ELECTRO - CHEMICAL MACHINING

PROJECT REPORT

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CERTIFICATE

THIS IS TO CERTIFY THAT THE REPORT ENTITLED

"ELECTRO - CHEMICAL MACHINING"

HAS BEEN SUBMITTED BY

Mr. ....

IN PARTIAL FULFILMENT OF THE AWARD OF BACHELOR OF ENGINEERING IN THE MECHANICAL ENGINEERING BRANCH OF THE BHARATHIYAR UNIVERSITY, COIMBATORE-641 046 DURING THE ACADEMIC YEARS 1989 - 90

25.4.90
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Guide.

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Head of the Department.

CERTIFIED THAT THE CANDIDATE WAS EXAMINED BY US IN THE PROJECT WORK VIVA-VOCE EXAMINATION HELD ON ....

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SYNOPSIS

This project work is concerned with the fabrication of an Electro chemical machining cell. In ECM there is no phsical contact between the tool and workpiece but the machining process is carried out by the process of electrolysis. The ECM is carried out in a plastic block called "Perspex". Perspex is transparent and the machining taking place in side it can be viewed from outside.

Machining operations like facing and deburring were chosen due to its simplicity in fabrication. Though ECM is used to machine very "difficult to machine" elements, we used copper as tool and mild steel as workpiece for demonstration purpose. Sodium chloride in water was used as the electrolyte in order to get better surface finish.

CHAPTER 1

INTRODUCTION

Modern manufacturing technology is developing some needs and trends of larfge scale and long-range nature which are laying severe demands on the existing system of conventional or traditional manufacturing. This developing challenge of new needs and trends must be met by continuously developing production equipment and processes. In recent years, some alloys have been produced which are exceedingly difficult to machine. These have been prepared to meet the demand for very high-strength, heat resistant materials, which often have to take complex shape with closer tolerances. With the development of new high strength materials, it has become essential to develop improved cutting tool materials which are necessary for machining the newly developed materials. Thus the new developed cutting tool materials which efficiently fulfil the requirements of any cutting process also raises an improvement in the field of machining technology.

It is therefore, clear that some new strategies of machining must be developed in order to deal with the problems created by development and use of the hard-to-machine and high strength, temperature resistant alloys. Consequently some non-traditional techniques of machining have been inventecd in order to supplement efectively the metal cutting methods, especially when a complicated shape is to be produced on any hard-to-machine and brittle material. Electrochemical Machining is one of the unconventional machining methods, which has been developed initially to machine hard, high strength and heat resistant materials although metal can be so machined.

Electrochemical metal removal is one of the latest and potentially the most useful of the non-traditional machining processes. It is essentially a process of controlled erosion. The operation employs electricity to produce chemical changes. They take place in an electrolytic cell, which contains an electrically conducting liquid (the electrolyte) that is in contact with two metal conductors (the electrodes) connected through an external circuit. The current that moves through the electrodes and the external circuit is carried by electrons, and the current that moves through the electrolyte is carried by ions, that is , atoms that have acquired a positive or negative charge by losing or gaining electrons. The electrode that carries electrons from the electrolyte into the external circuit is the anode, and the one that moves electrons into the electrolyte is the cathode. The key chemical changes occur at the electrode surfaces and are caused by the transfer of electrons between the electrodes and the ions.

What happens in electrochemical machining is the atom by atom removal of metal that is to be shaped (the workpiece) is made the anode and the metal tool giving rise to the shaping is made the cathode. They are connected to a source of low-voltage direct current. Then a strong electrolyte is pumped between the two electrodes. Without any physical contact of the tool and the workpiece, metal is removed from the workpiece in a pattern established by the shape of the tool as current flows between electrodes. The rate which the metal is removed is not influenced by the hardness of the workpiece. Moreover the process does not produce work hardening or induce stresses in the machined metal surface, which are both problems with conventional machining.

This properties of electro-chemical machining give it an unparalled advantage over conventional methods for machining the kind of metals commonly used in the aircraft and aerospace industries, namely high strength alloys designed to serve at high temperatures. Another advantage is that with the properly designed cathode the process can yeild complex shapes that are almost impossible to achieve by grinding. ECM achieves exceptionally smooth machined surfaces (Averaging 0.15 micrometre to 5 microinch in peak to valley roughness) with no scratchess, burrs or grooves.

Machining time is often reduced because the process eliminates the multiple operations required by conventional methods. Since no pressure is applied to the workpiece, thin foils and honeycombs can be machined without burring, warping or other distortions.

CHAPTER 2

LITERATURE SURVEY

2.1 History of Electrochemical Machining (ECM):

The phenomenon of electrolysis was first studied scientifically more than 160 years ago and intentional electrolytic removal of metals has been practised for many years in the electro-pickling process which makes use of electrolytic action to remove surface films from metal products.

However, the controlled electrolytic removal of the actual metal of a workpiece seems to have been the first practiced extensively for making polished surfaces. Electrolytic polishing was first developed by Jacquet in 1935. An electro chemical cutting-off machine was described in 1946. But the application of electrochemical methods was first used in about 1950 in the form of electrolytically-assisted grinding. After 8 or 10 years development in ECM were achieved in the form of drilling holes, cavity sinking, milling, turning and many other applications

ECM has been first proposed in 1929, by a Russian called W.Gusseff with many features almost identical to the process as now practised. Furthermore, an American Burgess had demonstrated the possibilities striking differences between mechanical and electrolytic methods of removing metals, former which is 'brute force and violence' compared to later which is 'cool, steady, non-deforming magic' of electrolytic process.

Although, the process was first invented many years before it came to be used at the final development to the commercial stage for machining processes dealing economically with the increasingly difficult to machine alloys.

As a practical process ECM had its birth in the United States when the Battelle Memorial Institute, sponsored by the Cleveland Twist Drill Company, developed an Electrochemical method for sharpening carbide tipped drills. This was accomplished and a patent was filed in 1954. This patent was later brought from Cleveland Twist Drill by the Steel Improvement and Forge Company. SIFCO then supported further work at the Battelle Memorial Institute and in its own research laboratories, and soon set up new methods for machining curved surfaces of complex gas-turbine blades and were quite successful. This was imported to England by Metachemical Machines Ltd. and made available to Rolls-Royce Ltd. They started mass production of all types of blades with this new technique.

While these developments were going on in the period 1956-66 other organizations were approaching ECM by the route of chemical assisted grinding. Other machining was on its way, it was clear many shaping and forming operations could be carried out electrochemically. Applications which were too difficult to apply were sought for this new technique. Further more this process is quick and can be readily automated. Nevertheless, ECM can be expected to play an important part in metal working technology.

2.2 The need for Electrochemical Machining:

The rapid developement in recent years of the co-called advance technological industries - aerospace, nuclear power etc has been accompanied by an increasing use of the difficult to machine alloys. Examples of these materials are air-frame components in high tensile steel and gas turbine blades in Nimonic.

Furthermore the materials and techniques used in these advanced industries are tending to spread to the other industries, with a result that the pattern of metalworking is beginning to change. Conventional methods of metal cutting are no longer adequate in meeting all requirements nor is there any real prospect that they can be further developed to do so. This is because the metals needed for high strength, high temperature tends to be as hard and strong as the materials used for making the cutting tools, with the result that they can be cut only very slowly if at all it can be cut.

In conventional machining the advances made in the metal cutting and machine tools are doubling every 10 years and the ultimate tensile strength of materials used seems to be doubling every 20 years as shown in figure 6-13. This is the cause for the slowing down of metalworking technology in some industries and in others it is undoubtably happening.

This shows that the new approach to metalworking is needed to deal with the problems created by the development and use of difficult materials. Attempts have been made to reduce difficulties by hot machining in which the workpiece is heated so as to reduce the difficulty of cutting or by development of ultrasonic machining. These have however, met with little success. What is really needed is a method of machining which does not affect the hardness of workpiece. That is the reason why we go in for Electrochemical machining.

2.3 Electrolysis

2.3.1 Faraday's Laws of Electrolysis.

In ECM the material is removed viz. electrolysis. An electrolytic cell consists of two non contacting electrodes immersed in an electrolyte solution and a potential difference is applied between them. The chemical process that takes place when an electric current is passed between the two electrodes dipped in electrolytic solution is called electrolysis.

The material is removed from the workpiece atom by atom. Removal of charges from the workpiece is effected by making it the anode. The potential gradient in the electrolyte helps to attract away the positive ions from the anode. The passage of current through a cell results in the removal of materials from the anode at a rate given by Faraday's Laws of Electrolysis which states that: -

i) The amount of chemical change produced by an electric current i.e. the amount of any substance deposited or dissolved, is proportional to the quantity of electricity passed.

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

Combination of the two laws of electrolysis leads to the combination that the weight 'm' in grams of material deposited or dissolved at an electrode is proportional to $I \times T \times \mathcal{E}$ and it is possible to write that

$$m = \frac{IxTx\mathcal{E}}{F}$$

where I = current strength in ampress

T = time in seconds

$\mathcal{E}$ = gram equivalent weight of the material

F = Faraday = 9,65,000 coulombs.

2.3.2 Mechanism of Electrolysis

When a potential is applied across the electrodes, the electric field in the electrolyte causes the ions to move; the (negatively charged) anions move towards the anode and the (positively charged) cations move towards the cathode. Flow of current (in the conventional sense) through the cell from anode to cathode is produced by movement of either anions or actions. This shows that both anions and cations are involved in any flow of current through the cell. As far as the current through the cell is concerned it is immaterial which ions are involved in the conduction process so long as the appropriate quantity of electricity is transferred across the solution and the electrodes. It is the hydrogen and hydroxyl ions which are involved in the transfer of charge to and from the electrodes.

The chemical reactions taking place during electrolysis are:-

At the anode the possible reactions are:

i) Dissolution of the anode; e.g. with an iron anode

$$Fe \dashrightarrow Fe \quad + \ 2e$$

ii) Discharge of anions

$2\ OH \longrightarrow H_2O + \frac{1}{2}O + 2e$

iii) Electrolysis of water

$H_2O \longrightarrow \frac{1}{2}O + 2H + 2e$

At the cathode the possible reactions are:

iv) Deposition of metal

$Fe + 2e \longrightarrow Fe$

v) Discharge of cations

$2H + 2e \longrightarrow H$

vi) Electrolysis of water

$2H_2O + 2e \longrightarrow H + 2\ OH$

As the current passes between the solution and the cathode is the same as that passing between the anode and the solution, in a given time the same charge must pass through each electrode.

The overall electrolysis process can be given by

$$Fe + 2H_2O \longrightarrow Fe(OH)_2 + H_2.$$

The ferrous hydroxide so formed further reacts with water and dissolved oxygen or oxygen from air to give ferric hydroxide which settles down as sludge in the wet state.

$4Fe(OH)_2 + 2H_2O + O_2 \longrightarrow 4Fe(OH)_3$

2.3.3 Electrolyte Flow

The electrolyte flow through the tool and workpiece gap must be violent so that there will be no concentration of ions near the surface of the electrode and the rate of reaction is governed by the diffusion of ions upto or away from electrodes.

By pumping electrolyte past the electrodes the concentration of ions are sufficiently low to allow large current densities to be passed.

When current is passed through the conductor, it gets heated up which would lead to the boiling of electrolyte. This will cause irregular current flow and it will lead to irregular metal removal. So the rate of electrolytic flow must be sufficient to prevent the temperatures of the electrolyte in the gap from rising to the boiling point. But there are many advantages in using hot electrolyte. It speeds up the electrode reactions and reduces the over voltages required. It also reduces the viscosity of flow and increases the electrical conductivity. The effect of temperature on the cell voltage is given in figure. 4·14.

In practical electrochemical machining turbulant flow is necessary to remove the ions at the electrodes which take part in the reactions.

It is also necessary to consider pressure required to produce the rate of electrolyte flow in the gap. Sometimes the pressure applied is great that it tends to separate the tool and workpiece. This difficulty is faced when the tool and workpiece involved are very large. In order to get the required accuracy of machining, the tool and workpiece must be rigidly mounted. Increasing pressure of electrolyte increases the boiling point of the electrolyte. The increased pressure of electrolyte compresses hydrogen gas to occupy a less volume so that large voltages can be maiintained.

2.4 Electrolytes for ECM:

2.4.1 Factors governing the choice of electrolytes:

The primary function of the electrolytes in ECM is to provide ions to carry electric current in the cell between the anode and the cathode. At the anode the electrolyte must be capable of continuously dissolving the workpiece material, so the composition of the electrolyte must be chosen such that the insoluble products formed must not passivate the surface of the products. The micro finish of an electrochemically machined surface is governed by the composition of the electrolyte. It is nature of the anions to influence this property of the electrolyte and many successful electrolytes contain ions of one of halogen elements.

To avoid large power losses the electrolyte used must have high electrical conductivity. This might increase the heat generation still further so the electrolytes must flow rapidly. The electrolyte should, therefore have low viscosity so that the pressures required do not become too high. Electrolytes for ECM must have high specific heat, high thermal conductivity and high boiling point so as to minimise any tendency of the electrolyte to boil.

During operating conditions the electrolyte should neither be toxic nor give rise to toxic products during machining so that handling does not become difficult. The cost associated with the usage and disposal of the electrolyte should be as low as possible.

2.4.2 Functions of electrolyte:

i) is to complete the circuit between tool and workpiece

ii) allow desirable machining reactions to occur.

iii) carry away heat generated during the machining process.

iv) carry away products of reaction from the zone of reaction.

2.4.3 Properties of electrolytes and its selection.

An efficient and effective electrolyte for the use in ECM should have:

i) High electrical conductivity.

ii) low viscosity and high specific heat.

iii) chemical stability.

iv) non-corrosive and non-toxic in nature.

v) inexpensive and readily available

While chosing an electrolyte the above mentioned points will have to be viewed upon with more importance. In many applications sodium chloride in water is found to be satisfactory, but it is corrosive. Sodium nitrate is non-corrosive but expensive. Its tendency to passivate the chemical reaction and somewhat lower electrical conductivity makes its adoption as an all purpose ECM electrolyte. Strong alkaline solutions are used for machining tungsten carbide

which is hard in nature. Other alkaline solutions used for this purpose are potassium nitrate, sodium sulphate, potassium chloride. Weak acidic solutions like sulphuric acid are used to produce good surface finish.

2.4.4 Electrolytes and their properties

Material	Electrolyte	Advantages	Disadvantages
Steel and iron base alloys	Sodium chloride upto 0.25 Kg/lr (or KCI which is more conductive but also more expensive.	Inexpensive & non-toxic. No fire hazard. Will machine a variety of materials. Produces smooth bleading of machined area into surrounding surfaces. At high concentration conductivity is easy to control and current efficiency is high.	Removes material from surrounding finished surfaces. May pit and damage surrounding surfaces Tends to selectively machine grain boundaries of stainless steels. Conductivity is affected by temperature.
	Na NO_3upto 0.5 Kg/lr	Produces better finish than Nacl Limits stray machining and pitting of adjacent surfaces	Twice the cost of Na cl. It is a fire hazard. High concentration if required for good conductivity. Electrical resistivity can vary with flow velocity to produce flow lines High voltages are required. Conductivity is temperature sensitive
Grey cast iron	Na cl upto 0.25 kg/lr or Na No_3 upto 0.5 kg/lr		Large machining gap must be used (0.050 to 0.080 mm) to allow graphite particles to be swept clear.
Nickel & Cobalt base alloys.	Na Cl 0.1 kg/lr + Na NO_3 0.1 kg/lr	Inexpensive simple mixture produces good surface finish	Produces flow lines on work surfaces. Electrochemically machined surface carries lightly adherent grey smut.

	Na No_3 upto 0.5 kg/lr	produces good surface finish	Disadvantages same as previous electrolyte. More expensive than previous electrolyte. Needs more oprating voltage. It is a fire hazard.
Titanium alloys	Na cl less than 0.1 kg/ litre	can produce surface finish better than previous electrolyte. Electrchemically machined surface does not have a loose oxide film.	High voltages are required. Flow lines may be formed on the work Bright raised areas may occur on the work surface. Surface is more prone to passivity during machining Close contourdimensions are diffifult to maintain. Pitting occurs on surfaces adjacent to machining area.

2.4.5 Concentration

A concentrated electrolyte offers low resistance to the flow of current. A highly concentrated electrolyte clogs the area in the machine work enclosure. Dilute electrolytes are advantageous in certain cases. For example, if surface finish is required then it is better to use high voltage, dilute electrolyte with a small gap instead of low voltage and concentrated electrolyte. This is because the higher voltage gradient in the former case will produce a smoother surface finish.

2.4.6 Working life of an electrolyte:

During working the composition of the elctrolyte begins to change. The main changes that can occur, with their effects, are listed below:

1. Loss of hydrogen, this may reduce the electrical conductivity of the electrolyte and increase its pH.
2. Loss of water, either by evaporation or carried off by the evolved hydrogen gas. This may increase the concentration of the solution and thus may affect its electrical conductivity and its viscosity.
3. Formation of a precipitate, which may increase the effective viscosity of the electrolyte and interfere with the process in the workpiece-tool gap.
4. Absorption of the salt by the precipitate, which will reduce the concentration of the solution and may affect its electrical conductivity.
5. Metal ions from the anode masy pass into the solution and gets deposited on the cathode.

These changes mean that the elctrolyte has a finite working life and in practice, the life may be limited because of

1. The need to maintain a reasonable constant electrical conductivity so as to facilitate control of the [illegible] process and ensure accuracy at machining.
2. The need to prevent plating-out on to the tool so as to ensure accuracy in machining.
3. The need to avoid excessive quantities of precipitate.

The first of these considerations applies to all electrolytes, the second mainly to acidic electrolytes and the third mainly to neutral electrolytes.

For maximum efficiency the elctrolyte must be pumped across the surface of workpiece

1. to remove the contaminated electrolyte from the working gap.
2. to minimise polarisation
3. to restrict the rise in temperature of electrolyte at higher densities.

Experience has shown that, in general, turbulent flow is to be preferredto get a better quality of surface finish and absence of ridges on the finished workpiece. For drilling small flow is required but largerflow rates are required for die-sinking or blade shaping. Pumps are generally used to obtain high pressures. Multistage centrifugal pumps are used to produce steady and smooth flow so that fine surface finish is obtained.

2.5 The Process of Electrochemical Machining:

ECM involves passing current through an eletrolyte in the gap between the workpiece and the suitably shaped tool. When current is passed through an electrolytic cell between a shaped anode and the plain workpiece, the distribution of current densities over the surface of the plain workpiece is determined by the shape of the anode. It is greatest at the points closest approach of tool so that the material removed from workpiece at such points will be more. As the anode is fed towards the workpiece there will a tendency for the current densities to become uniform over the whole surface and the shape of anode is brought on the workpiece.

The gap between the tool and workpiece may be about 0.125 mm and current densities upto 1000 amps are used to with the voltage between the electrodes ranging from 10 to 20 volts DC. The electrolyte carries away salts or hydroxides of the elemental metal in the workpiece. Electrolyte before recycling is filtered to remove sludge. Water has to be added to replace the consumed electrolyte. The working gap has to be maintained constant so that tool has to be provided with suitable adjustment to move it forward during the machining process. Safety measures which are elaborated in the succeeding pages of this book are to be followed to get good results. The front machining process like deep hole drilling, deburring, horning, turning and cutting off are given in the figure .

2.6 Electrochemistry of ECM:

A clear understanding of ECM process demands some knowledge of basic electrochemistry. Relevant information can be derived from the studies of the structure and properties of electrolytes, since these media largely determine the rates and types of reactions in ECM. However, in ECM the only anode reaction which is wanted is metal dissolution, and that is achieved by an externally applied potential difference between the two electrodes. This potential difference gives rise to corresponding current flow. It can be shown that the greater the current flow the greater is the difference between the equilibrium value and the working value. The difference of potential between these two is called over potential. In most of electrochemical reactions there are three specific types of over potential, namely ohmic, activation and concentration over potential.

1. Over Potential (E_R): This arises out of the resistance offered to the passage of current. Generally it is regarded as the potential drop across a thin layer of electrlyte or film layer (oxide film on the electrode surface. Its magnitude depends on the current flowing in the cell and the nature and conductivity of the electrolyte.

2. Activation over potential (E_A): It is an additional potential required for maintaining a slow electrode reaction at the desired rate. This activation over potential required is given by Tafel equation.

$$E = a + b \log J$$

where J = current density and

a,b = constant for particular reaction.

3: <u>Concentration over potential:</u> This occurs due to the difference in concentration at the electrode solution interface and in the bulk of the electrolyte solution. In ECM as the dissolution proceeds, the movement of ions in controlled by three processes.

i) Migration, movement under the influence of the electric field.

ii) Convection, bodily movement of the electrolyte solution. This is mainly affected by forced agitation of the electrolyte.

iii) Diffusion, movement due to ion concentration gradients in the solution.

In the study of these processes, the concept of the diffusion layer is very usful. Thus consider the anodic dissolution reaction. When the rate of metal dissolution is greater than the rate at which the metal ions can diffuse away from an electrode, a condition is reached in which an ionic conccentration gradient exists over a thin layer of electrolyte adjacent to the electrode. This layer is called the diffusion layer. A change in the electrode potential from the reversible value occurs due to this concentration gradient, and the numerical difference between the reversible and the new value is said to be the concentration over potential.

2.7 METAL REMOVAL RATES IN ECM:-

Electrochemical machining is unlike other, well established anodic dissolution process in that the current density is high and the electrolyte is in motion at a high velocity and is highly concentrated. Although the rate of rmoval in theory is only by the local current density, in practice this rate is strongly influenced by other factors, which include the process variables and relationship between the metal and electrolyte. The mode of removal is similarly afftected, which inturn consrols the dimensional accuracy as well as the quality of surface finish.

Theorectically, metal removal rate can be estimated as follows:

h = "tool-work' gap (cm)

a = Area of the current path (cm^2)

C = Specific resistance of the electrolyte (ohm-cm)

E = machining Voltage (volts)

I = current flowing through the gap (amp.)

t = time for which current flows (sec.)

Current density (amp/cm^2) S is given by

$$S = \frac{\text{Voltage} \quad)}{\text{Resistance x Area}}$$

$$= \frac{E}{\frac{C.h}{a} \times a} = \frac{E}{C.h}$$

According to Faraday's first law of Electrolysis, the chemical change produced during electrolysis is proportional to the quantity of electricity passed and to the electro chemical equivalent of the anode (work) material $\therefore \; m \; I.\, t.\, \left(\frac{A}{Z}\right)$

$$\text{or} \quad m = \frac{1}{96,500} \quad I.t.(\underline{A})$$

It is known that current density & field strength tend to be higher at sharp edges and corners. This results in non-uniform gap because of higher metal removal rates at those areas, and that is why sharp internal corners are difficult to machine by this process.

It is interesting to note the "self adjusting" feature of the ECM process. If the tool advances at a rate faster than that of metal removal, the gap becomes narrower, current density increases & in consequence, machining rate will also increase. Within a short time a steady gap will be established satisfying the relation $h = E.s/c.f$. Conversely, if the feed rate is lower than the material removal rate gapwill widen for a short time and current density will fall due to higher resistance, and again, the machining rate is so established that it matches the feed rate.

However, discrepancies are observed between the metal removal rates and electrode feed rates calculated from the above equations and actual experimental results. Metal removal rates in practice are often higher than the estimated values. The probable reasons for this are the following

(i) The exact valence at which a metal behaves in the electrochemical reaction is generally unknown. Some metals have only one valence; there are others, the valence at which they enter the reaction being not known, but chromium and nickel are metals for which exact metal removal rates cannot be estimated unless valences for these are assigned their correct percentages in the reaction.

(ii) Another reason for the discrepancies is attributed to additional "chemical machining" during the process of ECM. Electrochemical machining continuously exposes a new and clean surface to the electrolyte which is easily stacked chemically. The extent of chemical machining varies, depending upon the electrolyte used and the metal being machined. Metals like aluminium are easily attacked and quite a good proportion of chemical machining can occur in such metals. This chemical machining adds upto give higher metal removal rate than the theoretical one.

2.8 WORK TOOL GAP:

The controllable parameters, which determine the gap size are electrolyte temperature, composition, voltage and tool feed rate. Those relating to the electrolyte are normally not difficult to maintain at cnstant values. The gap can therefore be adjusted by voltage and tool feed rate. Under equilibrium conditions (or MRR) so directly proportional to current density. If the feed is increased, the electrical resistance of gap reduces to allow more current to flow. From this it follows that if the feed rate is doubled, the gap would be halved. While it holds good for some metals, there is a additional resistive losses that occur at the tool work surfaces. This loss is termed as 'anode potential'. The gap size thus becomes less than half in reducing the total resistive path to half to allow tool feed rate to be doubled.

In case of voltage variation also, the same reason holds good The change in gap is proportionate to change in voltage. No satisfactory methods are presently available while the process is in operation. Those employing lasers or electronic monitoring of current with imposed tool vibrations. A simple method of seasurement invariably used in ECM machines requires the tool position from a fixed datum. The gap size is then equal to the depth of machining minus total movement in to work surface during machining.

On further increase in the potential, conditions at an anode may change from passive to the transpassive state. It is caused by the anodic oxidation of the original, slightly soluble passive oxide film to a soluble form. With the occurance of the transpassivity efficient ECM takes place. Transpassive machining conditions can also be reached from an initial, active state dissolution. Then the transition becomes evident by the change from a dull etched finish, to a smooth bright finish.

The transition from the active to transpassive modes of the solution has been seen to be greatly influenced by the electrolyte flow rate and current density can also cause a consequent variation in finish over anode surface.

For instance, suppose that in the upstream a metal is undergoing polishing, but in the downstream some disturbance causes a locasl increase in the electrolyte velocity Over that latter region, an etched surface would be obtained. Alternatively local variations in velocity could result in intermittant changes from etching to polishing or partial passivation conditions. The extent of surface striations so produced can be deminished by a change in flow rate so that ECM is controlled by a single process over the whole surface.

2.9 DYNAMICS OF ECM PROCESS:

Although the rate of metal removal in theory is governed only by the local current density, in practice this rate is strongly influenced by other factors like electrolyte flow rates, gap height, voltage supplied etc.

The theoretical metal removal rate can be determined by Faraday's two laws of electrolysis.

First Law:-

The first law states that the mass(m) of an element liberated or deposited by the passage of electricity through an electrolyte is directly proportional to the quantity of electricity(q) which has flowed.

$m \propto q$

$m \propto IT$

$m = zIt$ .. (1)

Where I is the current flowing through the electrolyte in amperes.

t is the time of current flow in seconds,

z is the electrochemical equivalent of the metal liberated

in gm/coulomb (it is also defined as the mass of element liberated by passage of coulomb of electricity)

Second Law:-

The second law states that when the same quantity of electricity is passed through different electrolytes, the mass of the different elements liberated or deposited are directly proportional to their equivalent weights.

$\frac{E}{Z}$ = F, a constant called Faraday's constant = 96,500 coulombs (2)

Where E is the equivalent weight in grams

$$= \frac{\text{Atomic weight in gms.}}{\text{Valency}} = \frac{A}{Z} \quad (3)$$

From (1), (2) & (3), we get,

$$m = \frac{A\ I\ t}{Z\ F}$$

Thus the rate of metal removal (m) is

$$m = \frac{AI}{ZF} \quad .. \quad (4)$$

If d is the density of metal, then the volumetric rate of metal removal removal is $V = \frac{AI}{ZdF}$ ... (5)

Theoretical mass & volumetric removal rates for different elements are given in the table (II)

Theoretical calculation for the metal removal rate for an alloy is more difficult than that for an element because the electrochemical equivalent of the alloy is not readily known. Although the electrochemical equivalent of the individual constituents of the alloy may be available, a difficulty arises in choosing a value for the electrochemical equivalent which is representative of the whole alloy.

Two methods which have been most commonly used are the "percentage by weight" method & "super position of charge" method. The analysis for an alloy having the following particulars can be done as described below

Atomic weight of elements 1, 2, 3, ...etc.

respectively = A_1, A_2, A_3 .. ..etc.

Valency at which the ions of the elements are known to dissolve Z_1, Z_2, Z_3 etc.

Volume of metal removal by any quantity of electricity

$$= \frac{1}{96,500} \cdot I.t. \frac{A}{Z} \cdot \frac{1}{d} . n$$

Where A = atomic weight of work material

Z = Valency of work material

d = density of work material

n = current efficiency

Current efficiency may be defined as the efficiency of the current in removing the metal from the work piece. It is close to 100% when sodium chloride (NaCl) is used as the electrolyte with nitrate & sulphate solutions it is somewhat lower.

Specific metal removal rate (s) can be written as

$$s = \frac{1}{96500} \cdot \frac{A}{Z} \cdot \frac{1}{d} \cdot n \ (cm^3/amp.\ sec.)$$

and feed rate of electrode = f = S x s

$$= \frac{E}{C.h} \quad n \quad \frac{A}{Z} \cdot \frac{1}{d} \cdot \frac{1}{96,500} \ (cm/sec.)$$

A close study of the above equations, reveals that, if the voltage, feed rate and resistivity of the electrolyte could be maintained constant, a uniform gap would exist and absolute conformity to the tool shape would be obtained. But it is not so easy to analyse the process or predict the results.

Maintaining constant electrolyte resistivity in the gap is possible because of the influence of many parameters. Electrolyte temperature due to heat generated during the chemical reactions tends to reduce it. Evolution of hydrogen gas and any flow disturbances as the electrolyte progresses through the gap also affect the electrolyte resistivity. The progress is further complicated in practice by the presence of a polarised ion layer at either or both electrodes. The temperature rise reduces the viscosity and therefore "pressure-flow rate" relationship.

2.10 EFFECT OF HYDROGEN GAS:

As the eletrolyte flows downstream with the machining gap it collects in solution an increasing amount of the hydrogen generated at the cathode. The presense of the gas-electrolyte mixture has diverse effects on the ECM process, one principal effect being a decrease in effective conductivity of the solution. This decrease becomes more marked in the downstream direction and has consequential influence on the surface finish.

In order to have further observations in this study, polishing of the nickle anode was sought over the central machining region. At the same time, attempts were made to reduce the depth and numbeer of pits in the passive, stray current zone situated upstrem and downstream. The extent of stray current attack was found, in fact, to be diminished by a reduction in the concentration of the solution. But in the downstream, stray current zone, a further decrease in the effective conductivity of the colution by the accumulation of hydrogen gs bubbles. But the addition of small quantities of Na_2SO_4 and Na_2CO_3 to the main NaCl electrolyte led to an increased pitting in these area, mainly because these mixtures of electrolytes have a higher conductivity and are therefore less affected by the hydrogen gas.

2.11 Tool Design Of ECM

There are two main aspects for the design of tools for ECM the first is the determination of the shape of the tool, necessary to produce a desried workpiece shape. Theoretically it is possible but it is not yet practicable and there is necesary adjustment of tool shape on an embrical 'trial and try' basis. Alternative practiccal methods of obtaining approximate tool shapes can be used in certain circumstances

The second part of the tool design is concerned with making the tool in the appropriate material, fixing it to the machine, connecting it to the power supply, arranging an adequate supply of electrolyte between the tool and workpiece and insulating parts of the tool to prevent overcutting in undesired regions. Many of them may necessitate modification to the tool geometry.

Design of Equilibrium gap:

In calculating equilibrium tool shapes, it is essential to know the equilibrium gap at which machining is to take place. All dimensions are proportionate to equilibrium gap, taken as unit of distance. Greater accuracy will be obtained when this gap is smaller. The pressure to maintain a constant velocity is proportional to $(\text{gap thickness})^{-5/4}$ 7.

Due to small gap, less electrolyte is used to carry away the hydrogen bubbles so that effective conductivity variations along with the gap will increase. There is a chance of short circuit between the tool and workpiece due to solid matter in the electrolyte or due to imperfections in the surface of the workpiece.

The equilibrium gap is best measured when machining is in progress but if it is not possible then it is measured when the machining is stopped. Holes and cavities produced by ECM are easier to machine if a taper is allowed on the walls. Usually the taper is 0.1 inch/inch. Tapers can be removed if the tool is insulated fully. When cavities are machined minimum internal radius for cavities from 0.18 mm to 0.4 mm are obtained.

The effect of the tool on the workpiece when it is held in equilibrium position, held upto 10 gaps, held for infinitive steps is shown in figure (6.15) Similarly when a pointed tool is used with 60°, 90°and 120° angle between the two faces, is resultant product on the workpiece is shown in figure 6.16.

2.12 Design considerations of ECM

The factors considered while designing the machines are discussed in this chapter. The design process for ECM is simpler than the conventional machines.

1. Stiffness: There are 3 forces acting between the tool-workpiece when the electrolyte flows through them. They are electromagnetic, hydrostatic and hydrodynamic forces.

Electromagnetic forces are forces which act at right angles to the magnetic field and which will depend on the permeability of the electrodes. These forces affect the flow pattern.

Hydrostatic forces act between the tool and workpiece and the average pressure in the gap is in the order of one half of the applied pressure.

When the electrolyte is sent parallel between the tool and workpiece. viscose resistance will make the tool and workpiece to move sidewards. When machining larger work pieces this effect becomes greater. So fixtures have to be designed with adequate rigidity to prevent errors in alignment.

2. Protective coating: Most electrolyte tends to corrode metals so corrosion resistance is essential to safegaurd the system. The three main areas of an ECM in which corrosion may occur are

i) The face of cathode and anode.

ii) The machine bed, tool holder and tool feed machanism.

iii) Electrolyte pump, pipe and tanks used.

The flow guides and work box used in blade shaping is made of acrylic plastic called perspex which is not affected by dilute acid or dilute alkaline. Mild steel is usually coated with rubber or epoxy resin. Titanium is used to grip the workpiece since it is not much affected by the electrolyte. Components adjacent to workbox may be made of stainless steel. Machine sideways like in ECM drilling and milling cannot be protected permanently. So they are coated with grease which shields the surface.

To prevent the pump from corrosion the impellers are made of graphite ceramic or stainless steel. Tanks are made of plastic materials such as polyester or epoxy resins. Pipelines are made up of rigid PVC or steel lined with synthetic rubber.

3. Safety: When properly installed with safety precautions, ECM do not present any special hazards. But certain aspects of the process would become troublesome if proper care is not taken.

i) when acidic electrolytes are used care should be taken to avoid splashing of the elctrolyte. Operators should wear rubber boots and gloves. Chlorites and nitrites can constitute fire hazards. Emergency showers are to be installed in case any clothing catches fire.

ii) The hydrogen produced in the gap must be removed quickly because an arc might be produced between the tool and the workpiece which might lead to explosion. Usually air is passed in intervals through the gap so that the gas gets diluted and is exhausted to atmosphere.

4. Process Control: Once the tool is perfectly made it is possible to produce shapes according to the original design. accuracy during reproduction depends on

i) the deflection of tool and workpiece due to pressurised electrolyte flow.

ii) size of gap at the end of operation.

For accurate reproductivity the conductivity of the electrolyte has to be maintained constantly. Large storage tanks containing fresh electrolyte has to be made available. Water loss by evaporation and the presence of hydroxide will affect conductivity. Hotspots are produced when there is no perfect contact between the electrde and the external connection. There is an effect called "springback" in components which results from the relieving of internal stresses. This happens in all machining operation but in ECM it is probably more negligible since the process itself leaves no machining stress in the component.

If the above considerations are taken into account and the necessary precautions taken, it is possible to achieve surface finish of 0.025 mm on surfaces.

2.13 CAVITATION:

Non uniform flow can arise from the cavitation phenomena also. Even if their effect is not sufficiently great to cause a short circuit, the variation in the flow pattern usually becomes apparent by striations developed on the anode surface. As the electrolyte solution flows between the electrodes during ECM, its temperature will rise owing to, for example, the passage of current and pressure drop along the flow channel. This increase can lead to the growth of gas filled bubbles (cavities). If the growth of the buubbles is caused by temperature increase, boiling occurs. If their growth is due to pressuree reduction (at constant temperature)'caviation' is said to have occured.

Studies of caviation relate to (1) the formation of bubbles in the liquid caused by reductions in pressure below certain critical values determined by the physical condition of the liquid, and (2) the collapse of bubbles due to an associated increase in pressure. Caviation behaviour is known to take place either in the bulk of the liquid or at its interface with a boundary and the presence of cavities can lead to displacement of the liquid phase of the solution, causing alteration in the flow pattern. A further effect can be damage to the channel walls. Suppose that during ECM, the pressure conditions and the configuration of the electrodes lead to the formation of cavities which are later swept by the flow into the regions of higher pressure where the cavities collapse. If the point of collapse of cavity is is contact with either of the electrodes, the wall of the electrode will receive a blow. The consequence of successive blows may be damage to the electrode material.

In ECM cavitation is more likely to arise at a location where an abrupt change occurs in the direction of flow, associated with which is a sudden decrease in the local pressure. This problem has been the subject of a number of investigations. In one study of electro chemical die sinking, the electrolyte was pumped through a central nozzle, and then outwards in a radial direction. Calculations based on Bernoulli's equation and the equation for the pressure drop caused by viscous effects showed that pressures near the nozzle inlet could be less than the vapour pressure of the electrolyte, indicating that cavitation was likely in that region. It was also found that the onset of cavitation could be prevented by the application o a sufficiently high outlet or 'back' pressuure. Cavitation was also eliminated when the electrolyte was caused to flow in the reverse direction. The shape of the nozzle also played an important role.

2.14 PASSIVATION:

Hoar considers the principal action of passivation to be very rapid formation of an oxide layer which becomes firmly attached to the metal and which forms a barrier between it an the solution. The solid film so produced has a low ionic conductivity so that the rate of dissolution of the metal is decreased (partial passivation) or made negligible (total passivation). It is thought that passivating films can be either very poor electron conductors or good electron conductors.

Total passivation with anodic gas evolution encountered during polarisation studies of carbon steel in $NaNO_3$ electrolyte, has been attributed to an electronically conducting passive layer on the cathode surface. But an electronically nonconducting passive film is the proposed reason for total passivation without gas generation in further work with this metal inaqueous potassium fluoride electrolyte.

The passive oxide film which makes titanium so useful as a corrosion resistant material, renders the ECM of this metal very difficult. It has been claimed that the voltage required to break down the passive film can be reduced by the use of bromide and iodide electrolytes. Even then however, a severely pitted surface finish is obtained.

Tungsten carbide is another example in which passivation hinders machining. The cobalt in this metal forms a passive oxide film which has to be broken if machining is to be achieved. Although sodium nitrate is known to dissolve the basic tungsten carbide metal, the addition of an aggressive anion is helpful in breaking down the passive film formed by the cobalt.

Partial passivation characterised by a thick, tenacious dark film on the anode surface, is thought to be the cause of the coarse finish (surface roughnes in excess of 5,2 microns CLA) and low current efficiency (about 40 percent) obtained with the cast iron machined in 20 percent NaCl at current densities from about 7.7 to 15,7A/cm^2, flow rates in the range of 0.4 to 1.4 x $10^{-3}m^3/s$, being used

2.15.5 SURFACE FINISH:

Many factors which influence the rate of dissolution, also aeefect the manner in which the metal is removed from the anode, and hence they partly determine the surface finish. The quality of the workpiece material, the type of electrolyte used and the machining conditions like current density, electrolyte flow etc. influence the surface finish obtained.

Any variation in the composition of the workpiece from place to place, particularly in the different constituents have significantly different elctrode potentials, can lead to poor surface finish. When in homogenous materials are machined at low current densities the component with the lowest discharge potential is removed first. At low current densities the result at the surface of the metal is differntial dissolution of the constituents, observable as a variation in surface finish. At higher current densities, the effect of differences in electrode potentials of constituents is reduced, since the applied potential difference at the anode is then higher, and the potentials required for issolution of the constituents are more easily achieved.

A similar effect can be found with a metal whose surface includes a grain of different electrode potential from that of the surrounding material. If the electrode potential of the grain material is greater, then its dissolution will not occur until the potential at the anode surface reaches its electrode potential. During that time, the surrounding material will be machined, leaving the grain protruding at the surface. On the other hand, if the grain has a lower electrode potential, its dissolution will proceed first, leaving a recess on the surface. This effect is often observed as grain boundary attack. Owing to the traction forces created by the high rates of electrolyte flow in ECM, grains can even be dragged from metal surface increased surface roughness is then observed.

It can be noted that, of the many factors which affect the surface finish, the anode potential and current density plays a major part. Their role can be usefully studied from polarisation curves, which give us the necessary information regarding the different grades of surface finish likely to be found in ECM. In this connection, we may consider the case of etching relevant to ECM, the explanation for which has been given by Boden and Brock. Suppose that the individual crystals of the metal which are formed by the atomic lattice, can take almost any orientation of that lattice. Slight local variations in dissolution rates then occur, with the metal dissolving more rapidly from the areas which have a wider atomic spacing. Eventually an uneven surface is produced, the exposed face having the structure of the most closely spaced atoms. On further dissolution, these close-packed layers of atoms are also removed and the grains become disjuctive. If the grain boundaries are dissolved at a faster rate than their surrounding as indeed often happens, the entire grains can be dilodged from the metal surfce.

Variation in the effective conductivity of the electrolyte across the surface of the workpiece will cause corresponding variation in the current densities, which will in turn lead to variation in the surface production. Surface variations can arise from the pattern of flow of the electrolyte also. Any persistent turbulence (eddies for example) will mean that some of the electrolyte remains in the gap longer than the rest. The concentration or depleetion of ions in the eddies can result in a higher concentration polarisation than in the remainder of the electrolyte. The eddy pattern will then be reproduced on the workpiece surface as a result of local variations in current density.

An anode surface which initially is irregular, may also cause flow separation between the 'hills' and the 'valleys' on its surface, which may result in the variation of finish over the surface which are so often observed. The basis of the argument can be given as follows. Around the hills, the flow adheres to the metal surface and on dissolution of both large and small irregularities, the result should be a polished surface in that region. But in the valleys, a different situation arises. Here the flow separates from the metal surface, causing a rotation eddy in the region between the main stream of the electrolyte and the metal surface in which a large uniform concentration of metal ions may be built up. This may cause a high concentration over potential in that region, making the local removal of the smallest irregularities difficult. Polishing is then not achieved and an etched finish can be expected.

2.16 Economics of ECM

The initial cost for installing an ECM is high and cost for power,, its electro tooling and electrolyte is also high. So economic justification can be only brought by considering its merits during its application. Certain operations that cannot be performed by other operations can be done using ECM. Its high speed of metal removal and its ability to machine tough materials with good surface finish makes the process quite economical.

Holes upto 2286mm long and as small as 9.16mm can be produced on tough materials like nickel alloy. these holes are impossible to be produced conventionally.

In conventional machining profile shapes are made in "Hydrotal' and it took nearly 30 hours to complete the operation. But the same was machined using ECM.

An example to compare the ECM process with conventional machinig method by machining a profile assuming that the two machines are fully utilised.

	Copy milling	ECM
Capital cost	Rs.2,00,000	Rs.5.00,000
Labour cost/hr	Rs. 25	Rs. 25
Total tooling cost	Rs 25,000	Rs.1,00,000
Electric Power consumption	Rs. 5	Rs. 25
Production time	30 hours	1 hour

Let x be the number of components machined with both machines and various cost incurred for making one component is

	Copy milling	ECM
Machine cost	Rs.400	Rs.30
Labour cost	Rs.600	Rs.25
Electric Power cost	Rs.150	Rs.25
Tooling cost	Rs.20,000 /x	Rs.1,10,000/x

As time taken is same

$$1150 + 20{,}000/x = 80 + 1{,}10{,}000/x$$

$$x = 90$$

The break even point is $x = 90$ components. Above this value ECM is economical as shown in figure 6·10.

ECM requires constant maintenance when compared to "Hydrotel". It has complex electrical circuits and electrolyte handling equipment. Highly skilled and qualified staff are normally involved. It is clear that the cost of pioneering work can be recovered many times over when the technique is fully appreciated and its benefits fully utilised.

2.17 Advantages of ECM:

The process of ECM has been gaining rapid appreciation in the field of modern technology because of the following advantages of the process.

1. ECM process is applicable to all metals and alloys which are sufficiently good conductors of electricity. The chemical composition, structure, melting point, hardness or toughness of the material to be machined has no influence on the machining process. For this reason this process is worthy of application in the field of machining of the high strength, temperature resistant alloys required for structural elements of the air craft.
2. Any complicated profile can be easily machined in a single step. Usually the configurations which are beyond the capability of the conventional machining process or which can be made by combining several conventional processes, can be cut with ease in ECM process.
3. Any shape designed on the tool side can be reproduced on the workpiece. Thus a large number of shapes can be cut by this process.
4. The metal removal rate is very high when super hard metals are being machined. Also this ECM may be many times faster than the conventional machining of soft steel while machining any complicated shape.

5. The machining time of conventional finishing machine deburring, deep hole drilling etc has been reduced to a great extent by adoption of ECM process.
6. The low temperature developed during the time of machining of the workpiece causes no thermal damage to the workpiece structure.
7. For normal operation of the process there hs been no tool wear which is of great importance in the case of mass production of a particular product.
8. In ECM there is no possibility for workpiece distortion.
9. Working loads are lighter and less concentrated.
10. Material suffers no metallurgical changes and is free from cracks.
11. The process does not produce any chips or burrs during machining which eliminates the risk of short circuiting between the workpiece and the tool.
12. Surface finish obtained is very high of the order of 0.2 to 0.8 microns depending on the work material and the electrolyte used.
13. The dimentional accuracy is also quite satisfactory if the operation is carried out with a small gap, high density and an increased electrolyte flow.

2.18 EFFECTS OF ECM ON THE MECHANICAL PROPERTIES OF METALS:

Several tests conducted with regard to the study of the effects of ECM on mechanical properties of the metals have shown that the electrochemical machining does not aeefct the ductility yield strength, ultimate tensile strength or micro hardness of the metals. In fact for some metals, for example, beryllium and tungsten, ECM is claimed to be able to improve these mechanical properties by the removal of surface layers which ahve been damaged by conventional machining. But, of course, for these matals, the choice of a suitable electrolyte is another problem, since surface defects produced by ECM may be a source of reduced fatigue strength.

Thus, though the process does not affect the mechanical properties of the metals, a reduction in the compressive stresses would arise through the electrochemical removal of the surface layers. As a result of this, the fatigue strength is going to be reduced in the metals machined by ECM process. However, after ECM, treatments like vapour blasting or glass bead blsting can be given to the metal to restore its fatigue strength to its former levels. The removal of compressive stress appears to be the main reason for the possible reduction in fatigue life of metals undergoing ECM. Surface defects caused by the process itself seem to have only effects of secondary importance.

It may also be noted that the removal of the metal by electrochemical machining leaves the material in a natural undisturbed state, A stress-free surface so produced is the one from which the true fatigue strength of the metal can be measured.

According to Micheal Field, ECM has a tendency to produce a surface which contains no plastic deformation. The deleterious conditions associated with ECM, intergranular attack or preferential solutions of micro constituents. ECM has a tendency of producing a soft surface layer. This layer may be as much as five Rockwell points softer than the basic materials. ECM operations reduce the endurance limit by 10 per cent for the same surface finish.

2.19 DISADVANTAGES

1. Main drawback of the process is the high energy consumption which is about 150 times greater than conventional machining.

2. This process is not economical for a single job production.

3. Cost of tooling is high.

4. Corrosion problem shorten the life of the equipment.

5. If proper working conditions are not chosen, either pitting or etching may occur.

2.20 APPLICATIONS

The process can handle a large varieties of materials, limited only by their electrochemical properties and not their strength. Metal removal rates are high especially with high strength difficult to machine alloys. Fragile parts which are otherwise not easily machinable, can be shaped by ECM.

A parallelogram-form recess (1.25 mm) seep is to be machined in the end face of the port of a turbine stator blade. Because of the extreme hardness of this cast nickel-base alloys, conventional milling time was extended and cutter life short. ECM proved to be a satisfactory means of producing the recess, although some difficulty was experienced in providing adequate flow over the whole area to be machined.

2. DISC FACED TURNING

When a large surface of revolution has to be machined, it is often more convenient, and sometimes necessary, to sweep the component below and ECM tool whose area is only a fractioon of the total area of the surface to be machined. It may then be possible to satisfy the condition of minimum current density required for a satisfactory surface finish even though the total current available may be many times less than that needed if the whole area is to be machined in one plunge operation.

3. THINNING OF TRAILING EDGES

A convenient method of producing certain aerofoil blades is to fold a sheet in the desired form and then seam-weld the trailing edge. There naturally follows the requirement to thin down and radius the trailing edge. Although this can be adequately done by blinding, a simple ECM cell can be used which does not involve the use of a machine. The electrodes are fixed to the walls of the cell and the end to be thinned is placed walls. The tool is fed within a small chamber of insulating material which is pressurised with electrolyte. The flow is thus ' reversed' in that it exhausts through the center passage. Better accuracy and surface finish are thus produced, since the vertical walls are exposed to the fresh electrolyte.

4. SECTIONING OF THICK BARS AND BILLETS

Saw cutting of tough alloy bars is a slow and costly process. Tool wear is also high. ECM appears to be an attractive alternative where a cathode is made up of two plates secured together and externally insulated.

There are obvious differences between cutting a rectangular and a round bar. In the case of a rectangular bar, euilibrium conditions are achieved quite early in the operation and the whole bar width is wetted by the electrolyte. In the case of a round bar, electrolyte may escape from the area where it is needed at the beginning of the operation. Such problems can be overcome be careful cathode design.

2.21 LIMITATIONS

The main limitation of this process is that non conductive materials cannot be machined.

Another limitation is the inability to machine sharp interior edges and corners (less than 0.2 mm radius) because of very high current densities at those points. Blind holes cannot be machined in the solid block in one stage. Simple and straight forward shapes can be rapidly produced by conventional machining methods than ECM. Length of the components produced by the shaped electrode is restricted to about half a metre. However, improved tooling in the near future may overcome this limitation.

Corrosion and rust of ECM machine can be ahazard. But preventive measures can help in this regard. The interior parts may be coated by heat cured polyurethane, high intensity spray areas by keroseal; and brine tank may be lined by vinyl. Less corrosive, though slightly more expensive electrolytes like sodium nitrate can also be employed.

Although the parts produced by ECM are stress-free, they are found to have fatigue strength or endurance limit lowered by approximately 10 to 25 percent. In situations where fatigue is critical, a post-ECM shot peening are found to restore the strength.

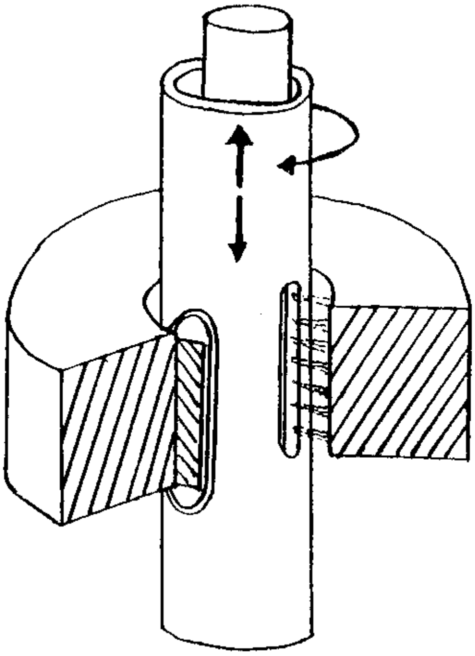


FIG: ELECTROLYTIC HONING

FIG NO: 6.1

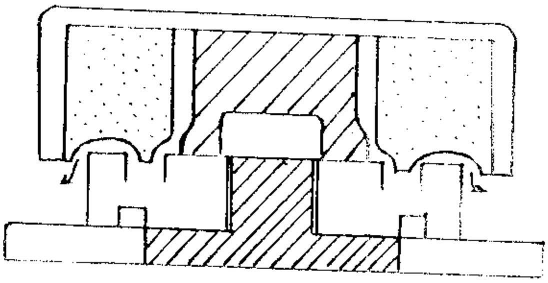
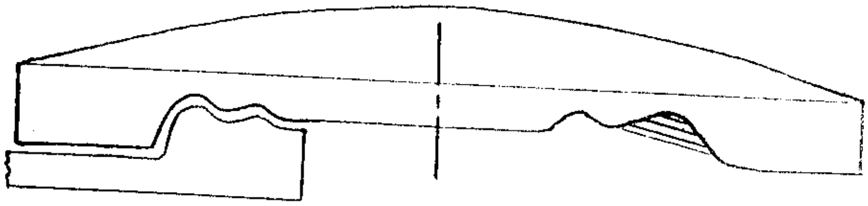


FIG: ELECTROLYTIC DEBURRING

FIG NO: 6.2

FIG: ELECTRO CHEMICAL TURNING FIG NO: 6



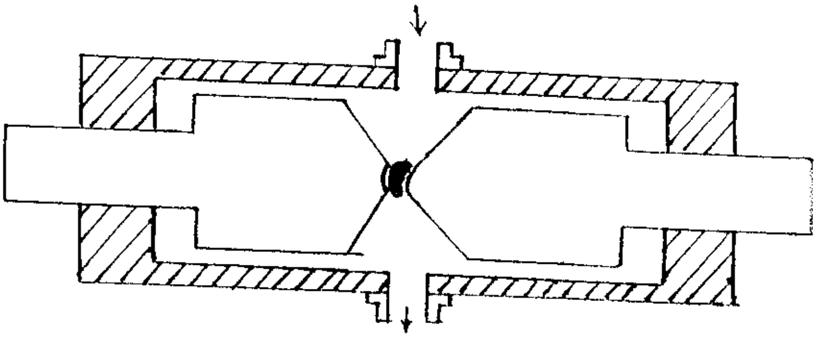
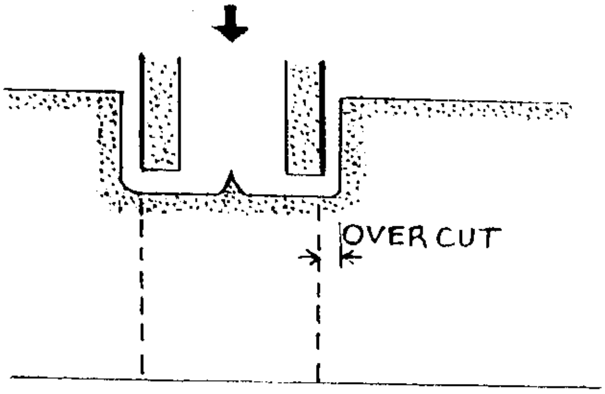
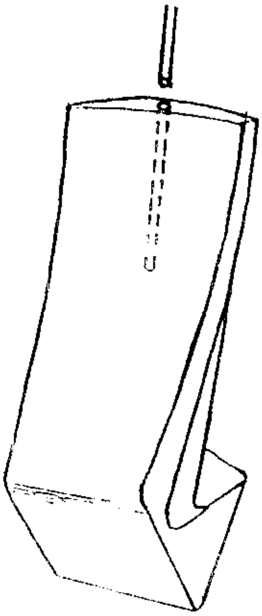


FIG: ELECTRO CHEMICAL SHAPING FIG NO: 6.4



DRILLING

FIG No: 6.5



DEEP HOLE DRILLING

FIG No: 6.6

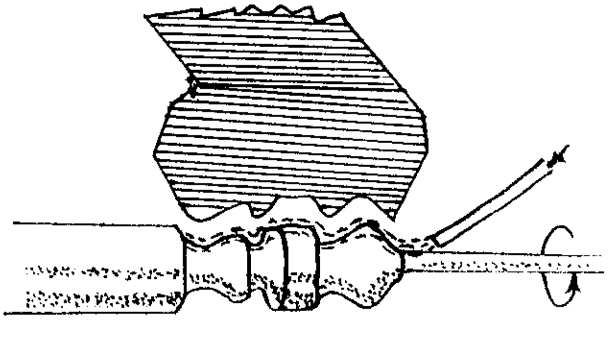


FIG: ELECTROCHEMICAL TURNING

FIG No: 6.7

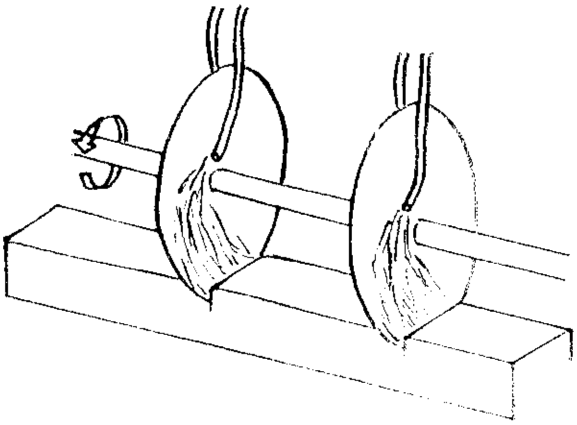
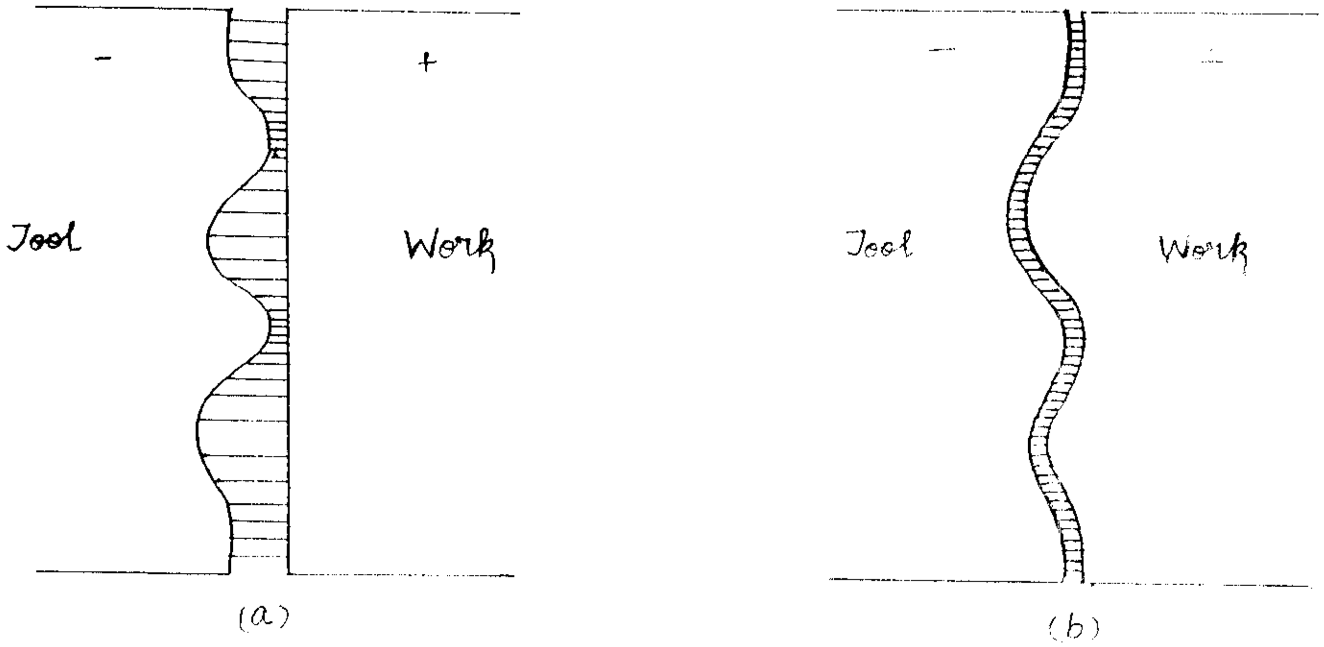


FIG: ELECTROCHEMICAL CUTTING-OF

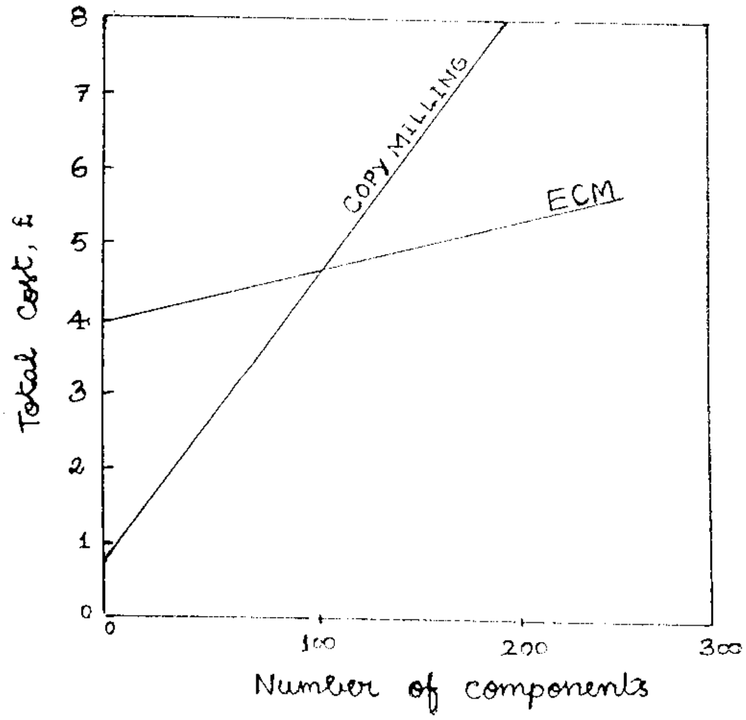
FIG No: 6.8



(a) (b)

Electro - Chemical Machining [illegible]

Comparison of cost of conventional milling and ECM



[illegible]

Effect of current density on Metal removal rate

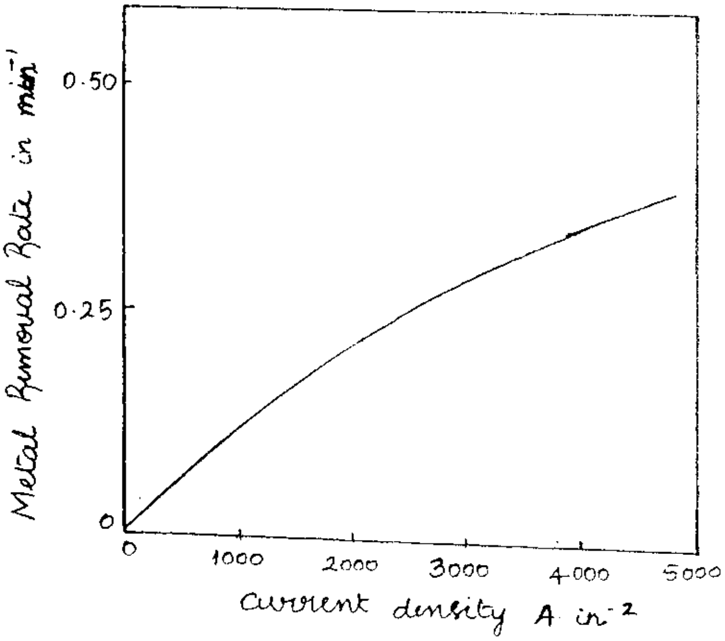
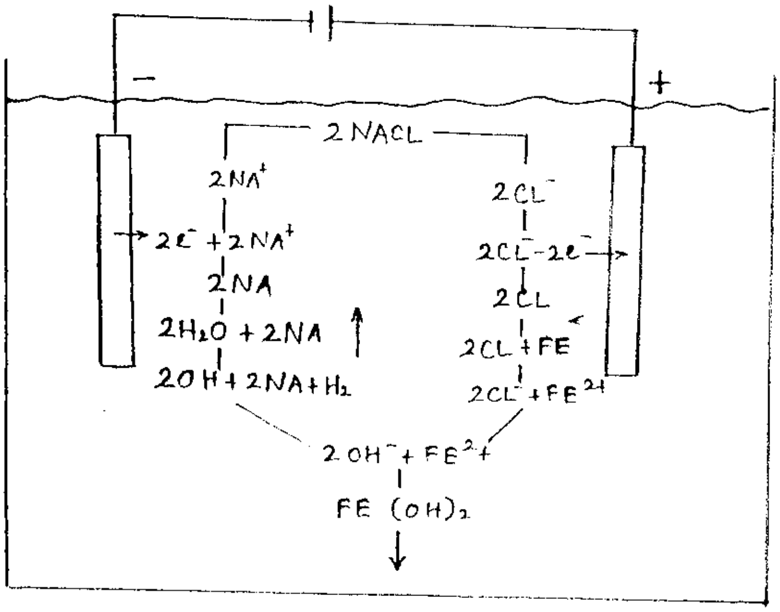


Figure 6.11



Basic Mechanism of Electrolysis

Figure 6.12

Trends of Metal removal rate with time

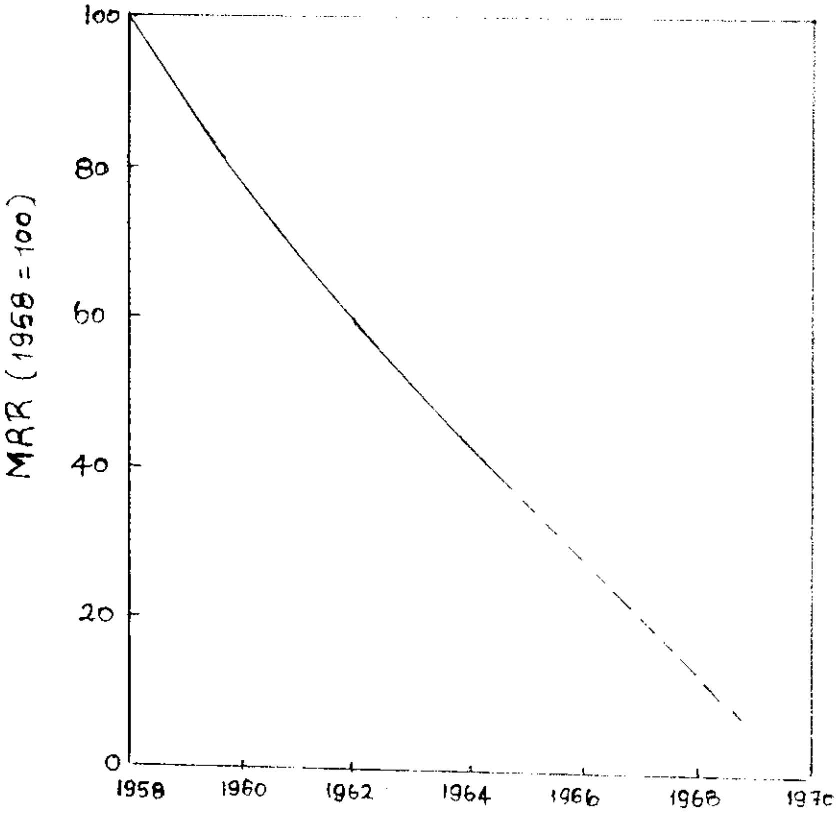


Figure 6.13

Effect of temperature on the cell voltage required to maintain a given current density

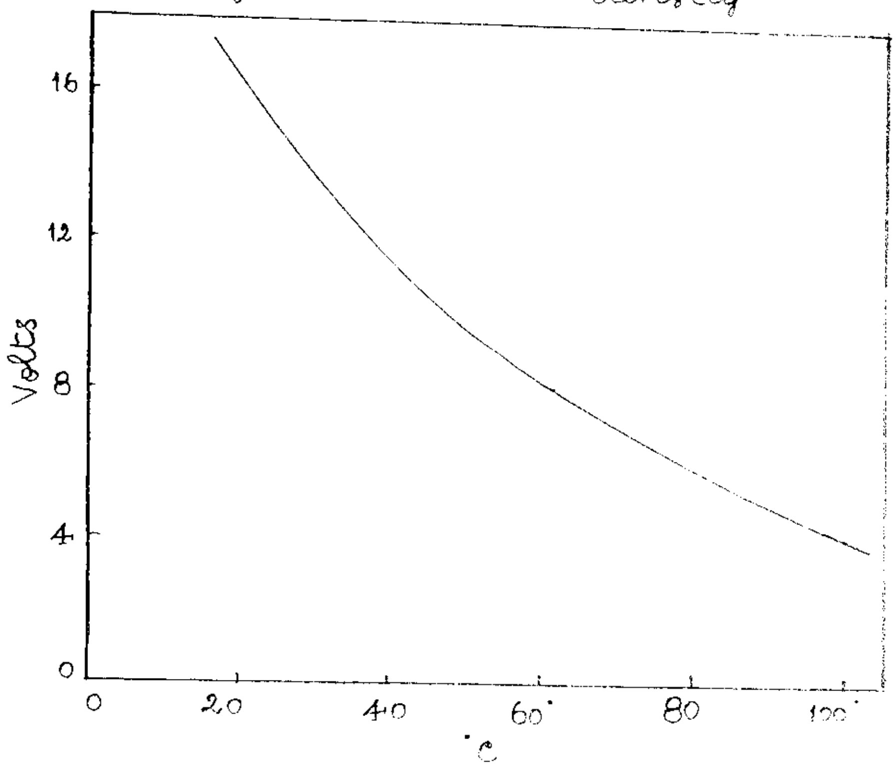


Figure 6.16

Workpiece shapes obtained for a stepped tool with various step sizes
(a) 1 equilibrium gap (b) 10 gaps (c) An infinite step

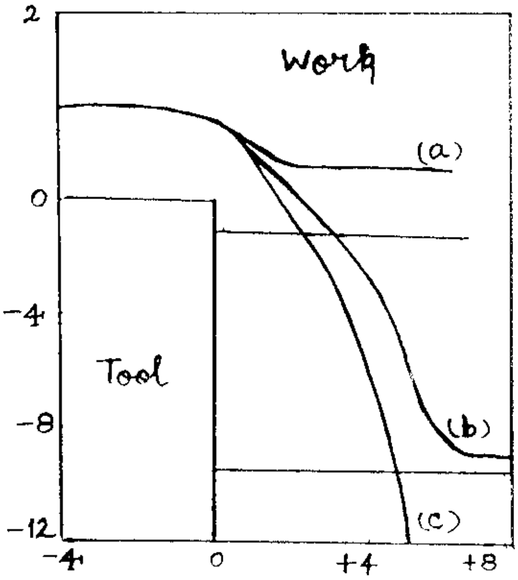


FIG. [illegible]

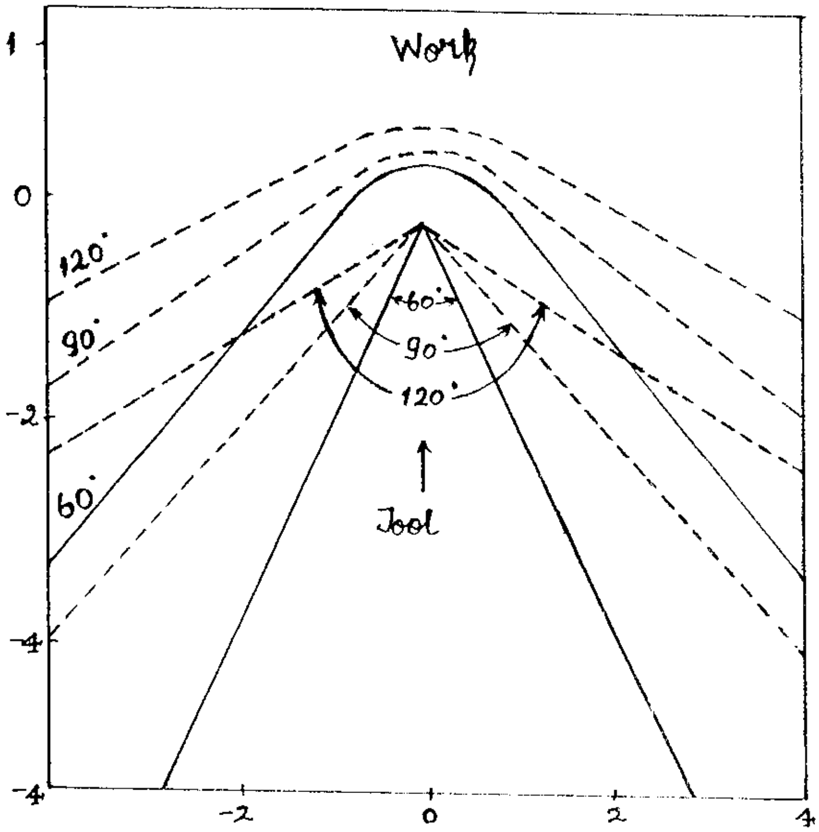
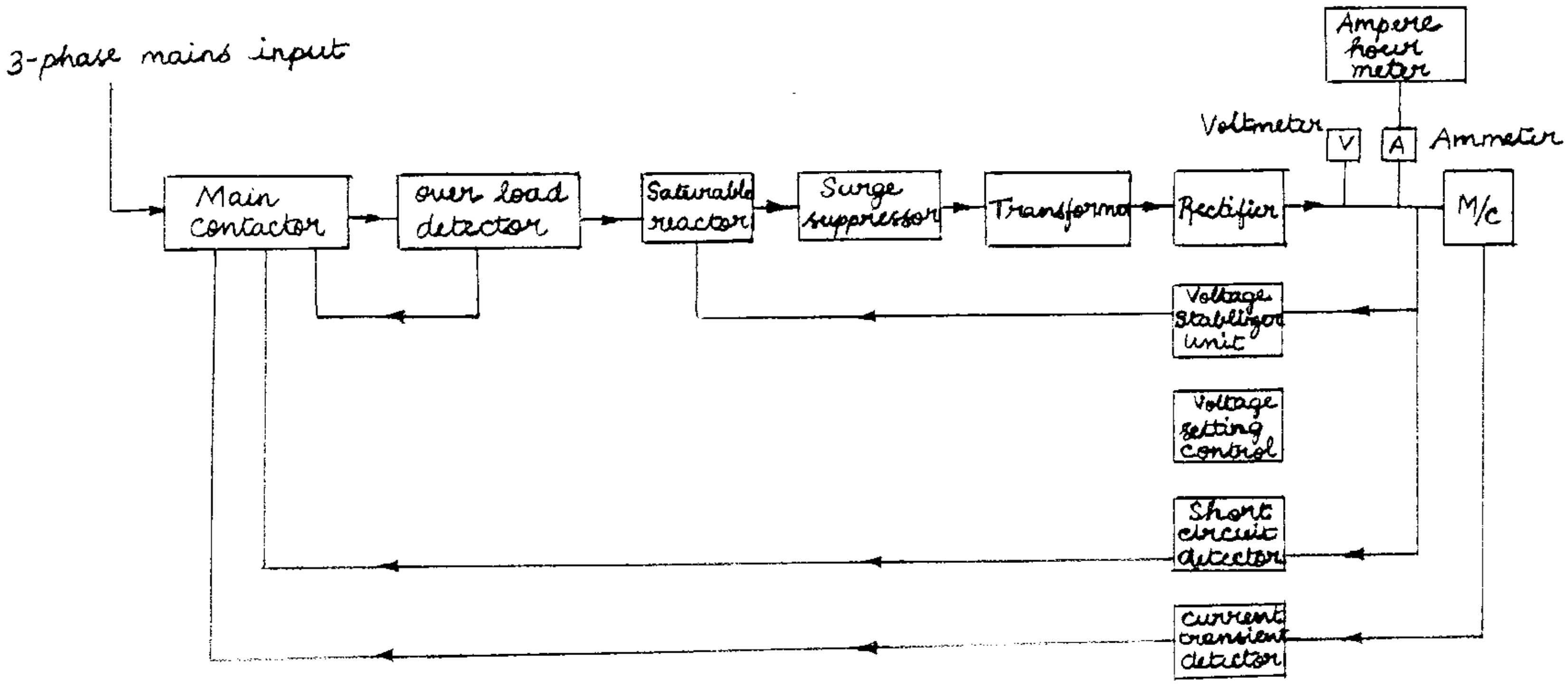


FIG. [illegible]

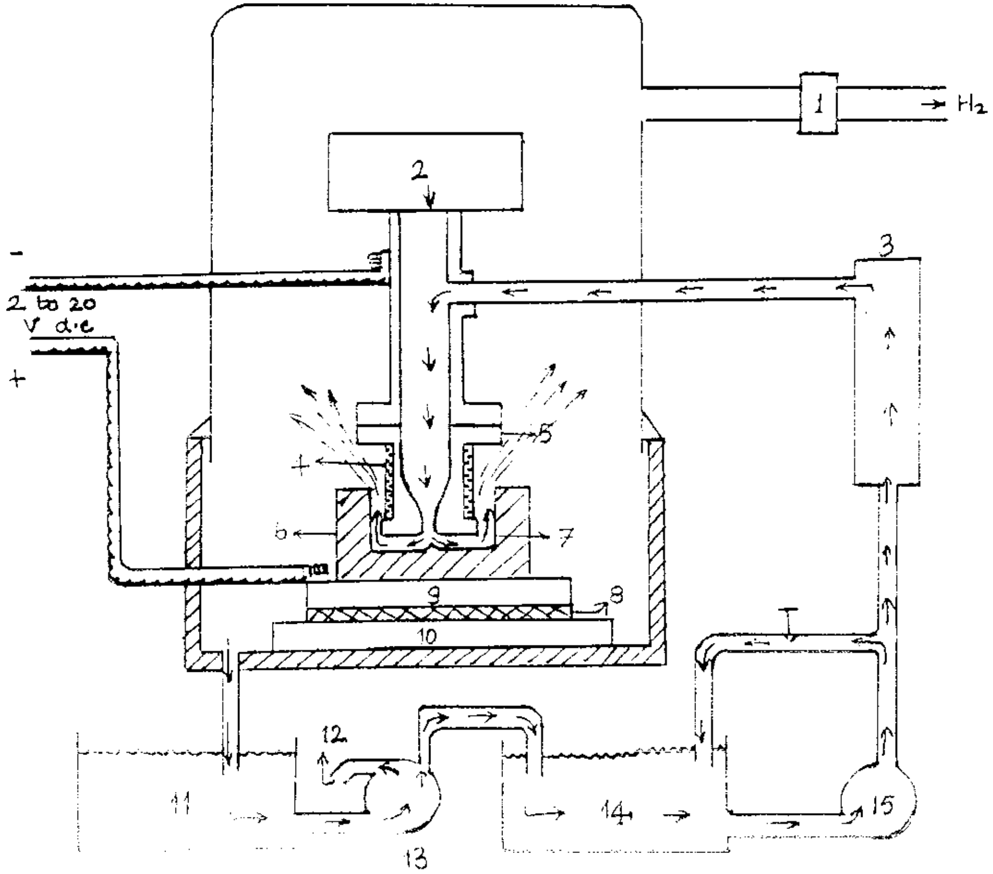
Workpiece shapes obtained for wedge-shaped tools of angles of 60°, 90° and 120°



Block schematic diagram of a typical power supply for an electrochemical machine

Figure No. 5.7

Schematic diagram of Electro chemical Machining



1. Fan
2. Constant tool feed
3. Filter
4. Insulation
5. Tool
6. Workpiece
7. Overcut
8. Insulation
9. Fixture
10. Base
11. Electrolyte
12. Sludge discharge
13. Centrifuge
14. Electrolyte
15. Pump

CHAPTER 3

FABRICATION OF ECM CELL

With the idea of making a brief study of ECM, we thought of fabricating a simple experimental set up. Due to financial constraints we had to adjust with the materials available and used all simple set ups.

Perspex block which was locally available was bought and adhered into two pieces. The added advantage of using Perspex was that it is transparent and chemical reactions taking place inside the block can be viewed from outside. It is not affected by electrolyte solution. As the process has to take place within the cell, arrangements had to be made within it.

The other requirements for such a set up to be designed are

1. The tool-workpiece had to be gripped firmly.
2. Provision for external connection for the tool-workpiece
3. Adjustments for the tool to move forward.
4. The electrolyte must flow freely.
5. Leakage must be prevented.

These requirements were seriously viewed upon and all factors were considered for the experimental set up.

3.1 Design of Perspex Block.

The Perspex was got as a 640 x 160 x 30 mm and was cut into four pieces with the size of 160 x 160 x 30 mm each. These blocks were cleaned with Carbon Tetra chloride and two blocks each were adhered together with chloroform. Chloroform when poured on Perspex, forms a thin film and this film formed sticks together the pieces. The blocks were held in a vice and kept as such for an hour.

On one piece of the block, rectangular hole of 18 x 3 mm was milled. Care was taken for the rectangle hole to be milled properly. This was used for the flow of electrolyte. Perpendicular to this rectangular slot, a hole of 17 mm diameter was drilled. The same process was followed for the other block. On the sides of these blocks holes of 28 mm diameter were bored. These bores are used to accomodate oil seals of outer diameter 28 mm and inner diameter 16 mm. Oil seals are used to prevent leakage of electrolyte through the sides of the tool and workpiece.

To have external connections for the flow of electrolyte, the sides of the block having rectangular slots was drilled to accomodate bolts. Flanges were connected to the block through these bolts. The Perspex blocks were held tight with four long screws drilled on the sides of the block. A view of Perspex block is shown in the figure 6.19.

3.2 Design of flanges

The material of flanges is cast iron. A circular blank of outer diameter 90 mm was got and a hole of 25.4 mm was drilled. A small hollow cylindrical piece of outer diameter 25.4mm was welded to it. Four holes of 6mm diameter was drilled on the flange. Using bolts this flange was fixed to the perspex block and the bolts were tightened firmly.

The flanges provide support for external connection from the tank to the perspex block. This flange is provided on the other side of the perspex block. Rubber packings were placed between the flange and the perspex block so that the leakage of the electrolyte solution is prevented. Serrations were made on the outside of the flange pipe so that it grips the pipe firmly. The two views of the flange is given in the figure 6·24.

3.3 Design of Electrodes

Workpiece: The workpiece is made up of mild steel. The length of the workpiece is 120 mm and diameter is 19 mm. This diameter was reduced to 16 mm to a length of 60 mm in a lathe. After a length of 20 mm a step of 3 mm was given for a length of 20 mm. This provision was given to hold the workpiece to the supports. The sides and face of the workpiece was polished using emery paper. Provisions were also given to have external connection.

Tools: The tool is made up of copper. The length of the tool is 120 mm and 19 mm diameter. This diameter was reduced to 16 mm to a length of 60 mm in a lathe. After a length of 20 mm a step of 3 mm was given for a length of 20 mm. This provision was given to hold the tool to the supports. The face of the tool was smoothened using emery paper. Provisions were given to have external connection. The figure of tool and workpiece is given in page 6·23.

3.4 Design of Base plates, Angles and Supports.

Base Plate: The Base plate is made up of cast iron. It is 240 x 120 x 3 mm in size. The Base plate holds the Perspex block angles and supporting plates. Slotted holes were provided on the sides of the plates to accomodate the movement of the angles. This is done by moving the screws to and fro. The figure of Base plate is given on page 6·22.

Angles: Angles are provided on the sides of the Perspex block. It is made up of cast iron and is 120 x 40 x 5 mm in size. This angle is screwed to the Base plate through the slotted hole, on both sides of the block. The figure of the angle is given in page 6·20.

Supports: Supports are made up of cast iron. The size of support is 120 x 120 x 5 mm. The supports are welded to the angles. A hole is drilled to a diameter of 22 mm on the support. This hole mainly used to hold the tool and workpiece.

CHAPTER 4

EXPERIMENTAL SET UP FOR ECM

Figure 6.18 shows the experimental set up of ECM used for our experiments. The experimental set up of ECM consists of different systems.

1. ECM Cell.
2. Electrolyte circulating system.
3. Electrical power supply system.

ECM Cell: The parts of working ECM cell has been clearly explained in the earlier chapter. The Perspex block is placed on the Base plate, angles with supports are fixed on it. The tool and workpiece are inserted into the block. The external connections are given for electrolyte flow and electric current. Insulations are provided in different places to prevent short circuiting.

Electrolyte circulating system: Sodium chloride in water is used as electrolyte for ECM. This electrolyte is filled in a tank and the tank is placed at a higher level. Electrolyte flows in a natural draft into the block and it is collected in a tank kept below. A stand by tank is used so that when filled with electrolyte and kept still, the sludge in the electrlyte settles down and the filterate is recirculated.

Electrical power supply system: The three phase current from the mains is connected to a DC transformer. This transformer converts the three phase current into DC current. This current can be varied. Copper flexibles are used to connect the tool and workpiece to the transformer. Current at the range of 50 amps wer passed through the copper flexible.

4.1 Working procedure of ECM:

The ECM was fabricated and the parts were put together. The mild steel and copper elctrodes were placed in position and the gaps were adjusted. One end of the copper flexibles were connected to the electrodes and the other ends were connected to the DC transformer. The workpiece-tool gap was kept at 0.5 mm and the current supply was in the range of 50 amps. Sodium chloride mixed with water was used as the electrolyte solution. As the electrolyte solution passed through the gap the machining took place.The electrolyte with sludge was removed and filled in a tank. The electrolyte was allowed to settle and the filterate was allowed to recirculate. The machining was allowed to ber carried out for 10 to 12 minutes. The transformer was switched off.

The electrodes were removed along with the electrical connections and supporting plate. The workpiece was removed and examined for results.

4.2 CONCLUSION

ECM should be attractive to the production engineer because it offers high metal removal rates, independent of the hardness of the workpiece or the complexity of the machining required. In principle, therefore, ECM should offer substantial advantagesin a very wide range of cavity sinking and shaped-hole operations. But, like all new methods, ECM has its strengths and weaknesses. Some of the disadvantages to the production engineer are:

i) Unfamiliarity with the techniques involved - for example, circulation of corrosive liquids, filtration, effluent disposal and large electric currents.

ii) The high capital cost of the equipment, which arises from the need for stiff, corrosion-resistant structures and large electric currents.

iii) The difficulty of controllingthe process, which arises from lack of knowledge of electrochemistry at high current densities and of the flow of fluids containing solid particles and gas bubbles.

iv) The probelm of tool design for ECM which give rise to long lead time and high cost in developing the tooling for ech specific application.

Of these disadvantages (i) will be overcome only by experience. Many suuccessful installations are already in operation so that it is already clear that the difficulties can be overcome. There is at present a real need for more production engineers to become acquainted at first hand with the advantages and disadvantages of ECM.

The most suitable equipment will be developed only as a result of extensive feedback of user experience.

Little hope can be held out for substantial reductions in the capital cost of equipment for ECM but capital cost in itself should not be the criterion by which a new machine is judged. If, despite the high capital cost, ECM enables components to be produced more cheaply, then the process is economic.

The control of the process of ECM is closely related to that of tool design but there is a clear need for more basic information on electrode phenomena at high current densities and high rates of electrolyte flow, a need which could be met by well directed electrochemical, research. The related problems of fluid flow are more difficcult and will probably have to be solved empirically and by ingenious design.

But major outstanding problem associated with the successful use of ECM is that of tool design - how to design, for each specific application, a tooling system so that the electrolyte flows uniformly and at sufficient rate between the tool and the workpiece, and so that the rate of metal removal varies across the surface of the workpiece in just the manner necessary to produce the required size and shape of workpiece.

4.3 Results:

This project deals primarily with the fabrication of ECM working cell. After the machining was over the workpieces were taken for observations. As the surface measuring instruments like Talysurf was not available in our college we had to decide the surface finish by feeling with the hand. Though a very fine finish was expected we were only able to make a little smooth finish. This can still be improved by increasing concentration, pressure and bringing the workpiece-tool gap closer.

Due to continuous use of the electrolyte it soon got contaminated with metal particles as it was used again and again. This can be rectified by using filters and a centrifuge is used to remove metal particles.

As the workpiece-tool gap is always changing due to the pressurised flow of electrolyte, it must be provided with automatic adjustment so that the gap is maintained constant and better results can be expected.

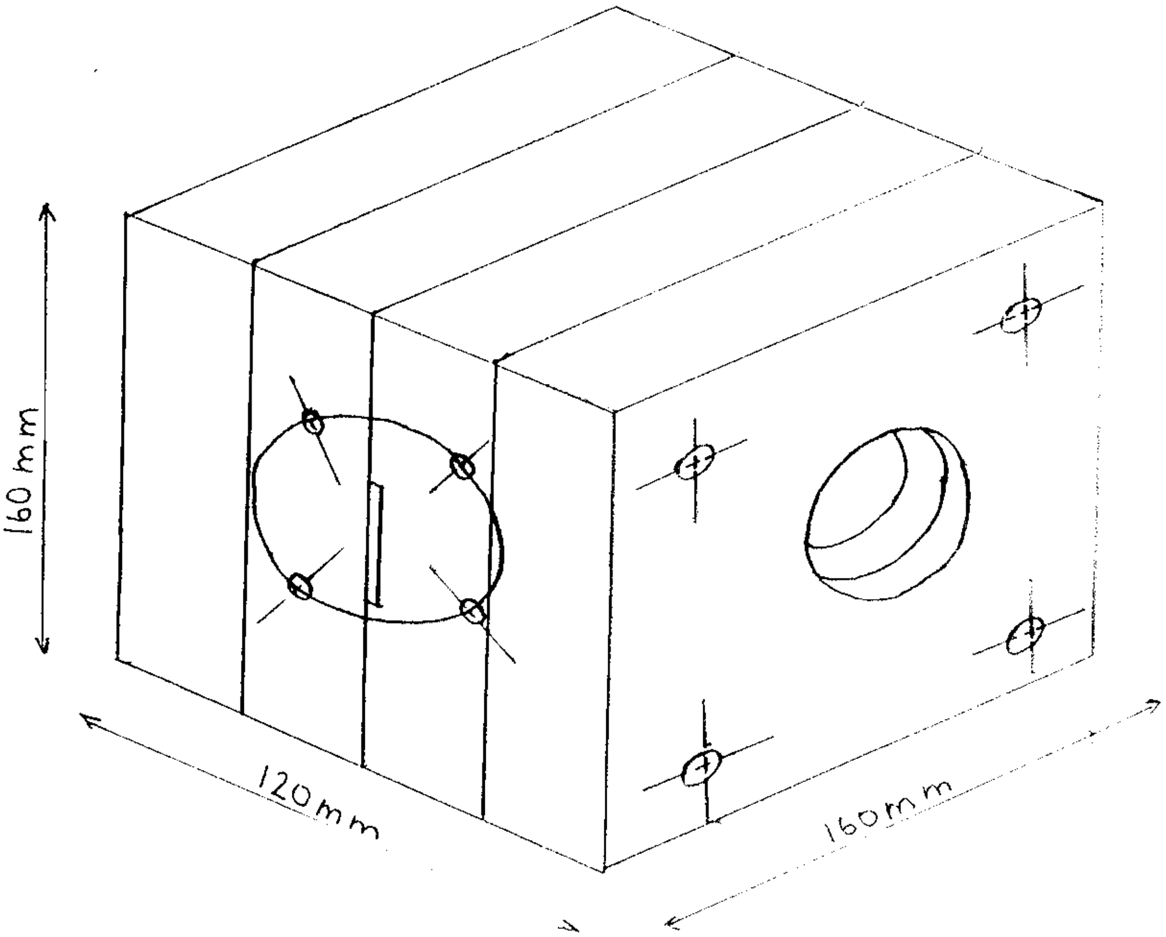


FIG NO: 6·19 PERSPEX BLOCK.

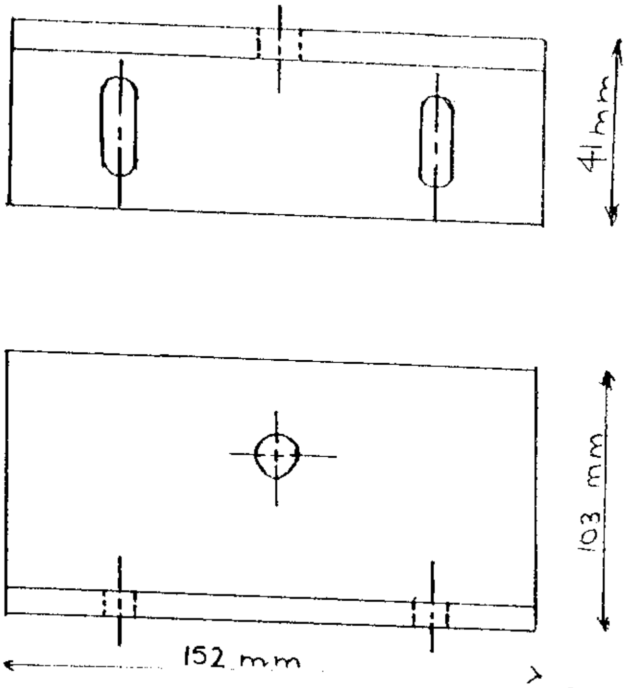
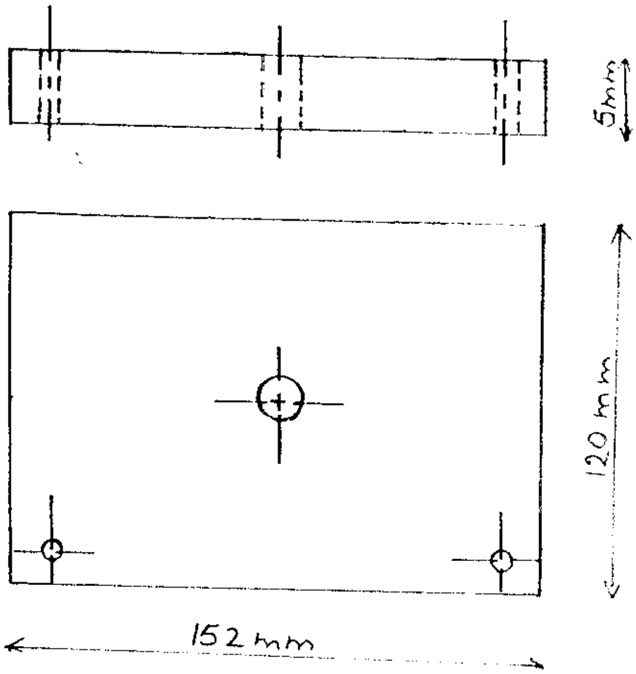


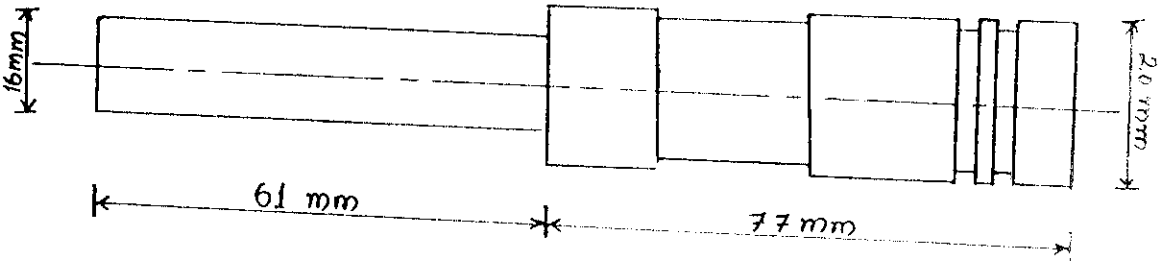
FIG NO 6.20 ANGLE PLATE



WORK SUPPORTING PLATE

FIG NO 6.21

Workpiece



Tool

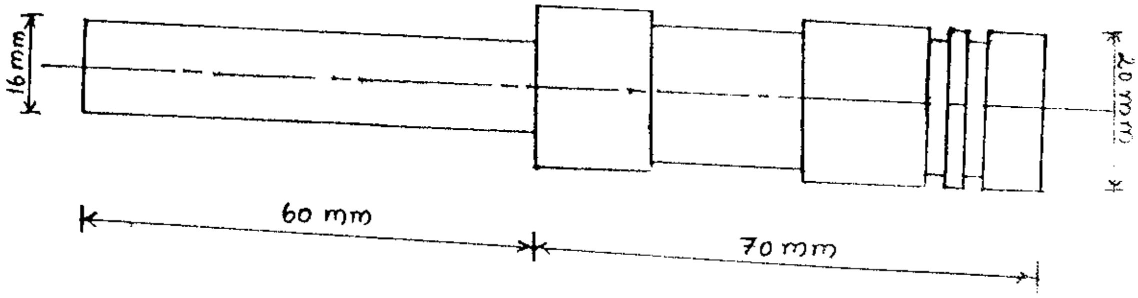


FIG NO: 6.23

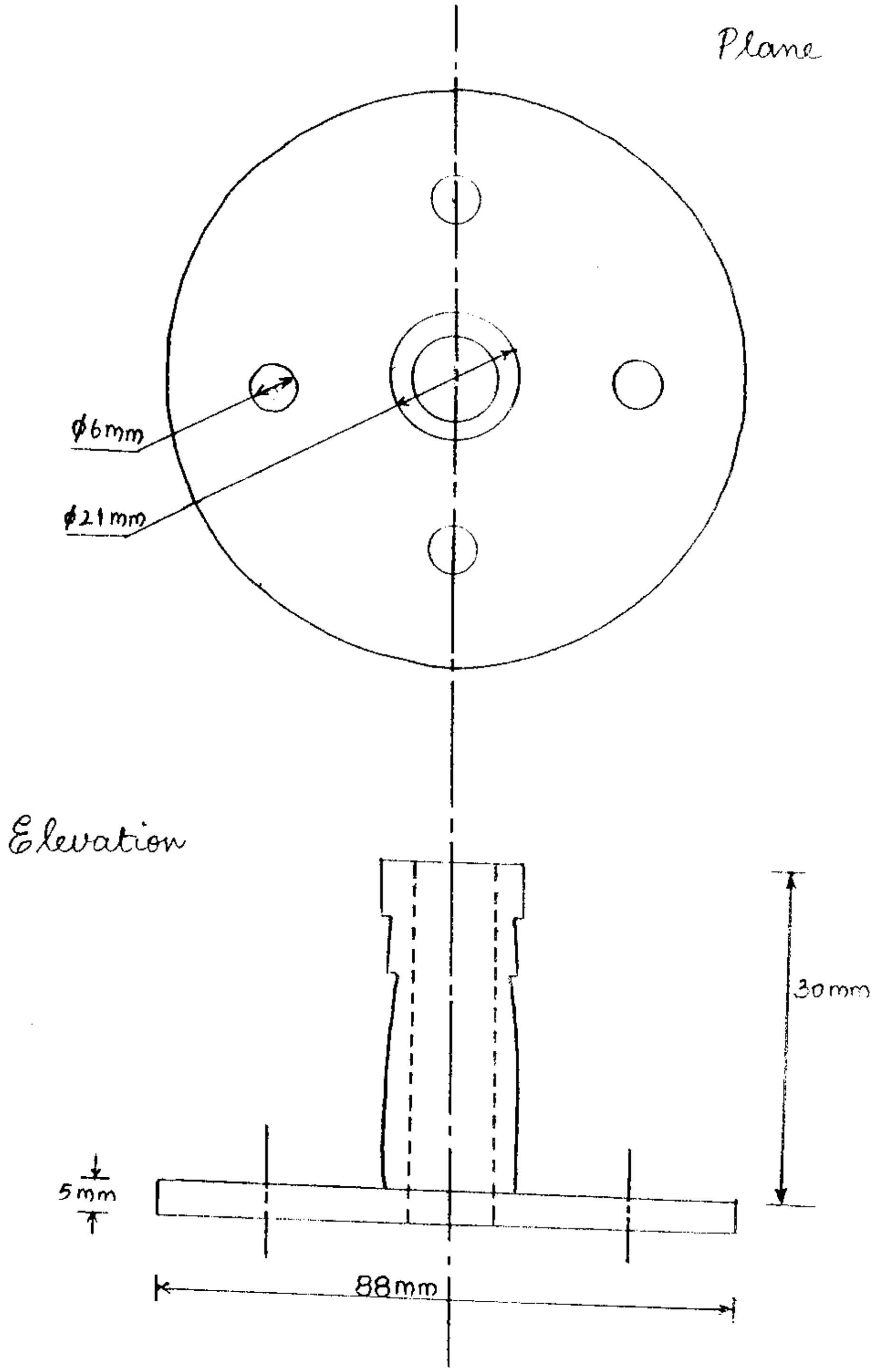


FIG NO: 6.24. Flange

CHAPTER 5

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TABLE -1

ORGANIC COATINGS TO PROTECT METALS AGAINST CORROSION BY ECM ELECTROLYTES

Coating	*Chemical resistance*			*Resistance to abrasion*	*Remarks*
	Dilute hydrochloric and sulphuric acids	*Brine solution*	*Dilute alkalis*		
1 Polyvinyl chloride (PVC)	S	S	S	Good	
2 Polythene (high density)	S	S	S	Good	Preferred to the low density material for electrical applications
3 Polythene (low density)	S	S	S	Fair	
4 Nylon	Limited	S	Limited	Very good	Very low water absorption. Electrical insulation excellent
5 PTFE	Good, but difficult to obtain coatings free of pores			Poor	
6 Chlorinated polyether (Penton)	S	S	S	Very good	
7 Solvent-based epoxy resin	Generally S, depending on formulation	S	As for acids	Good	Stoving preferred to air drying
8 Solventless epoxy resin	S	S	S	Good	Better performance than solvent-based compositions
9 Polyurethane	S	S	S	Said to be similar to vitreous enamel	
10 Chlorinated rubber	S	S	S	Good	
11 Neoprene	Limited	S	S	Very good	

S = Satisfactory