ESTIMATION OF MRR USING U-SHAPE ELECTRODE IN ELECTROCHEMICAL MACHINING

A THESIS SUBMITTED IN PARTIAL FULFILMENT
OF THE REQUIREMENTS FOR THE DEGREE OF

Master of Technology

In

Mechanical Engineering

BY

UMASANKAR MALLICK

DEPARTMENT OF MECHANICAL ENGINEERING

NATIONAL INSTITUTE OF TECHNOLOGY

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UNDER THE GUIDENCE OF

Prof. C.K.BISWAS

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CERTIFICATE

This is to certify that thesis entitled, “**ESTIMATION OF MRR USING U-SHAPE ELECTRODE IN ELECTROCHEMICAL MACHINING”** submitted by UMASANKAR MALLICK in partial fulfillment of the requirements for the award of Master of Technology Degree in Mechanical Engineering with specialization in “Production Engineering” at National Institute of Technology, Rourkela (Deemed University) is an authentic work carried out by him under my supervision and guidance. To the best of my knowledge, the matter embodied in this thesis has not been submitted to any other university/ institute for award of any Degree or Diploma.

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ABSTRACT

Non-traditional machining has grown out of the need to machine exotic engineering metallic materials, composite materials and high tech ceramics having good mechanical properties and thermal characteristics as well as sufficient electrical conductivity. Electrochemical Machining developed in late 1950's has been accepted worldwide as a standard process in manufacturing and is capable of machining geometrically complex or hard material components, that are precise and difficult-to-machine such as heat treated tool steels, composites, super alloys, ceramics, carbides, heat resistant steels etc. being widely used in die and mold making industries, aerospace, aeronautics and nuclear industries. The principle of anodic dissolution of metal theory is the most accepted mathematical model for evaluating material removal from electrodes during electrochemical process. If two suitable metal poles are placed in a conducting electrolyte and a direct current passed through them, the metal on the positive pole get depleted and its material is deposited on the negative pole. Keeping this in view, the present work has been undertaken to finding the material removal rate by electrochemical dissolution of an anodically polarized work piece with a U-shaped tubular copper electrode. In the experiment, AISI D2 steel is used as specimen. Experiments were carried out to study the influence of machining parameters such as feed rate, applied voltage, conductivity and flow rate on the over cuts in length, width and height of the specified cavity.

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1.1BACKGROUND:

Electrochemical Machining (ECM) is a non-traditional machining (NTM) process belonging to electrochemical category. ECM is opposite of electrochemical or galvanic coating or deposition process. Thus 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.

The new concept of manufacturing uses non-conventional energy sources like sound, light, mechanical, chemical, electrical, electrons and ions. With the industrial and technological growth, development of harder and difficult to machine materials, which find wide application in aerospace, nuclear engineering and other industries owing to their high strength to weight ratio, hardness and heat resistance qualities has been witnessed. New developments in the field of material science have led to new engineering metallic materials, composite materials and high tech ceramics having good mechanical properties and thermal characteristics as well as sufficient electrical conductivity so that they can readily be machined by spark erosion. Non-traditional machining has grown out of the need to machine these exotic materials. The machining processes are non-traditional in the sense that they do not employ traditional tools for metal removal and instead they directly use other forms of energy. The problems of high complexity in shape, size and higher demand for product accuracy and surface finish can be solved through non-traditional methods. Currently, non-traditional processes possess virtually unlimited capabilities except for volumetric material removal rates, for which great advances have been made in the past few years to increase the material removal rates. As removal rate increases, the cost effectiveness of operations also increase, stimulating ever greater uses of non traditional processes.

Electrochemical Machining (ECM) is the controlled removal of metal by anodic dissolution in an electrolytic cell in which the work piece is the anode and the tool is cathode. The electrolyte is pumped through the gap between the tool and the work piece, while direct current is passed through the cell, to dissolve metal from the work piece. ECM is widely used in machining of jobs involving intricate shapes and to machine very hard or tough materials those are difficult or impossible to machine by conventional machining. It is now routinely used for the machining of aerospace components, critical deburring, Fuel injection system components, ordnance components etc. ECM is also most suitable for manufacturing various types of dies and moulds.

For the first time ECM is developed for educational institutions, after years of experience and expertise demonstrating various aspects of electrochemical machining technology. The set up has robust construction, reliable and sophisticated technology, user friendly operation and is easy for maintenance. Extra care is taken while designing for operator safety by providing various protections.

The job to be machined is fixed in the vice, in the machining chamber, that is sealed for any leakage of electrolyte and is corrosion resistant, having window to see machining operation. Tool is brought near the job with the help of press buttons provided on the control panel and table lifting arrangement, maintaining particular gap. The tool progress is observed vertically by servo motor and is governed by micro controller based programmable drive. Then the process parameters are set like tool feed rate, voltage, timer, auto/manual mode, etc.

The process is started in the presence of an electrolyte flow that is circulated with the help of special pump filling the gap between anode (job) and cathode (tool)shown in fig 1.1. Electrolyte flow is adjusted by flow control valve. The machining is achieved by sinking of tool forming its replica. During the operation sophisticated control panel takes care of any damage to the machine by over load and short circuit protections. After desired time interval hooter gives an indication of completion of the time / process. The small machining area with given power supply be machined within 30 mins to one hour.

Prior procedures for cathode (tool) design in electrochemical machining have been plagued by limited applicability, inaccuracy, and no convergence. A least-squares minimization of the deviation of the simulated anode (work piece) shape from that desired is performed, yielding a set of parameters in a predefined representation which uniquely define an optimal cathode shape. Cathode shapes are designed to produce a variety of anode shapes; even anode profiles with nearly discontinuous slope have been obtained.

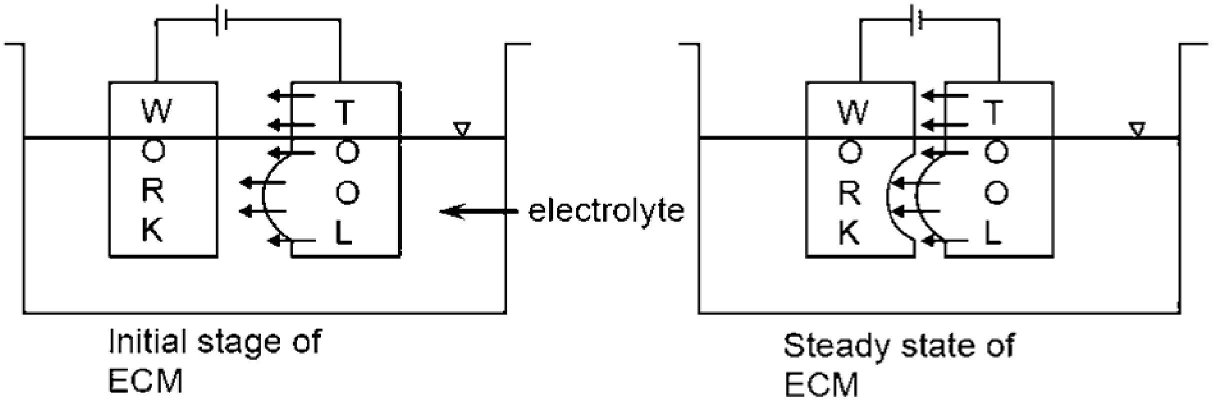

Fig1.1 ECM reaction

Material removal rate in electrochemical machining is analyzed in context of over voltage and conductivity of the electrolyte solution. Electrolyte has three main functions in ECM: It carries the current between the tool and work piece; it removes the products of the reaction from the cutting region; and it removes heat produced in operation. Normal electrolyte used for ECM for all common metals & alloys is solution of Sodium Chloride (NaCl) in water. When supply is switched on, the negative ions Cl migrate towards the anode. They react with the work piece and form a salt which dissolves in electrolyte. Thus if a job is steel (Fe) and electrolyte is common salt (NaCl) the following reacting takes place at the anode.

It is observed that over voltage is very sensitive to equilibrium gap and tool feed rate. Material removal rate decreases due to increase in over voltage and decrease in current efficiency, which is directly related to the conductivity of the electrolyte solution. It is observed that the corrected current density is always lower than the actual current. The calculated material removal rate efficiency is found to be 57%.

1.2 PRINCIPLE OF ECM:

Electrochemical machining is developed on the principle of Faradays and Ohm. In this process, an electrolyte cell is formed by the anode (work piece) and the cathode (tool) in the midst of a following electrolyte. The metal is removed by the controlled dissolution of the anode according to the well known Faradays law of electrolysis. when the electrode are connected to about 20 v electric supply source, flow of current in the electrolyte is established due to positively charged ion being attracted towards cathode and vice-versa. Due to electrolysis process at cathode hydroxyl ion are released which combine with the metal ions of anode to form insoluble metal hydroxide. Thus the metal is removed in the form of sludge and precipitated in electrolytic cell. This process continues till the tool has produced its shape in the work piece.

1.3 STEPS BY WHICH ECM PROCEEDS:

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.

$NaCl \leftrightarrow Na^{+} + Cl^{-}$

$H_2O \leftrightarrow H^{+} + (OH)^{-}$

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 from hydrogen gas as:

$2H^{+} + 2e^{-} = H_2\uparrow$ at cathode

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

$Fe = Fe^{++} + 2e^{-}$

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.

$Na^{+} + OH^{-} = NaOH$

In practice $FeCl_2$ and $Fe\ (OH)_2$ 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. 1.2 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.

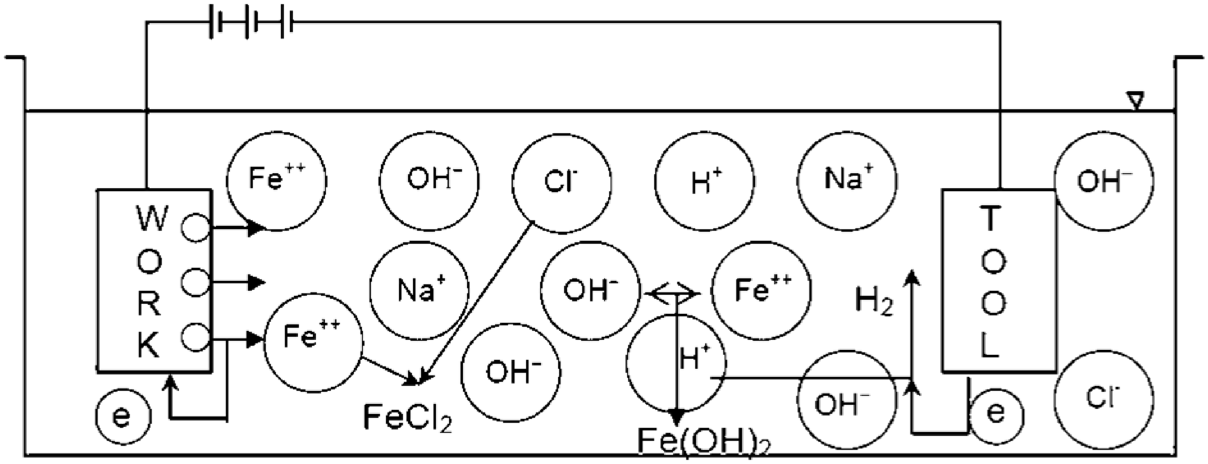

Fig. 1.2 Schematic representation of electro-chemical reactions

REACTION AT ANODE:

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

$Fe^{2+} + 2Cl \leftrightarrow FeCl_2$

$Fe^{2+} + 2OH \leftrightarrow Fe\ (OH)_2$

$FeCl_2 + 2\ OH \leftrightarrow Fe(OH)_2 + 2\ Cl^-$

$2Cl^- \leftrightarrow Cl_2\ (g) + 2e^-$

$2FeCl_2 + Cl2 \leftrightarrow 2FeCl_3$

$H^+ + Cl^- \leftrightarrow HCl$

$2Fe\ (OH)_2 + H_2O + O_2 \leftrightarrow 2Fe(OH)_3\downarrow$

$Fe(OH)_3 + 3HCl \leftrightarrow FeCl_3 + 3H_2O$

$FeCl_3 + 3\ NaOH \leftrightarrow Fe(OH)_3\downarrow + 3NaCl$

REACTION AT CATHOD:

$Na^+ + e^- \leftrightarrow Na$

$Na + H_2O \leftrightarrow Na\ (OH) + H^+$

$2H^+ + 2e^- \leftrightarrow H_2\uparrow$

It shows that only hydrogen gas will evolve at cathode and there will be no deposition.

1.4 CLASSIFICATION OF ECM PROCESS

1.4.1 ELECTROCHEMICAL GRINDING PROCESS:

In the electrochemical grinding process metal is removed by electrochemical decomposition and abrasion of the metal. In this process electrode wheel revolved in the close proximity to the work piece. Wheel is made of fine diamond particles in metal matrix. The particle is slightly projecting out from the surface and come in contact with the work surface with very little pressure. Work piece is connected to the positive terminal and the wheel to the negative terminal. Thus current flow between the work and wheel. Wheel and its spindle are insulated from the rest of the machine. During the grinding process, a continuous stream of non corrosive salt solution is passed through work and tool and it acts both as electrolyte and coolant. This process is best suited for very precession grinding of hard metal like tungsten carbide tool tips as the grinding pressure is very less due to which the defect like grinding cracks, tempering of works, transformation of layer and dimension control difficulties are eliminated. Accuracy of the order of 0.01mm can be achieved by proper selection of wheel grit size and abrasive particles.

1.4.2ELECTROCHEMICAL TURNING PROCESS:

In this process the machine has motion of lathe and metal removal tool is a cathode which is separated from the rotating work surface (anode) by a film of electrolyte. A suitably shaped tool can produce a desired form on a hard metal in a very short time.

1.4.3 ELECTROCHEMICAL MILLING PROCESS:

This is a form of etching process. In this process job is first cleaned properly. And then some sort of preventing coating is applied on the particular portion which is not to be machined. The preventive coating is of vinyl plastic. This is applied with the help of a template. Then the job is exposed to the etching material. Times depend upon the metal to be removed and the strength of chemical reagent. The metal is removed by the chemical conversion of the metal in to metallic salt. Material removal rate is mainly dependent on the selected etchant. If the metal is removed at fast rate with certain etchant then under cutting increases, surface finish decreases and more heating takes place. The etch rate is therefore limited to 0.02 to 0.04mm per minute. This process can give complicated shaped pattern on work material. But much depend upon skill of operator. It is mostly used in aircraft industry. However depth of etching is very less otherwise long time will be required and at the same time surface finish will decreases. It is mainly used for embossing, coining, engraving operation. The tooling set up cost is low. Machining is done without production of burr. And even thin sheet of metal can be processed with ease without distortion. Material which are brittle in nature can be processed with ease. This process is best suited for production of printed circuit. Where the basic connection s of the circuit consists of thin metal strip attached to an insulating phase. These circuits are produced from insulating board faced with a thin layer of copper. The copper is coated with photosensitive resist and an imagine of the required circuit is printed photographically on the surface. Etching removed all the unwanted copper. The etching vapor is very corrosive in nature and therefore, the process equipment must be kept safe from the etching and other operating equipment.

1.4.4 ELECTROCHEMICAL WIRE CUTTING:

Electrochemical wire cutting process for removal of metal using a wire tool as cathode and work piece as anode. The work piece can be shaped by relative movement between it and the wire. The process is similar to wire discharge machining. This process is found to be best suited for cutting in one or two direction and fine drilling .rectangular wire appears to be better choice over circular section wire. This process has a limited feed rate compared with conventional ECM. The feed rate is depending on the width of wire and the diameter of work piece. This process is best suited super finishing with higher surface finish up to 0.15µm. This process is very suitable with small work piece dimension. Surface finish is better for flat surface than cylindrical. The power consumption is low and tooling system is cheap. The material removal rate can be controlled precisely. The surface finish is affected by parameters like feed rate, work piece relation speed and electrolyte flow rate.

1.5 ECM MACHINE STRUCTUREAND PARAMETERS:

Electrochemical Machining (ECM) is the controlled removal of metal by anodic dissolution in an electrolytic cell in which the work piece is the anode and the tool is cathode. The electrolyte is pumped through the gap between the tool and the work piece, while direct current is passed through the cell, to dissolve metal from the work piece. ECM is widely used in machining of jobs involving intricate shapes and to machine very hard or tough materials those are difficult or impossible to machine by conventional machining. It is now routinely used for the machining of aerospace components, critical deburring, Fuel injection system components, ordnance components etc. ECM is also most suitable for manufacturing various types of dies and moulds.

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1.5.1 SERVO SYSTEM:

The servo system controls the tool motion relative to the work piece to follow the desired path. It also controls the gap width within such a range that the discharge process can continue. If tool electrode moves too fast and touches the work piece, short circuit occurs. Short circuit contributes little to material removal because the voltage drop between electrodes is small and the current is limited by the generator. If tool electrode moves too slowly, the gap becomes too wide and electrical discharge never occurs. Another function of servo system is to retract the tool electrode when deterioration of gap condition is detected. The width cannot be measured during machining; other measurable variables are required for servo control.

1.5.2 TOOL FEED RATE

In ECM process gap about 0.01 to 0.07 mm is maintained between tool and work piece. For smaller gap, the electrical resistance between the tool and work is least and the current is maximum and accordingly maximum metal is removed. The tool is feed in to the work depending upon the how fast the metal is to be removed. The movement of the tool slide is controlled by a hydraulic cylinder giving some range of feed rate.

1.5.3 ELECTROLYTE

The electrolyte is essential for the electrolytic process to work. In addition to removing the heat generated in the cutting zone to the flow of high current, it also carries the high current and removes the product of machining. The electrolyte is pumped at about 14kg/cm^2 and at speed of at lest 30 m/s in order to constantly replenish the solution, which must never be allowed to reach boiling point as it would disturb the current flow. The electrolyte should be of high electrical conductivity. And be chemically active enough to cause efficient metal removal, and not very corrosive. The electrolyte must have a good chemical stability.

1.5.4 TEMPERATURE CONTROL

Since the conductivity of electrolyte varies with range in temperature, it must be held reasonably constant; otherwise the equilibrium of the machining gap will change. It may be noted that low electrolyte temperature result in low metal removal rate and high temperature leads to vaporization of the electrolyte .It is maintained around (25-60) ^{o}C.

1.5.5 TOOL DESIGN

As no tool wear takes place, any good conductor is satisfactory as a tool material, but it must be designed strong enough to withstand the hydrostatic force, caused by electrolyte being forced at high speed through the gap between tool and work. The tool is made hollow for drilling holes so that electrolyte can pass along the bore in tool. Cavitations, stagnation and vortex formation in electrolyte flow must be avoided because these result a poor surface finish. It should be given such a shape that the desired shape of job is achieved for the given machining condition.

1.5.6MATERIAL REMOVAL RATE:

It is a function of feed rate which dictates the current passed between the work and the tool. As the tool advances towards work, gap decreases and current increases which increases more metal at a rate corresponding to tool advance. A stable spacing between tool and work is thus established .It may be noted that high feed rate not only is productive but also produces best quality of surface finish. However feed rate is limited by removal of hydrogen gas and products of machining. Metal removal rate is lower with low voltage, low electrolyte concentration and low temperature.

1.5.7 SURFACE FINISH:

ECM can produce surface finish order of 0.4 μm by rotation of tool or work. Any defect on tool face produce replica on work piece. Tool surface should therefore be polished. The finish is better in harder material. For optimum surface finish, careful electrode design, maximum feed rate, and surface improving additives in electrolyte are selected. Low voltage decreases the equilibrium machining gap and result in better surface finish and tolerance control. Low electrolyte concentration decreases the machining gap and gives the better surface finish. Low electrolytic temperature also promotes better surface finish.

1.6 CHARACTERSTICS OF ELECTROCHEMICAL MACHINING PROCESS:

Material removal mechanism controlled removal of metal by anodic dissolution in an electrolytic medium. It consists of advantage of ECM, Disadvantage of ECM and application of ECM.

Table-1.1 ECM specification

Tool	Copper, brass or steel
Power supply	Constant voltage 5-30 DC volt
Current	50-40,000 amp
Material removal rate	1600 mm3/min
Specific power consumption	7w/mm3/min
Electrolytic solution	Neutral salt, brine solution,
Accuracy and surface finish	0.02 mm, 0.4µm
Application	Machining hard material
Limitation	High specific energy consumption
Mechanical properties	Stress free machining, reduce tool wear
Surface properties	No thermal damage

1.6.1 ADVANTAGE OF ECM:

Electrochemical machining is a promising alternative if conventional mechanical manufacturing processes reach technical as well as economical limitations. Nowadays, ECM is established for burr removing, shape manufacturing and drilling of jet engine parts. Considering these advantages ECM is a suitable technique for machining mechanical hard to cut materials such as carbide metals or cermets.

[1] No mechanical stress impact into the processed work piece.

[2] No thermal impact of the work piece.

[3] The removal rate is not determined by the hardness and toughness of the material.

[4] No process related tool wear.

[5] Great versatility for machining of geometrical complex shapes.

[6] No burr formation.

1.6.2DISADVANTEGE OF ECM:

[1] High specific energy consumption.

[2] Not suited for non-conducting pieces.

[3] High initial and working cost.

1.6.3 APPLICATION OF ECM:

ECM technique removes material by atomic level dissolution of the same by electrochemical action. Thus the material removal rate or machining is not dependent on the mechanical or physical properties of the work material. It only depends on the atomic weight and valency of the work material and the condition that it should be electrically conductive. Thus ECM can machine any electrically conductive work material irrespective of their hardness, strength or even thermal properties. Moreover as ECM leads to atomic level dissolution, the surface finish is excellent with almost stress free machined surface and without any thermal damage.

ECM is used for:

- Die sinking (Fig 1.3)
- Profiling and contouring (Fig 1.4)
- Trepanning (Fig 1.6)
- Grinding
- Drilling (Fig 1.5)
- Micro-machining

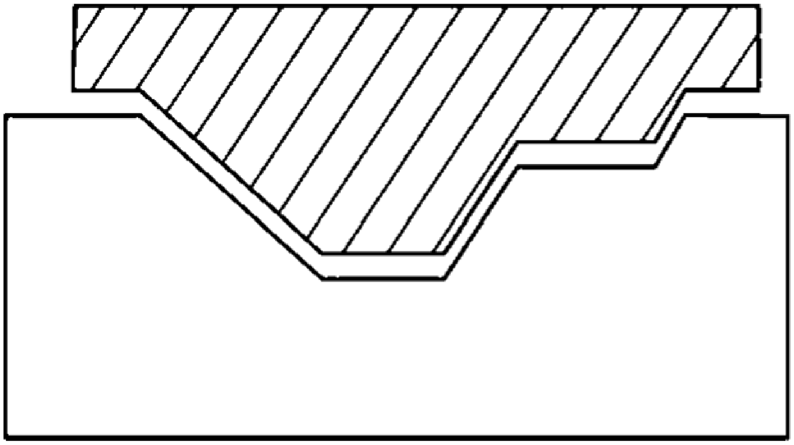

Fig 1.3 DIE SINKING

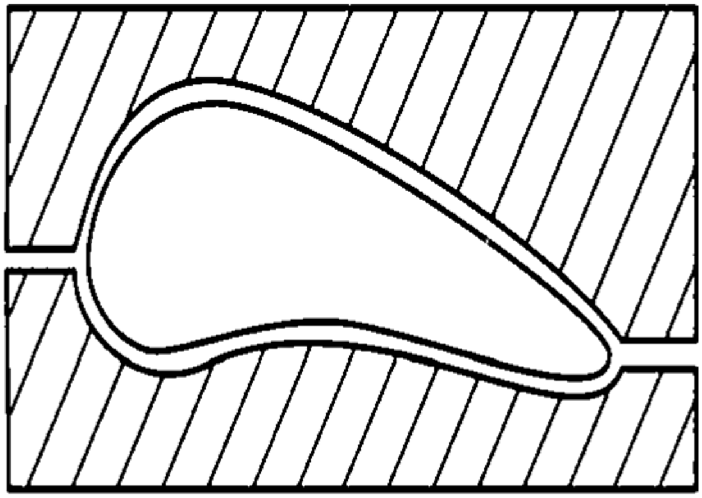

Fig1.4 3D profiling

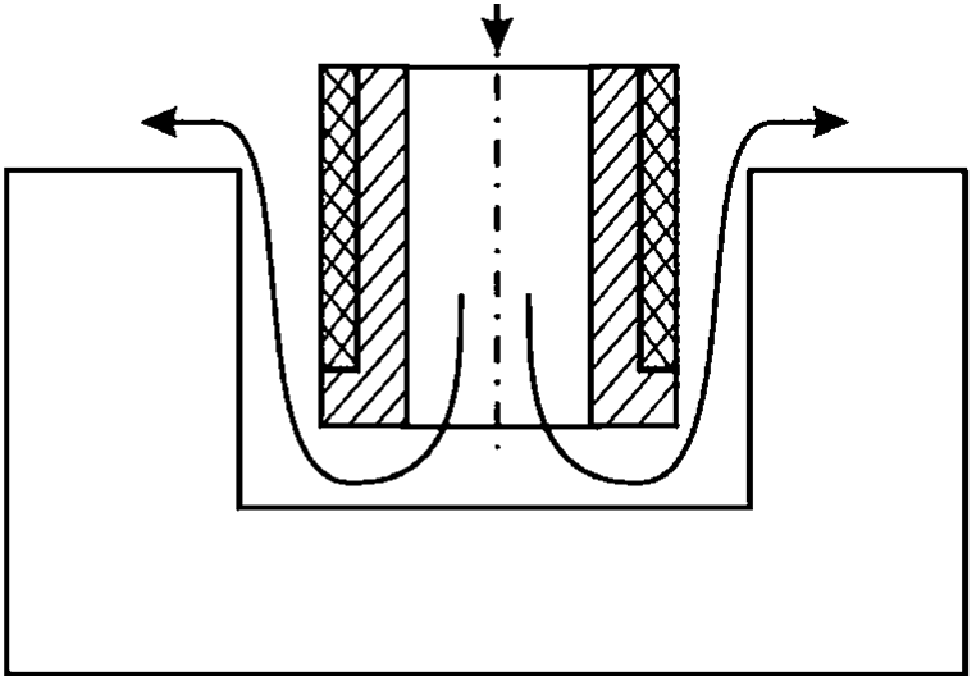

Fig1.5 Drilling

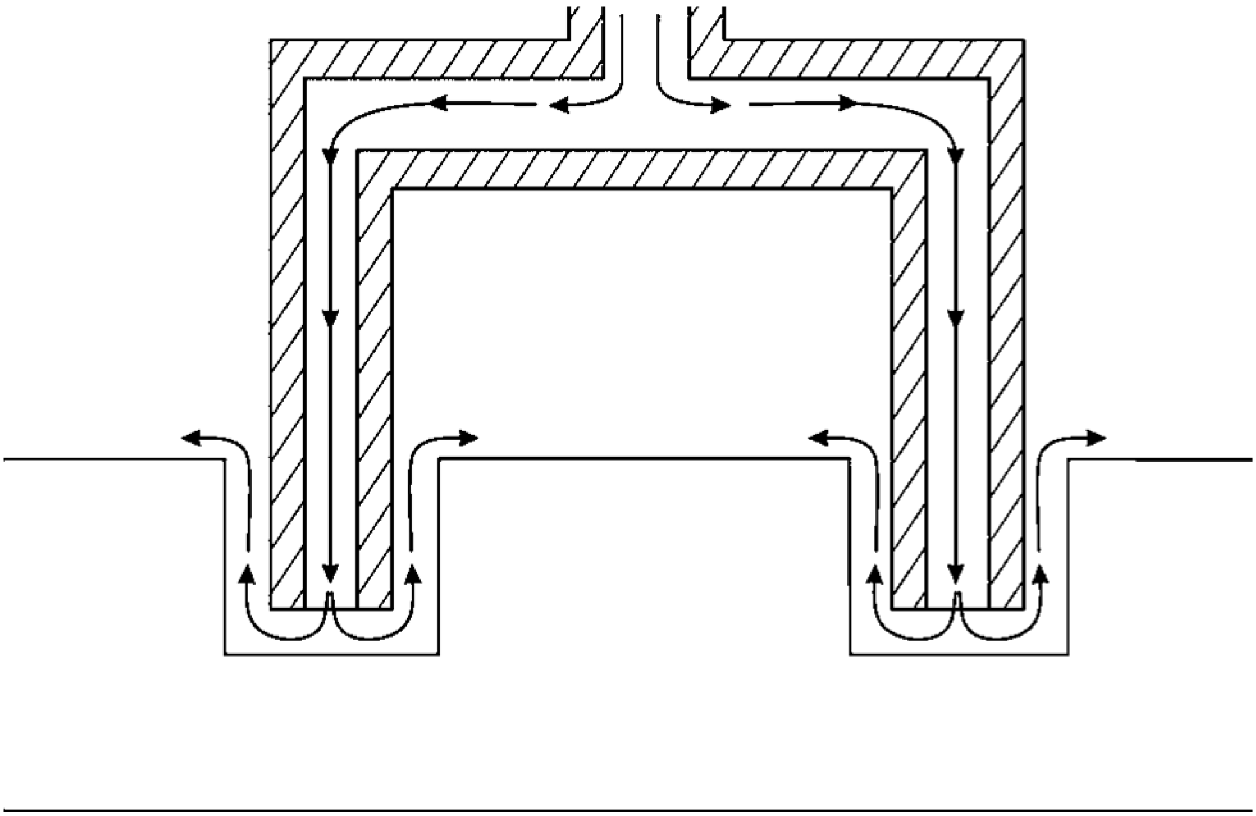

Fig1.6 Drilling and Trepanning

CHAPTER 2 LITERATURE REVIEW:

After going through all the selected paper related to MRR, we are broadly classified all the paper in to three different category, i.e. paper related to material removal rate and effect of parameters on MRR, some paper related to tool design and rest of the paper related to micro ECM.

2.1 Overview on MRR and effect of parameters on MRR:

B. Bhattacharyya et.al [1] has reported that the electrochemical micro-machining (EMM) appears to be promising as a future micro-machining technique since in many areas of applications, it offers several advantages. A suitable micro-tool vibration system has been developed, which consists of tool-holding unit, micro-tool vibrating unit, etc. The developed system was used successfully to control material removal rate (MRR) and machining accuracy to meet the micro-machining requirements. Micro-holes have been produced on thin copper work piece by EMM with stainless-steel micro-tool. Experiments have been carried out to investigate the most effective values of process parameters such as micro-tool vibration frequency, amplitude and electrolyte concentration for producing micro-hole with high accuracy and appreciable amount of MRR.

Jo ao Cirilo da Silva Neto et.al [2] shows a study of the intervening variables in electrochemical machining (ECM). The material removal rate (MRR), roughness and over-cut were studied in this paper. Four parameters were changed during the experiments: feed rate, electrolyte, flow rate of the electrolyte and voltage. Two electrolytic solutions were used: sodium chloride (NaCl) and sodium nitrate (NaNO3). The results show that feed rate was the main parameter affecting the material removal rate.

S K Mukherjee et.al [3] discusses about role of electrolyte [NaCl] in current-carrying processes in electrochemical machining of iron work piece has been analyses in light of Onsager equation of strong electrolyte. Over-voltage-calculated with respect to equilibrium gap and penetration rate, shows that only a narrow range of equilibrium gap and penetration rate are admissible.

K. P. Rajurkar et.al [4] discussed about the main advantages of the electrochemical machining (ECM) process, such as high material removal rates and smooth, damage-free machined surface, are often offset by the poor dimensional control . This paper presents an ECM control model based on the basic ECM dynamics that accounts for the dynamic nature of the ECM process. The state space methodology is applied to transform it into the control model applicable to an ECM control system based on a digital computer. The simulations have been made for the model verification and controller design.

***S.K.* Mukherjee** et.al [5] defined that Material removal rate (MRR) of aluminum work piece has been obtained by electrochemical machining using NaCl electrolyte at different current densities and compared with the theoretical values. It is also concluded that resistance of the electrolyte solution decrease sharply with increasing current densities, and simultaneously the over-voltage of the system initially increases and then attains a saturation value with increasing current densities.

V.K. Jain et.al [6] has reported that electrochemical spark machining (ECSM) process has been successfully applied for cutting of quartz using a controlled feed and a wedge edged tool. Only cathode works as a tool, i.e. ECSM with reverse polarity (ECSMWRP) as well as ECSM with direct polarity (ECSWDP) have been used to machine quartz plates. In ECSMWRP, deep crater on the anode (as a tool) and work piece interface is formed because of chemical reaction. The cutting is possible even if we make auxiliary electrode of small size.

K.L. Bhondwe et.al [7] in this paper attempts to develop a thermal model for the calculation of material removal rate (MRR) during ECSM. First, temperature distribution within zone of influence of single spark is obtained with the application of finite element method (FEM). The nodal temperature plays an important role estimating MRR. The developed FEM based thermal model is found to be in the range of accuracy with the experimental results. The increase in MRR is found to increase with increase in electrolyte concentration.

S. Kumara et.al [8] discussed about the Material removal rate (MRR) of aluminum work piece has been obtained by electrochemical machining using NaCl electrolyte at different current densities. Also resistance of the electrolyte solution decrease sharply with increasing current densities. The over-voltage of the system initially increases and then attains a saturation value with increasing current densities.

V.K. Jain et.al [9] has shown that the electrochemical spark machining (ECSM) process has been useful for machining of low machine ability high-strength electrically non-conducting materials. In the present work, the electrochemical discharge is modeled as a phenomenon similar to that which occurs in arc discharge valves. The spark energy and the approximate order of hydrogen gas bubble diameter are computed by the proposed valve theory. Material removal rate is evaluated by modeling the problem as a *3-D* unsteady state heat conduction problem.

R V Rao et.al [10] discussed about the values of important process parameters of electrochemical machining processes such as the tool feed rate, electrolyte flow velocity, and applied voltage play a significant role in optimizing the measures of process performance. These include dimensional accuracy, tool life, material removal rate, and machining cost. In this paper, a particle optimization algorithm is presented to find the optimal combination of process parameters for an electrochemical machining process. The objectives considered are dimensional accuracy, tool life, and the material removal rate.

B. Bhattacharyya et.al [11] has highlighted that features of the development of mathematical model for correlating the interactive and higher-order influences of various machining parameters. I.e. the metal removal rate and the overcut phenomena, through response surface methodology (RSM), utilizing relevant experimental data as obtained through experimentation. This paper also highlights mathematical models for analyzing the effects of various process parameters on the machining rate and overcut phenomena. These parameters can be used in order to achieve maximization of the metal removal rate and the minimum overcut effects for optimal accuracy of shape features.

2.2 Overview on tool design:

Yuming Zhou et.al [12] discussed about the Prior procedures for cathode (tool) design in electrochemical machining. In this paper actually develop and test a new approach to this problem which overcomes these difficulties by employing a finite element method within an optimization formulation. A least-squares minimization of the deviation of the simulated anode (work piece) shape from that desired is performed, yielding a set of parameters in a predefined representation which uniquely define an optimal cathode shape.

Jerzy Kozak et.al [13] discussed about the theoretical and experimental investigations of the relationship between the characteristic shape dimensions imported upon the anode-work piece surface by the micro-features of the cathode-tool electrode under given machining conditions are presented. This research included the study of electrochemical copying of slots, mini-holes, grooves and insulating groove features. The limiting conditions of micro-ECM are considered from the point of view of copying and micro-shaping using non-profiled tool electrodes. For improving micro-machining capabilities of ECM processes, the application of ultra-short pulse current and ultra-small gap size is recommended.

K.P. Rajurkar et.al [14] had shown that ECM process now increasingly being applied in other industries where parts with difficult-to-cut materials and complex geometry are required. In this paper the latest advances are discussed, and the principal issues in ECM development and related research are raised. Developments in tool design, pulse current, micro-shaping, finishing, numerically controlled, environmental concerns, hybrid processes, and recent industrial applications, are covered.

J.A. Westley et.al [15] discussed about the study electrolyte flow. This paper tries to identify the factors, such as insulation requirements and machined face considerations that could relate to other ECM components. These observations would then be made use of when producing subsequent ECM electrodes. In this paper work has been carried out by adapting new electrodes for a casting gate removal process.

Chunhua Sun et.al [16] highlighted about the accurate prediction of tool shape for electrochemical machining (ECM). This paper proposes an approach using finite element method (FEM) to design tool in ECM. This method is capable of designing three-dimensional freeform surface tool from the scanned data of known work piece. It possesses high computing efficiency, good accuracy and flexible boundary treatment without the need for iterative procedure.

2.3 Overview on Micro ECM:

H. Hocheng et.al [17] reported about the process to erode a hole of hundreds of micrometers on the metal surface. The paper also discusses the influence of experimental variables including time of electrolysis, voltage, molar concentration of electrolyte and electrode gap upon the amount of material removal and diameter of machined hole. The results of experiment show the material removal increases with increasing electrical voltage, molar concentration of electrolyte.

Anjali V. Kulkarni et.al [18] discussed about the current trends and techniques used for micro fabrication of parts. This paper tries to establish a viable, cost effective and fast micro fabrication process. Focus is on the use of Electrochemical spark (ECS) for layered manufacturing in micron.

S. K. Mukherjee et.al [19] reported about the Material removal rate in electrochemical machining by using over voltage and conductivity of the electrolyte solution. It is observed that over voltage plays an important role equilibrium gap and tool feed rate. Material removal rate decreases due to increase in over voltage and decrease in current efficiency, which is directly related to the conductivity of the electrolyte solution.

A. K. M. De Silva et.al [20] discussed about the Electrochemical machining (ECM), which is used to achieve accuracy better than 5 μm and surface finish 0.03ms μRa by using pulsed power of relatively short durations (1 - 10 μs) and narrow inter-electrode gaps (10 – 50 μm). The narrow gaps make the process much more complex than normal ECM. An empirical model is developed to predict and optimize the process parameters such as dissolution efficiency, current density, electrolyte concentration and pulse duration, in narrow gaps.

K.L. Bhondwe et.al [21] written about the Electro-chemical spark machining (ECSM) and electro discharge machining (EDM). It shows like ECM and EDM, ECSM is capable of machining electrically non-conducting materials. This paper attempts to develop a thermal model for the calculation of material removal rate (MRR) by using ECS. The developed FEM based thermal model is found to be suitable for this experimental result. The increase in MRR is found to increase with increase in electrolyte concentration due to ECSM of soda lime glass work piece material.

Mohan Sen et.al [22] discussed about the Electrochemical machining processes provide for drilling macro- and micro-holes with exceptionally smooth surface and reasonably acceptable taper in numerous industrial applications particularly in aerospace, electronic, computer and micro-mechanics industries. Also this paper highlights about the hole-drilling processes like jet-electrochemical drilling have found acceptance in producing large number of quality holes in difficult-to-machine materials. This paper highlights the recent developments, new trends and the effect of key factors influencing the quality of the holes produced by these processes.

B. H. Kim et.al [23] discussed about the Micro electrochemical machining (ECM) using ultra short pulses. 0.1 M sulfuric acid was used as electrolyte and 3D micro structures were machined on stainless steel. In this paper it shows how to prevent taper, by using a disk-type electrode. To improve productivity, multiple electrodes were applied and multiple structures were machined simultaneously. Since the wear of tool electrode is negligible in ECM

Jerzy Kozak et.al [24] has reported that this research included the study of electrochemical copying of slots, mini-holes, grooves and insulating groove features. The limiting conditions of micro-ECM are considered from the point of view of copying and micro-shaping using non-profiled tool electrodes. For improving micro-machining capabilities of ECM processes, the application of ultra-short pulse current and ultra-small gap size is recommended which is the main point of discussion in this paper.

M.S. Hewidy et.al [25] discussed about the practical application of electrochemical machining. By using low frequency vibration to the tool electrode in electrochemical machining we can improve accuracy and quality of the machined surface. This paper presents an analytical approach to establish mathematical model to asses the mechanism of metal removal for this novel and hybrid technique. The effect of input parameters and machining conditions on the effectiveness of tool vibration during ECM has been taken in to account.

M. Kock et.al [26] has reported about the application of ultra short voltage pulses electrochemical reactions which can be used for nanometer accuracy, and allows for high precision machining of electrochemical active materials. Depending on the average potentials of tool and work piece, overall corrosion of the work piece and the location of the counter reaction of work piece dissolution can be controlled.

Se Hyun Ahna et.al [27] discussed about the rare application of Electro-chemical machining in micro machining because the electric field is not localized. In this work, ultra short pulses with tens of nanosecond duration are used to localize dissolution area. The effects of voltage, pulse duration, and pulse frequency on the localization distance were studied. High quality micro hole with 8 μm diameter was drilled on 304 stainless steel foil with 20 μm thickness used as work piece.

2.4 OBJECTIVE OF PRESENT WORK:

The objective of present work is an attempt to finding out the feasibility of making blind cavity using U-shaped tubular copper electrode in electrochemical machining. The work piece material is AISI D2 steel and the machining parameters selected for study are feed rate, diameter of electrode, flow rate and electrolyte conductivity, with Taguchi design approach. In my work, the voltage across the work piece-tool is kept constant.

CHAPTER 3 *EXPERIMENTAL WORK*

INTRODUCTION:

In this chapter we are going to discuss about the experimental work which is consisting about experimental set up, selection of work piece of material, design of electrode, making of electrolytic solution and formation of factor level using Taguchi design. By taking all this information in account we will calculate the material removal rate.

3.1 EXPERIMENTAL SET UP:

For this experiment the whole work has been carried out by Electrochemical Machining set up from Metatech-Industry, Pune which is having Supply of - 415 v +/- 10%, 3 phase AC, 50 HZ. And consist of three major sub systems which are being discussed in this chapter.

The set up consists of three major sub systems.

1. Machining Cell
2. Control Panel
3. Electrolyte Circulation

Machining Cell

This electro-mechanical assembly is a sturdy structure, associated with precision machined components, servo motorized vertical up / down movement of tool, an electrolyte dispensing arrangement, illuminated machining chamber with see through window, job fixing vice, job table lifting mechanism and sturdy stand. All the exposed components, parts have undergone proper material selection and coating / plating for corrosion protection.

Technical Data

- Tool area - 30 mm^2.
- Cross head stroke - 150 mm.
- Job holder - 100 mm opening X 50 mm depth X 100 mm width.
- Tool feed motor - DC Servo type.

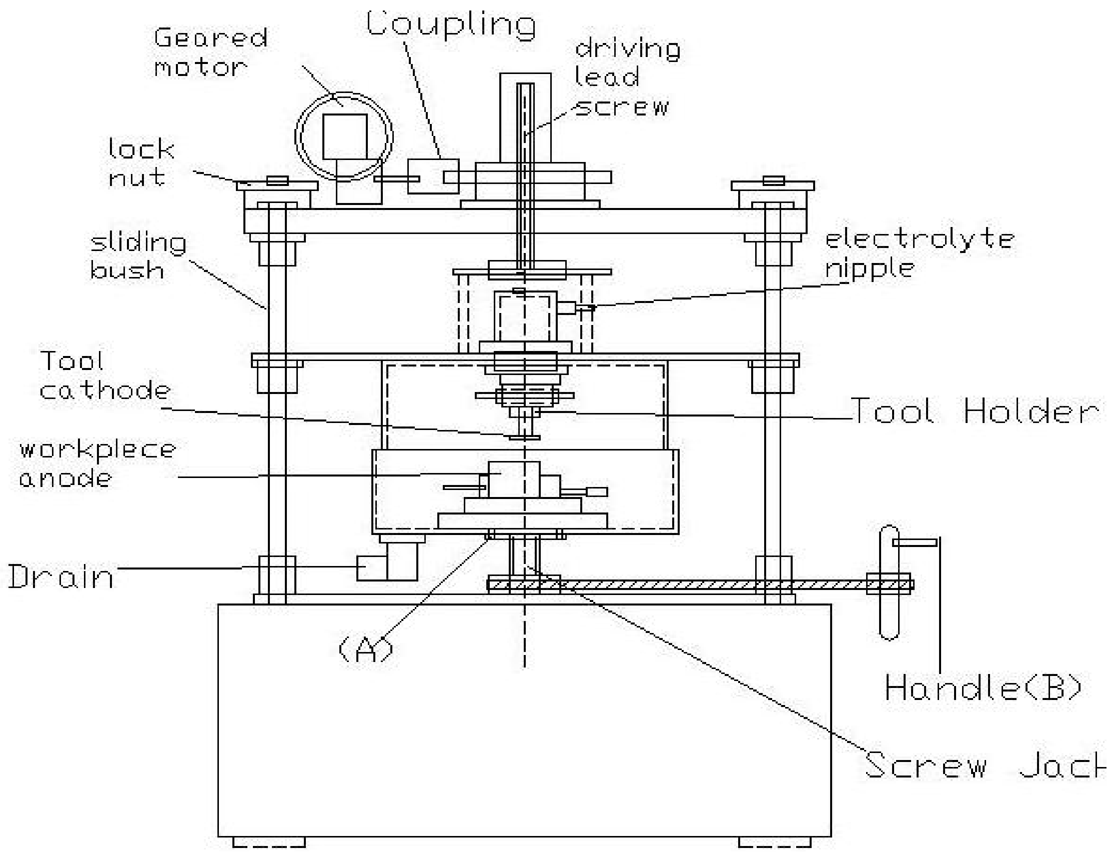

Fig 3.1 Schamatic diagram of ECM

Fig 3.2 ECM set up

Control Panel

The power supply is a perfect integration of, high current electrical, power electronics and precision programmable microcontroller based technologies. Since the machine operates at very low voltage, there are no chances of any electrical shocks during operation. Which shown in fig 3.3.

Technical Data:

- Electrical Out Put Rating - 0-300 Amps. DC at any voltage from 0 - 20 V.
- Efficiency - Better than 80% at partial & full load condition.
- Power Factor - Better than 85.
- Protections - Over load, Short circuit, single phasing.
- Operation Modes - Manual / Automatic.
- Timer - 0 - 99.9 min.
- Tool Feed - 0.2 to 2 mm / min.
- Z Axis Control - Forward, reverse, auto forward / reverse, through micro controller.
- Supply - 415 v +/- 10%, 3 phase AC, 50 HZ

Fig 3.3 control panel

Electrolyte Circulation system:

The electrolyte is pumped from a tank, lined by corrosion resistant coating with the help of corrosion resistant pump & is fed to the job. Spent electrolyte will return to the tank. The hydroxide sludge arising will settle at the bottom of the tank & can be easily drained out. Electrolyte supply shall be governed by flow control valve. Extra electrolyte flow is by-passed to the tank. Reservoir provides separate settling and siphoning compartments. All fittings are of corrosion resistant material or of S.S., as necessary.

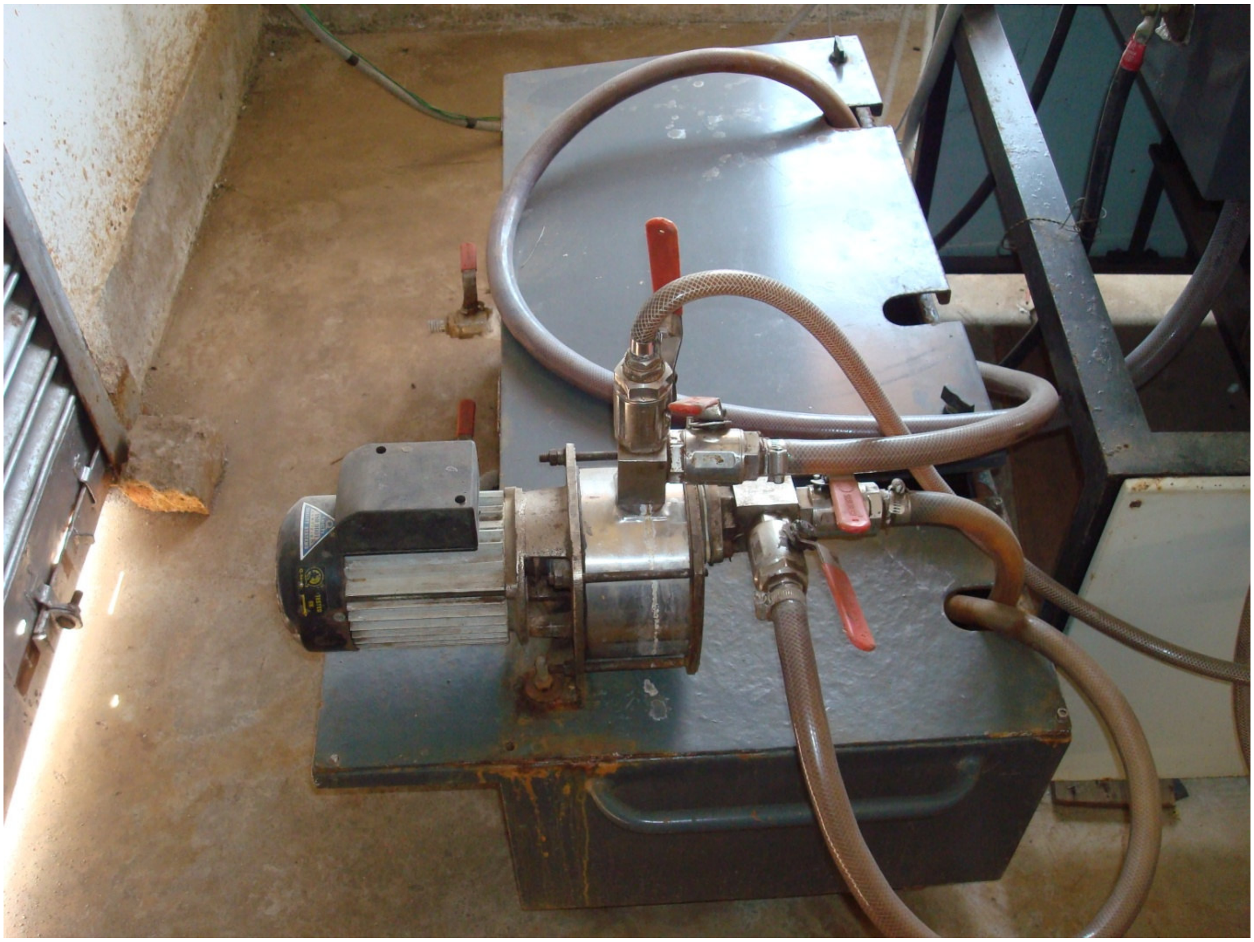

Fig 3.4 electrolyte chamber

Fig 3.5 Sample ECM tools

3.2 MAKING OF BRINE SOLUTION OR ELECTROLYTE:

In the ECM process the making of brine solution plays an important role in material removal rate. Brine solution is prepared by adding common salt with water by maintaining the conductivity of the water. So we have to take salt solution and with the help of conductivity meter instrument we have to calculate the conductivity of that solution. And we have to maintain it through out the end of the experiment in order to maintain the material removal rate correctly. For this experiment I have taken 37.5 gm of salt and 75 gm of salt sample in 1000 mL of water to measure the conductivity of the solution in room temperature. And the conductivity was found to be 63.28 mS/cm and 110mS/cm. After the measurement of conductivity the whole experiment was carried out.

3.3 SPECFICATION OF WORKPIECE MATERIAL:

Work piece material: AISI D2 Tool Steel

Electrochemical machining (ECM) employs anodic dissolution to shape metals and was developed as a method for machining high-strength, heat-resistant alloys which were extremely difficult to cut by any other established methods. The ECM process connects the work piece (anode) to the tool (cathode) via an electrolytic cell, through which an electrolyte is pumped when a potential difference is applied, current flows as the result of electrochemical reactions taking place at the surfaces of both electrodes. The reaction at the anode surface removes material by the oxidation of metal atoms, while the cathode surface is unaffected by the hydrogen reduction reaction typically occurring there.

For my experiment we have chosen AISI D2 steel as work piece. Work piece is having dimension of 100 mm in diameter and 60 mm in thickness. I have taken 4 pieces of AISI D2 material and carried out the experiment .In each work piece two cavities are done keeping the length of 35mm, width of 45mm, and height of 25mm in dimension. And the corresponding material removal rate is calculated by taking initial and final weight of work piece before and after the experiment.

Table 3.1 Description of work piece material

Category	Steel
Class	Tool steel
Type	High-carbon, high-chromium cold work steel
Designations	**Germany**: DIN 1.2379 **Italy**: UNI KU **United Kingdom**: B.S. BD 2 **United States**: ASTM A681 , FED QQ-T-570 , SAE J437 , SAE J438 , UNS T30402

Table 3.2 Mechanical and Thermal Properties

Parameter	value
Density (×1000 kg/m^3) at 25 ° C	7.7
Poisson's Ratio	0.27-0.30
Elastic Modulus (GPa)	190-210
Thermal Expansion (10^{-6}/ºC) at 20-100 ° C	10.4

Table3.3 Material composition

Element	**Weight %**
C	1.40-1.60
Mn	0.60
Si	0.60
Cr	11.00-13.00
Ni	0.30
Mo	0.70-1.20
V	1.10
Co	1.00
Cu	0.25
P	0.03
S	0.03

3.4 METHODOLOGY OF MACHINING:

STEP 1:

After setting all the parameters in the control panel and setting work piece in the chamber cutting was started by using U-shaped electrode. In this step work piece kept in horizontal position, and by using a vertical U-shaped electrode cutting started from the centre position. We should be very much careful such that tip of the electrode should not touch the surface of the electrode. The

U-shaped electrode should penetrate up to the length of 25mm in the work piece. Then we have to stop the process, and we have to go for step 2. Fig. 3.6 describes the step 1.

STEP 2:

Again all the defined parameters are to be set in the control panel. Now the position of the work piece is being changed from horizontal to vertical position. In the same manner electrode also changed. In this step electrode cut the work piece in vertical manner, i.e. electrode comes from top position to bottom of the work piece. Here electrodes have to cut a length of 35 mm distance in the work piece. During the whole process the time of cutting of the work piece at certain feed rate is being noted down. And we have to go for step 3. Illustration of step 2 is given in Fig.3.7.

STEP-3:

Again after finishing step 2 all the parameters of the corresponding experiment again set in the control panel. We have to place in the work piece again in horizontal position to cut left portion of the work piece. Again vertical electrode is being used the work piece from the end position. Here the penetration of the electrode is less than the 1st step and the corresponding time requirement also less than step 1. After the electrode penetrates about 25mm the cavity is being made in the work piece. A small piece is left after cutting is over .We had to measure the weight of the left piece. Then the final weight of the work piece is being measured. And MRR is calculated. The machining step 3 is given in Fig 3.8.

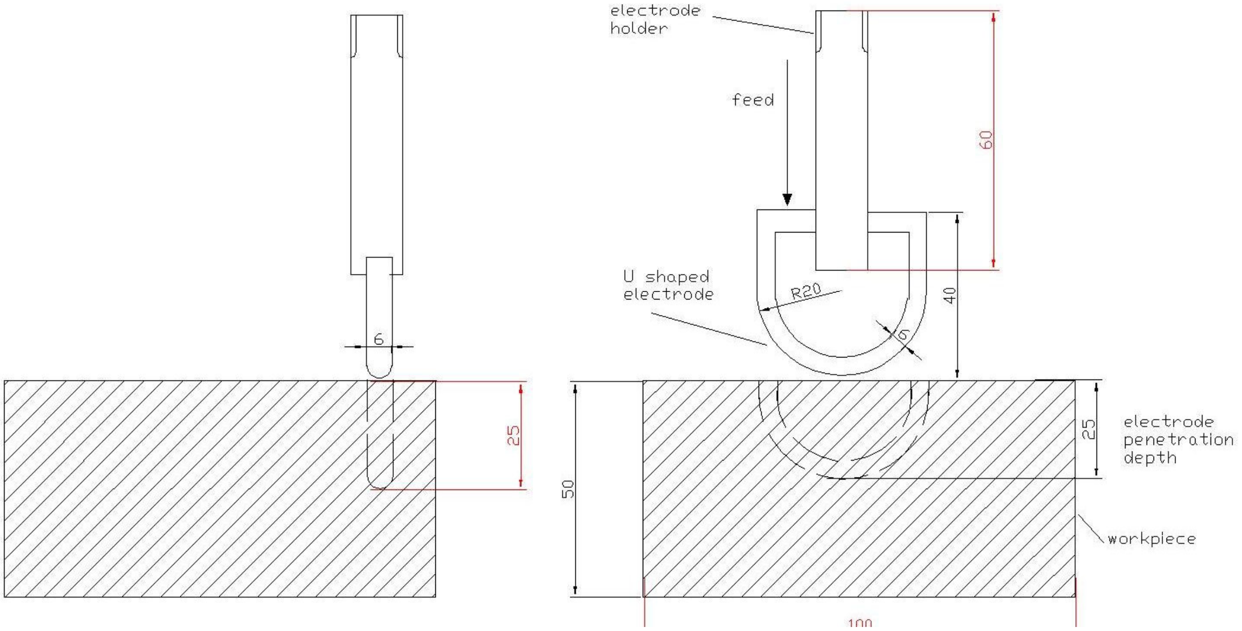

Figure 3.6 Step 1

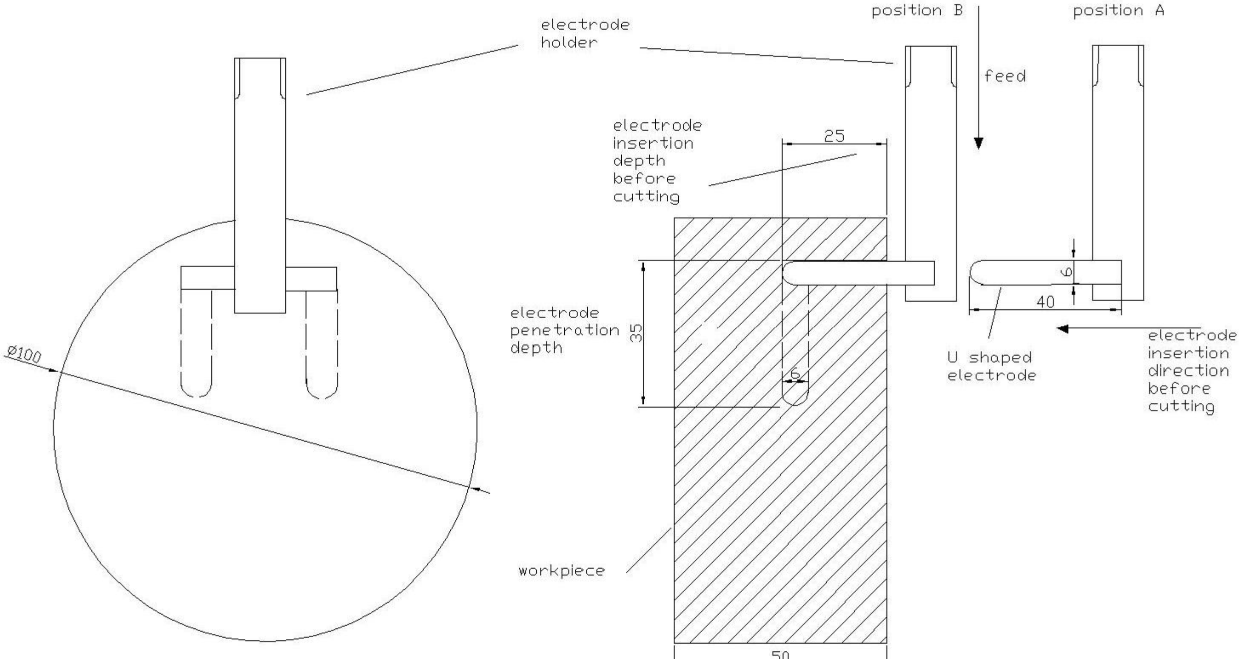

Figure 3.7 Step 2

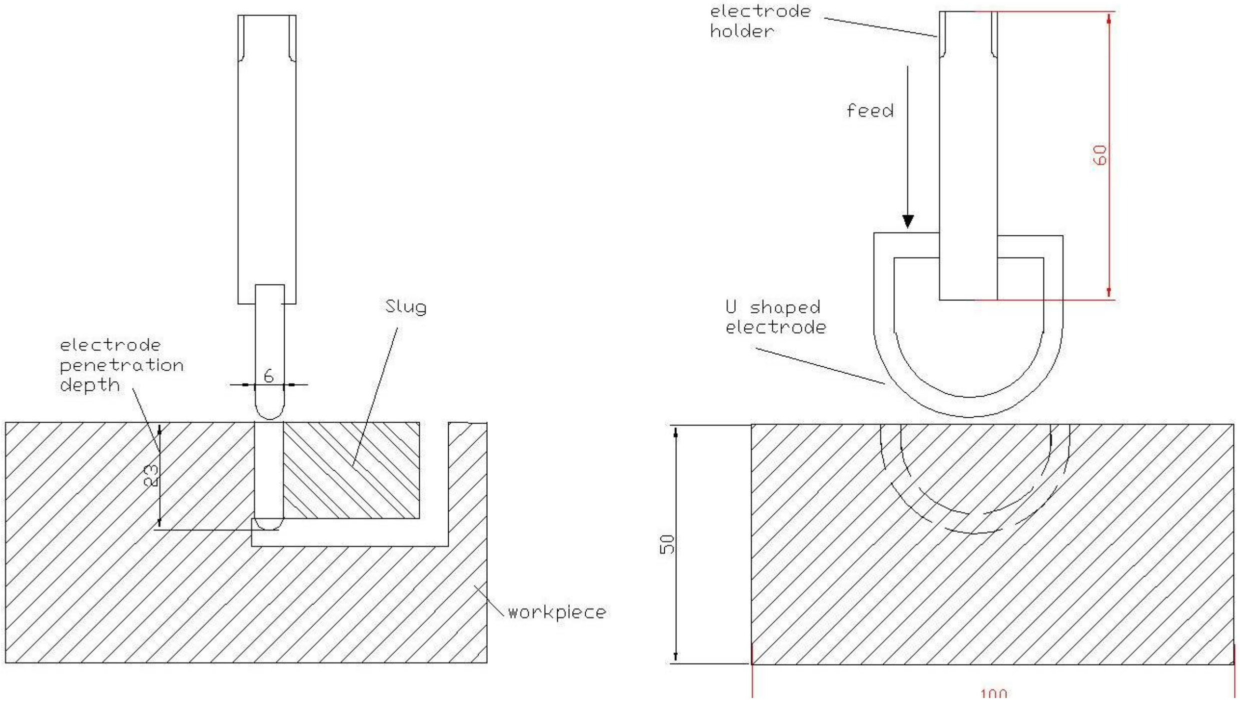

Figure3.8 Step 3

3.5 DESIGN OF ELECTRODE:

In ECM generally tool which is cathode, is made out of non reacting material such as Copper. We want to study the tool design problem in ECM, only to determine a cathode shape which will machine a specified work piece shape.

In this experiment we have taken cupper as electrode material at cathode. It is designed in U shape so as to cut the cavity in AISI D2 steel in the similar profile. A long hollow cupper pipe was taken having length of 70mm. The internal and external dia of that cupper pipe was taken 8mm and 12 mm respectively. In one side of the copper pipe a thread was done up to 10mm with the help of threading die for M12 thread. After that a through hole is made by the help of drilling machine up to 60mm from the threading point. The pith of the thread was kept 2mm.From the side of the cupper tube two through hole has been made in order o placed the U tube cupper pipe. The hole is made in the cupper pipe is of different dia of 4mm and 6mm.

For making U tube electrode shown in fig 3.9, other two cupper pipe was needed of dia 4mm and 6mm.It is then bent to make the shape of U tube. During bending of the cupper pipe we have to be careful so that internal dia should not be closed. This bend electrode then fitted to the cupper pipe in vertical and horizontal manner and brazing was done to make it properly closed. With the help of 2 mm drill bit 3 holes has been made in each U shaped cupper tube shown in fig 3.10, to make the electrolyte freely flow to the work piece. In this way electrode design has been made.

In order to making the cavity and calculating the material removal rate we have design a U – shaped electrode using cupper as electrode material. A 70 mm electrode holder first designed which is having a thread in one end and a through hole was made up to a distance of 60mm.Then two side hole was made in the order of 4mm and 6mm.Then a special designed U-shaped electrode of the order of 4mm and 6mm inserted in that side hole and brazing was done to make it completely closed. In that U-shaped electrode 3 holes have been made using 2 mm drill bit in order to flow of electrolyte through it. By setting all the parameters in the proper way a cavity was made in the work piece. By measuring the corresponding weight the MRR is to be calculated.

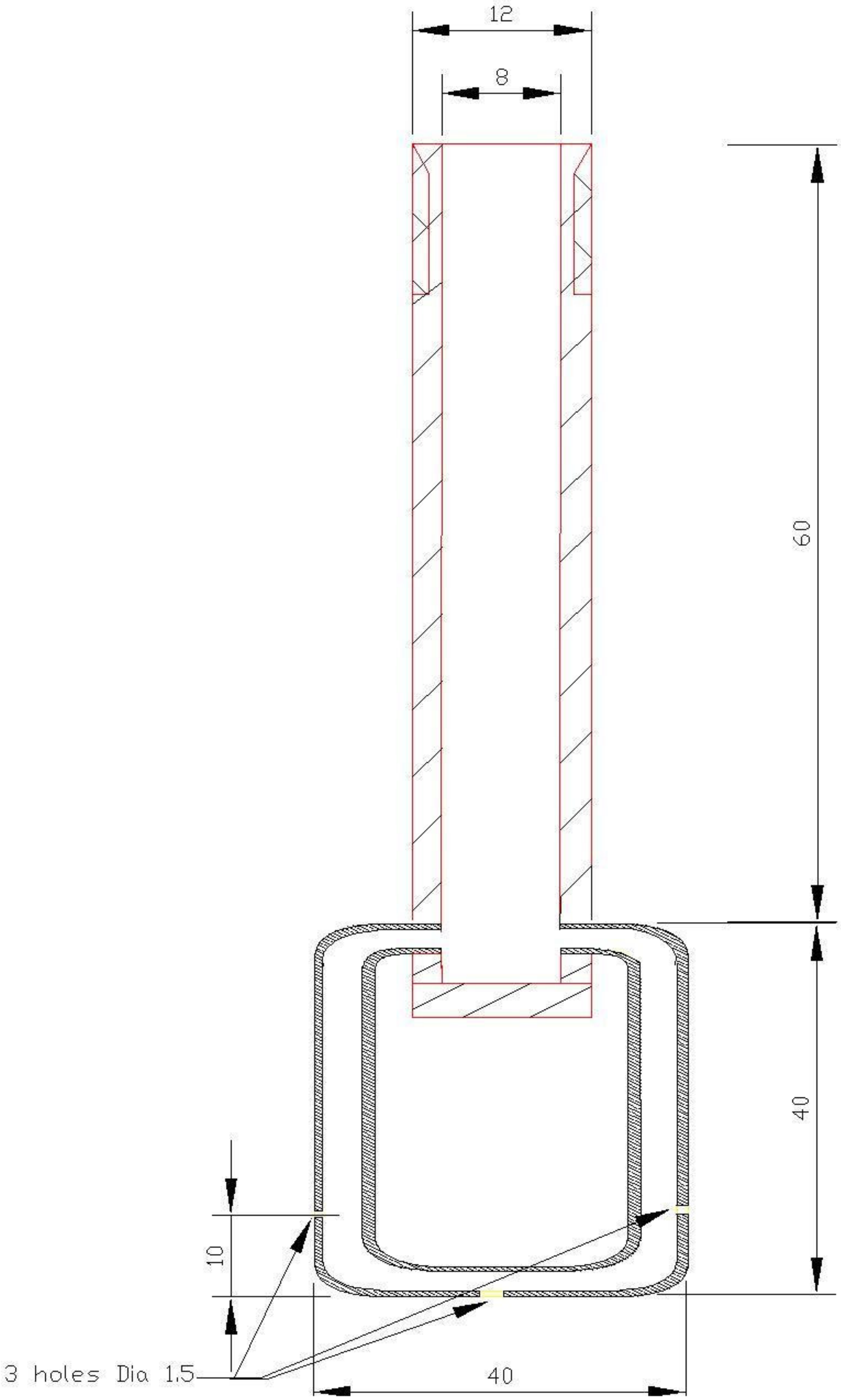

Fig. 3.9 Electrode design for machining steps 1 & 3

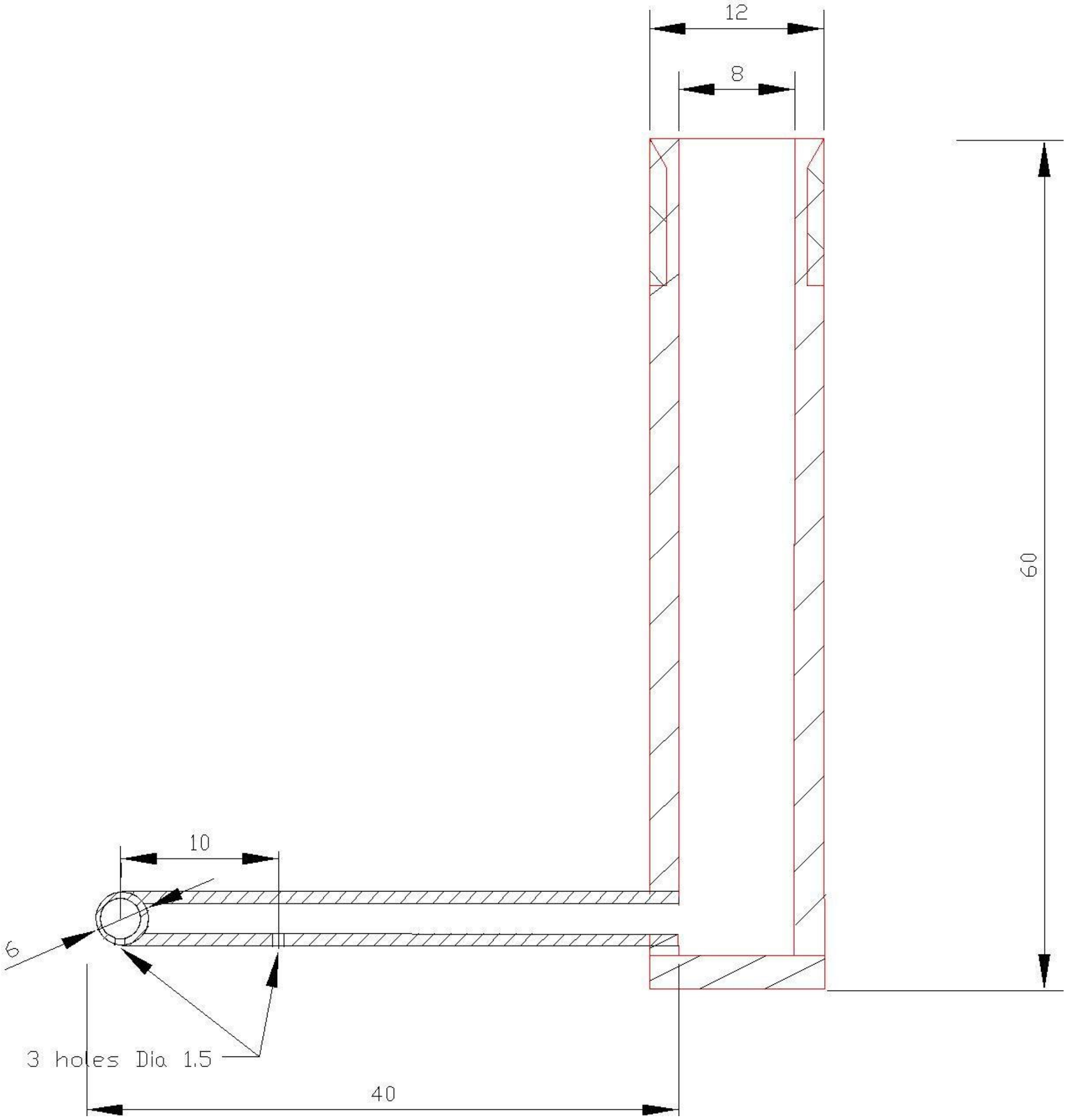

Fig. 3.10 Electrode design for machining steps 2

Fig. 3.11 U-Shaped tubular electrode of dia 4mm & 6 mm for machining step 2

Fig. 3.12 U-Shaped tubular electrode of dia 4mm & 6 mm for machining step 1 & 3

3.6 Taguchi Design:

Prof. Genichi Taguchi, a Japanese engineer, proposed several approaches to experimental designs that are sometimes called "Taguchi Methods." These methods utilize two-, three-, and mixed-level fractional factorial designs. Taguchi refers to experimental design as "off-line quality control" because it is a method of ensuring good performance in the design stage of products or processes. The aim here is to make a product or process less variable (more robust) in the face of variation over which we have little or no control.

Table- 3.4 Factor levels

Levels	Feed mm/min	Flow Rate L/min	Dia mm	K mS/cm
1.	0.21	3	4	63
2.	0.32	6	6	118
3.	0.45			
4.	0.54			

Table 3.5 L8 orthogonal array

Run	A-Feed mm/min	B-Flow Rate L/min	C-Dia mm	D-Conductivity mS/cm
1	1	1	1	2
5	1	2	2	1
2	2	1	1	1
6	2	2	2	2
3	3	2	1	2
7	3	1	2	1
4	4	2	1	1
8	4	1	2	2

Table3.6 Observation Table

run	Feed mm/min	Flow Rate L/min	Dia Mm	K mS/cm	Initial wt Kg	Final Wt kg	Slug wt gm	T1 min	T2 min	T3 min	Length Mm	Width mm	Height mm
1	0.21	3	4	118	3.085	2.862	21.78	120	120	85	37.75	42.752	27.76
2	0.32	3	4	63	2.721	2.504	16.70	78	78	56	37.52	42.522	26.73
3	0.45	6	4	118	2.862	2.656	19.90	56	60	33	37.29	42.297	26.95
4	0.54	6	4	63	2.504	2.303	20.15	46	46	28	36.43	41.432	26.63
5	0.21	6	6	63	3.040	2.810	10.97	120	120	77	37.96	42.964	27.63
6	0.32	6	6	118	2.906	2.642	15.64	78	75	49	37.82	42.823	27.13
7	0.45	3	6	63	2.810	2.530	16.58	56	63	42	37.52	42.525	26.28
8	0.54	3	6	118	2.642	2.378	18.97	46	50	32	36.81	41.814	26.28

Fig 3.13 Work piece after machining for run 1 and 2

Fig 3.14work piece after machining for run 3and 4

Fig 3.15work piece after machining run 5 and 6

Fig 3.16 work piece after machining run 7and 8

3.7 Sample Calculation

MRR is calculated as given by the following formula

$$MRR = \frac{Initial \quad wt - final \quad wt}{T1 + T2 + T3} \tag{3.1}$$

MRR effective is calculated as given by the following formula

$$MRR \quad effective = \frac{Initial \quad wt - final \quad wt + Slug \quad wt}{T1 + T2 + T3} \tag{3.2}$$

Over-cut, GL is calculated as given by the following formula

$$GL = \frac{length - cut \quad length}{2} = \frac{length - 35}{2} \tag{3.3}$$

Over-cut, GW is calculated as given by the following formula

$$GW = \frac{width - cut \quad width}{2} = \frac{width - 40}{2} \tag{3.4}$$

Over-cut, GH is calculated as given by the following formula

$$GH = \frac{height - cut \quad height}{2} = \frac{height - 25}{2} \tag{3.5}$$

Sample calculation for observation no 1 (run 1) is presented below and the results are shown in Table 3.6

$$MRR = \frac{3.085 - 2.862}{120 + 120 + 85} = 0.696154 \tag{3.6}$$

MRR effective is calculated as given by the following formula

$$MRR \quad effective = \frac{3.085 - 2.862 - 21.78/1000}{120 + 120 + 85} = 0.763169 \tag{3.7}$$

Over-cut, GL is calculated as given by the following formula

$$GL = \frac{37.75 - 35}{2} = 1.375 \qquad (3.8)$$

Over-cut, GW is calculated as given by the following formula

$$GW = \frac{42.752 - 40}{2} = 1.376 \qquad (3.9)$$

Over-cut, GH is calculated as given by the following formula

$$GH = \frac{27.76}{2} - 25 = 1.380 \qquad (3.10)$$

Table 3.7 Response table

run	Control parameters				Responses					
	Feed mm/min	Flow Rate L/min	Dia mm	K mS/cm	Slug wt Gm	MRR gm/min	MRR effective gm/min	GL Mm	GW mm	GH mm
1	0.21	3	4	118	21.78	0.696154	0.763169	1.375	1.376	1.380
2	0.32	3	4	63	16.70	1.023585	1.102358	1.260	1.261	0.865
3	0.45	6	4	118	19.90	1.449664	1.583221	1.145	1.149	0.975
4	0.54	6	4	63	20.15	1.775000	1.942917	0.715	0.716	0.815
5	0.21	6	6	63	10.97	0.715552	0.750158	1.480	1.482	1.315
6	0.32	6	6	118	15.64	1.306931	1.384356	1.410	1.412	1.065
7	0.45	3	6	63	16.58	1.739130	1.842112	1.260	1.263	0.640
8	0.54	3	6	118	18.97	2.015625	2.163828	0.905	0.907	0.640

3.8 CONCLUSION

Experiments were conducted according to Taguchi method by using the machining set up and the designed U-shaped tubular electrodes. The control parameters like feed, diameter of electrode, flow rate, and conductivity were varied to conduct 8 different experiments and the weights of the work piece and dimensional measurements of the cavity were taken for calculation of MRR and over cuts.

Introduction

In this chapter, the responses such as MRR, MRR effective, slug wt and various over-cuts are calculated from the observation table, which are analyses and discussed.

4.1 ANALYSIS OF EXPERIMENT AND DISCUSSION:

Effect on MRR and effective MRR

The machinability of ECM depends on the electrical conductivity of the electrolyte, feed rate of electrode, inter electrode gap and electrolyte flow rate [27, 3]. The influence of various machining parameters on MRR (means) are shown in Fig. 4.1. The electrode feed rate has enormous effect on MRR and it increases with increase in feed rate. This result was expected because the material removal rate increases with feed rate because the machining time decreases. MRR also increases with larger diameter of electrode; however, the effect is less than the feed rate on MRR. The electrolyte flow rate and conductivity has very little effect on MRR and doesn’t give any conclusive evidence of any impact on MRR. Similar trends are shown by the plot of main effects for SN ratios on MRR in Fig.4.2. In Table 4.2, the main effects of feed, diameter of electrode, flow rate, conductivity are 1.1895, 0.2082, 0.0568 and 0.0538, respectively, on MRR in gm/min, in order of significance. These results are in good agreement with the observations of many researchers.

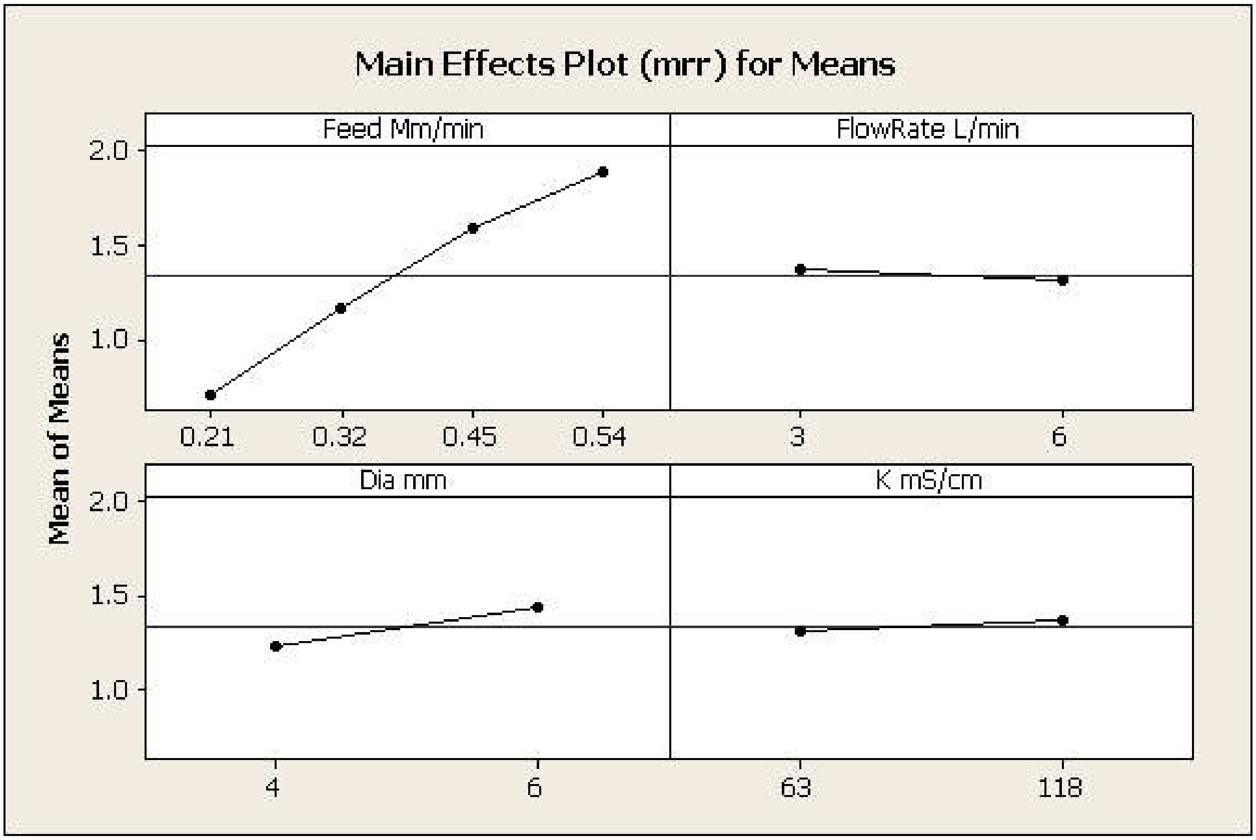

Figure 4.1 Main effects of machining parameters on MRR (data means)

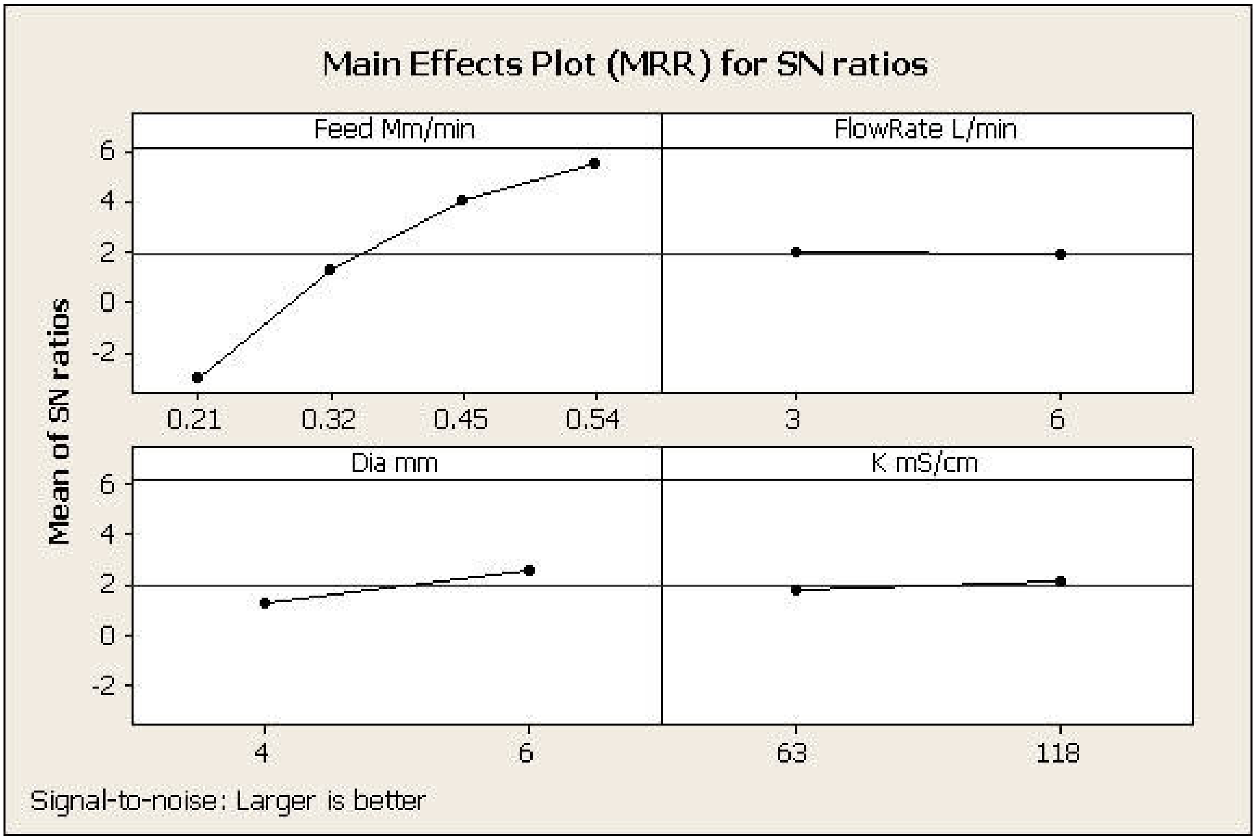

Figure 4.2 Main effects of machining parameters on MRR (SN ratios)

Table 4.1 Taguchi analysis response table for MRR: larger is better

	Level	Feed Mm/min	Flow Rate L/min	Dia mm	K mS/cm
SN ratios	1	-3.027	1.988	1.316	1.771
	2	1.264	1.907	2.578	2.123
	3	4.016			
	4	5.536			
	Delta	8.563	0.081	1.262	0.352
	Rank	1	4	2	3
Means	1	0.7059	1.3686	1.2361	1.3133
	2	1.1653	1.3118	1.4443	1.3671
	3	1.5944			
	4	1.8953			
	Delta	1.1895	0.0568	0.2082	0.0538
	Rank	1	3	2	4

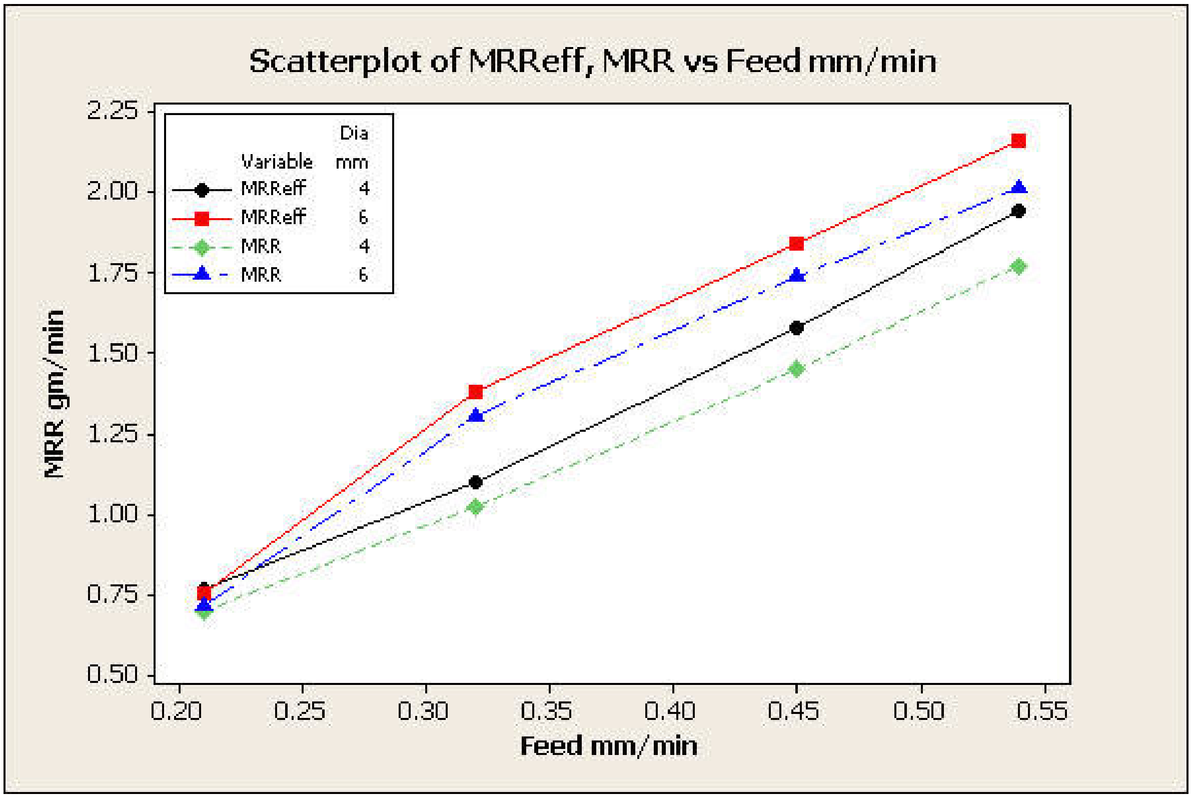

Figure 4.3 Scatter plot of MRR effective, MRR vs. feed for various electrode diameters.

Since, MRR effective is always more than MRR, for positive slug weight, the graph in Fig 4.3 shows that with feed, both the MRR's increases. The effect of electrode diameter on MRR effective is obvious as the projected area of electrode having fewer diameters is less than that of larger diameter electrode; the actual material removed under the projected area is less. Thus, with smaller electrode diameter, similar sized cavity can be made with lesser amount of material removed and saving energy. The influence of various machining parameters on MRR effective (means) are shown in Fig. 4.4. The electrode feed rate has enormous effect on MRR effective and it increases with increase in feed rate. MRR effective also increases with larger diameter of electrode; however, the effect is less than the feed rate on MRR effective. The electrolyte flow rate and conductivity has very little effect on MRR and doesn't give any conclusive evidence of any impact on MRR. Similar trends are shown by the plot of main effects for SN ratios on MRR effective in Fig.4.5. In Table 4.3, the main effects of feed, diameter of electrode, flow rate, conductivity are 8.659, 1.020, 0.105 and 0.437, respectively, on MRR effective in gm/min, in order of significance. There is very less difference between the graph of MRR and Effective MRR.

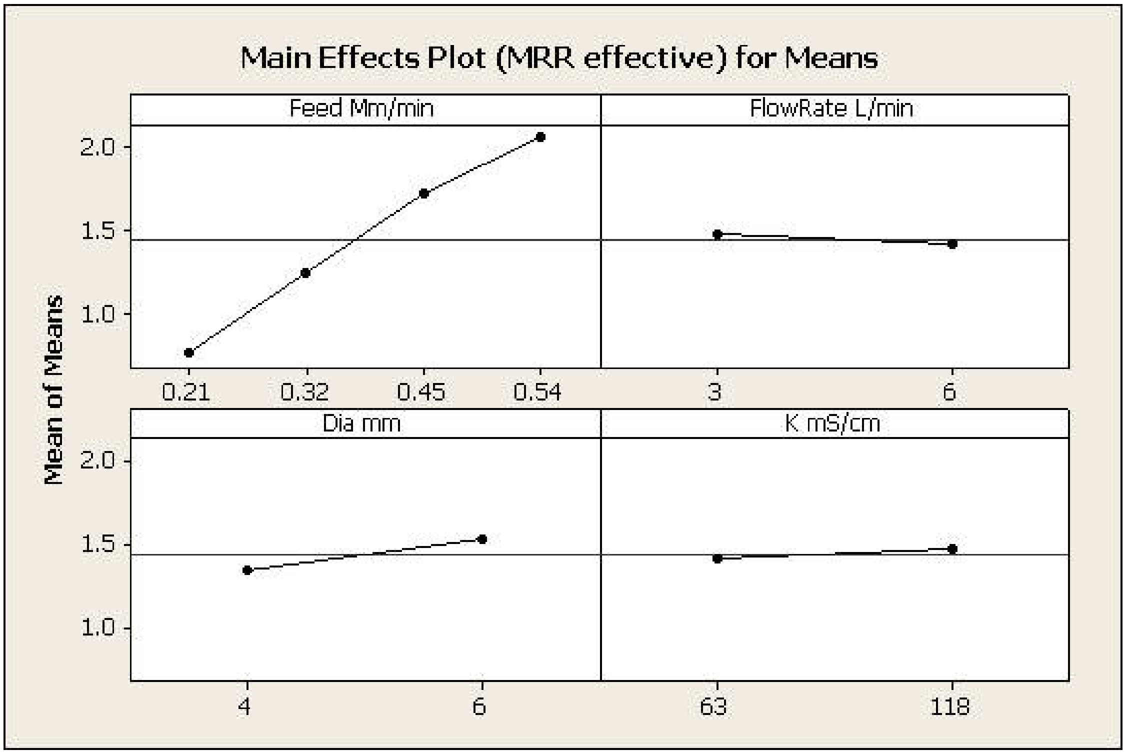

Fig 4.4 Main effects of machining parameters on MRR Effective

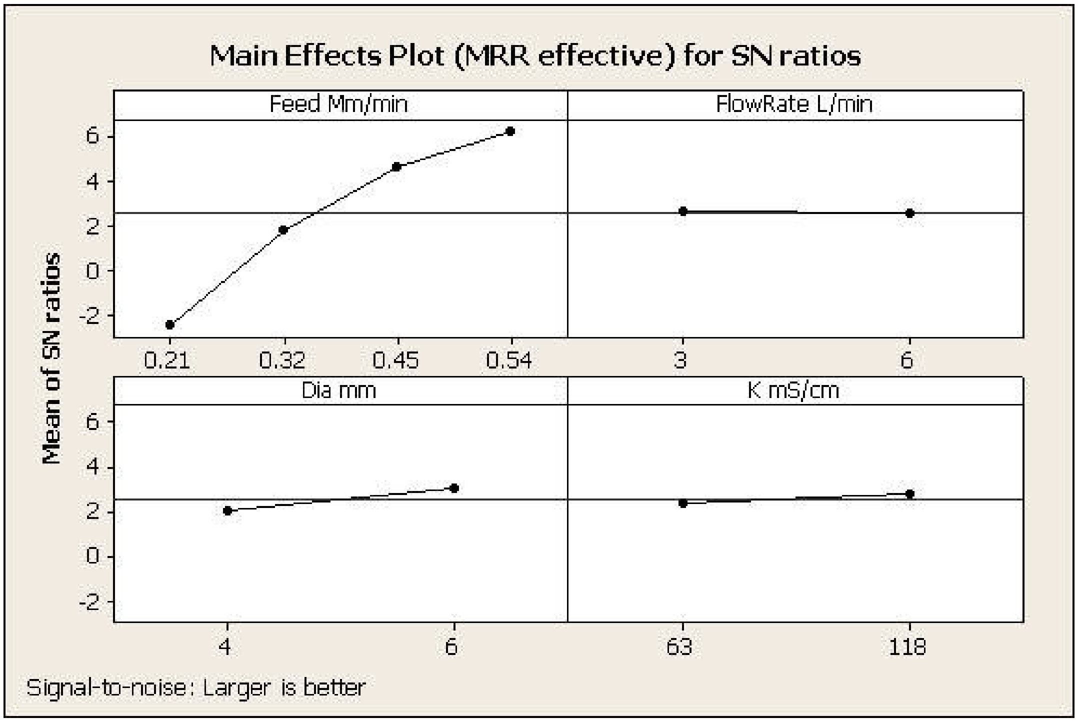

Fig 4.5 Main effects of machining parameters on MRR effective (SN ratios)

Table-4.2 Taguchi analysis response table for MRR effective: larger is better

	Level	Feed Mm/min	Flow Rate L/min	Dia mm	K mS/cm
SN ratios	1	-2.422	2.627	2.065	2.356
	2	1.836	2.522	3.085	2.793
	3	4.649			
	4	6.237			
	Delta	8.659	0.105	1.020	0.437
	Rank	1	4	2	3
Means	1	0.7567	1.4679	1.3479	1.4094
	2	1.2434	1.4152	1.5351	1.4736
	3	1.7127			
	4	2.0534			
	Delta	1.2967	0.0527	0.1872	0.0643
	Rank	1	4	2	3

4.2 Effect on slug wt:

Similarly the influence of various machining parameters on slug wt (means) are shown in Fig. 4.6. The electrode feed rate and conductivity has enormous effect on slug weight and it increases with increase in feed rate and conductivity. Slug wt also decreases with larger diameter of electrode; with increase of flow rate slug wt decreases. Similar trends are shown by the plot of main effects for SN ratios on Slug wt in Fig.4.7. In Table 4.3, the main effects of diameter of electrode, feed, conductivity, flow rate are 4.09, 3.39, 2.97 and 1.84, respectively, on slug wt in gm, in order of significance.

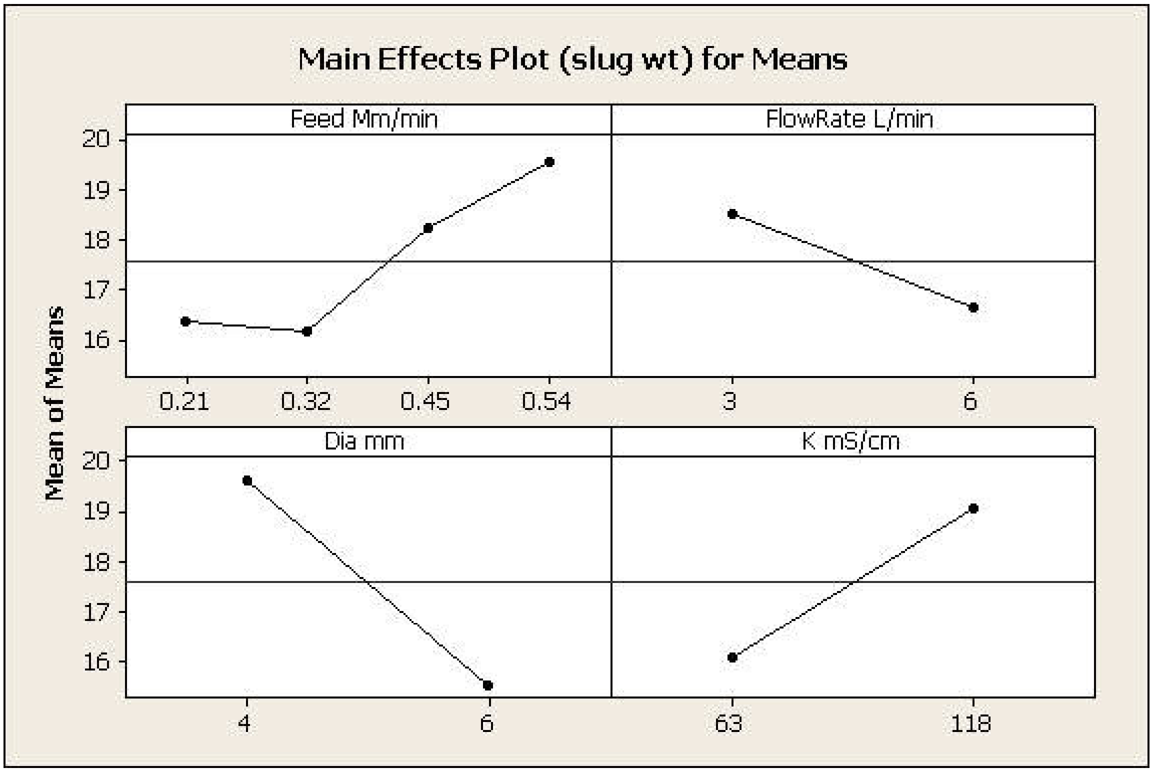

Fig 4.6 Main effects of machining parameters on slug wt

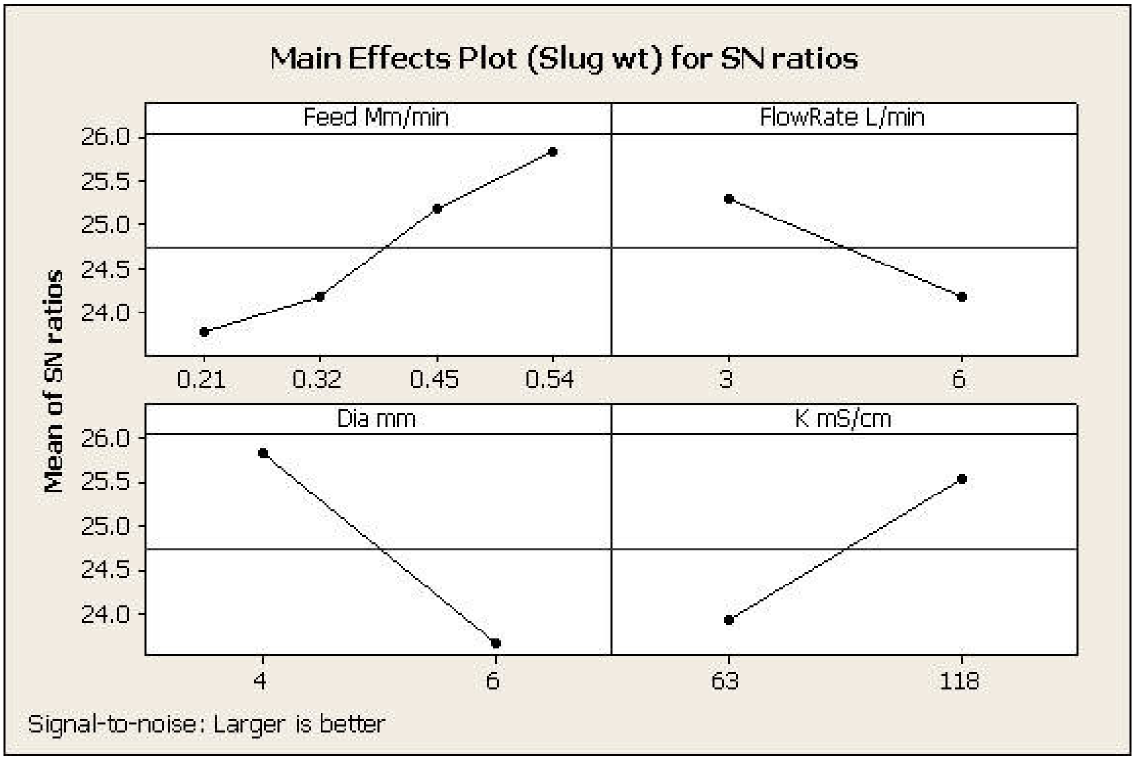

Fig 4.7 Main effects of machining parameters on slug wt (SN ratios)

Table 4.3 Taguchi analysis response table for slug weight: larger is better

	Level	Feed Mm/min	Flow Rate L/min	Dia mm	K mS/cm
SN ratios	1	23.78	25.29	25.82	23.93
	2	24.17	24.19	23.66	25.55
	3	25.18			
	4	25.82			
	Delta	2.04	1.10	2.16	1.61
	Rank	2	4	1	3
Means	1	16.38	18.51	19.63	16.10
	2	16.17	16.67	15.54	19.07
	3	18.24			
	4	19.56			
	Delta	3.39	1.84	4.09	2.97
	Rank	2	4	1	3

4.3 Effect on over cut (GL):

One of the major challenges in ECM is the control of the cavity oversize (or over cut). Over cut depends on the characteristics of electrolyte, e.g. concentration, flow rate, and its throwing power and sludge formation. In the machining area, just below the machining face of the tool, anodic reaction rate and conductivity of the electrolyte is constant. Away from the main machining zone, current density decreases asymptotically to zero with increasing distance along the work piece surface. Up to a certain distance, current density is sufficient for metal dissolution, which causes over cut. Due to the increase in electrolyte concentration, ions associated with the machining operation in the machining zone also increase. A Higher concentration of ions reduces the localization effect of electrochemical material removal reactions. This leads to the higher over cut of the work piece and thus reduces the machining accuracy. Removal of material by the stray current increases with the increase of electrolyte concentration. This stray current effect is more predominant at higher concentrations of electrolyte. Electrolyte temperature directly affects the conductivity of the electrolyte. A temperature increase results in over cut increase up to the point at which the electrolyte vaporizes in the machining gap [24].

The effect of various machining parameters on over cut GL (means) are shown in Fig.4.8. The electrode feed rate has enormous effect on length over cut and it decreases with increase in feed rate. It is due to the fact that with increasing feed rate, the machining of cavity neighborhood is reduced. Over cut GL also increases with larger diameter of electrode. The electrolyte flow rate and conductivity has very little effect on length over cut and doesn’t give any conclusive evidence of any impact on length over cut. But the main effect of parameter on SN ratio on over cut is varying. With increase of feed rate over cut of length increases. But with increases of electrode dia length over cut decreases. Effect of conductivity and flow rate is very less. In Table

4.5, the main effects of feed, diameter of electrode, flow rate, conductivity are 0.6175, 0.1400, 0.0125 and 0.0300, respectively, on GL in mm, in order of significance.

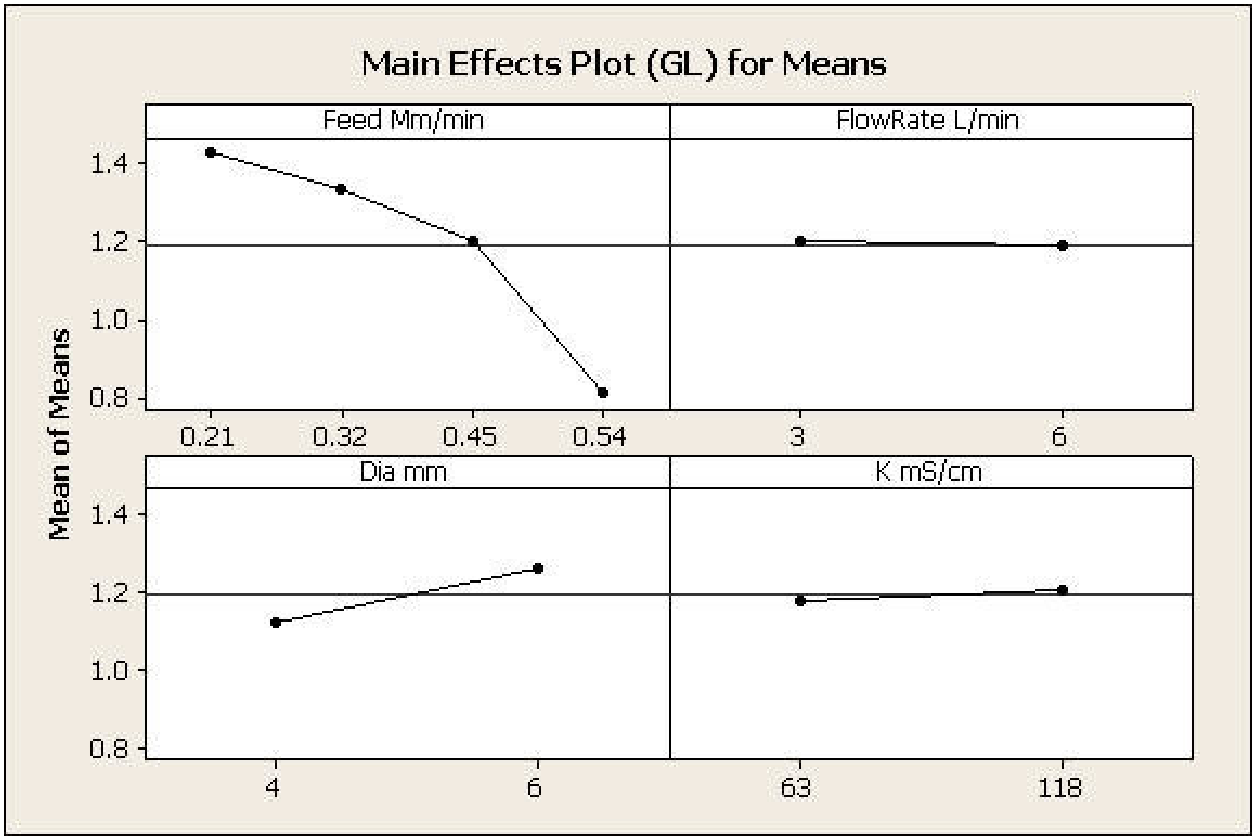

Fig 4.8 Main effects of machining parameters on GL

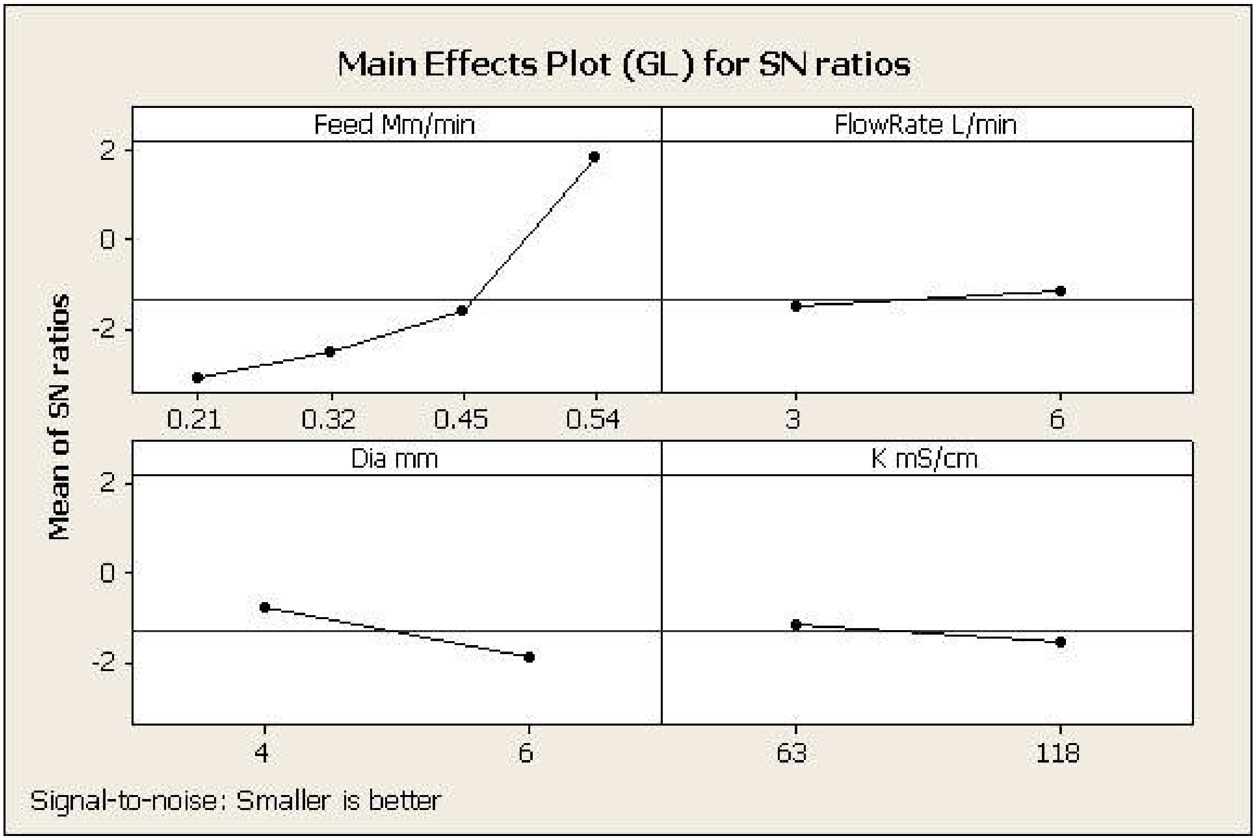

Fig 4.9 Main effects of machining parameters on GL(SN ratio)

Table 4.4 Taguchi analysis response table for GL: smaller is better

	Level	Feed Mm/min	Flow Rate L/min	Dia mm	K mS/cm
SN ratios	1	-3.0856	-1.4785	-0.7589	-1.1265
	2	-2.4959	-1.1630	-1.8825	-1.5149
	3	-1.5918			
	4	1.8905			
	Delta	4.9761	0.3155	1.1236	0.3883
	Rank	1	4	2	3
Means	1	1.4275	1.200	1.1238	1.1788
	2	1.3350	1.1875	1.2638	1.2088
	3	1.2025			
	4	0.8100			
	Delta	0.6175	0.0125	0.1400	0.0300
	Rank	1	4	2	3

4.4Effect on overcut (GW):

The influence of various machining parameters on Width over cut, GW (means) are shown in Fig. 5.0. The electrode feed rate has enormous effect on width over cut and it decreases with increase in feed rate. Width over cut also increases with larger diameter of electrode. The electrolyte flow rate and conductivity has very little effect on width over cut. Similarly width over cut increases significantly with increase of feed rate. Width over cut also gradually decreases with increase of diameter of the electrode. Effect of flow rate and conductivity has very little effect on width over cut. Trends are shown by the plot of main effects for SN ratios on width over cut in Fig.5.1. In Table 4.6 the main effects of feed, diameter of electrode, flow rate, conductivity are 0.6175, 0.1404, 0.0121 and 0.0304, respectively, on width over cut in mm, in order of significance.

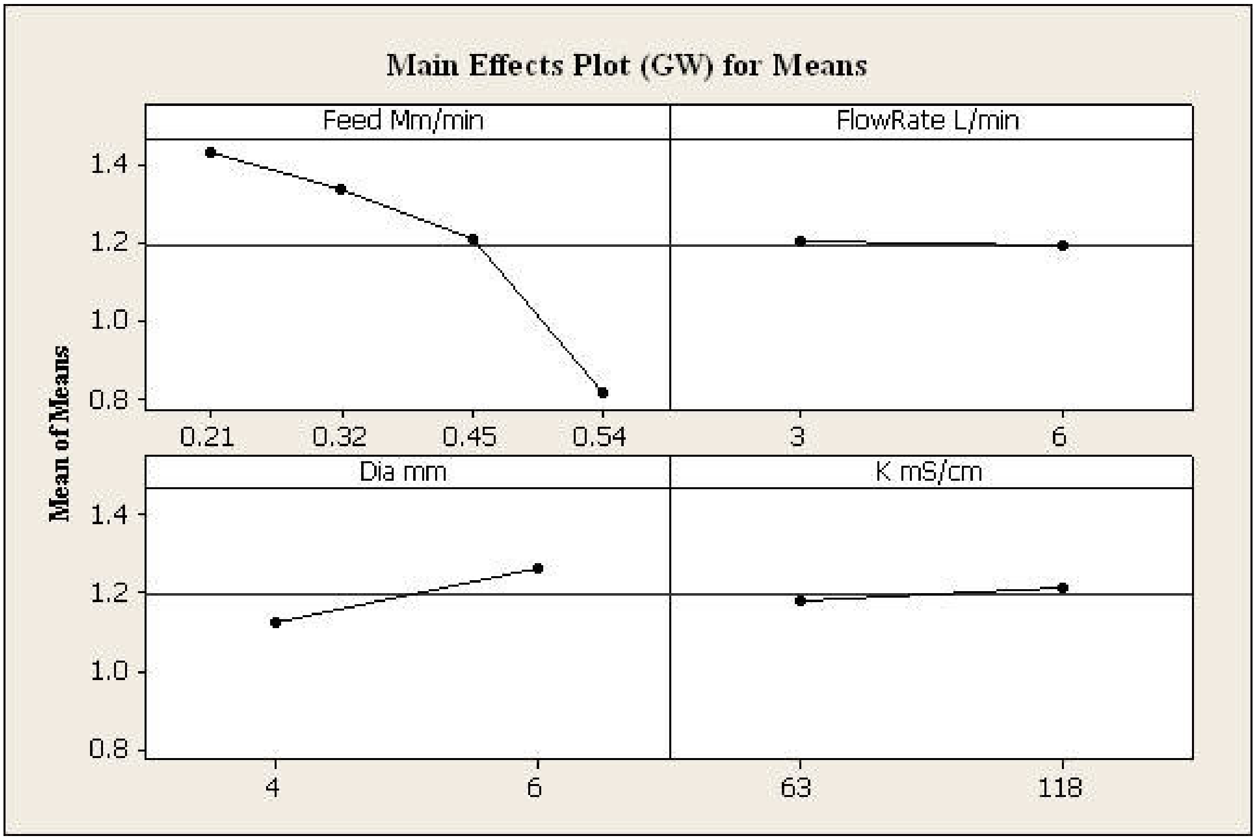

Figure 4.10 Main effects of machining parameters on GW

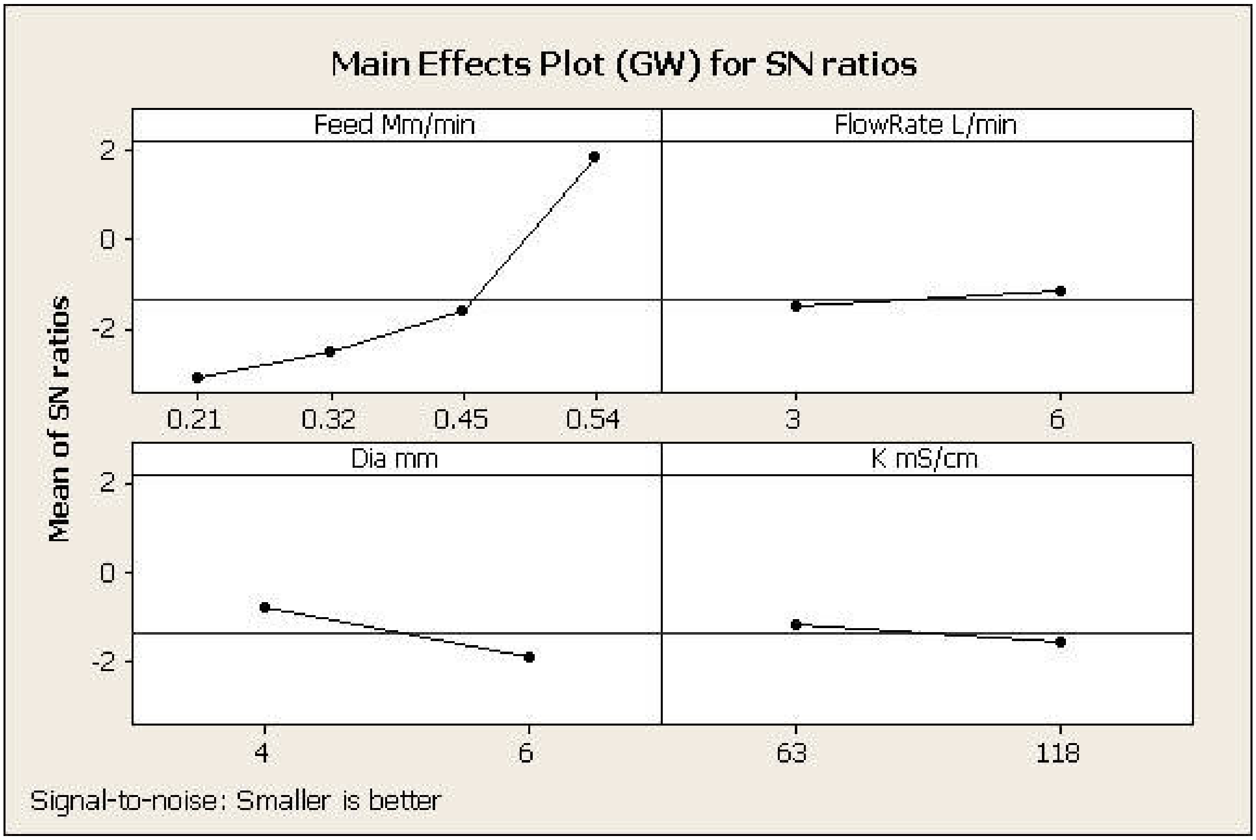

Fig. 4.10 Main effects of machining parameters on GW (SN ratios)

Table 4.5 Taguchi analysis response table for slug weight: smaller is better

	Level	Feed Mm/min	Flow Rate L/min	Dia mm	K mS/cm
SN ratios	1	-3.0947	-1.4909	-0.7719	-1.1385
	2	-2.5040	-1.1779	-1.8968	-1.5302
	3	-1.6136			
	4	1.8748			
	Delta	4.9695	0.3130	1.1250	0.3916
	Rank	1	4	2	3
Means	1	1.4290	1.2016	1.1254	1.1804
	2	1.3363	1.1895	1.2658	1.2108
	3	1.2055			
	4	0.8115			
	Delta	0.6175	0.0121	0.1404	0.0304
	Rank	1	4	2	3

4.5 Effect on over cut (GH):

The influence of various machining parameters on height over cut, GH (means) are shown in Fig5.2. The electrode feed rate has enormous effect on height over cut and it gradually decreases increase in feed rate. Height over cut also increases with flow rate and conductivity. But height over cut decrease with increase of diameter of the electrode. Main effects for SN ratios height over cut are shown in Fig.5.3.The height over cut is gradually increases with increase of feed rate and diameter of the electrode. But with increases of conductivity and flow rate the height over cut decreases In Table 4.7 the main effects of feed, diameter of electrode, flow rate, conductivity are 0.6200, 0.0938, 0.1612 and 0.1063, respectively, on height over cut in mm, in order of significance.

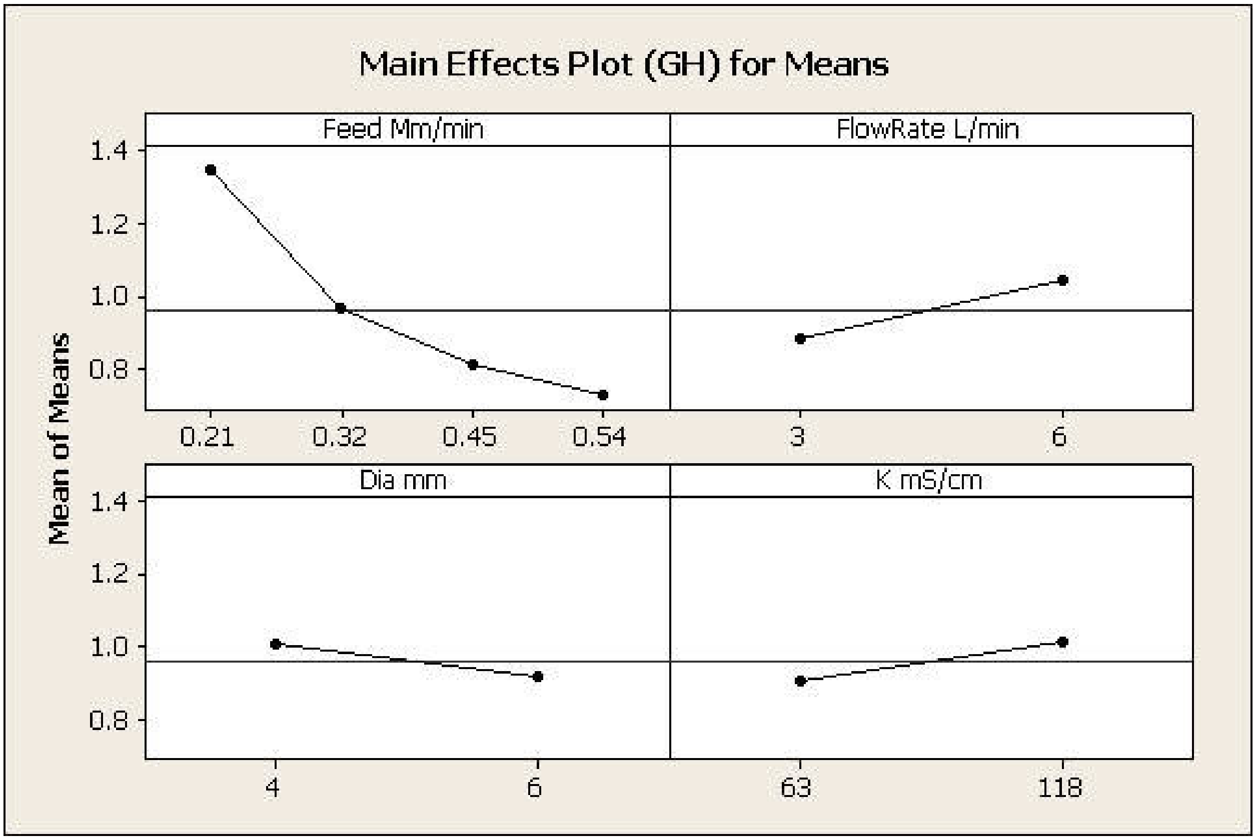

Fig 4.12 Main effects of machining parameters on GH

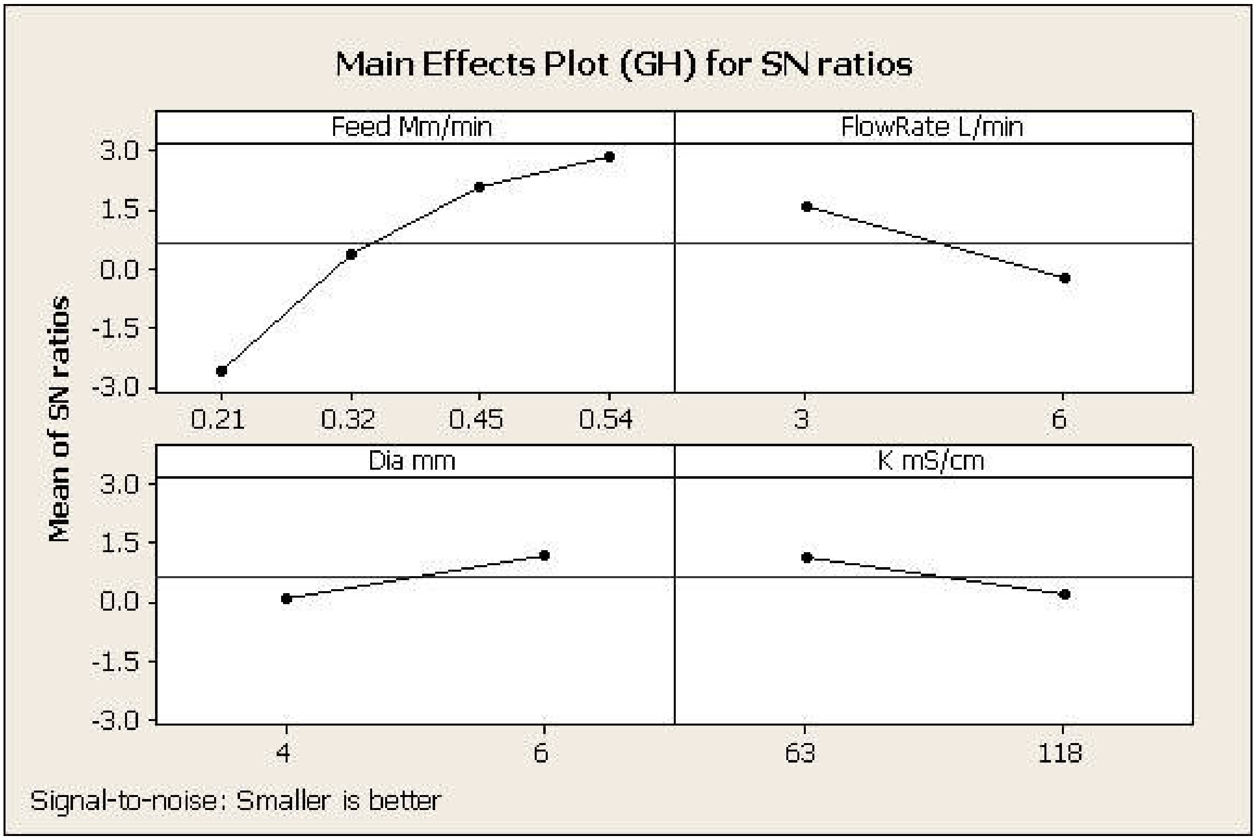

Fig 4.13 Main effects of machining parameters on GH (SN ratios)

Table 4.6 Taguchi analysis response table for slug weight: smaller is better

	Level	Feed Mm/min	Flow Rate L/min	Dia mm	K mS/cm
SN ratios	1	-2.5880	1.5537	0.1147	1.1336
	2	0.9650	1.0425	0.9150	1.0150
	3	2.0486			
	4	2.8266			
	Delta	5.4147	1.7859	1.0921	0.9475
	Rank	1	2	3	4
Means	1	1.3475	0.8813	1.0088	0.9088
	2	0.9650	1.0425	0.9150	1.0150
	3	0.8075			
	4	0.7275			
	Delta	0.6200	0.1612	0.0938	0.1063
	Rank	1	2	4	3

Table 4.7 shows the ANOVA results of over cut GL and feed and diameter of electrode are found to be significant. The linear model has R^2 fit value of 99.98 and R^2(Adj) fit value of 99.84

which justify that the two significant factors contribute mostly for over cut GL. Similarly, in Table 4.8 and 4.9, the ANOVA tables for over cut GW and GH, respectively, are presented. These tables show that the feed and diameter are significant factors for controlling over cut.

Table 4.7 Analysis of Variance for GL

Source	DF	SeqSS	AdjSS	AdjMS	F	P
Feed	3	0.443863	0.443863	0.147954	1315.15	0.020
Flow Rate	1	0.000313	0.000313	0.000313	2.78	0.344
Dia	1	0.039200	0.039200	0.039200	348.44	0.034
K	1	0.001800	0.001800	0.001800	16.00	0.156
Error	1	0.000113	0.000113	0.000113		
Total	7	0.485288				
S = 0.0106066			R-Sq = 99.98%		R-Sq(adj) = 99.84%	

Table 4.8 Analysis of Variance for GW

Source	DF	SeqSS	AdjSS	AdjMS	F	P
Feed	3	0.443778	0.443778	0.147926	1120.39	0.022
Flow Rate	1	0.000294	0.000294	0.000294	2.23	0.376
Dia	1	0.039410	0.039410	0.039410	298.49	0.037
K	1	0.001845	0.001845	0.001845	13.98	0.166
Error	1	0.000132	0.000132	0.000132		
Total	7	0.485459				
S = 0.0114905			R-Sq = 99.97%		R-Sq(adj) = 99.81%	

Table 4.9 Analysis of Variance for GH

Source	DF	SeqSS	AdjSS	AdjMS	F	P
Feed	3	0.454959	0.454959	0.151653	110.04	0.070
Flow Rate	1	0.052003	0.052003	0.052003	37.73	0.103
Dia	1	0.017578	0.017578	0.017578	12.76	0.174
K	1	0.022578	0.022578	0.022578	16.38	0.154
Error	1	0.001378	0.001378	0.001378		
Total	7	0.548497				
S = 0.0371231			R-Sq = 99.75%		R-Sq(adj) = 98.24%	

Conclusion

The work evaluates the feasibility of machining blind cavity on AISI D2 tool steel in ECM with U-shaped electrode. The performance parameters like MRR, MRR effective, slug weight and various over cuts are studied under various machining parameters. The most significant factors for MRR and MRR effective are found to be feed and diameter of electrode. Both the response increases with increase in feed and electrode diameter. Furthermore, the flow rate and electrolyte concentration has very little effect. The feed has positive effects the slug weight and diameter of electrode is inversely proportional to slug weight. The over cuts GL, GW, GH are influenced by feed and diameter of electrode. With feed over cuts reduce and diameter of electrode tends to increase the over cuts.

Chapter 5 *CONCLUSION*

The present work is an attempt to study the feasibility of machining blind cavity on AISI D2 tool steel in ECM with U-shaped electrode. The MRR, MRR effective, slug weight and various over cuts are studied with various setting of electrode feed rate, electrolyte flow rate, electrolyte concentration and diameter of electrode. The most significant factors for MRR and MRR effective are found to be feed and diameter of electrode. Both the response increases with increase in feed and electrode diameter. Furthermore, the flow rate and electrolyte concentration has very little effect. The feed has positive effects the slug weight and diameter of electrode is inversely proportional to slug weight. The over cuts along length, width and height of cavity are influenced by feed and diameter of electrode. All these over cuts reduce with increase in feed and diameter of electrode tends to increase the over cuts.

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