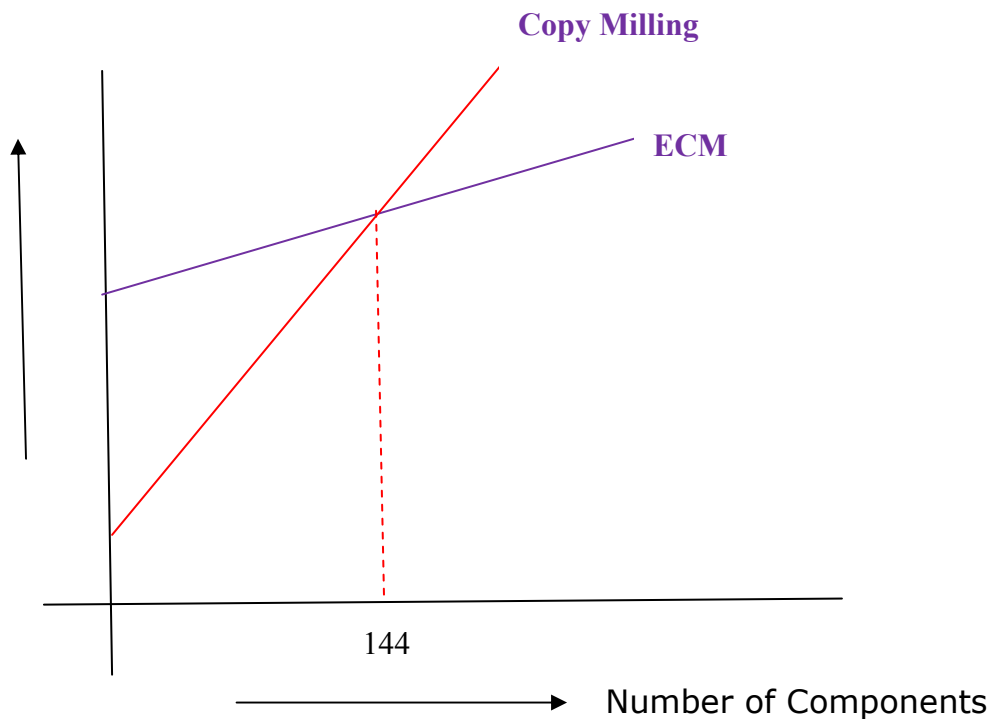
Various costs per component are

	Copy milling	ECM
Machining Cost/Comp	$60 \times 40 = \text{Rs. } 2400$	Rs.300
Labour Cost	$100 \times 40 = \text{Rs. } 4000$	Rs. 100
Power Cost	$8 \times 40 = \text{Rs. } 320$	Rs. 80
Tooling Cost	$225000/x$	$1125000/x$

$$2400 + 400 + 320 + 225000/x = 300 + 100 + 80 + 1125000/x$$

Solving we get $x = 144$.

ECM is more economical than copy milling machine. In the above calculations, it is implied that both machines are fully utilized; however, this might not always be true. Break even analysis chart is shown below.



2 In a certain electro chemical dissolution process of iron ,a MRR of 2 cm³ /min was desired .determine the amount of account of current required for the process.

Solution

Assume Atomic weight of iron =56gm
Valancy at which dissolution occur =2
Density of iron =7.8 gm/cm.

Grams equivalent weigh of iron (ECE) = m/v = 28;

$$MRR = \frac{(ECE)It}{F\rho}$$

F=1609 amp/min;

$$2 = \frac{28 I}{1609 \times 7.8}$$

I=896 amp