BENHA UNIVERSITY

SHOUBRA FACULITY OF ENGINEERING

CONTROLLING OF ELECTROCHEMICAL MACHINING PROCESS

THESIS

Submitted in Partial Fulfillment the

Requirements for the Degree of Master

of Science in Mechanical Engineering

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Abstract

Electrochemical – turning (ECT) is an important nontraditional or advanced manufacturing process that provides a better alternative in machining components. Complex geometrical shapes can be machined repeatedly and accurately surface can be obtained without surface treatment.

The present work investigates the effect of applied feed rate, rotational speed workpiece, applied voltage and electrode size or machining area on metal removal rate, hardness and surface roughness in electrochemical turning of mild steel. The objective of this on-going investigation is to develop a better understanding of (ECT) performance. It was found that

1- Material removal (MRR) increases with increasing the applied feed rate of the electrode or velocity of tool electrode displacement. Moreover, material removal rate increases with increasing the applied voltage, as the voltage increases the current density increases and material removal rate increases. Moreover, material removal rate increases with increasing the applied rotational speed of workpiece.

2- Hardness of workpiece decreases with increases the applied feed rate, also hardness of workpiece decreases with increases the applied rotational speed of workpiece and decreases the tool electrode dimension.

3- Surface roughness decreases with decreasing applied voltage, increasing feed rate and increasing tool electrode area. By increasing the feed rate, stray machining will be less because of small time interval. This will, therefore, result in better surface finish, further, an increase in feed rate causes an increase in the electrolyte flow rate, surface roughness decreases as the rotational speed of workpiece increases. High rotational speed of the workpiece produces better surface finish, since the rotational energy provides better discharge mobility by inducing more turbulent flow of electrolyte.

4- Making an experimental design using response surface methodology of matlab software to produce a mathematical predicted model related between material removal rate, surface roughness and working parameter of (feed rate, applied voltage and rotational workpiece speed).

Summary

The ECT process offers great of advantages over conventional turning, such as low induced stress, complex geometrical shape can be machined repeatedly and accurately, and there is no tool wear during electrochemical turning. However, one disadvantage is the difficulty of controlling the dimensional accuracy of the workpiece. This thesis presents an experimental investigation on some aspects of the performance of ECT. The objective of current investigation is to develop a better understanding of ECT performance.

All the tests were run on an Electrochemical turning machine fitted with 600Amper D.C. power source, which generates a current corresponding to the applied voltage. An inverter of (1hp) equipped with a variable frequency control is used to control the rotational speed of workpiece, a copper (Cu) tool electrode with rectangle cross section area is used with 25% sodium nitrite $NaNo_2$, a stepper motor (10V/0.65 A) with 4 connections is used to control the gap between workpiece and tool electrode, DC motor of 12 Volt, 10 Ampere, and 150 rpm is used to control the velocity of tool electrode or feed rate of tool electrode.

A constant flow rate of 27 l/min was used in all experiments. The workpiece is made from mild steel with 15mm diameter and 50mm long.

The experimental work studies the effect of independent variables of feed rate or velocity of electrode displacement, rotational speed of workpiece, applied voltage and tool electrode size on the dependant variables of material excess removed, material removal rate, hardness and surface roughness of workpiece.

Nomenclature

Symbols	Definition	Units
ΔY_s	:Side gap	mm
Z	:Effective metal removal rate	mm^3/min
j_{si}	:Current density at the workpiece	mA/cm^2
Δt	:machining time	sec
dg	:Metal removal thickness	mm
K	:Conductivity of the electrolyte	
Δb	:Distance along the electrolyte flow direction	mm
F	:Farady's constant	Coulomb
f	:Feed rate	mm/sec
C	:Constant of electric efficiency	
m	:Mass dissolved	gr
Ơ	:Gap size	mm
I	:Current	Ampere
Q_v	:Material amount removed per unite time (MRR)	gr/min
V_n	:Velocity of anodic dissolution	mm/min
ɳ	:Current efficiency	
K	:Electrochemical equivalent of the workpiece material	
Δm	:Mass of metal removed	gr
z	:Valency	
Δh	:Material removal thickness	mm
ρ	:Density of material of the workpiece	gr/cm^3
ΔA	:Surface area	cm^2
K_v	:Coefficient of electrochemical machinability	
a_i	:Thickness of material excess removed	mm
N	:Rotational speed of workpiece	rpm
B	:Constant of machining process	
U	:Mean inter electrode voltage	

E	:Mean drop of potential layer adjacent to the electrode and workpiece	V
F_1	:Surface of flat electrode	cm^2
F_2	:Surface of the ball ended electrode main cross-section	cm^2
D_{wp}	:Workpiece diameter	cm^2
D_i	:Tool diameter	cm^2
A.C	:Alternating current	Ampere
D.C	:Direct Current	Ampere

Contents

Introduction

The ECM process has acquired renewed importance due to its increasing applications in manufacturing of a wide range components received wide acceptance in the duplicating, drilling and sinking operations in the manufacture of dies, press and glass-making moulds, the manufacture of turbine and compressor blades for gas-turbine engines, the generation of passages, cavities, holes and slots in parts, deburring of gears, hydraulic and fuel-system parts, small electronic.

Electrochemical turning (ECT) is a special form of electrochemical machining (ECM) and an important non-traditional machining process, electrochemical machining utilizes both actions of electrical and chemical actions to remove material. The workpiece is charged positively with an electric potential provided by a D.C power supply.

This thesis presents results of an experimental investigation of some aspects of the performance of ECT. The objective of this on-going investigation is to understanding of ECT performance and the working parameters that affect the material removal rate, hardness and surface roughness. From experimental design using matlab program of response surface methodology, empirical equations are deduced to show the relation between working parameters and the response.

A review of the ECT process mechanism, influences of the main process parameters and related researches are presented in chapter 1. A theoretical study of electrochemical (laws of electrolysis and electrochemical solution rate) is illustrated in chapter 2. Experimental procedures and design (ECT machine, measurement instrument test procedures, and experimental design) are given in chapter 3. Experimental results are discussed in chapter 4.

Chapter 1

Literature Review

1.1 Introduction

In metal working industry, the machining techniques can be classified as traditional and non-traditional. In traditional operation, such as turning, milling, and grinding, electrical energy is converted into mechanical energy. This mechanical energy provides to the workpiece through the medium of cutting tools or abrasive grit. In removing metal to form parts of determinate shapes and sizes, the metal removed is plastically deformed to produce metal chips, with the simultaneous generation of heat and the creation of stresses within the work piece. The rapid growth in the development of materials has been resulted in increasingly harder and more difficult to machine new exotic metals and alloys during the last three decades[1]. Conventional machining processes are uneconomical for such materials especially hard materials.

The newer machining processes often referred to, as (non-traditional machining processes), have made possible to machine some of the materials that were formerly considered unmachinable under normal conditions. In non-traditional machining processes, metal is removed by the direct application of electrical energy to the work piece. Such processes include Electrical discharge machining (EDM), Electrochemical Machining (ECM), and Electrochemical Grinding (ECG). There are several other variants, such as electrpolishing, electrochemical discharge Machining, and electrochemical Deburring.

1.2 Electrochemical machining (ECM)

The electrochemical cutting off was described in 1946, but the application of electrochemical methods for actual machining seems to have been first put to general use about 1950 in the form of electrolytic or electrolytically assisted grinding. The extension to pure electrochemical removal came eight or ten years later, with the development of electrochemical machines for drilling holes and shaping turbine blades, i.e. the process now known as electrochemical machining and which is capable of hole-drilling, cavity-sinking, milling, turning and many other applications. The Anocut Company of Chicago was also developing electrochemical machines and the process of electrochemical machining for a wide range of applications, this company has developed and manufactured a large number of both special and general-purpose electrochemical machines and is now the leading supplier of this kind of equipment [1]. Electrochemical turning is a special form of electrochemical machining (ECM) and an important non-traditional machining process. Electrochemical machining utilizes both actions of electrical and chemical actions to remove material. The workpiece charged positively with an electric potential provided by a D.C. power source. During electrochemical action, electrolyte solution pumped into the machining gap between the tool and workpiece, so the current flows between the electrodes. Due to the composition of electrolyte, chemical reactions occur in the machining gap and the work material is dissolved by anodic action. The applied DC voltage, the machining gap, and the contact area between the workpiece and tool, mainly determine the amount of current flowing through the gap and the metal removal rate. The machining gap and the contact area are significantly affected by the process variables such as feed rate and depth of cut. The fundamental elements of the ECM system presents in Fig. 1.1.

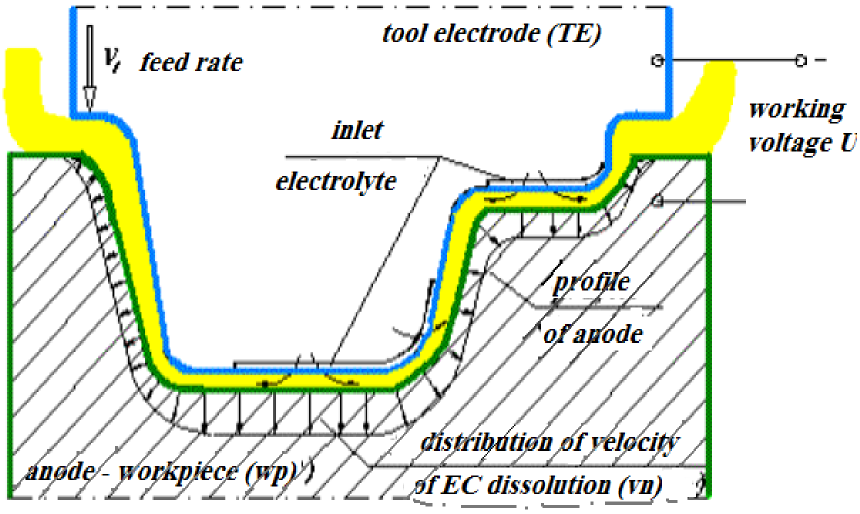


Fig. 1.1 Principal scheme of electrochemical machining (ECM) [2]

1.2.1 ECM Process Capabilities

The DC power supplies provide voltage control from 0-60 Volts. Standard amperage ratings are 300, 600, and 1000 A but higher amperages are available. For high accuracy in shape duplication and high rates of metal removal, the process is effected at very high current densities of the order 10 – 100 A/cm^2, at relative low voltage usually from 8 to 30 V, while maintaining a very narrow machining gap (of the order of 0.1 mm) by feeding the tool electrode in the direction of metal removal from the work surface, with feed rate from 0.1

to 20 mm/min. Dissolved material, gas, and heat are removed from the narrow machining gap by the flow of electrolyte pumped through the gap at a high velocity (5 – 50 m/s). The accuracy of ECM depends on shape and dimensions of tool electrode and approximately is from 0.05 mm to 0.3 mm at using continuous current, and from 0.02 mm to 0.05 mm at using pulse ECM. The surface roughness of machined surface is decreasing with increasing machining rate (for typical materials) and approximately is equal from Ra=0.1 μm to Ra= 2.5 μm

1.2.2 Advantages and Disadvantages of ECM

Electrochemical machining (ECM) has seen a resurgence of industrial interest in the last decade due to its various advantages, such as

- The components do not subjected to either thermal or mechanical stress,
- There is no tool wear during Electrochemical machining [3,4],
- Non-rigid and open work pieces can be machined easily as there is no contact between the tool and workpiece Complex geometrical shapes can be machined repeatedly and accurately surface can be obtained without surface treatment [5, 6, and 7],
- Complex geometrical shapes can be machined repeatedly and accurately,
- Electrochemical machining is a time saving process when compared with conventional machining,
- During drilling, deep holes can be made or several holes at once,
- ECM deburring can deburr difficult to access areas of parts.

However, like all new methods, ECM has its strengths and weak-nesses some of its disadvantages to the production engineer are

- Unfamiliarity with the techniques involved for example, circulation of

  corrosive liquids, filtration, effluent disposal, and large electric currents.

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

- Difficulty of controlling the process, which arises from the lake of knowledge of electrochemistry at high current densities and of the flow of fluids containing solid particles and gas bubbles.

- The problem of tool design for ECM needs to long lead times and high cost in developing the tooling for each specific application.

1.2.3 Applications for ECM process

The ECM process has received wide acceptance in the duplicating, drilling and sinking operations in the manufacture of dies, press and glass-making moulds, the manufacture of turbine and compressor blades for gas-turbine engine, the generation of passages, cavities, holes and slots in parts, deburring of gears, hydraulic and fuel-system parts, small electronic components, engine parts.

The most common uses for ECM include the following:

Duplicating, drilling and sinking operations in the manufacture of die press and glass-making moulds, the manufacture of turbine and compressor blades for gas-turbine engine, the generation of passages, cavities, holes and slots in parts as shown in Fig. 1.2 where E tool electrode, W is the workpiece, G is the ground, EL is the electrolyte tank and V is a vee block used to make tool fixation. Some examples of machined parts using ECM shaping operations are presented in Fig. 1.3 Electrochemical deburring of gears, hydraulic and fuel-system parts, small electronic components, engine parts, etc. Fig. 1.4. Parts after using electrochemical deburring, radiusing and smoothing are shown in Fig. 1.5. Electrochemical broaching as a method of making spines, gear sizing, reducing the wall thickness of shaped parts from high-temperature and titanium alloys, and preliminary generation of screw threads Fig. 1.6.

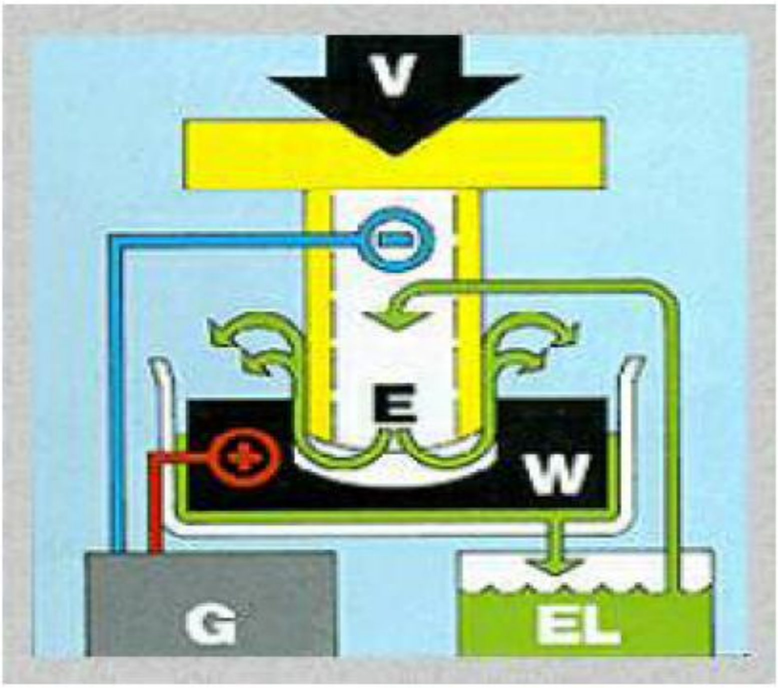


Fig. 1.2 Electrochemical sinking operation

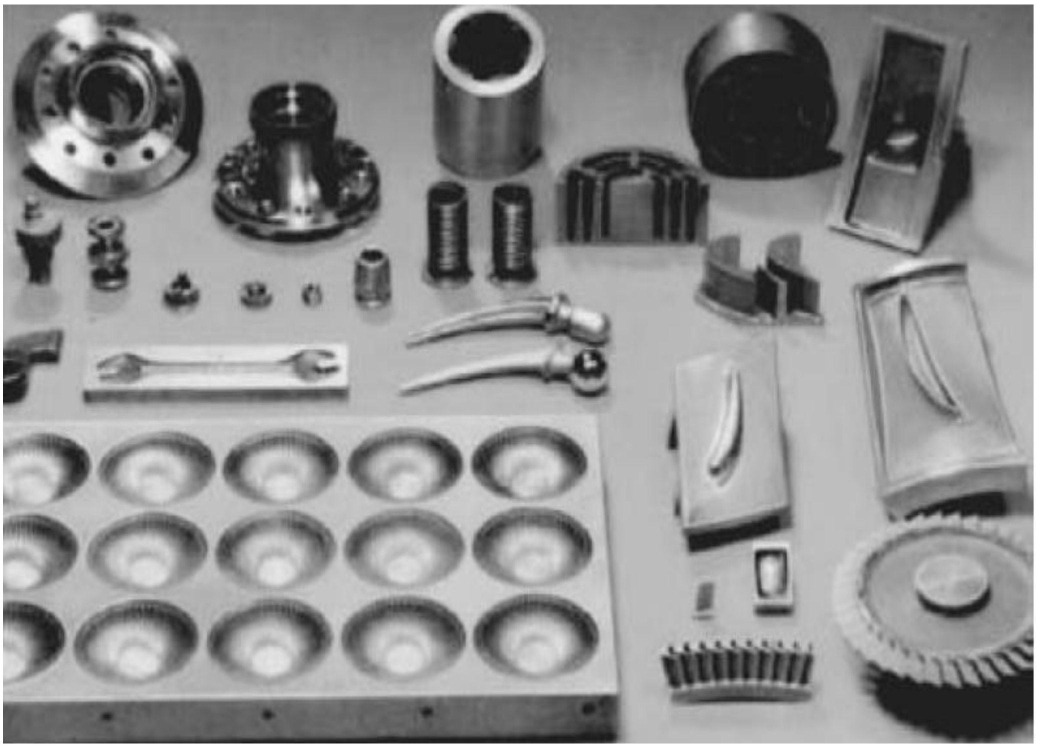


Fig. 1.3 ECM component

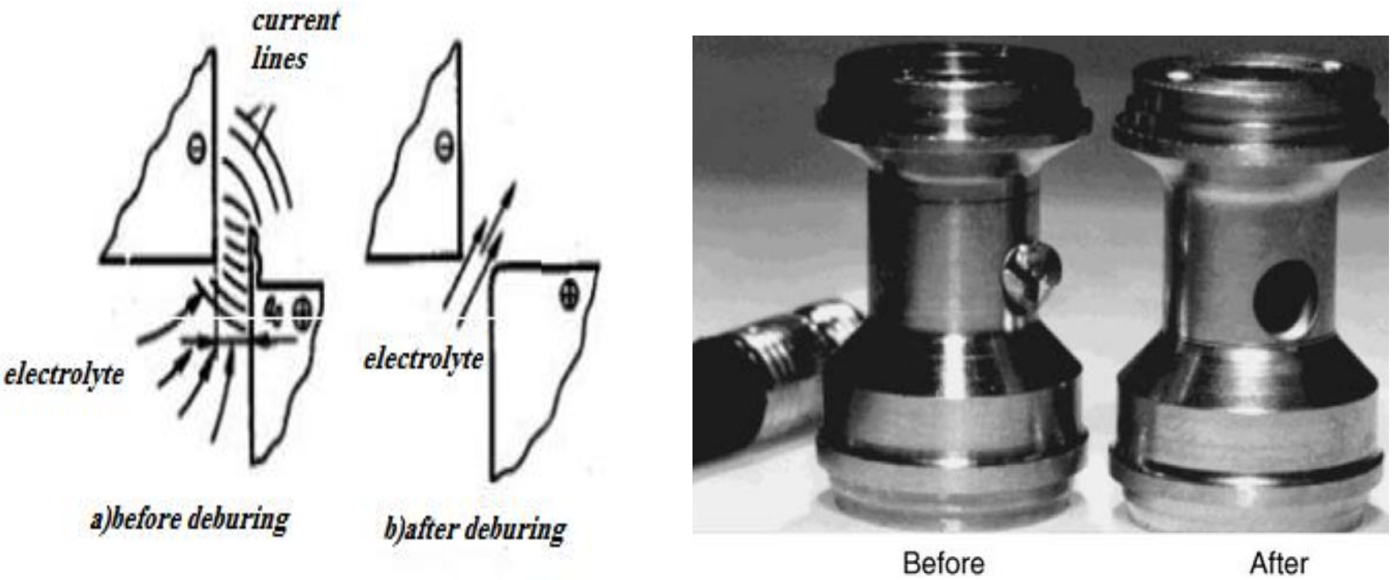


Fig. 1.4 Scheme of electrochemical deburring and radiusing

Fig. 1.5 Examples of machine parts after deburring

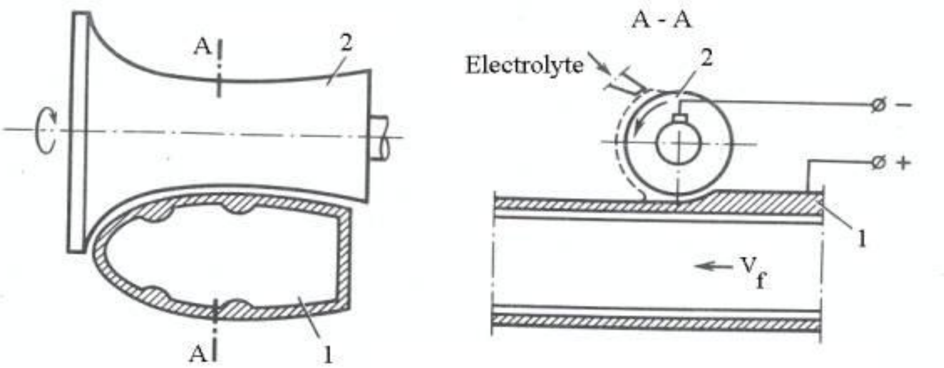


Fig. 1.6 ECM using rotating tool-electrode (Electrochemical Grinding ECG)

A number of compound methods have been developed in which ECM is ganged up with some other form of metal-working, for example, mechanical (as in abrasive ECM), erosion (electric discharge-electrochemical machining), ultrasonic, etc. Among other things, diamond EC grinding makes it possible to handle cemented-carbide plates, blade flanges and locks, outer and inner surfaces of parts made of magnetic alloys, and to grind cutting tools.

1.3 Material Removal Mechanism

For high accuracy in shape duplication and high rates of metal removal, the process is affected at very high current densities of the order 10 – 100 A/cm^2, at relative low voltage usually from 8 to 30 V, while maintaining a very narrow machining gap (of the order of 0.1 mm) by feeding the tool electrode in the direction of metal removal from the work surface, with feed rate from 0.1 to 20 mm/min. Dissolved material, gas, and heat are removed from the narrow machining gap by the flow of electrolyte pumped through the gap at a high velocity (5 – 50 m/s). J.C.Dasilvo et al.[8] have estimated the material removal rate of Electrochemical machining of SAE-XEV-F Valve-Steel. The value was 43.55mm^3/min under condition of (10V, 200/h, at T=12.39 min).

1.3.1 Effect of Applied Voltage

H. Hocheng et al.[9] have found from the experiments on the desktop CNC machine using 3/7 copper alloy as tool and the workpiece is SKD 61 stainless steel under the conditions of (voltage from 0 to 15 V, the flow rate 6 cm^3/s, time setting is 60, 120 and 240 s and The electrolyte is 2.5 and 5 M $NaNO_3$) that the volume of material removal increases with voltage across the electrode gap. Higher voltage brings more electrical current and stronger electrical field across the electrode gap, but the amount of the electrochemical erosion is larger. Also M.S. Hewidy [10] in his research of controlling the metal removal thickness in ECM process, the metal removal thickness along the side gap ΔY_{si} computed as a function of current density J_{si}, and time of machining Δt, and computes the metal removal thickness d_g as a function of feed rate f and distance along the electrolyte flow direction Δ*b,* where each tool element (Δ*b*) enters the interelectrode gap at different side gap lengths (Y_{si}), and each element causes different and specific metal removal thickness (Δ*dg*) of workpiece surface, under the condition of (*v* = 20 V, Δ*v* = 2.3 V, feed rate *f* = 20 mm/min and initial side gap (Y_{si}) = 0.5 mm) the effect of the applied voltage on the metal removal thickness. It has been observed that as the applied voltage increases, the final metal removal thickness also increases, this has been attributed to the increase of current density as the applied voltage increases. B.Bhattacharyya and J Munda [11] have studied the influence of various machining parameters on specimens were maskless copper plates of the size of 6 mm×4 mm×0.4 mm using micro-tools, made up of platinum wires of diameter of 250 μm were used for the experimentations. The side walls of the micro-tools were coated with silicon nitride (Si_3N_4) by chemical vapour decomposition (CVD) the experiment shows that, the MRR increases with the voltage at a particular machining parametric combination (25 g/l concentration, 50 Hz, and puls on time, 15 ms) with increase in voltage, current also increases based on Faraday's law.

1.3.2 Effect of Feed Rate and Applied Speed

M.S. Hewidy [10] studied the effect of feed rate on metal removal thickness, he found that as the feed rate increases the material removal thickness decreases, such as when using feed rate

(f) 10 mm/min, material removal thickness (d_g) is 0.6183 mm but at (f) 50 mm/min, (d_g) is 0.0246 mm at 12Volt, also studied the effect of machining strokes on (dg) at different feed rates and found that as the number of tool strokes increases, accumulated metal removal thickness increases, However, it has been submitted to emphasize the possibility that this technique can achieve the required metal removal thickness through the increase of tool strokes instead of the increase of the tool length, which sometimes leads to poor controllability of the ECM process. João Cirilo [8] has studied the influence of four parameters which changed during the experiments: feed rate, electrolyte, flow rate of the electrolyte and voltage, from his research he showed that, the material removal rate MRR increases with feed rate because the machining time decreases. For this condition, the voltage was 10V and the flow rate of the electrolyte was 200 h^{-1}. The electrolytic solutions, sodium chloride (NaCl) and sodium nitrate ($NaNO_3$), were used. The results show that feed rate was the main parameter affecting the material removal rate. The electrochemical machining with the electrolytic solution sodium nitrate presented the best results concerning roughness and over-cut. Also Adam Ruszaj et al.[12] found from their research that with electrode cross feed increase the time of machining decreases which is the reason of thickness of material excess removed decreases and metal removal rate increases.

1.3.3 Effect of Electrolyte and Flow Velocity

B.Bhattacharyya et al.[11] have studied the effect of electrolyte concentration on MRR at particular machining condition, their results showed a linear relationship at low concentration between electrolyte concentration and metal removal rate i.e. from 10 to 20 g/l, because in this zone increment rate of dissolution efficiency is almost constant. At higher concentration, the larger number of ions associated with the machining process increases current and thus results in higher MRR. The dissolution efficiency increases at lower rate at high electrolyte concentration zone than low electrolyte concentration zone, so the MRR increases at a low rate in the electrolyte concentration zone of 20–25 g/l than that of 10–20 g/l.

1.3.4 Effect of Gap

The effect of gap on metal removal rate was studied by many authors such as [9] the result of this investigation showed that the material removal rate increasing with decreasing the interelectrode gap and influence the eroded profile significantly. When the gap is set small, the reaction will be acute. If the gap is smaller than 0.1 mm, the undesired electric discharge will happen If the voltage is set too high, the electric arc causing electrochemical discharge machining is produced. To avoid the formation of the electric arc, the voltage is limited below 10 V and kept constant in the experiments.

1.3.5 Effect of Tool Electrode Design

Metal removal is effected by a suitably shaped tool electrode, and the parts thus produced have the specified shape, dimensions, and surface finish. ECM forming is carried out so that the shape of the tool electrode is transferred onto, or duplicated in, the workpiece. some works [13-14] showed from their Investigations in the field of electrochemical machining with ball ended electrode proved that this way of machining is very useful, especially in sculptured surfaces finishing. The main disadvantage of machining with ball ended electrode is small metal removal rate. Adam Ruszaj et al. [12] perform an investigation using ball end electrode and rectangle flat end electrode of flat electrode. They found that, with flat electrode it is possible to reach higher metal removal rate and smaller machined surface waviness than in the case of machining with ball-ended electrode. This statement is true for the electrodes with the same machining surface. Also Tipton [15] developed a very simple theory called the cos(ϑ)-theory which could yield satisfactory results for jobs with gentle profiles.

S. Bhattacharyya et al.[16] based their work on their research for determining the equilibrium job shape for the assumed trial tool the following assumptions are made:

(i) the electric field in the tool-job gap is purely ohmic ;

(ii) the material removal is due to electrochemical dissolution only;

(iii) the machining efficiency is 100%;

(iv) the process is quasi-steady, and

(v) the effects of anodic over potential, valancy variation and gas generation are small and can be neglected. also the size or the cross section of machining area of the tool electrode affects on the machining rate [17]. As the tool electrode becomes larger, the actual rising time of the double layer potential increases because cell impedance decreases. Therefore, there is a minimum pulse on-time to obtain an effective potential for the successful machining according to the tool electrode size.

1.4 Overcut Phenomenon:

Over-cut is the material removal in excess in the lateral of the hole. High values can affect accuracy of the workpiece. It is deriving from irregular anodic dissolution of material. In other word, it is the removal of metal caused by the flow of ions through the oxide insulating films by slow diffusion. Metal is removed that is not conforming to the shape or depth of the cathode tool. The phenomenon occurs beneath and on the sides of the tool during and immediately after machining. The overcut phenomenon is affected by almost all the parameters and variables involved in the ECM process, beginning with the power supply, the machining tool (type and profile) and the workpiece (material and shape) through the electrolyte (type and concentration) and ending with the feed rate, the voltage across the electrodes and the depth of the machining.

1.4.1 Effect of Applied Voltage and Feed Rate

Many investigators were aware of the facts that for a certain machine and a given setup and job, the dominant parameters are the feed rate and the voltage across the electrodes. Although not many of the investigators studied the problem of the overcut, yet, it is well known that the overcut is one of the main limitations of the high-potential process the peripheral profiled ECM. Most of the researches express in one way or another the importance of being able to predict, control or reduce this phenomenon.

It is mentioned many times, that in order to minimize the overcut dimentions, one should increase the feed rate and decreases the electric tension between the electrodes. B Bhattacharyya and J Munda [11,18] showed that overcut increases with the increase of machining voltage. With the increase of machining voltage, the localization effect of current flux flow decreases. Due to less localization effect, which actually increases the stray current flow in the micromachining zone in turn effects more material removal from the larger area of the workpiece, which causes increase in over cut. At higher voltage, i.e. more than 7 V overcut phenomenon is more predominant. Electrochemical reactions generate hydrogen gas at micro-tool. At higher machining voltage hydrogen gas bubbles break down resulting in the occurrence of micro-sparking. This micro-sparking causes uncontrolled material removal from the workpiece and results in larger overcut. Hence at higher machining voltage zone overcut increment rate is more. Mohansen et al. [19] estimated the overcut at different feed rates, they found that, the value of overcut is 0.98 mm at feed rate 5.33×10^{-3} mm and 1.56mm at feed rate 2.80×10^{-1} mm^{-1}. S. J. Ebeid, et al. [20] found that, overcut value increases non-linearly with increase in the applied voltage for every vibration amplitudes. This is because the increase in the voltage at particular vibration amplitude causes greater electrolyzing current to be available in the machining gap, as well as causing a greater stray current intensity, also they received that feed rate has a significant effect on overcut value at different vibration amplitudes. This is in agreement with the interactive effects of the process parameters and physicochemical phenomenal changes under such controlled operating conditions.

1.4.2 Effect of Electrolyte Characteristics

The effect of electrolyte characteristics on overcut was studied by Mohansen et al. [19] their investigation was applied for electrochemical drilling process for small and fine holes by controlled anodic dissolution invariably and observed that overcut is high in capillary drilling (CD), electro stream drilling (ESD) and jet electrolytic drilling JED as compared to shaped tube electrolytic machining (STEM) The reason for this is attributed to the electrolyte flow path length in these processes. As the machined area is closest to the direct path of the electrolyte and the lines of current distribution follows the path of flow and since CD has the longer electrolyte flow path, the process results in higher overcut. However, too low an overcut would not allow entry of the glass capillary. Overcut is also high in ESD compared to the particular electrode diameter being used. ESD and JED tend to produce holes with bell mouthed entry and exit ports because of the electrolyte flow pattern. J. C. Dasilva [8] focused his work to investigate the electrolyte variable such as NaCl and $NaNo_3$ on the material removal rate, overcut phenomena and surface roughness, he investigated that the electrochemical machining with NaCl presented greater over-cut than the electrochemical machining with $NaNO_3$. B. Bhattacharyya et al.[11] studied The effect of electrolyte concentration on overcut at particular machining parametric condition and found that, with the increase in electrolyte concentration, ions associated with the machining operation in the machining zone also increase. Dissolution of material in the stray current region increases with the increase of electrolyte concentration. Thus the material removal in the stray current region is considerably higher at higher zone of electrolyte concentration.

1.5 Surface Finish

The accuracy of ECM depends on the shape and dimensions of machining tool and approximately is from 0.05 mm to 0.3 mm at using continuous current, and from 0.02 mm to 0.05 mm at using pulse ECM; the surface roughness of machined surface decreases with increasing machining rate (for typical materials) and approximately is equal from Ra=0.1 μm to Ra= 2.5 μm; but the typical surface appearance is adull finish caused by oxide residue by products of the ECM process although this film is easily removed from the machined surface, special operations are rarely implemented to do.

1.5.1 Effect of Interelectrode Gap

H. Hocheng et al.[9] have investigated the effect of the interelectrode gap on the machined surface of the workpiece. They estimated the actual eroded depth caused by the equivalent line electrode at each time increment can be calculated by iteration. Continuing the iteration operation, the model describes the development of the surface of workpiece during the ECM process. From their experiment and their result they showed that when the gap is set small, the reaction will be acute. If the gap is smaller than 0.1 mm, the undesired electric discharge will happen. If the voltage is set too high, the electric arc causing electrochemical discharge machining is produced. To avoid the formation of the electric arc, the voltage is limited below 10 V and kept constant in the experiments based on the experiment.

1.5.2 Effect of Electrolyte

Electrolyte selection plays an important role in ECM. sodium chloride, for example, yields much less accurate components than sodium nitrate. The latter electrolyte has far better dimensional control owing to its current efficiency–current density characteristics. Using sodium nitrate electrolyte, the current efficiency is greatest at the highest current densities. In hole drilling these high current densities occur between the leading edge of the drilling tool and the workpiece. In the side gap there is no direct movement between the tool and workpiece surface, so the gap widens and the current densities are lower. The current efficiencies are consequently lower in the side gap. Thus the overcut in the side gap is reduced with this type of electrolyte. If another electrolyte such as sodium chloride solution was used instead, then the overcut could be much greater. Using sodium chloride solutions, its current efficiency remains steady at almost 100% for a wide range of current densities. Thus, even in the side gap, metal removal proceeds at a rate which is mainly determined by current density, in accordance with Faraday's law. A wider overcut then ensues. However, machined surface quality using electrolyte of very low concentration is poor because of the depletion of ions. Therefore, 0.1M H_2SO_4 solution was selected experimentally also they showed the reasons for the taper generation can be explained by the followings.

Firstly, because it is difficult for the electrolyte to flow into the deepst part of the hole, the metal cannot be easily dissolved.

Secondly, the bubbles in the machining gap due to boiling of the electrolyte raise the local electrolyte resistance. Then the electric current flows mainly to the side and outside of the tool whose resistance is relatively small and then, the entrance becomes large.

Thirdly, during the dissolution of stainless steel, the chromium oxide layer may be formed at a specific voltage range. This passive layer not only is the cause of the taper but also prevents further dissolution. Finally, the taper can be generated due to the difference in machining time between the entrance and the bottom of the hole shows the taper generation procedure according to machining depth. In the initial stage of drilling, overcut is generated at the entrance and the taper angle is the largest. As the tool feeds, the taper angle diminishes due to increased machining depth but the difference between the entrance and the bottom diameters does not diminish. After perforation, the taper is reduced rapidly because of the sudden increase in the exit diameter. The taper in a through hole is greatly reduced by several minutes of machining after perforation. S.J.Ebeid et al.[20] study highlights the development of mathematical models for correlating the interrelationships of various machining parameters such as applied voltage, feed rate, back pressure and vibration amplitude on overcut and conicity for achieving high controlled accuracy as:

1-The hydrogen gas bubbles and Joule heat generated in the inter-electrode gap cause a varying local electrolyte conductivity and hence non-uniform distribution of the gap

2- The stray removal in ECM adversely affects dimensional accuracy and surface quality of the machined component

3-The machining accuracy in ECM critically depends on the electrolyte flow field distribution. Some flow field disrupting phenomena such as cavitations and striations in the electrolyte sometimes result in abnormal dissolution and uneven sparking so to improve the machining accuracy this problem must be solved by:

1- Improving the electrolyte flow condition in the interlelectrode gap and also to reduce the occurrence of cavitations, high electrolyte pressures have been recommended in certain cases, the applied pressure was in the form of pulses in an endeavor to increase the turbulence in the electrolytic cell and hence help eradicate flow marks. Pressurized electrolytes purged with gas have also been submitted. The gases used were air, nitrogen, a mixture of the two gases and CO_2.

2- Improving of the ECM accuracy has been reported as a result of using complex tool feed motion, it has been termed as pulse cyclic ECM . The integration of an orbital movement of workpiece electrode to enhance the ECM accuracy was also adopted. They reported that orbital ECM distributes the electrolyte flow more uniformly and hence leads to a reduction in the flow field-disrupting phenomenon that adversely affects machining accuracy.

1.5.3 Effect of Applied Voltage and Feed Rate

S.J. Ebeid et al. [20] Investigate the influence of the applied voltage on the workpiece conicity under varying vibration amplitudes. it can be seen that the applied voltage has a little effect on the workpiece conicity that feed rate causes a linear decrease in the hole conicity at different vibration amplitudes. This result is based on the fact that the increase of the feed rate leads to the decrease of the frontal gap value which increases the MRR in the frontal zone and decreases the effect of the stray current which frequently decreases the conicity in the produced hole also they found from their study using low-frequency vibration to the ECM tool reduces workpiece conicity with a ratio of about 23% than that with the case of ECM without tool vibration this because low-frequency vibration for the tool in the ECM process has a significant effect on improving the conicity of the produced hole. This effect is due to the powerfulness of the pumping action at the frontal zone. This result is related to the intense flushing of the interelectrode gap with the fresh electrolyte and evacuation of the machining products. This leads to the decrease of the effect of the unnecessary machining at the wall side and accordingly improves the conicity of the hole.

1.6 Scope of This Work

The past research pertained to material removed mechanisms in ECM, overcut, surface finish, optimization and influence of ECM parameters have showed that dimensional control and bad surface finish are basic problem in ECM. But they did not study the mechanisms that give these parameters as electrical, mechanical and electrolyte systems so the present study will take into consideration these systems and show to control in it to give the required parameters that affect the electrochemical machining process.

There are numerous works [10,11,and 13] studied the effect of varying of different parameters such as voltage, feed rate, depth of cut, gap and tool size on the change of material removal thickness and material removal rates, these works had studied electrochemical drilling, polishing, sinking and honing but because the controlling in the gap size is very complicated and sensitive process and very cost process as in works [21and 22], so the present work fixed the initial gap to 0.5 mm and studied, the effect of other parameters; voltage, feed rate, rotational speed of workpiece and electrode size on material removal rate, hardness and surface roughness on electrochemical turning process, also the aims of the present work are understanding the electrochemical turning process and the factors that affecting turning process performance.

Chapter 2

Theoretical Background

Theoretical study of electrical and chemical aspects of electrochemical machining aspects to understand the influence of the working parameters on the result of ECM. The law of electrolysis, fundamental description of the ECM process, electrical and chemical metal removal rates discussed in this chapter.

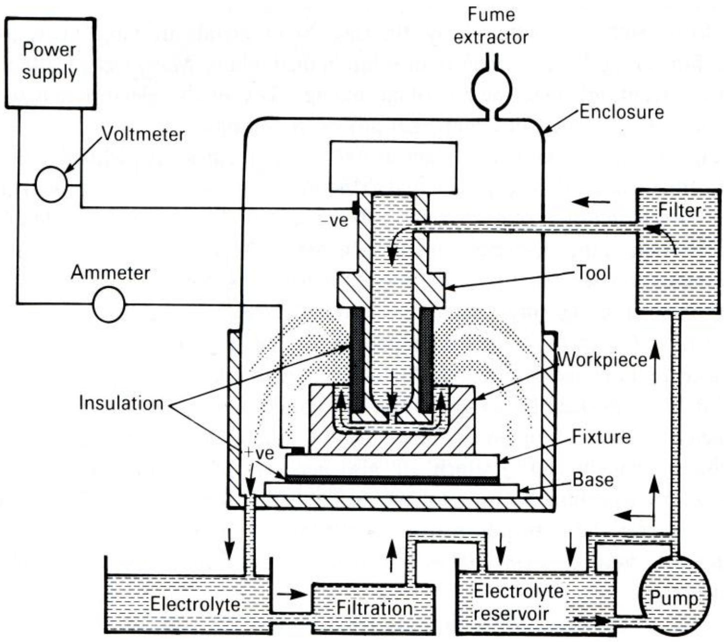
2.1 General Conceptions

Michael Faraday, early metallurgical researcher, from 1818 to 1824, anticipated the developments which have led to the widespread use today of alloy steels and conductive materials. The applications of these materials, their service as cutting tools in machining practice have been recognized from outset, and much effort has been expended to improve their performance. The aim has always been to yield higher rates of machining and to tackle harder metals, which are developed (on the principle that tool material must be harder than that of the workpiece which is to be machined), To that end, various heat-treatments and compositions of tool materials and formations of tools continued to be tried. Much progress has been made, but in recent years some alloys have been produced which are exceedingly difficult to machine. These have been prepared to meet a demand for very high-strength, heat resistant materials that, moreover, often have to take a complex shape. The evolution of suitable tooling has not kept pace with these advances, and accordingly, a search has had to be made for alternative methods of machining.

Electrochemical machining (ECM) has been developed initially to machine these conductive materials and alloys, although any metal can be so machined. Its basis is the phenomenon of electrolysis, whose laws established by Faraday in 1833, and which, with his electrical studies, were mainly responsible for diverting his attention from his work on metals. A typical electrochemical machining system is shown in Fig. 2.1 that has four major subsystems:

- The machine itself
- The power supply
- The electrolyte circulation system
- The control system

An actual example of a cathode tool and anode workpiece as shown in Fig. 2.2



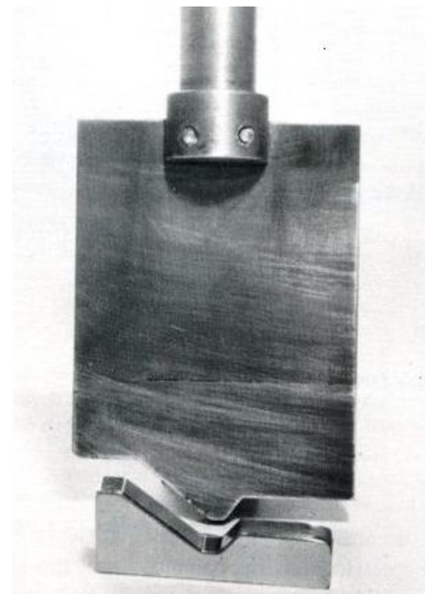


Fig. 2.1 Industrial electrochemical machine   Fig. 2.2 Example of cathode tool

2.2 Electrolysis

Electrolysis is the name given to the chemical process which occurs, for example, when an electric current is passes between two electrodes dipped into a liquid solution. A typical example is that of two copper wires connected to a source of direct current and immersed in a solution of copper sulfate in water as shown in Fig. 2.3. An ammeter, placed in the circuit, will register the flow of current. From this indication, the electric circuit can be determined to be complete. It is clear that copper sulfate solution obviously has the property that it can conduct electricity. Such a solution is termed as electrolyte. The wires called electrodes*,* the one with positive polarity being the anode and the one with negative polarity the cathode. The system of electrodes and electrolyte referred to as the electrolytic cell*,* while the chemical reactions which occur at the electrodes are called the anodic or cathodic reactions or processes. Electrolytes are different from metallic conductors of electricity in that the current is carried not by electrons but by atoms, or groups of atoms, which have either lost or gained electrons thus acquiring either positive or negative charges move atoms are called ions. Ions, which carry positive current move towards the cathode, and are called cations. Similarly, the negatively charged ions travel towards the anode are called onions.

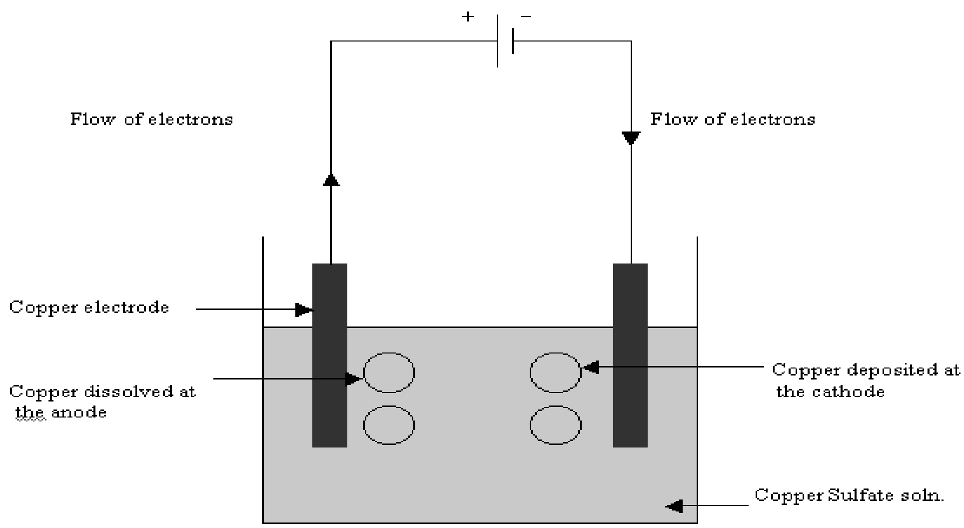


Fig. 2.3 Electrolysis of copper sulphate solution

the movement of ion is accompanied by the flow of electron in the opposite sense outside the cell, and both action are a consequence of applied potential difference (or voltage) from the electric source. A cation reaching the cathode is neutralized, or discharged, by the negative electrons on the cathode. Since the cation usually the positively charged atom of a metal (in above case, copper) the result of this reaction is the deposition of metal (copper) atoms. For copper, the reaction may be written

$$Cu^{++} \ +2e \ \text{----------} \ Cu$$

Where e is one electron. To maintain the cathodic reaction, electrons are required to pass round the external circuit. These obtained from the atoms of the metal anode, and these atoms thus become the positively charged cations, which pass into solution. In this case, the reaction is reverse of the cathodic . For the above example it is

$$Cu \ \text{----------------} \ Cu^{++} \ +2e$$

The electrolyte in its bulk must be electrically neutral; that is must be equal the numbers of opposite charges within solution, and thus there must be equal amounts of reactions at both electrodes.

Therefore, in the electrolysis of copper sulphate solution with copper electrodes, the overall cell reaction is simply the transfer of copper metal from anode to cathode. These results are embodied in Farady's two laws of electrolysis:

(1) The amount of any substance dissolved or deposited is directly proportional to the amount of electricity has flowed.

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

The two laws may be combined to give the equation

$$m = (CI / 96500\ n) \tag{2.3}$$

where m is the mass dissolved from, or deposited upon, the metal by a current (I) passed for time (S). the reacting ions have atomic weigh C and valiancy n, the quantity C/n being the chemical equivalent, 96500 is a universal constant known as Faraday's constant. It is the amount of electric charge necessary to liberate one gram- equivalent (C/n) of an ion in electrolysis.

A popular applications of electrolysis, are the electroplating and electroforming processes in which metal coatings deposited upon the surface of a cathode-workpiece. An example of anodic dissolution operation is electro-polishing. Here the workpiece, which is to be polished, is made the anode in an electrolytic cell. Irregularities on its surface are dissolved preferentially so that, on their removal, the surface becomes smooth and polished.

Electrochemical Machining (ECM) is similar to electro-polishing in that it also is an electrochemical anodic dissolution process in which a direct current with high density passes between a workpiece and a pre-shaped tool (the cathode). However, the rate of metal removal offered by the polishing process is considerably less than those needed in metal machining practice. To find how ECM meets these requirements and, moreover, how it is used to shape metals, study first another type of electrolysis, namely that arising from iron in aqueous sodium chlorides, several possible reactions can occur at the anode and cathode. Anodic is dissolution of iron, eg.

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

At the cathode, the reaction is likely to be generation of hydrogen gas and the hydroxyl ions:

$$2H_2O + 2e \rightarrow H_2 + 2OH^-$$

The outcome of these electrochemical reactions is that the iron ions combine with other ions to precipitate out as iron hydroxide $Fe(OH)_2$ as;

$$Fe + 2H_2O \text{------------------} Fe(OH)_2 + H_2$$

The ferrous hydroxide may react further with water and oxygen to form ferric hydroxide. With this metal-electrolyte combination, the electrolysis has involved the dissolution of iron from the anode, and the generation of hydrogen at the cathode, no other action-taking place at the electrodes as shown an Fig. 2.4.

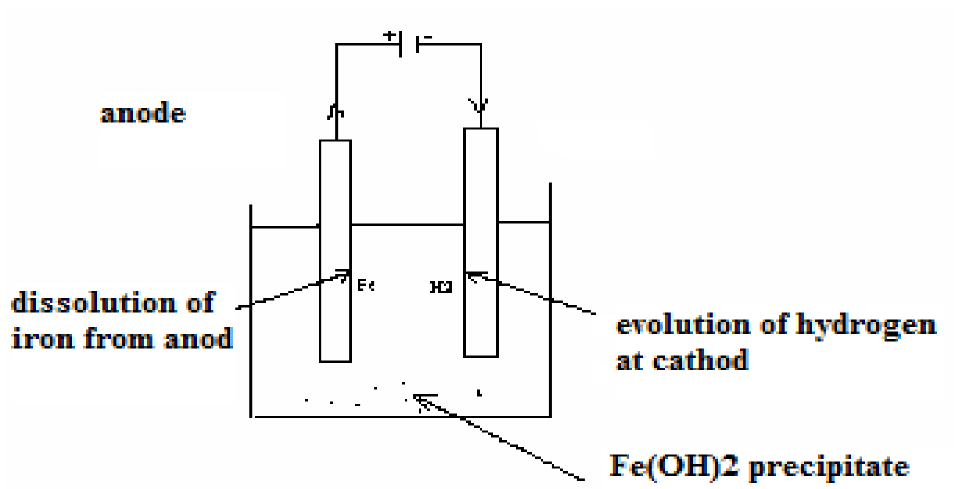


Fig. 2.4 Electrolyte dissolution of iron

Certain observations relevant to ECM can be made at stage:

(i) The rate of dissolutions (or machining) depends only upon the atomic weight C and valency n of ions produced, the current which passes, and the time S for which the current passes. The dissolution rate is not influenced by the hardness or other characteristics of the metal.

(ii) The shape of that electrode remains unaltered during the electrolysis, since only hydrogen gas is evolved at the cathode.

The material removal in the (ECM) process is based on a controlled anodic electrochemical dissolution process of the work piece (anode) with the tool (cathode) in an electrolytic cell, during an electrolysis process both of tool and work piece are conductors. A D.C power supplier insures the electric tension between the two electrodes. The anode is held at appositive potential relative to the cathode, which is practically grounded. A salt solution (usually consisting of $NaNO_{3,}$ $KNO_{3,}$ $NaNO_{2,}$ $KNO_{2,}$ and NaCL) is inserted into the gap between the two electrodes in order to create the working zone (sometimes called working gap) in which the electrolysis process takes place. A fundamental description of the ECM setup is shown in Fig. 2.5.

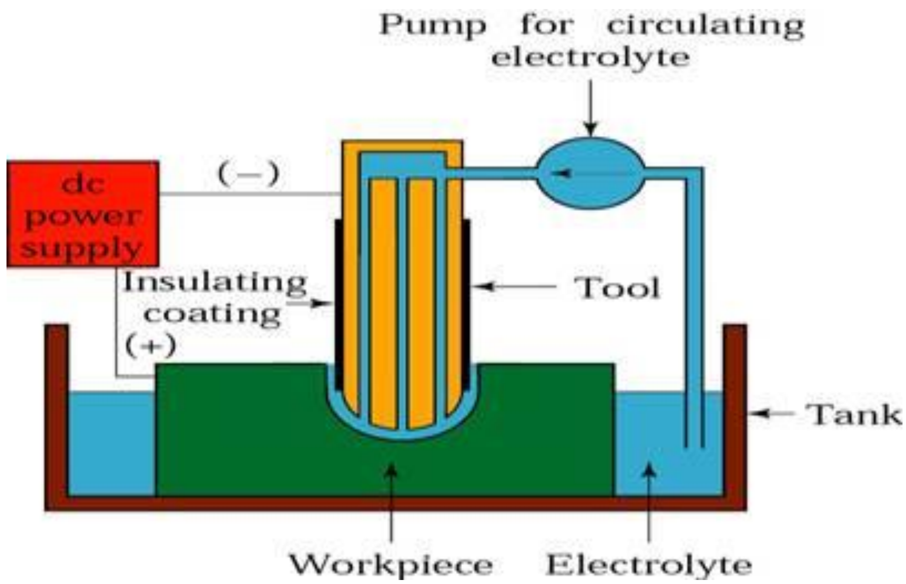


Fig. 2.5 Fundamental description of the ECM setup

The electrolysis process in which atoms move from the metallic workpiece into the solution is described for ferrous, as an example, by the following reactions.

Anode: $Fe \longrightarrow Fe^{++} + 2e^{-}$

Cathode: $2H_2O \longleftrightarrow 2H + 2(OH)$

$2H^{+} + 2e^{-} \longrightarrow H_2\uparrow$

Solution: $Fe^{++} + 2(OH)^{-} \longrightarrow Fe(OH)_2\downarrow$

And totally: $Fe + 2H_2O \longrightarrow H_2\uparrow + Fe(OH)\downarrow$

The electrolysis process, which is usually governed by Faraday's law of electrolysis, is disturbed by the hydrogen produced beside the cathode as well as by passive layer (sometimes called the anodic layer) which coats the anode. Both of these phenomena disturb the motion of the charged ions into and in the solution and finally stop the anodic dissolution.

The composition of the electrolyte being to change as soon as machining commences. The principal changes that can occur, and their effects, are listed as ;

(i) Loss of hydrogen, which may reduce the electrical conductivity of the electrolyte and increase its pH

(ii) Loss of water, either by evaporation or carried off by the hydrogen gas evolved, which may increase the concentration of the solution and thus may affect its electrical conductivity and its viscosity.

(iii) Formation of precipate, which may increase the effective viscosity of the electrolyte and interfere with the process in the workpiece/tool gap.

(iv) Absorption of salt by the precipitate, which will reduce the concentration of the solution and may affect its electrical conductivity.

(v) Metal ions from the anode may pass into the solution and may be deposited on the cathode.

These changes mean that the electrolyte has a finite working life and, in practice, the life may be limited due to the following reasons.

(1) The need to maintain a reasonably constant electrical conductivity so as facilitate control of the process and ensure accuracy of machining.

(2) The need to prevent plating-out on the tool so as to ensure accuracy of machining;

(3) The need to avoid excessive quantities of precipitate. The first of these considerations apply to all electrolytes, the second mainly to acidic electrolytes and the third mainly to neutral electrolytes.

2.3 Metal Removal Rate by Electrochemical Machining

From Faraday's law, the material removal rate (MRR, Q_V) defined as material amount removed per unit time: Q_V =dm/dt, therefore, material removal rate is,

$$Q_V = K_V I \qquad (2.2)$$

material removal rate in ECM depends on electrochemical properties of workpiece material (K_V) and proportional to total current. A non-uniform distribution of material removal rate on machining surface results in changes of workpiece shape. In ECM this rate is equal to velocity of anodic dissolution V_n, which is normal to surface anode. For example shaping process is shown in Fig.2.6.

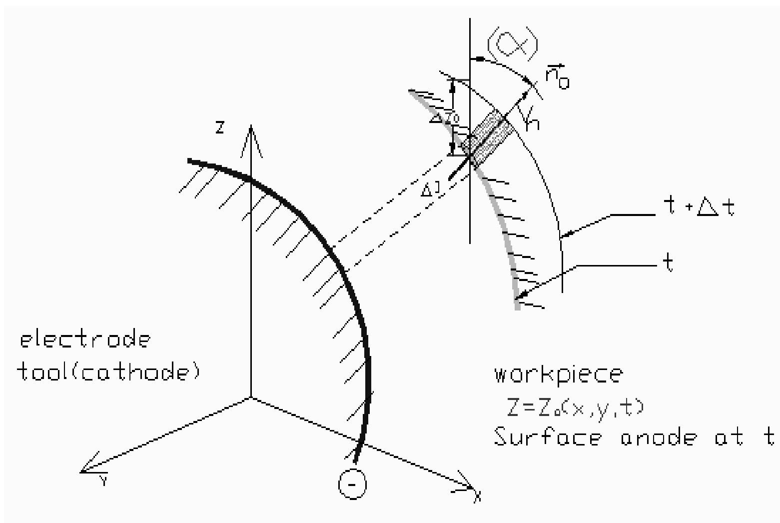


Fig. 2.6 Scheme of electrochemical shaping process

Current efficiency of anodic dissolution is defined as The ratio of current ΔI_{+}, which is responsible for metal dissolution to total current ΔI

$$\eta \stackrel{def}{=} \frac{\Delta I_{+}}{\Delta I} \qquad (2.3)$$

Current efficiency η depends greatly on the material of the workpiece, type of electrolyte as well as machining conditions, mainly on the current density, the temperature and the flow rate of electrolyte. For an efficiency of 100%, the total current carried by ions of dissolved metal. For zero efficiency, the current passes without metal dissolution.

In many of references, the current efficiency has defined as the ratio of the observed mass change to the theoretical one predicted from Faraday's laws, with assumption of 100% current efficiency of the anodic dissolution process. When material removal is purely by electrochemical processes, there is no mechanical material removal such as hydrodynamic erosion, electric erosion or micro cutting by abrasive, material removal rate can be obtained from first law of Faraday.

According to first laws of Faraday, the mass of metal removed Δm i.e. mass of metal ions) corresponding to current ΔI_+ during time $\Delta\tau$ (i.e. to electric charge $\Delta I_+\Delta\tau$) is given by:

$$\Delta m = k\Delta I_+ \Delta t \tag{2.4}$$

where k is the electrochemical equivalent of the workpiece material, which is equals mass of ions carrying unit electric charge of 1 coulomb. On the basis of Faraday's second Law, the electrochemical equivalent for reaction:

is given by

$$k = \frac{A}{zF} \tag{2.5}$$

where: *A* is atomic weight of the metal *M*, and *F* is Faraday's constant (96500 C). Combination of atomic weight of reacting ions and valency *z*, expressed by the quantity *A/z* being the chemical equivalent.

The material removal thickness can be calculated from the following equation:

$$\Delta h = \eta \frac{k}{\rho_m} \frac{\Delta I}{\Delta A} \Delta t \tag{2.6}$$

Where ρ_μ : is density of material of the workpiece , ΔA is the surface area

2.3.1 Current Distribution

The electrical field and mass transport between both electrodes determine the current density distribution. The current, which flows through the electrolyte, is due to the motion of charged particles-ions. Mass transfer in electrochemical systems, which determines current, is thoroughly treated in many texts and monographs. The goal of this section is to treat the determination of current density from the point of view of practice ECM and its conditions. Mass transfer in an electrolyte solution requires a description of the movement of mobile ionic species, material balances, current flow, electro neutrality, and fluid mechanics, also the velocity of dissolution is affected by the current distribution as

$$V_n = \eta \frac{k}{\rho_m} i_a \tag{2.7}$$

or

$$V_a = K_v i_a \qquad (2.8)$$

where: $i_a = \lim_{\Delta A \to 0} \frac{\Delta I}{\Delta A}$ is the current density on the anode

The term $K_v = \eta k/\rho$ is known as the coefficient of electrochemical machinability, and is equal to the volume of material dissolved from the anode per unit electrical charge and this value can only be determined experimentally, by various methods.

2.4 Tool-Electrode Design

Dealing with ECM in an unsteady state when the part configuration varies with time and tends to some form asymptotically as can be observed by using computer simulation software. For example, Fig. 2.7 shows asymptotical shape of workpiece i.e. in steady state ECM with using the circular tool electrode.

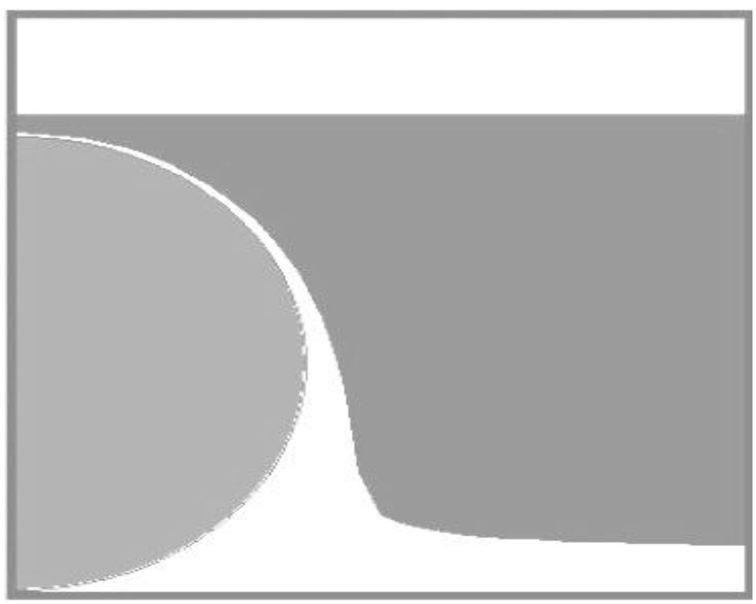


Fig. 2.7. Profile of workpiece in steady state

ECM using [circular tool electrode]

Once the gap geometry is stabilized, ECM is said to have achieved a steady state – part configuration is no longer changing for all practical purpose because the work material at all points on the workpiece surface (A_1, A_2- A_3, A_4) is moving along feed tool direction at the same velocity equal to tool feed rate V_f) see Fig. 2.8.

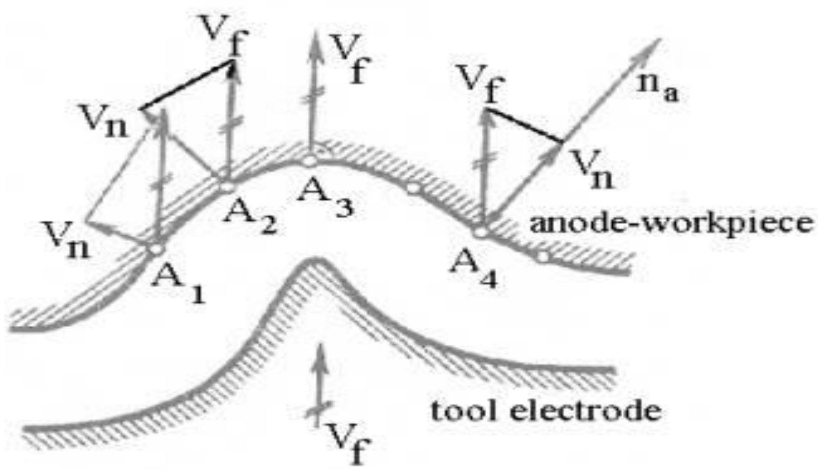


Fig. 2.8 Distribution of dissolution velocity in steady state ECM process [2]

Now the metal-removal rate (velocity of dissolution) V_n and the current density i_a on the workpiece are given by

$$V_n = V_f \cos\alpha \tag{2.9}$$

$$i_a = \frac{V_f}{K_v} \cos\alpha \tag{2.10}$$

Where α is angle between normal to anode n_a and feed tool direction (V_f). The equations (2.9) and (2.10) describe conditions of steady state ECM and are used for determination of anode-profile given the shape of tool electrode or shape of tool electrode at tool design, when is required given shape of workpiece.

2.5 Control Systems of ECM Machines

Control of the ECM process refers to a predetermined adjustment of the process parameters in order to obtain the desired machining accuracy, machining rate, surface finish, and other performance indices.

A distinction of control in the case of ECM is the fact that the controlled plant, that is, the proper machine, its power unit, electrolyte supply and purification facilities, and so on, is exposed to a wide range of disturbance factors. In practice, they reduce gap control, electrolyte flow control, and process parameters control, above all temperature. Generally, the control system of an ECM machine includes a subsystem that controls the machine and electrolyte supply, the position of the tool electrode, and the gap width.

The machine control subsystem starts and stops the various units and subassemblies of the machine. The electrolyte control subsystem provides for

the maintenance of the electrolyte at entry to the gap within a specified range. This could be done by varying the flow rate of electrolyte through the heat exchanger, but the time constant of this form of control would be too large. The time constant is kept to a low value through the use of thermocouples and resistance thermometers as temperature sensors.

The gap control system has as its objective to control the ECM process by directly adjusting the tool feed drive. The gap width can be controlled continuously or in steps to a predetermined program.

The gap maintenance system is based on the principle of self - regulation. It provides for precise stabilization of tool travel rate and basic process parameters.

In some ECM units utilizing the principle of self-regulation, a provision is made for periodic gap correction. Basically, such a system operates as follows: the machining cycle is interrupted, the actual gap is measured, and its width is restored to its initial value. The gap is restored by causing the tool to touch the work and to recede from it while the machining current is turned off. The amount by which the tool electrode should recede from the work in order to re-establish the specified gap may be a function of time or distance. The duration of the machining cycle between 'touch-and-go' steps depends on how accurately the gap is maintained. With this arrangement, the gap can be monitored and restored while ECM is in progress.

The ECM of large-size parts may use a fixed tool electrode, in which case the gap should be restored by discontinuing the operation and restoring the gap at regular intervals. In some operations, use may be made of systems which maintain the gap as a function of current or voltage. They are especially good in machining parts whose surface area remains unchanged, as well as the current density. The signal picked off a current sensor is compared with a reference signal, and the difference is applied as an error or control signal to a D.C. amplifier. The amplified signal then goes to a power amplifier built around. a thyratron whose anode circuit contains the armature winding of a D.C. motor. The motor is connected in the circuit so that the error signal, if there is any, causes the tool electrode to move towards the work or to come to stop. When ECM uses a complex –shaped tool electrode, the distance traveled by electrolyte does not remain unchanged as the operation progresses. For the same reason, the back pressure in the gap will not remain the same at all times. As a result, the ECM process may be de-stabilized, and the gap may be either increased or decreased so that a short-circuit occurs. In these circumstances, the ECM process can be stabilized by automatic control of equilibrium at the gap through the compensation of back pressure.

2.6 Safety in ECM and Waste Disposal

As both studies and experience have shown, the ECM of metals is associated with the following risk factors:

1. Chemical attack by electrolytes.
2. The risk of an electric shock.
3. The danger of a burn in the case of a short circuit between the positive and negative leads. .
4. The danger of a fire damp explosion.
5. The effect of the electromagnetic field.

The gases and aerosols produced in the course of ECM, when inhaled, may cause severe injury to the internal organs. They may also produce an overall poisoning and local irritations. To avoid this, measures should be taken to protect operatives against unhealthy exposures, as recommended in applicable Codes of Practice for Industrial Locations. More specifically, ECM machines must be installed in a separate, isolated room. Hydrogen analyzers should be installed at strategic points in the ECM department so that a timely warning could be given that the hydrogen concentration has risen too high and there is a risk of a fire-damp explosion. Regular checks should be run on the gas analyzers, ventilation, air ducts, and interlocks. At least five air changes per hour should be maintained in the ECM department. Foul air should be withdrawn right from the sources of objectionable emissions. About 98 % of the air removed by local and general ventilation should be replenished by mechanical dilution. To avoid explosions, the exhaust ventilation system should be built explosion proof and interlocked with the startup of the ECM machines. All pieces of ECM equipment should be reliably grounded. The power units should include an overload protection feature, which will interrupt the machining circuit in the case of an overload. Interlocks should also be built into machines so that power and electrolyte supply could be discontinued automatically in an emergency. For protection of attending personnel against the effects of the magnetic field, the current leads should be enclosed in metal shields or resorts should be made to use coaxial cable instead of solid buses.

As a further precaution against fire damp explosions, the various pieces of ECM equipment should be started in the following sequence: the fan for removal of hydrogen from the ECM chamber; the pump-supplying electrolyte to the gap; the power unit; the tool feed drive. As a precaution against an electric shock, the operator of an ECM machine should work standing on a wooden grate covered with a dielectric rubber material.

Chapter 3

Experimental Procedures and Design

The objective of the current work is to study the effect of turning parameters on the performance of ECM turning. The major aim is to control the ECT process parameters to achieve smooth, better surface finish. The description of ECM, measuring instrument and the plan of the experiments discussed in detail in this chapter.

3.1 Description of ECM Design

In the present investigation, An ECM machine was designed and manufactured as shown in Fig. 3.1(a) and 3.1(b), since there is no ECM machine found so it is a tray to make small model to simulate the ECM machine to carry out the experimental work. Using 600A D.C. Power source. A (one) hp motor was utilized to drive the main spindle, The speed of spindle can be controlled by 3 phase inverter, Fig 3.2 shows a block diagram of the main components used in the ECT machine.

The machine consists of the following main parts :

1- Direct current power supply.

2- The control system.

3- The electrolyte circulation system.

4- Mechanical operation – spindle elevation, cross feed positioning, manual table movement and preparation for electrochemical machining.

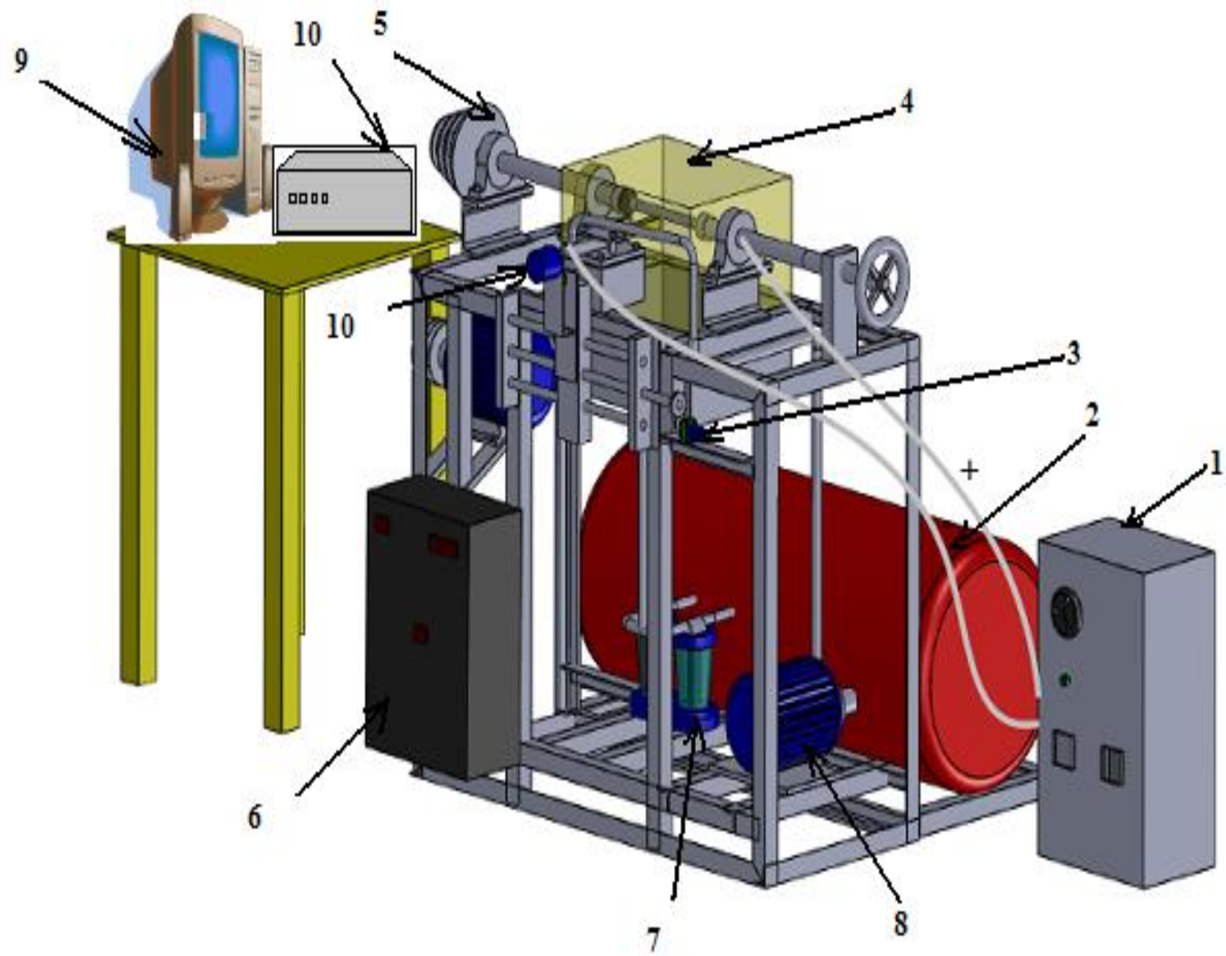


Fig. 3.1(a) Schematic illustration of the ECM machine

1- DC power supply, 2- Electrolyte tank ($NaNO_2$), 3- DC motor, 4- Machining cell, 5- Stepper motor controller(Interface Card), 6- Control circuit of DC motor and power of main motor and electrolyte tank, 7- Two filter, 8- Electrolyte pump, 9- Computer, 10- stepper motor

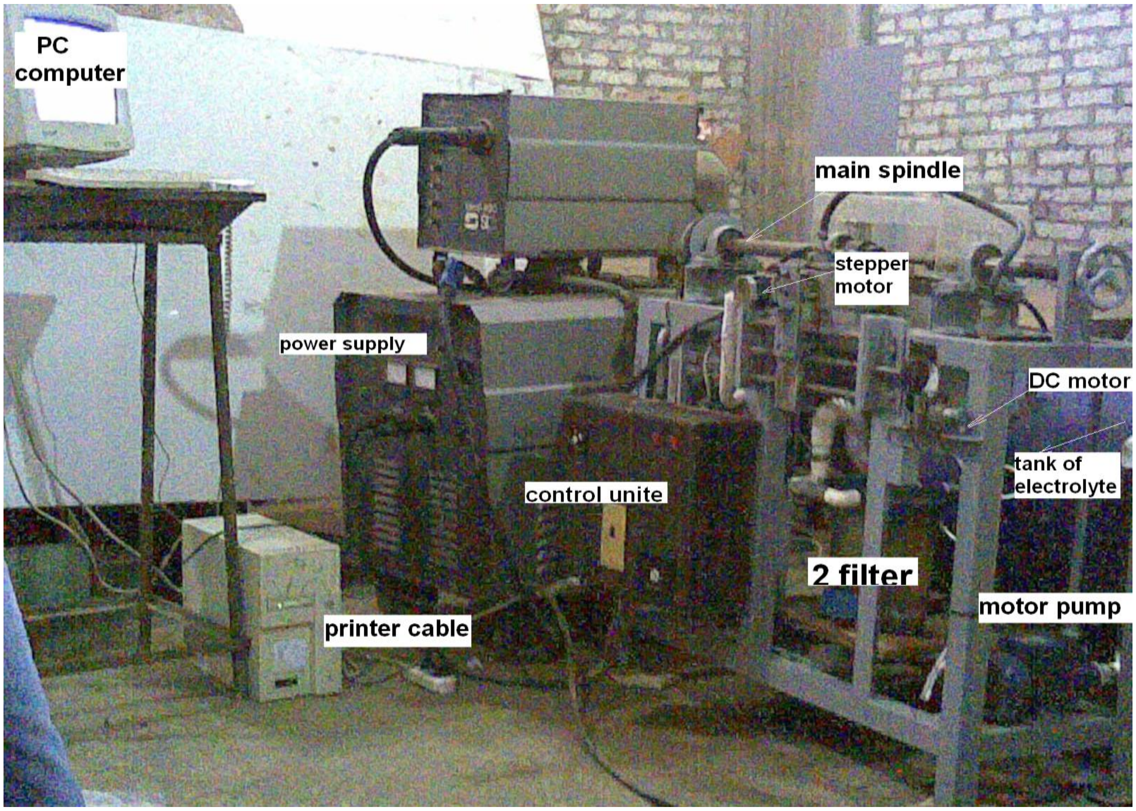


Fig. 3.1(b) Photograph of Electrochemical machining

3.1.1 Power Supply

The power supply for an electrochemical machine is usually the most ex-pensive single item of the instillation and may account for a substantial part of the total cost of the complete machine.

As electrochemical machines require a low- voltage D.C. supply and as the main supply available is usually high-voltage a.c. a step down transformer, rectifier and the machine itself against overload and short-circuit conditions. These conditions can occur accidentally for various reasons, such as mishandling or bad fitting of electrodes or work pieces, accumulation of conducting debris in the working gap or malfunction of the gap-control system. It will also be necessary to provide suitable current- and voltage-measuring devices and in certain cases ampere-hour meters and recorders might be justified.

On large installations it is desirable to site the power supply as close as possible to the machine in order to reduce the cost and power consumption of the interconnecting busbars, the range of voltage required will be 0-35 V, and the current rating can range from as little as few tens of amperes to 10000 A or more power supply of (0 to 60 V) and 0 to 600A was used in the machine.

3.1.2 Control System

It is very difficult process to control the (ECT) turning process, There is various system components to control the electrochemical turning process as DC motor controller to control the linear motion of the carriage carrying the tool, stepper motor to control the gap between tool and workpiece, electrolyte supplies by a pump and the main motor provides the rotational speed of the workpiece, these systems are clearly shown in the schematic drawing below Fig. 3.2.

3.1.2.1 DC Motor Control Circuit

DC motor controls the carriage motion and the circuit of the DC respecting to the feed rate range which is between 0.05 : 1 mm/rev ,the gear box reduction ratio, the main pair gears of DC motor Z_1=60, Z_2=40 and carriage power screw so, the power screw should be fed by ½ revolution per second. This motor operates at 12 Volt, 10 Amper and moves 5.3 kg, which is the total weight of the carriage system. The motor can operate at minimum torque when rotates at 150 rpm. After the gear box. The direction of the carriage or the tool electrode direction can be also controlled by reversing the polarity of potentiometer, the schematic representation and block diagram are shown in Fig. 3.3 and Fig. 3.4 represent the DC control circuit. Also table 3.1 illustrates the main components of DC control circuit.

3.1.2.2 Stepper Motor Control Circuit

A stepper motor is a brushless, synchronous electric motor that converts digital pulses into mechanical shaft rotation. Every revolution of the stepper motor is divided into a discrete number of steps, in many cases 200 steps, and the motor must be sent a separate pulse for each step. The stepper motor can only take one step at a time and each step is the same size. Since each pulse causes the motor to rotate a precise angle, typically 1.8°, the motor's position can be controlled without any feedback mechanism. As the digital pulses increase in frequency, the step movement changes into continuous rotation, with the speed of rotation directly proportional to the frequency of the pulses. Step motors have used every day in both industrial and commercial applications because of their low cost, high reliability, high torque at low speeds and simple, rugged construction that operates in almost any environment. The specification of the stepper motor is shown in table 3.2.

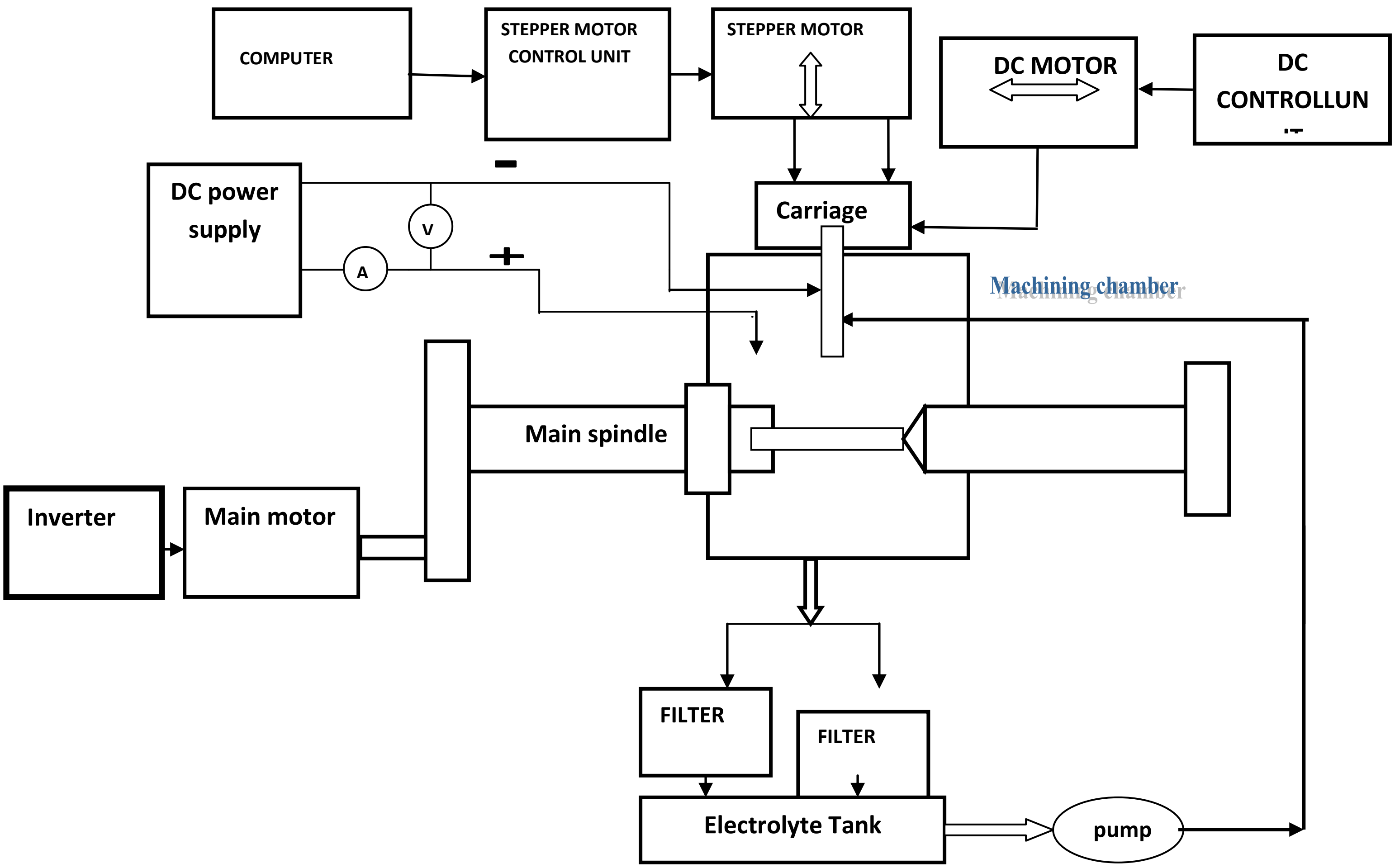


Fig. 3.2 Block diagram of the various systems of the ECT process

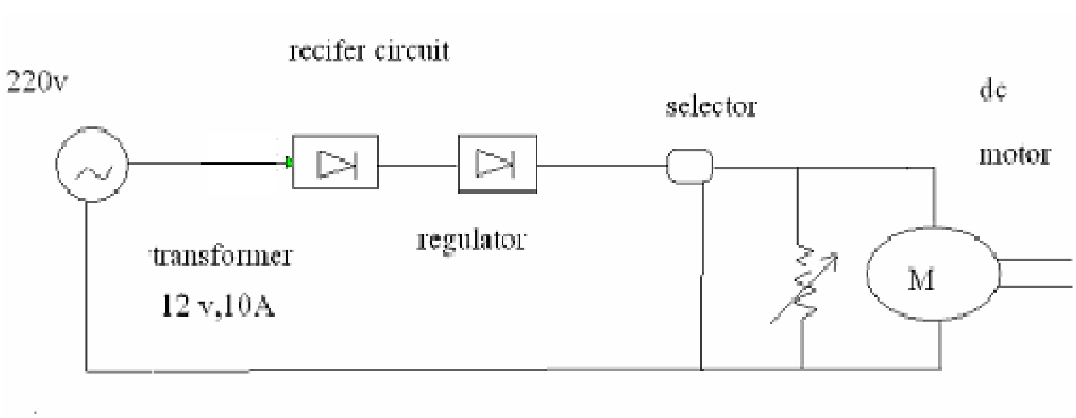


Fig. 3.3 schematic representation of DC motor circuit

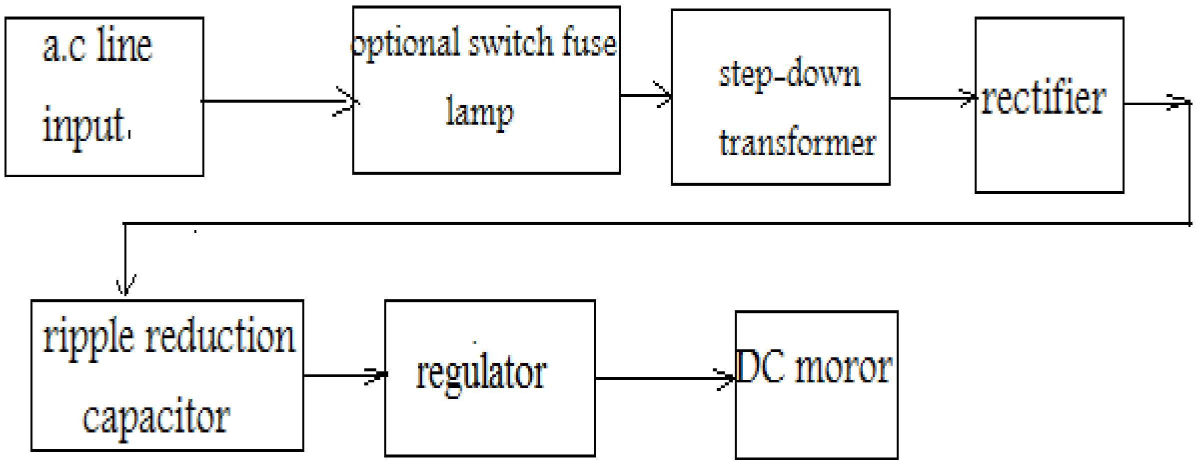


Fig. 3.4 Block diagram represents DC motor circuit

Fig. 3.5 The body of electrochemical turning machine

Table.3.1: Specifications of the DC circuit

Element	**specification**
Dc motor	12 Volt, 10 Ampere,150 rpm, 30rpm
Transformer	12Volt, 10 Ampere converts AC current to DC or to isolate the power supply from the a.c line input
Rectifier circuit	Consists of regulator with fans to cool it, 3 diode and capacitor connected to the transformer to generate d.c voltage with little a.c ripple
Potentiometer	Used to control the speed of the DC motor
Selector switch	Used to change the direction set of DC motor

Table 3.2: Specifications of stepper motor

Stepper motor steps	48steps/rotation
Connection	4 connections
Resistance	Approx. 15Ohm per winding
Operating voltage	Approx.10V/0.65 A
dimensions without axis	Approx 66x37mm

The stepper motor controller by Interface card connected with computer. The Interface card works as a translator between the computer and the stepper motor as it takes a signal from the motor and translates it to rotate the motor. Computer is connected with the interface card by parallel port, the interface card element consists of four pins and has already the programming software [KEMO stepper software M106] with a higher frequency over 50 HZ only enters the number of steps to move the electrode with depth of cut then the motor rotates to reach the required gap and when the current coming from DC power supply decreases this mean that the gap increases, so inter a number of steps to substitute the decresing in the DC current of power supply. The photograph in Fig. 3.5 shows the stepper motor fixation, Fig. 3.6 shows the electrical circuit of stepper motor and how the stepper motor controls and how this motor works, also Fig. 3.8 shows the stepper motor software, and Fig. 3.9 shows the block diagram of the stepper motor control circut.

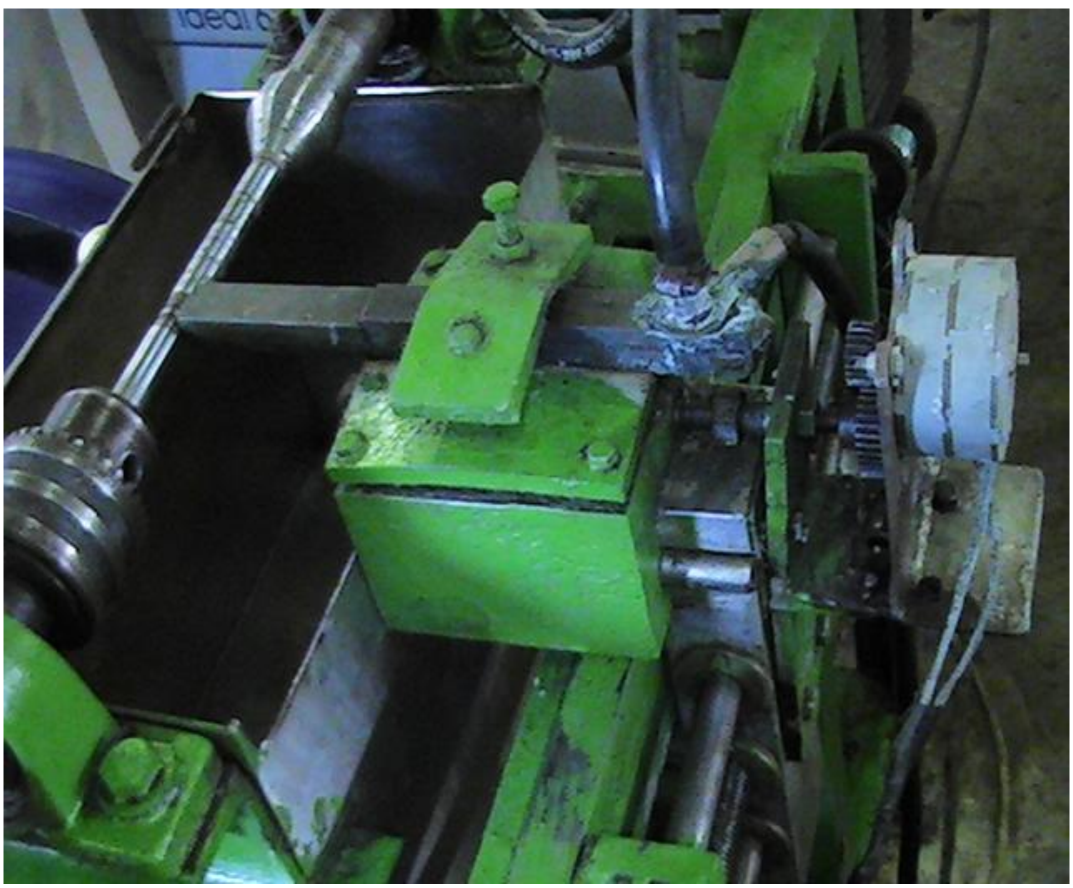


Fig. 3.6 Photograph of stepper motor

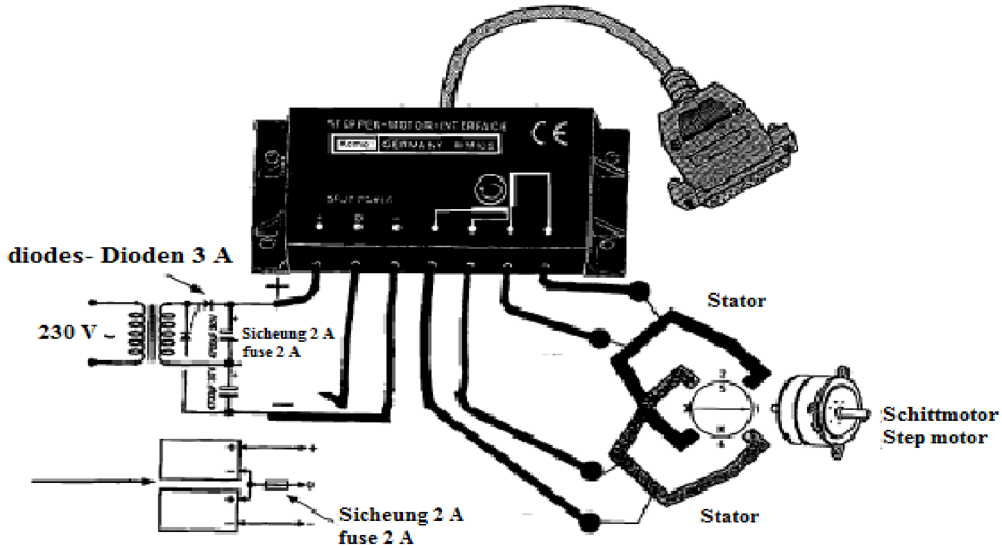


Fig. 3.7 Stepper motor connection with interface card

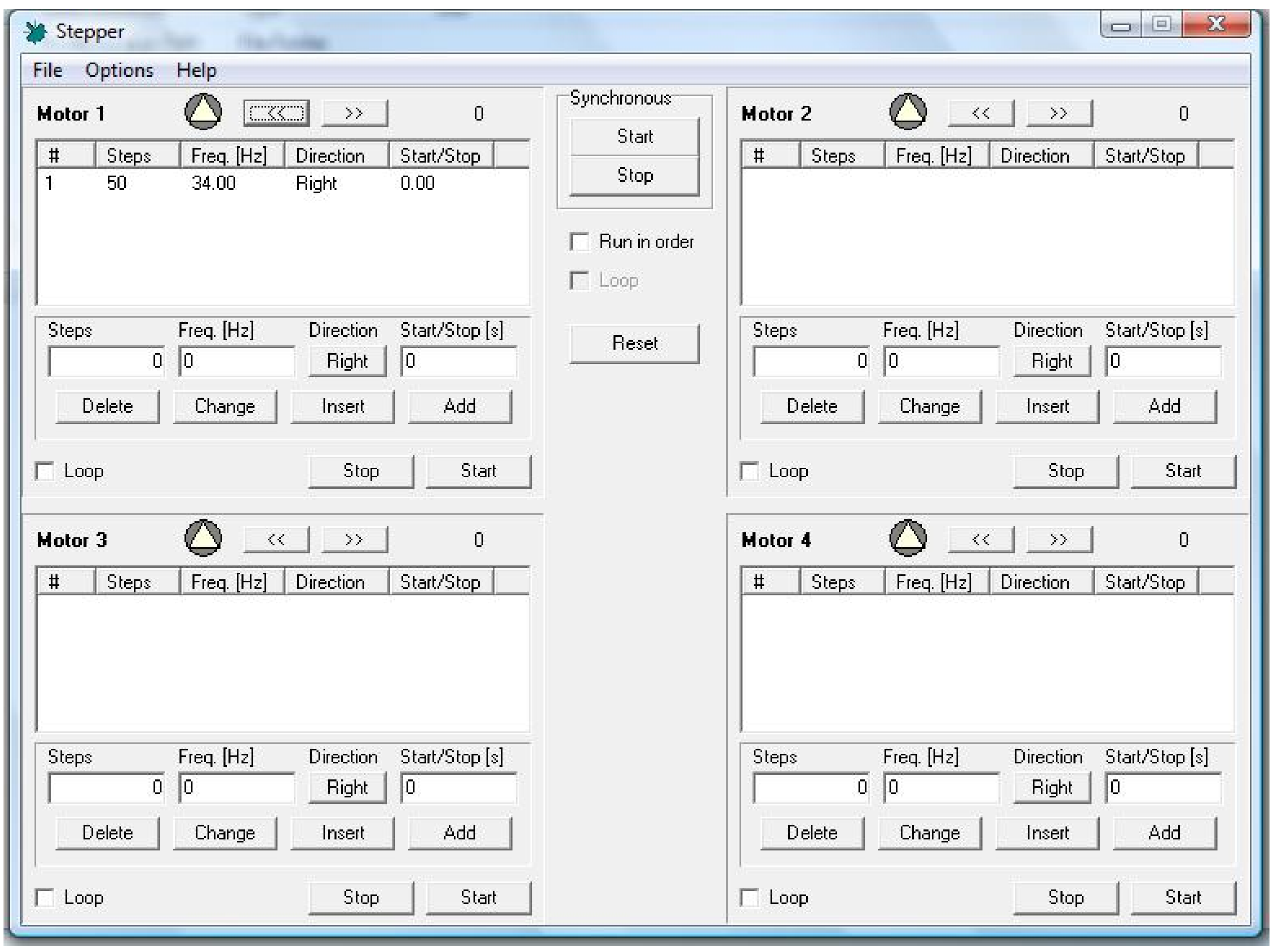


Fig. 3.8 Stepper motor software

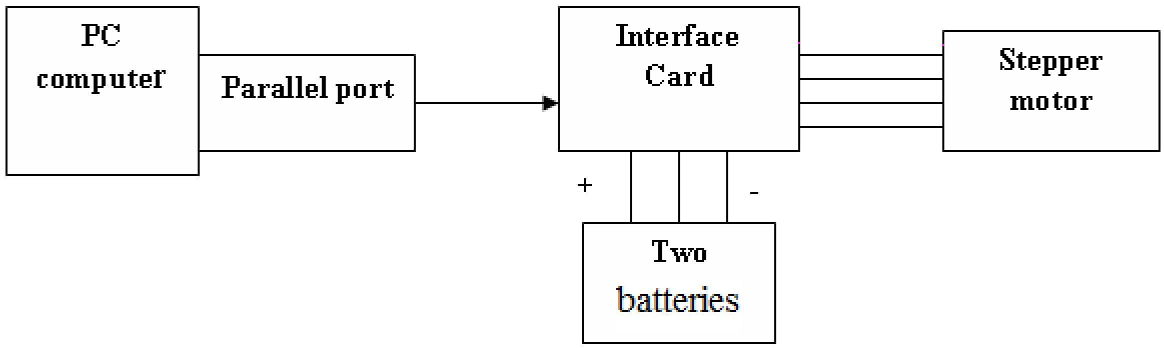


Fig. 3.9 Schematic representation of stepper motor circuit

3.1.2.3 Electrical Circuit of the Main Motor

The motor which provides the machine spindle with the power in form of torque and speed; this power is transmitted to the spindle by V-belt, which has good acceptable power transmission ratio, and easy to change the number of revolutions of the main spindle by two aluminum pulleys, these speeds are fed to the main spindle which carries the machine chuck, this chuck enables the machine to hold the workpiece these speeds are fed to the main spindle which carry the machine. the rotational motion of the spindle is controlled with the main motor (220-380V, 1400 rpm, and 1HP). The experimental work based on changing the spindle speed, The spindle speed can be changed by changing the the groove of aluminum pulley, since this pulley has three grooves with different diameters but gives only three speeds so to increase the number of speed the inverter is used to increase the number of speeds. Tachometer instrument is used to measure the speed by calibrated the inverter frequency with rotational speed of the spindle shaft this is clearly shown in block diagram Fig. 3.10.

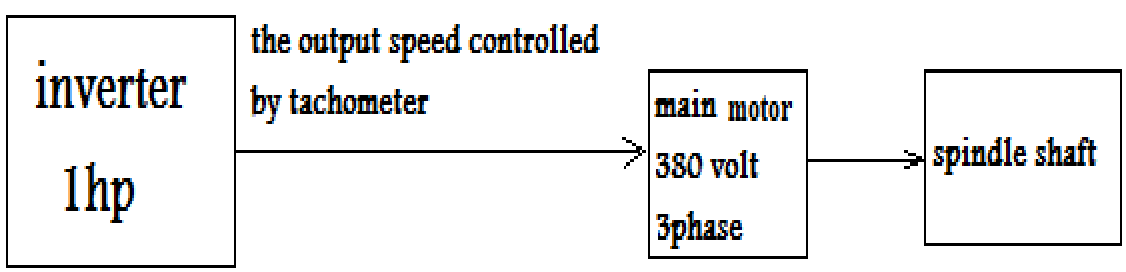


Fig. 3.10 Block diagram represents the circuit of spindle motor

3.1.3 Electrolyte Circulation System

3.1.3.1 The Electrolyte

The electrolyte passes high current from the anode to the cathode (tool), and provides the necessary chemicals for electrolytic oxidation of the work surface. In most of the investigations, researchers recommended $NaClO_3$, $NaNO_3$ and NaCl solution with different concentrations. The type of electrolyte was used is ionized or passive electrolyte with 25% concentration sodium nitrate $NaNO_2$ because $NaNo_3$ is not available and not allowable, so nitrate sodium $NaNO_2$ is used because it is available and gives higher surface accuracy than NaCl. The electrolyte must be dispensed through properly designed and adjusted nozzle penetrates effectively into the interface between tool and workpiece the electrolyte moves through a nozzle within the tool, Fig. 3.11 shows the machining and hydraulic circuit of the electrolyte

3.1.3.2 Electrolytic Pump

The amount of electrolyte must be adjusted to the actual operational conditions. An insufficient or non-continuous supply will retard the stock-removal process and causes increasing tool wear, while excessive amounts of electrolyte may result in uncontrolled etching of the work material; so there is a pump attached to the tank and the outlet of the pump directed to the end of the electrode. The direction of the outlet and the electrolyte circulating system is controlled carefully to maintain the stability of the current. The electrolyte which is generally a concentrated salt solution is pumped at high pressure through inter electrode gap in order to remove the reaction products, to dissipate the generated heat and to allow high rate of metal dissolution. the hydrulic circuit of electrochemical turning process is shown in Fig. 3.11, the flow rate of the pump is 27 L/min. Table 3.3 states the specifications of the electrolytic pump.

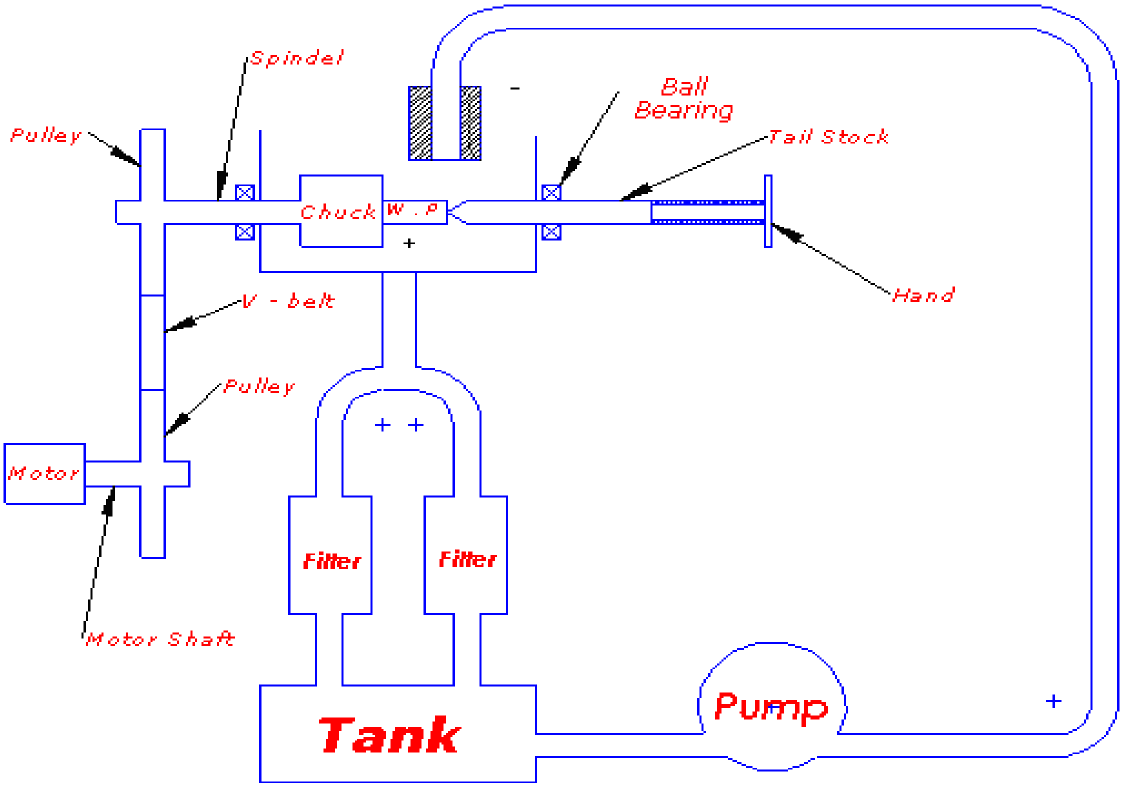


Fig. 3.11 Machining and hydraulic circuit

Table 3.3: Specifications of the electrolytic pump

Model	Specification
Power	0.5 Hp
Frequency	50 Hz
Flow rate	27 l/min

3.1.3.3 Filter

The electrolyte reaching to the working area must be cleaned by filtered out the removed metal, which ends to contaminate the electrolyte and reduces its effectiveness. There is two filters are used to be satisfied to the high flow rate of the pump

3.1.4 Mechanical operation – spindle elevation, cross feed positioning Carriage movement and preparation for electrochemical machining.

The spindle of the machine takes its motion from the main motor that rotates with three speeds (800, 1000, and 1200 rpm) according to the diameter of the drive pulley , the tool must match the required shape of the workpiece based on the material and the profile to be produced. The tool materials which are used in ECT process must have good thermal and electrical conductivity, corrosion resistance, high machinability and should be stiff enough to withstand the electrolytic pressure without vibrating. A highly conductive material having thermal resistant characteristics can be used for the tool material in ECM systems. The most commonly materials used are copper, brass and bronze or stainless steel, so a copper tool material that has high conductivity with different areas or sizes , the carriage that carries the tool must be insulated from the electrolyte causes wear of machine, the tool carriage and fixation are shown in Fig. 3.12, also Fig. 3.13 shows the shape of the tool electrod that made from copper. Table 3.4: state the specification of tool dimensions used in the present work.

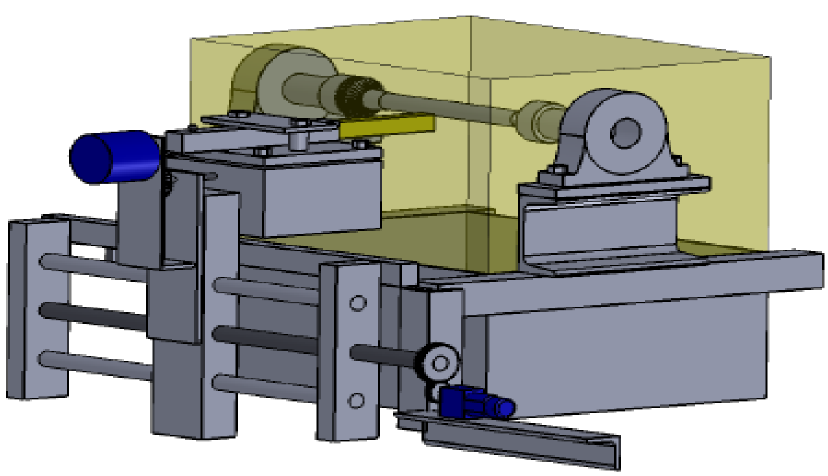


Fig. 3.12 Machining cell of ECM turning

Table 3.4: Specification of tool electrode

No	Tool Dimension (mm)
1	19 × 30
2	19 × 19
3	19 × 15

Fig. 3.13 Section in tool electrode

3.2 Description of Measuring Instrument

3.2.1 Measurement of Surface Roughness

The surface topography of the specimens is measured using a Mitutoyo surface roughness meter which is shown in Fig. 3.14. The styles radius is 2.5 um and this stylus traverses the surface with velocity 0.5 mm/sec. All the measurements were taken using cut off value of 0.8

mm with 4mm evaluation length. The roughness value represents an average of three readings measured along the length of the specimen. The surface roughness value for the machined surface is measured using the arithmetic value R_a was measured across the lay, Fig. 3.14 shows a photograph of the surface roughness instrumentum.

Fig. 3.14 Mitutoyo surface roughness meter

3.2.2 Measurement of Hardness

The micro hardness of the specimen is measured using Brinell micro hardness tester controllab (Hoytom) type, all measurements were taken using 60 kg for 10 second using a hard steel ball of 2.5 mm diameter, the micro hardness values represent an average of three readings measured along the length of the specimen. The microscope which used to measure the indentation diameter, has a minimum division or accuracy 0.02 mm. Table 3.5: state the specification of BHN instrument.

Table 3.5: Specification of BHN instrument

Model	Hoytom MBH
Loading mechanism	Automatic unloading type
Test load	60 kgf
Load duration time	10 sec, 20 sec, and 30 sec
Magnification of microscope	X(100 objective X10 and ocular X10) X400 (objective X40 and ocular)
Measuring eyepiece	Minimum division 0.02mm/div

3.3 Description of Tests

The tests can be divided into two categories;

1-Tests under tool electrode 19 × 15 mm

2- Tests under tool electrode 19 × 19 mm

3.3.1 First set

The first set was designed to study the effect of applied voltage, feed rate and spindle speed at small tool electrode dimensions and fixed gap on the surface roughness, hardness and metal removing rate. The following surface integrity parameters were evaluated.

(a) Brinell hardness number BHN was measured using Mitutoyo hardness tester at load of 60 kg for 10 second.

(b) The surface roughness R_a in um was measured using a Mitutoyo surface roughness meter.

(c) The metal removal rate was calculated by measuring the weight of workpeice before turning and after turning, total metal removal rate was obtained as:

Total weight of material removed $M = m_1 - m_2$

$$MRR = \frac{m_1 - m_2}{\rho t}$$

where m_1 is weight of the specimen before machining (gr), m_2 is the weight of specimen after machining (gr) , ρ is the density of workpiece material (gr/cm^3) and t is time of machining (sec).

Table 3.6: ECT process variable level for the first experimental test

ECM VARIABLES	VARIABL LEVEL					
	LEVEL 1	LEVEL 2	LEVEL 3	LEVEL 4	LEVEL 5	UNITS
Feed Rate	0.5	0.78	1	1.2	1.5	mm/sec
Voltage	9	11	14	16	-	V
Spindle speed	400	600	800	1000	1200	rpm

3.3.2 Second set

The second set was designed to study the effect of voltage, feed rate with changing spindle speed on the surface roughness, hardness and metal removal rate at fixed gap and tool electrode 19 × 19 mm. Table 3.7: ECT process variable level for the second experimental tes

ECM VARIABLES	VARIABL LEVEL					
	LEVEL 1	LEVEL 2	LEVEL 3	LEVEL 4	LEVEL 5	UNITS
Feed Rate	0.5	0.78	1	1.2	1.5	mm/sec
Voltage	9	11	14	16	-	V
Spindle speed	400	600	800	1000	1200	rpm

3.4 Experimental Design

The experimentation plays an important role in science, engineering, and industry. The experimentation is an application of treatments to experimental units, and then measurement of one or more responses. It is a part of scientific method. It requires observing and collecting information about how process and system works. In an experiment, some input *x*'s transform into an output that has one or more observable response variables *y*. Therefore, useful results and conclusions can be drawn by experiment. In order to obtain an objective conclusion, an experimenter needs to plan and design the experiment, and analyze the results. When treatments are from a continuous range of values then the true relationship between *y* and *x*'s might not be known. The approximation of the response function $y= f(x_1, x_2,\ldots, x_q) + e$ is called *Response Surface Methodology*. This thesis puts emphasis on designing and analyzing the *Response Surface Methodology*.

3.4.1 Response Surface Methodology

As an important subject in the statistical design of experiments, the *Response Surface Methodology* (*RSM*) is a collection of mathematical and statistical techniques useful for the modeling and analysis of problems in which a response of interest is influenced by several variables and the objective is to optimize this response, in the present work the material removal rate, material excess removal and surface roughness is affected by many variables as feed rate, spindle speed and applied voltage, When treatments are from a continuous range of values, then Response Surface Methodology [23] is useful for developing, improving and optimizing the response variable. In this case, the output response variables function of the input or independent variables.

There are two basic concepts in RSM, first the choice of the approximate model and, second, the plan of experiments where the response has to be evaluated, An

approximation model that can capture interactions between *N* design variables, a full factorial approach may be necessary to investigate all possible combinations. A *factorial* experiment is an experimental strategy in which design variables are varied together, instead of one at a time.

3.4.2 Response Surface Methods and Design

Factorial designs can be used for fitting second-order models. A second-order model can significantly improve the optimization process when a first-order model suffers lack of fit due to interaction between variables and surface curvature. A general second-order model is defined as,

$$Y= \beta_0 + \beta_1 x_1 + \beta_2 x_2 + \beta_3 x_3 + \beta_{12} x_1 x_2 + \beta_{13} x_1 x_3 + \beta_{23} x_2 x_3 + \beta_{11} x^2_1 + \beta_{22} x_2^2 + \beta_{33} x_3^2$$

Where x_1, x_2 and x_3 are the coded value of independent variables and β are the tuning parameters.

The construction of a quadratic response surface model in *N* variables requires the study at three levels so that the tuning parameters can be estimated, the number of tuning parameter can be calculated from this equation

$$\text{number of regression factor} = \frac{(N+1)\,(N+2)}{2}$$

In the present work a full factorial design is used for three independent variables N so 3^3 and number of tuning parameter is 10 parameters.

In response surface methodology method the independent variable converted to coded value. In order to simplify the calculation, it is appropriate to use *coded variables* for describing independent variables in the (-1, 1) interval. The independent variables are rescaled therefore 0 is in the middle of the center of the design, and ±1 are the distance from the center with direction. The variables f*, N* and V are usually called *variables*, because they are expressed in the natural units of measurement. Therefore, if f*,* N and V denote the variables feed rate, spindle speed and applied voltage respectively then the transformation of these n variables to coded variables is:

$$X_1 = \frac{f - fo}{\Delta f} \qquad X_2 = \frac{N - No}{\Delta N} \qquad X_3 = \frac{V - Vo}{\Delta V}$$

$$X_1 = \frac{f - 0.5}{0.5} \qquad X_2 = \frac{N - 1000}{200} \qquad x_3 = \frac{V - 12}{3}$$

where X_1, X_2, X_3, are coded value of independent parameters of feed rate, rotational speed of workpiece, and applied voltage.

The Matlab software computes the linear, quadratic, and interactions terms in the model using tool box (rstool).

Variables			Coded Values		
F	N	V	X_1	X_2	X_3
0.5	800	9	1	1	-1
1	800	9	0	1	-1
1.5	800	9	-1	1	-1
0.5	1000	9	1	0	-1
1	1000	9	0	0	-1
1.5	1000	9	-1	0	-1
0.5	1200	9	1	-1	-1
1	1200	9	0	-1	-1
1.5	1200	9	-1	-1	-1
0.5	800	12	1	1	0
1	800	12	0	1	0
1.5	800	12	-1	1	0
0.5	1000	12	1	0	0
1	1000	12	0	0	0
1.5	1000	12	-1	0	0
0.5	1200	12	1	-1	0
1	1200	12	0	-1	0
1.5	1200	12	-1	-1	0
0.5	800	14	1	1	1
1	800	14	0	1	1
1.5	800	14	-1	1	1
0.5	1000	14	1	0	1
1	1000	14	0	0	1
1.5	1000	14	-1	0	1
0.5	1200	14	1	-1	0
1	1200	14	0	-1	0
1.5	1200	14	-1	-1	0

Chapter 4

Results and Discussion

4.1 Introduction

It has been mentioned that electrochemical turning utilizes both electrical and chemical actions to remove material. The electrochemical portion is mainly influenced by the current density that controlled it by the DC voltage applied, the concentration, type of the electrolyte, and feed rate of the electrode. In addition, the gap resistance is the main factor controlling the mechanical action that controlled from stepper motor software. Material removal rate and feed of the electrode are linked to one another in which the increase in feed rate increase the current density and hence increase the material removal.

4.2 Material Removal Rate MRR

4.2.1 Effect of Feed rate at Different Applied Speeds

The relationships (material removal rate – feed rate) at different applied rotational speeds of workpiece at voltage 14 V and tool electrode size 19 × 15 mm are shown in Fig. 4.1. It was found out that, the material removal rate increases with increasing applied feed rate at different applied rotational speeds of workpiece (800, 1000, 1200 rpm), also the figure shows that material removal rate increases with increasing the applied rotational speed of workpiece. Fig. 4.2 shows the effect of feed rate on material removal rate at different applied rotational speeds of workpiece and tool electrode size 19 × 19 mm and voltage 14 V, from Fig. 4.1 and Fig. 4.2 it is cleared that material removal rate when using tool electrode size 19 × 15 mm is higher than when using tool electrode size 19 ×19 mm, this due to as the tool electrode area decreases the current density passing and applied current increases. The relationship between material removal rate and working parameter obtained from experimental design using response surface methodology using tool box (rstool) of matlab software shown in this formula,

$$MRR = 32.9345 - 23.1989X_1 + 0.0199X_2 - 7.3638X_3 + 0.0102X_1X_2 + 1.8569X_1X_3 + 0.0011X_2X_3 + 1.9966X_1^2 - 1.180\times10^{-5}X_2^2 + 0.2833X_3^2$$

Fig. 4.3 to Fig. 4.5 shows the comparison between experimental and predicted results of material removal rate at constant speed and constant applied voltage. From Fig 4.3 it is cleared that the values from the experimental results and predicted model are very close at feed rate (0.5, 0.78, 1, 1.2 mm/sec) but at 1.5 mm/sec there is different between experimental and predicted results. Fig 4.4 shows the relationship between experimental and predicted results at constant rotational workpiece speed 1200 rpm and constant applied voltage v=14 V, from the figure it is cleared that the relationship between experimental and predicted results are very close at feed rate (0.5, 1, 1.2, 1.5) but at feed rate 0.78 there is different. Also Fig. 4.5 shows the relation between experimental and predicted results at constant rotational speed of workpiece N=800 rpm and constant voltage v=14 V, from the figure it is cleared that, the relationship between experimental and predicted results is approximately the same. Fig. 4.6 shows the effect of feed rate on material removal rate at different applied rotational speeds of workpiece and constant applied tool electrode size 19 × 15 mm and applied voltage v= 11V, Fig. 4.7 show the relationship between material removal rate and applied feed rate at constant tool electrode size 19 × 19 mm and applied voltage v= 11V, from the figure it is cleared that material removal rate increases with increasing the rotational speed of workpiece. Fig 4.8 and Fig 4.9 shows the relationship between experimental and predicted results, Fig. 4.8 shows the relationship between experimental and predicted results at constant rotational speed of workpiece N= 1200 rpm and constant applied voltage v= 11 V, it is cleared from the figure that the relation between experimental and predicted are very close to each other at point(0.5, 0.78, 1, 1.5 mm/sec) but at 1.2 mm/sec there is different between the results, also Fig. 4.9 shows the comparision between experimental and predicted results at constant applied rotational speed of workpiece N= 1000 rpm and applied voltage v= 11V, from the figure it is cleared that the relation between experimental and predicted values are very close to each other at feed rates (0.5, 1.2, and 1.5 mm/sec) but there is different between experimental and predicted values at feed rate 0.78, and 1 mm/sec.

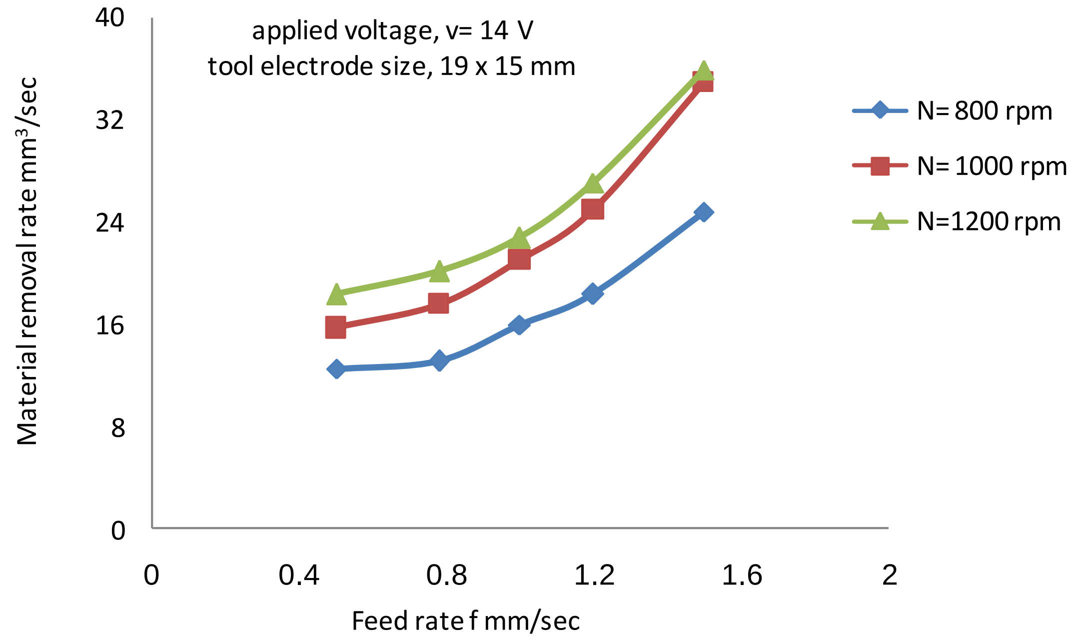


Fig. 4.1 material removal rate vs, feed rate at different applied rotational speeds of workpiece

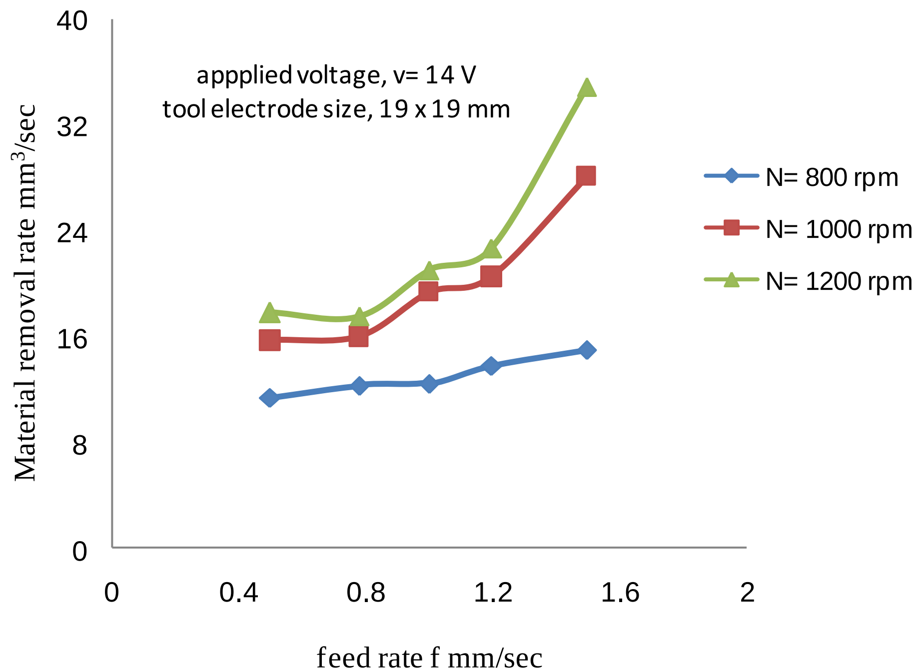


Fig. 4.2 material removal rate vs. feed rate at different applied rotational speeds of workpiece

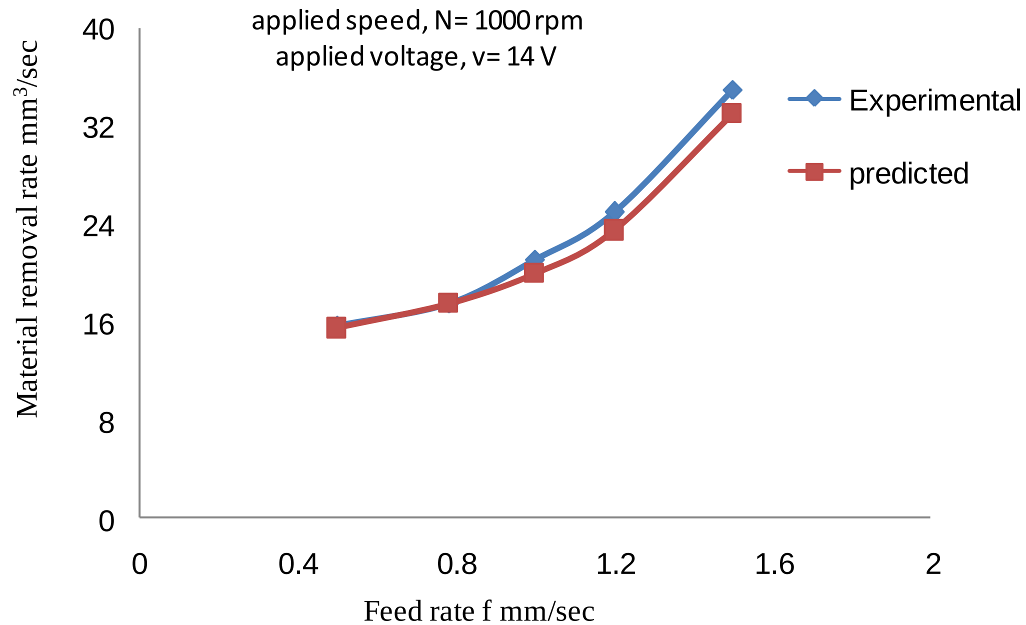


Fig. 4.3 material removal rate vs, feed rate at constant tool electrode size (experimental and predicted results)

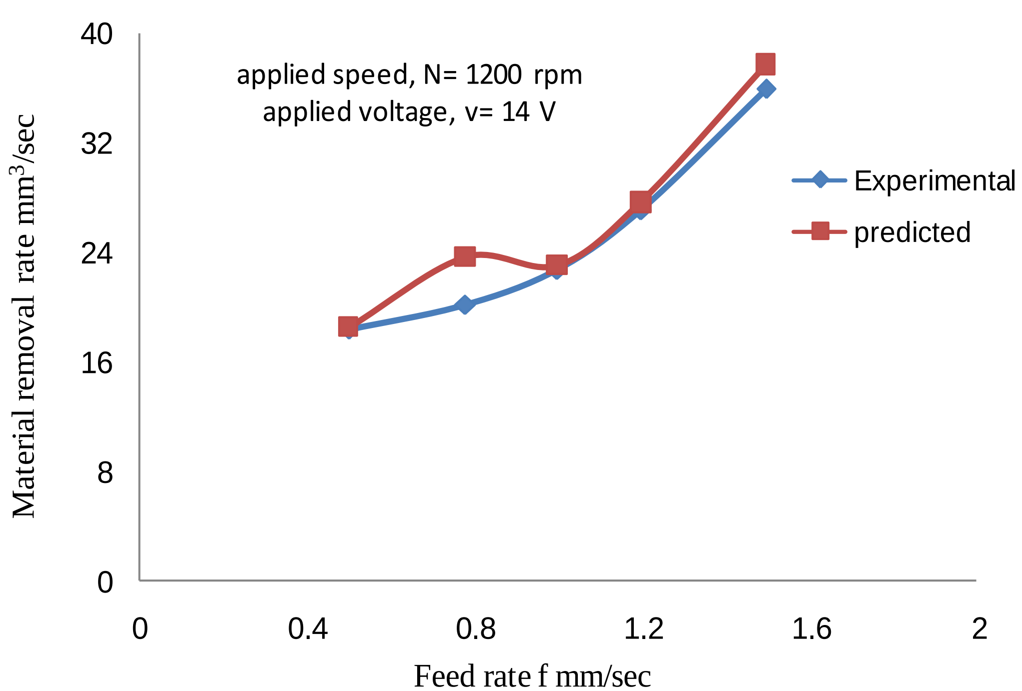


Fig. 4.4 material removal rate vs, feed rate at constat speed and tool electrode size(experimental and predicted results)

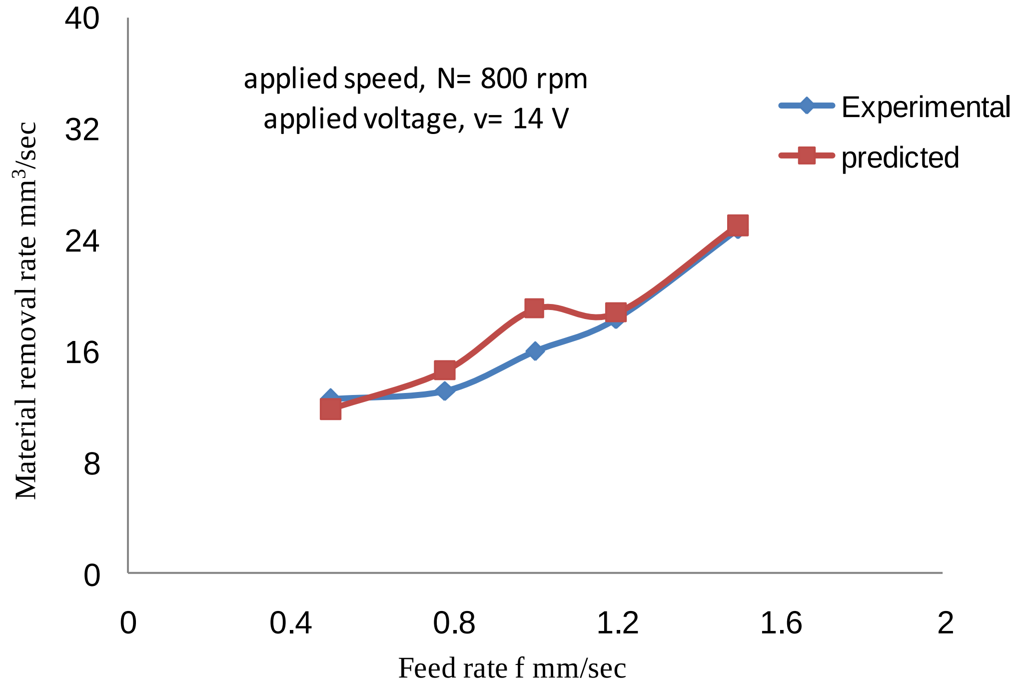


Fig. 4.5 material removal rate vs, feed rate at constat tool electrode size (experimental and predicted results)

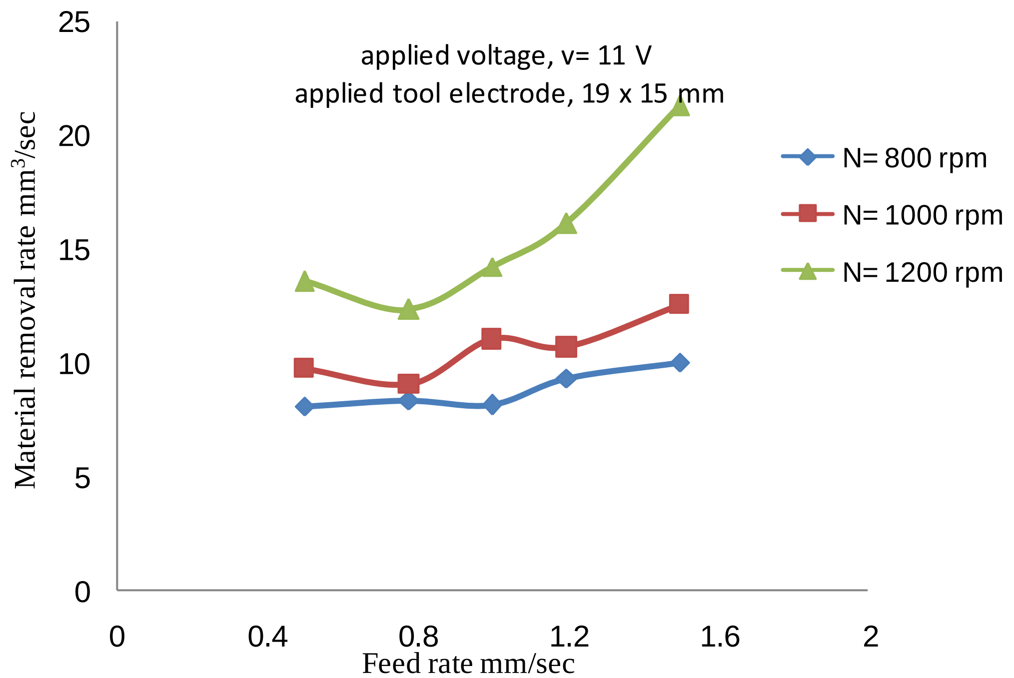


Fig. 4.6 material removal rate vs. feed rate f at different applied rotational speeds of workpiece

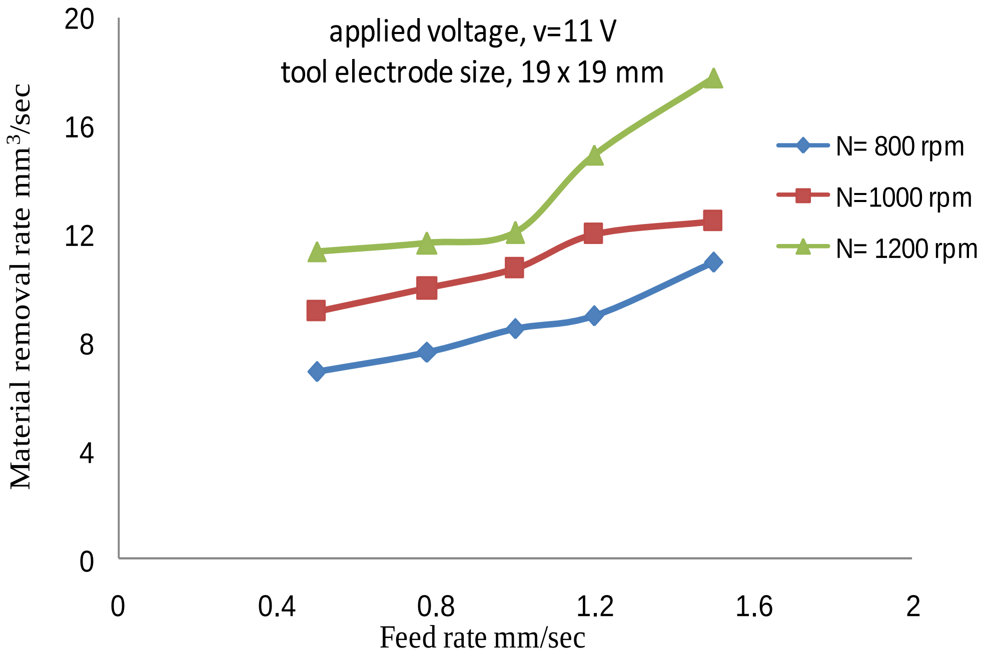


Fig. 4.7 material removal rate vs. feed rate at different rotational speeds of workpiece

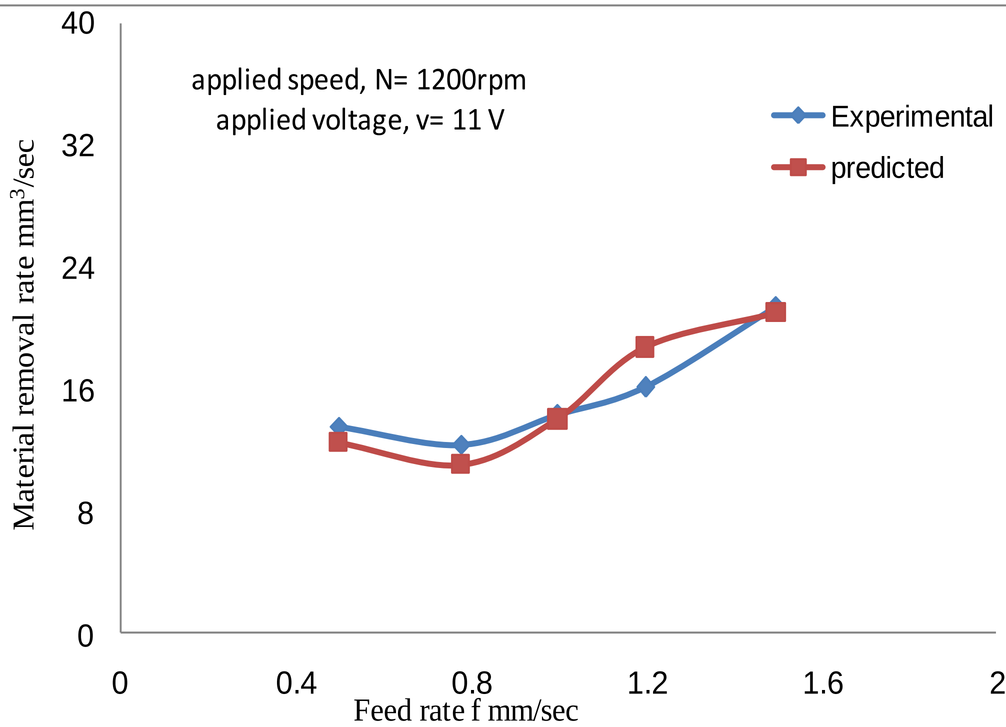


Fig. 4.8 material removal rate vs, feed rate at constant tool electrode size (experimental and predicted results)

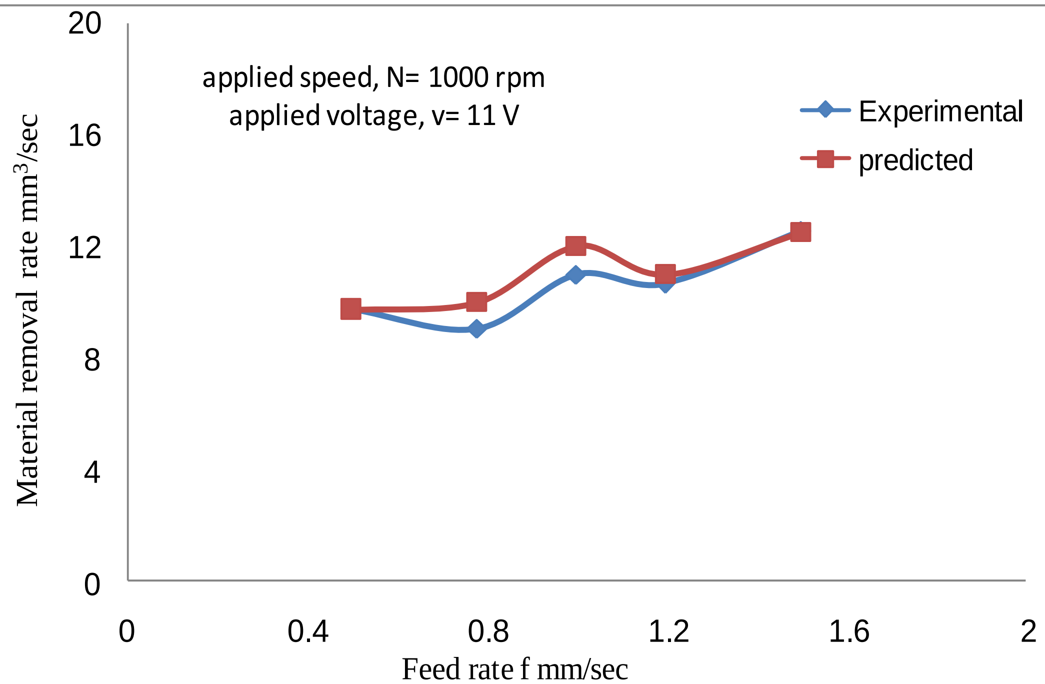


Fig. 4.9 material removal rate vs, feed rate at constant tool electrode size (experimental and predicted results)

4.2.2 Effect of Rotational Speed of Workpiece at Different Feed Rate

The relationship between material removal rate and rotational speed of workpiece at different applied feed rates of tool electrode (0.5, 1, 1.5 mm/sec) is shown in Fig. 4.10 at constant applied tool electrode size 19 × 15 mm and constant applied voltage 14 V. Fig. 4.11 shows the comparison between experimental and predicted results at voltage 14 V and constant applied feed rate 1.5 mm/sec, from the figure its cleared that the values of experimental and predicted results are very close to each other at (400, 800, 1200 rpm) but at speed (600, 1000 rpm) there is different. Also Fig 4.12 shows the relationship between material removal rate and rotational speed of workpiece at different feed rates (0.5, 1, and 1.5 mm/sec) and tool electrode size 19 × 15 mm and constant applied voltage 11V, Fig. 4.13 shows the relationship between material removal rate and rotational speed of workpiece at tool electrode size 19 × 19 mm and voltage 14V. Fig. 4.14 shows the relationship between material removal rate and rotational speed of workpiece at tool electrode size 19 × 19 mm and voltage 11V. The material removal rate increases with increasing the applied rotational speed of workpiece due to increasing in rotational workpiece speed make increases in the electrolyte flow and this make the concentration of electrolyte high and produce high current during the turning and make the material removal rate increases.

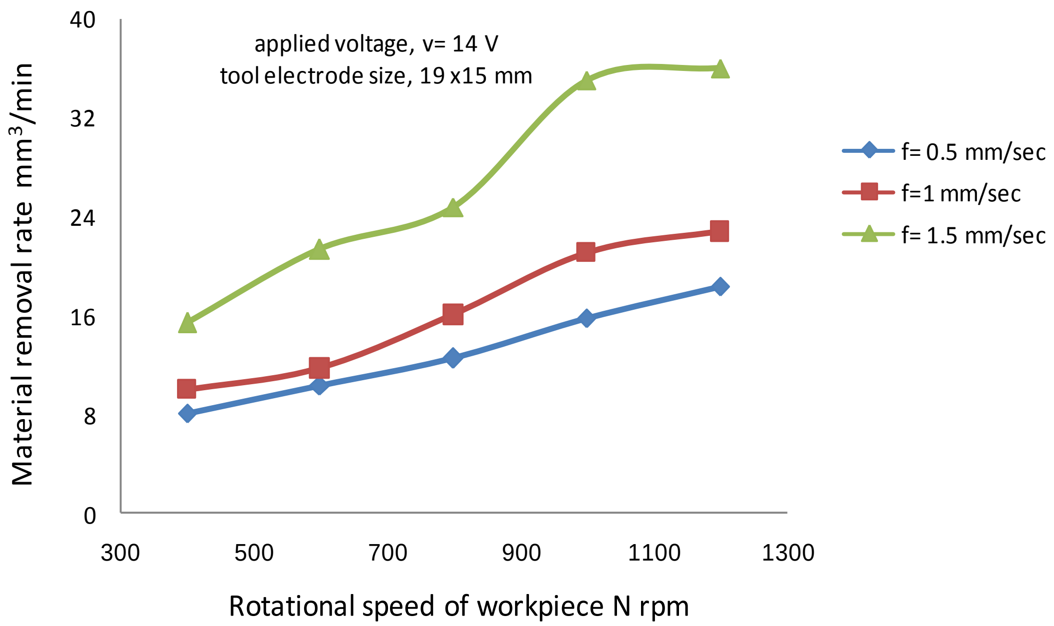


Fig. 4.10 material removal rate vs applied rotational speed of workpiece at different applied feed rates

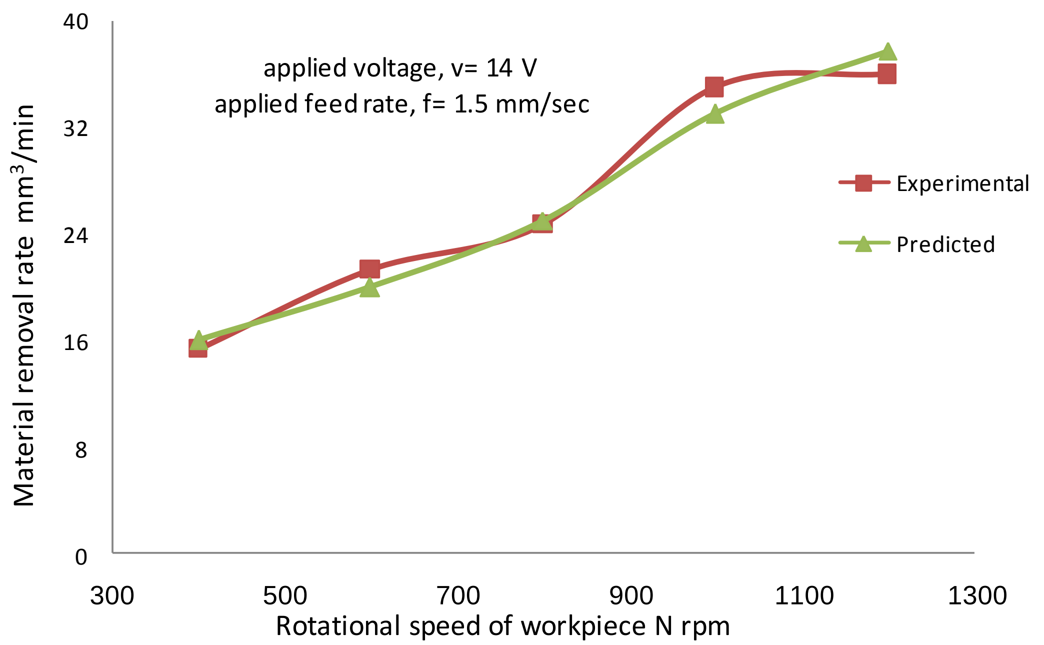


Fig. 4.11 material removal rate vs applied rotational speed at constant rool electrode size (experimental and predicted result)

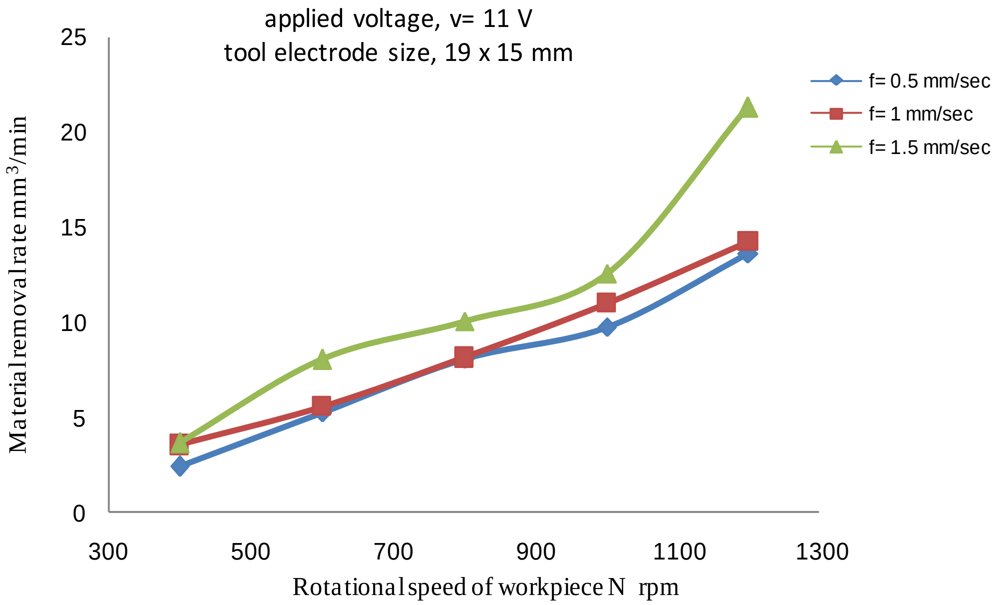


Fig. 4.12 material removal rate vs, applied rotational speed of workpiece at different applied feed rates

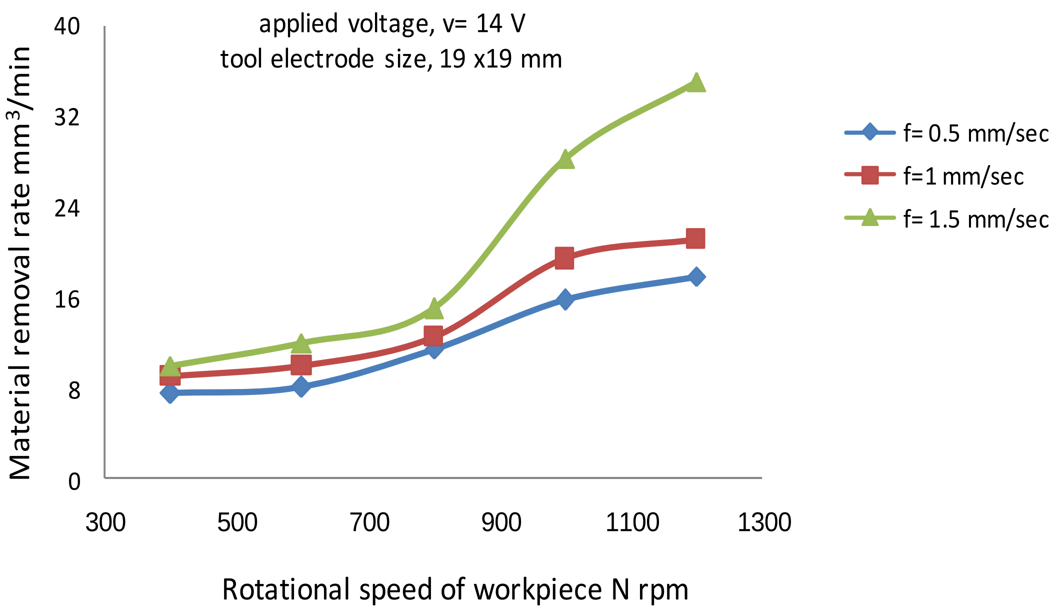


Fig. 4.13 material removal rate vs applied rotational speeds of workpiece at different applied feed rate

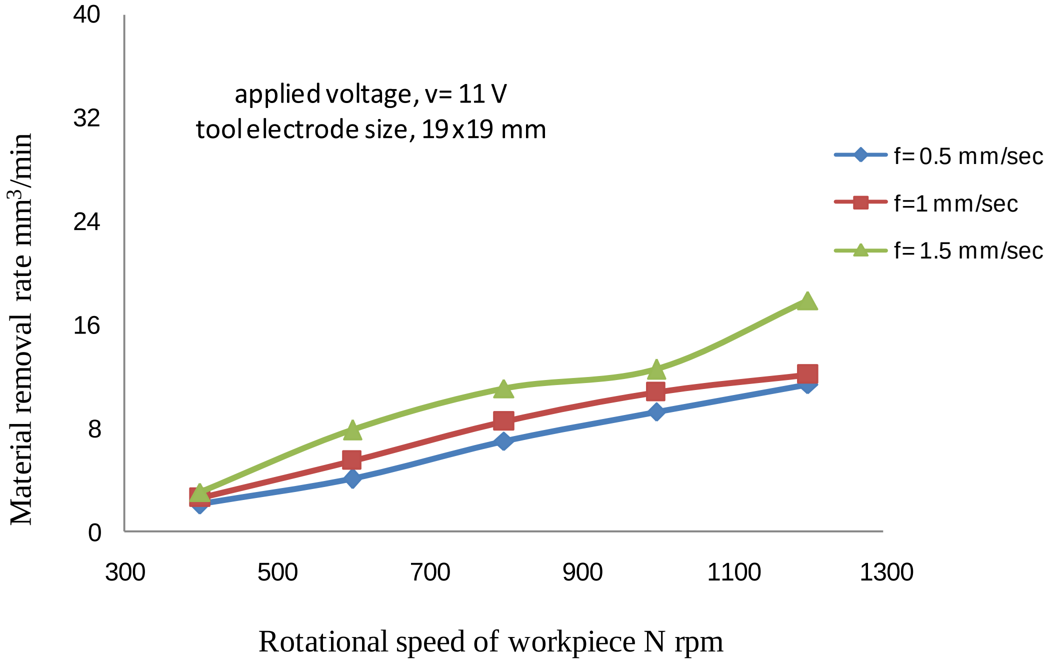


Fig. 4.14 material removal rate vs applied rotational speeds of workpiece at different applied feed rates

4.2.3 Effect of Applied Voltage

The effect of applied voltage on material removal rate is clearly shown when comparing Fig. 4.1, Fig. 4.6, and Fig 4.1 shows the relation between material removal rate and feed rate at voltage 14 V, Fig 4.6 show the same relation but at voltage 11 V, by comparing the two figures its cleared that when using 14V the material removal rate is higher than when using 11V, this because as the voltage increases the current density increases and current also increases. Also the effect of applied voltage shown when comparing Fig. 4.2 with Fig. 4.7 that occurs at the same condition only change the applied voltage. From Fig. 4.15 its cleared that with higher voltage the material removal rate increases.

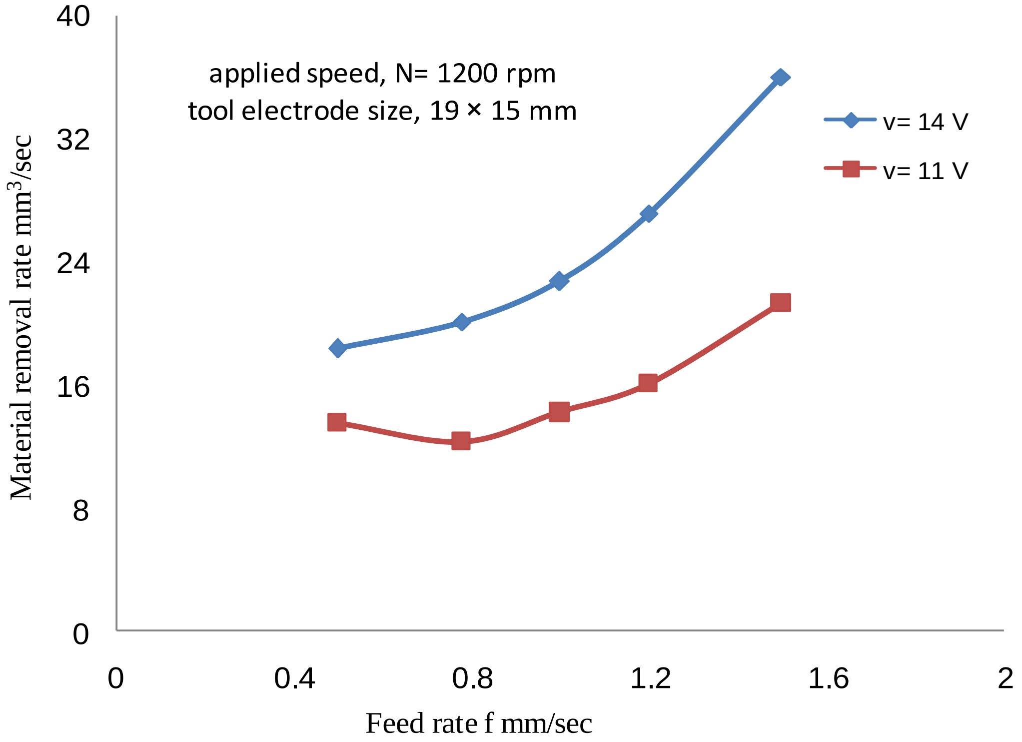


Fig. 4.15 material removal rate vs, feed rate
at different applied voltage

4.2.4 Effect of Tool electrode size

The relationship between material removal rate and feed rate at different tool electrode sizes 19 ×15 mm and 19 × 19 mm and different applied voltages (14 and 11 V) is shown in Fig. 4.16, from the figure it is cleared that when using tool electrode size 19 × 15 mm, the material removal rate is higher than when using tool electrode size 19 × 19 mm, this because as the machining area or tool electrode size increases the current density decreases this due to the material removal rate decreases, also when using higher voltage the material removal rate MRR increases as the current increases with increasing the applied voltage. Also from the figure it is cleared that to obtain higher material removal rate, we must use tool electrode size 19 × 15 mm with 14 V.

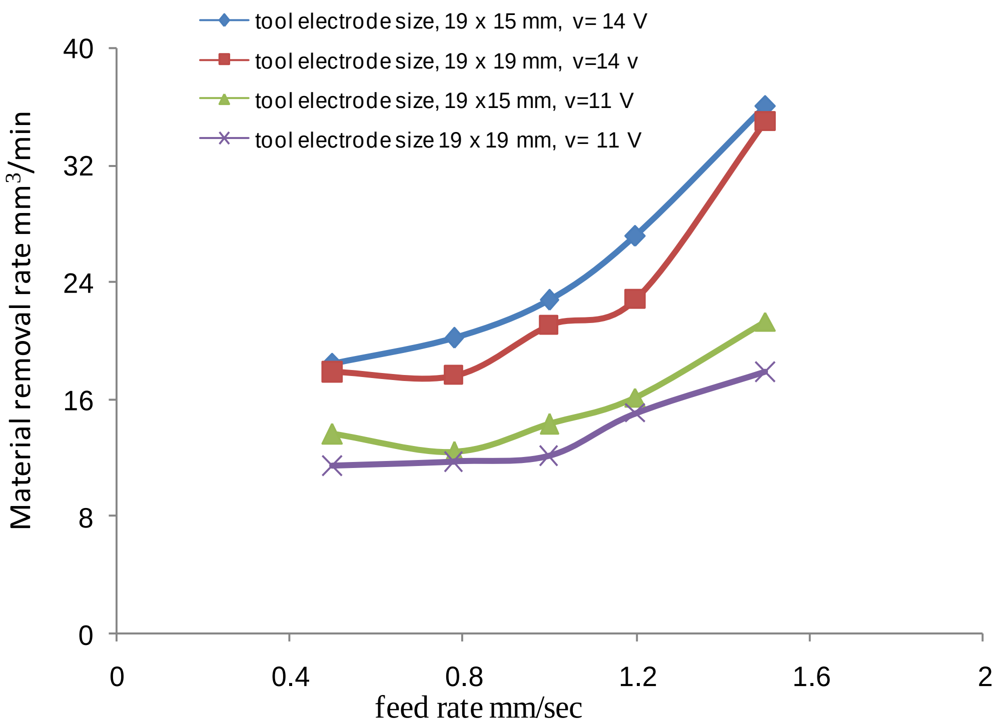


Fig. 4.16. Material removal rate vs.applied feed rate at constant speed N = 1200 rpm

4.2 Hardness

The relationship (Brinell hardness number- feed rate at different electrode sizes is shown in Fig. 4.17) at different applied speeds (800, 1000, and 1200 rpm) and constant applied voltage V= 14 V and constant applied tool electrode area (19 × 19 mm), the figure shows that hardness number decreases with increases the applied feed rate of tool electrode also hardness number decrease with decreases the applied rotational speed of workpiece. Fig 4.18 also shows the same relation but at tool electrode area 19 × 15 mm, by comparing the Fig. 4.17 and Fig. 4.18 it shows that BHN decreases with the increases the tool electrode size when using electrode tool area (19 × 19 mm) higher than when using (19 ×15 mm) in Fig. 4.17.

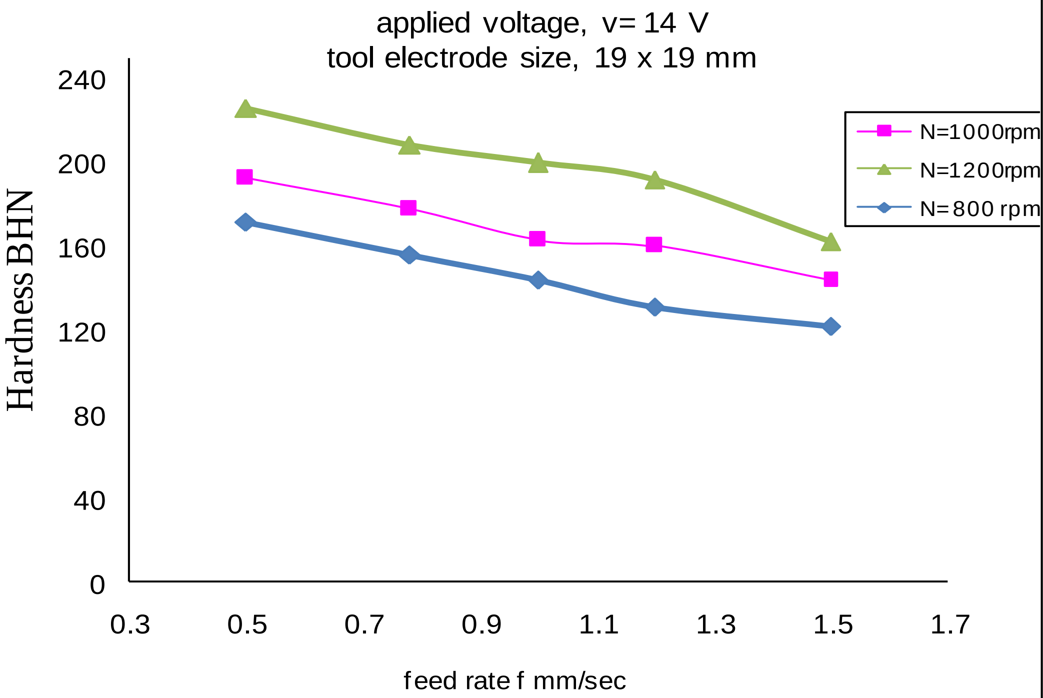


Fig. 5.17 Hardness vs feed rate at different applied speed

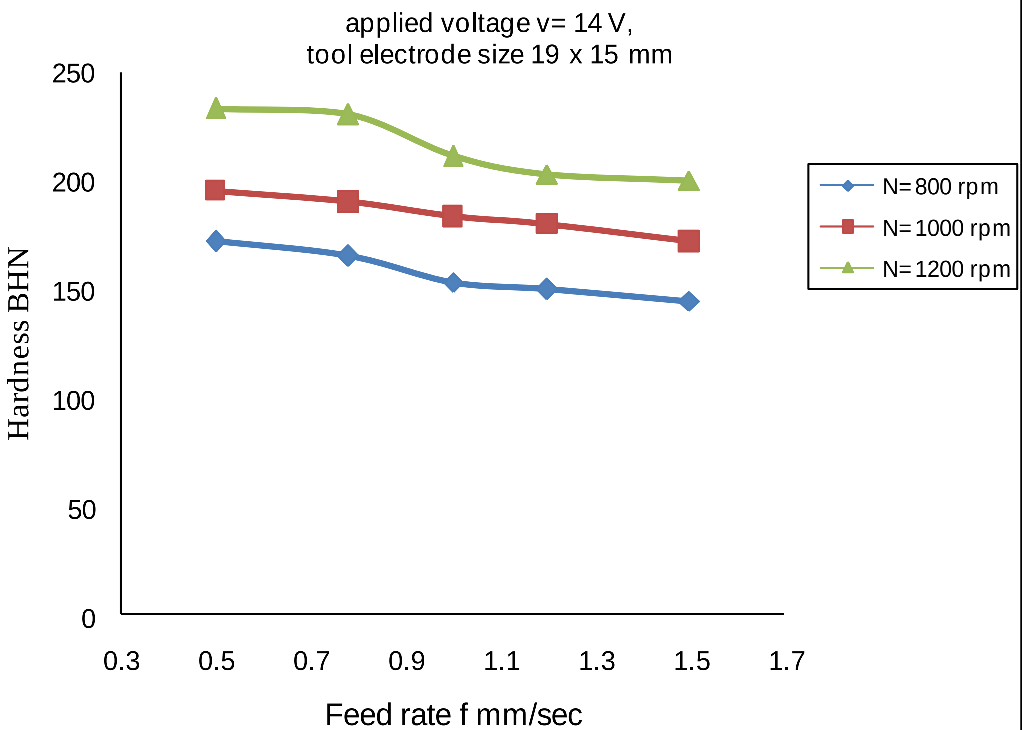


Fig. 5 .18. Hardness vs feed rate at at different applied speeds

4.3 Surface roughness

4.3.1. Effect of feed rate at different rotational speeds

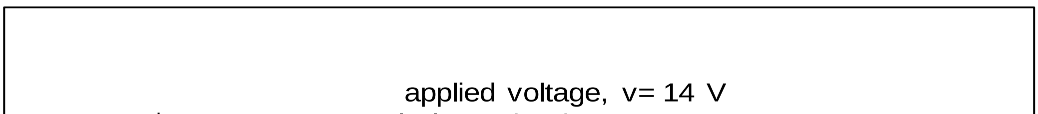
The relationship (surface roughness - feed rate) at different applied speeds and constant applied voltage and tool electrode size is shown in Fig. 4.19 and Fig. 4.20. It was found out that, the surface roughness increases with increasing applied voltage and decreases with increasing feed rate. The particularly bad surface finish at low feed rates and high-applied voltage are believed to have been due to stray machining of tool electrode. By increasing the feed rate, stray machining will be less because of small time interval. This will, therefore, result in better surface finish. Further, an increase in feed rate causes an increase in the electrolyte flow rate.

The relationship between surface roughness and working parameters depending on the experimental design using response surface methodology (rstool) by matlab software is shown in this predicted equation,

$$Ra = 1.9087 - 4.02577\ X_1 - 0.00323\ X_2 + 0.568833\ X_3 + 0.00077 X_1 X_2 + 0.044689 X_1 X_3 - 1.95 \times 10^{-5} X_2 X_3 + 0.975556 X_1^2 + 5.86 \times 10^{-7} X_2^2 - 0.01912\ X_3^2 \qquad (4.3)$$

Fig. 4.21, Fig. 4.22 and Fig. 4.23 shows the experimental and predicted results of surface roughness. From Fig. 4.21 it is cleared that experimental and predicted results are very close to each other, and Fig. 4.22 also shows how the values from experimental and predicted results are very close to each other only at feed rate 1.5mm/sec the experimental and predicted results is different. From Fig. 4.23 it is cleared that the relation between experimental and predicted results is very close. Fig. 4.24 and Fig. 4.25 shows the relation between surface roughness and feed rate at constant speed (N=1200 rpm) and constant applied voltage v= 14V and different applied tool electrode area, from this figure its cleared that when using tool electrode area 19 × 19 mm the surface roughness is lower than using tool electrode area 19 ×15 mm.

Also surface roughness decreases as the rotational speed of workpiece increases, High rotational speed of the workpiece produces better surface finish, since the rotational energy provides better discharge mobility by inducing more turbulent flow of electrolyte. The higher electrolyte flow rate removes the hydrogen bubbles more effectively and, therefore, there is better, effective and uniform metal removal on the anode surface. This seems to be another reason due to which the surface roughness improves with increase in feed rat. Higher hydrogen gases evolution was obtained with increasing applied voltage.



The accumulation of hydrogen gas bubbles at the anode decreases the effective conductivity of the solution. The resulting surface finish is worse due to local variations in conductivity in the anode contact area.

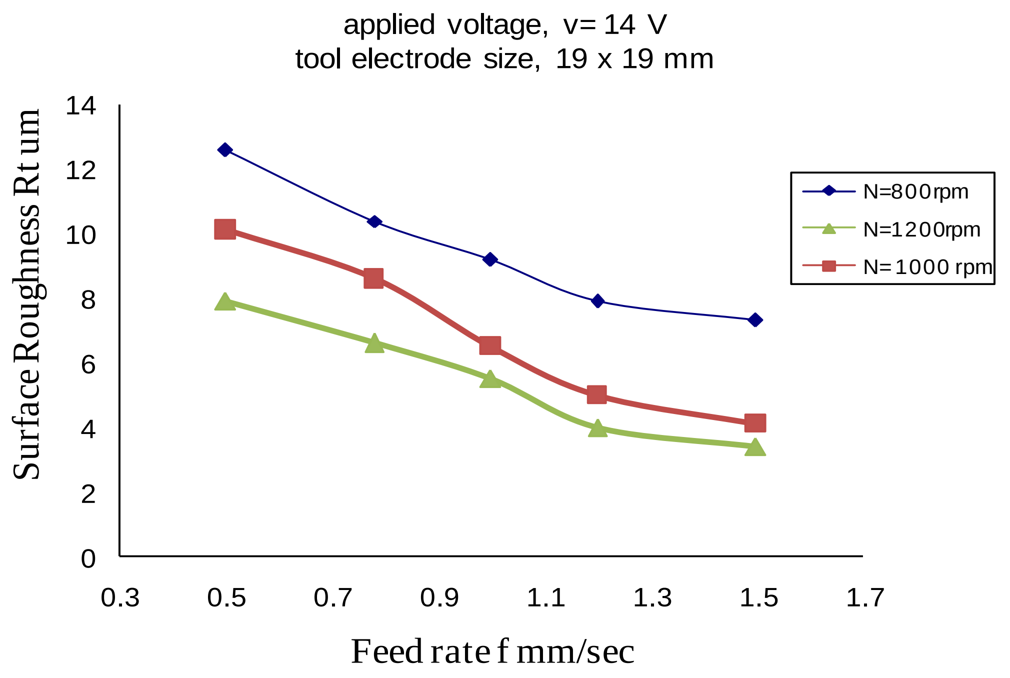


Fig. 4.20 surface roughness Rt vs feed rate at different applied speeds

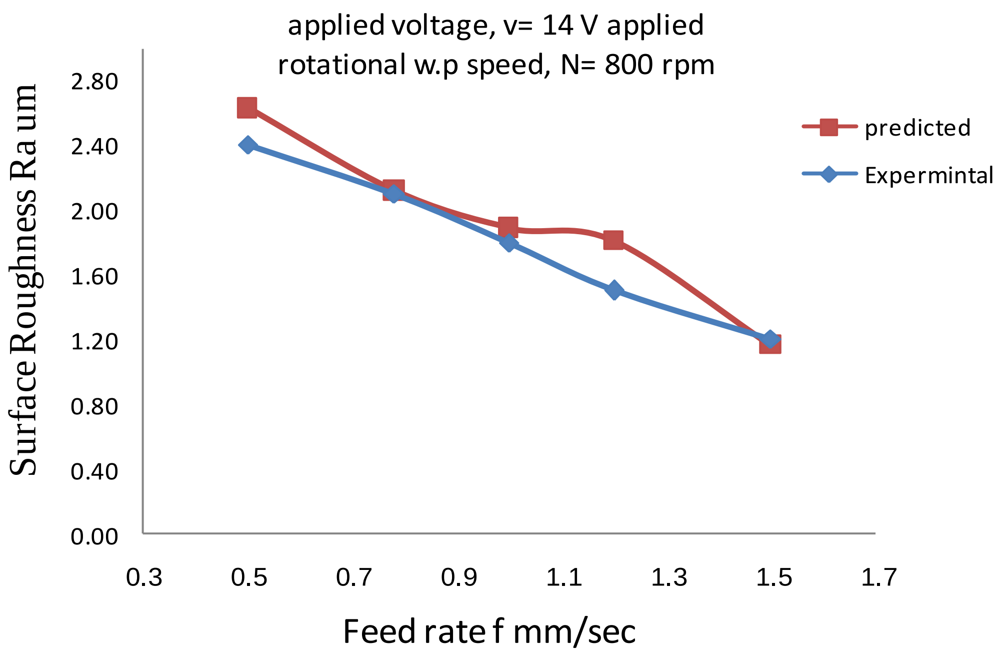


Fig. 4.21 surface roughness vs feed rate at constant electrode size (predictedand Expermental result),

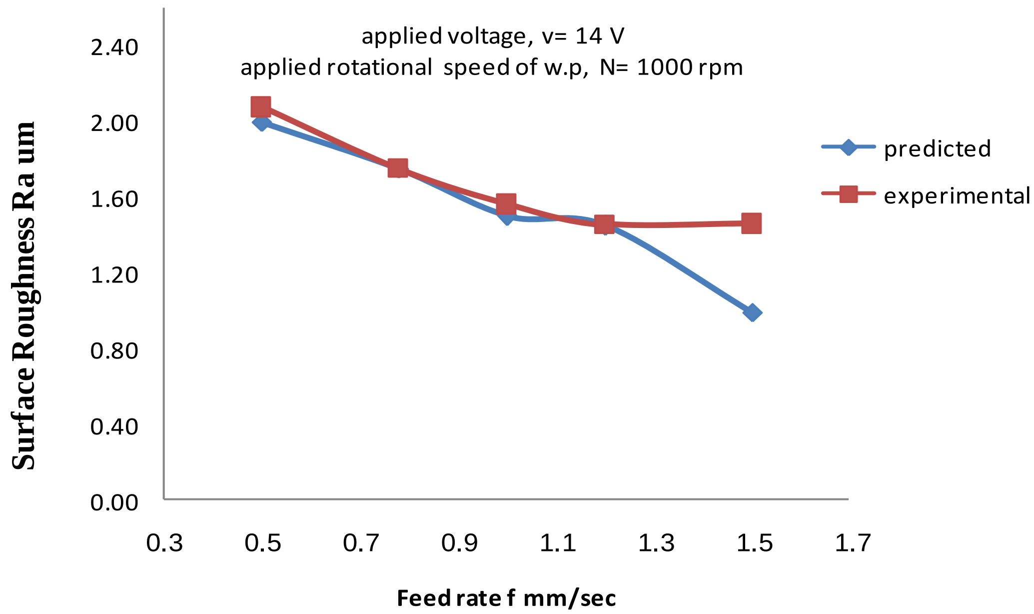


Fig.4.22. surface roughness vs feed rate at constant tool electrode size(experimental and practical result)

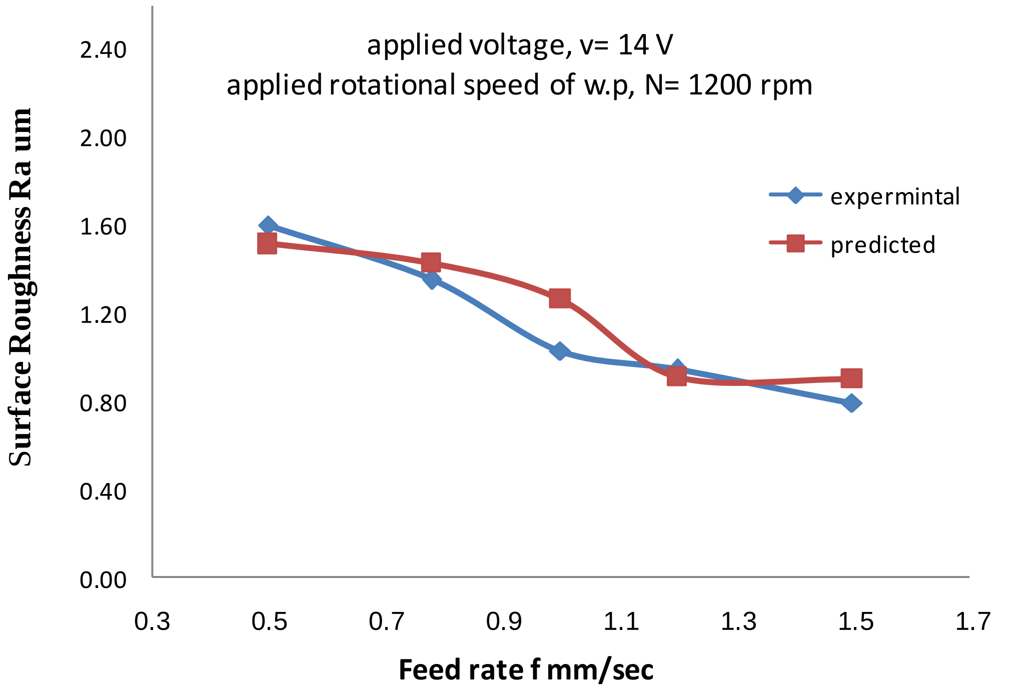


Fig. 4.23 surface roughness vs, feed rate at constant electrode size
(Predicted and Expermintal results)

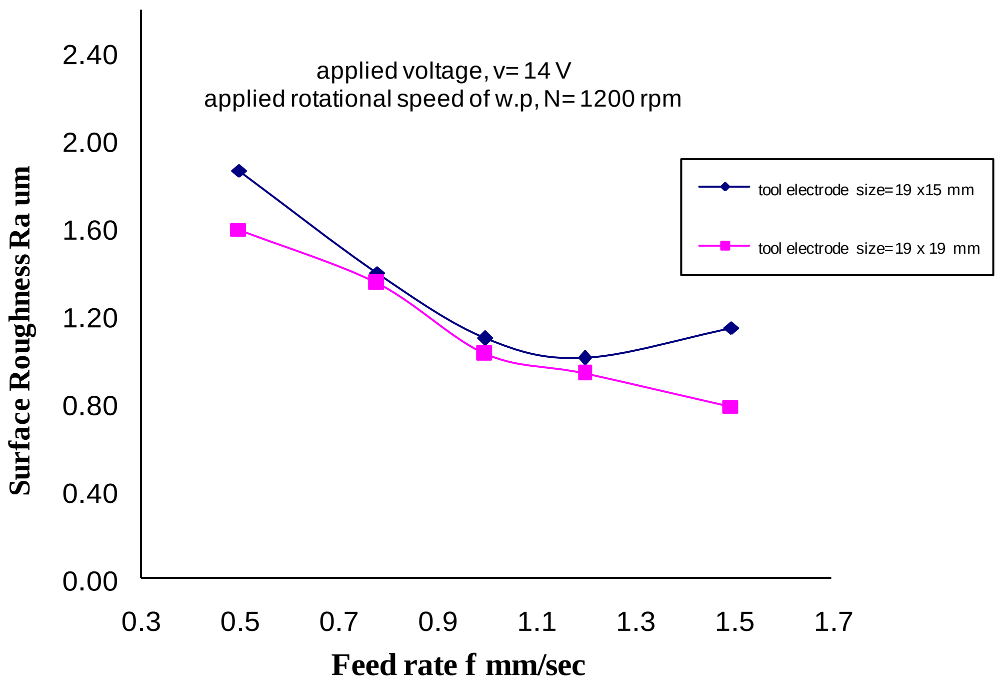


Fig . 4.24 surface roughness vs, feed rate
at different tool electrode size

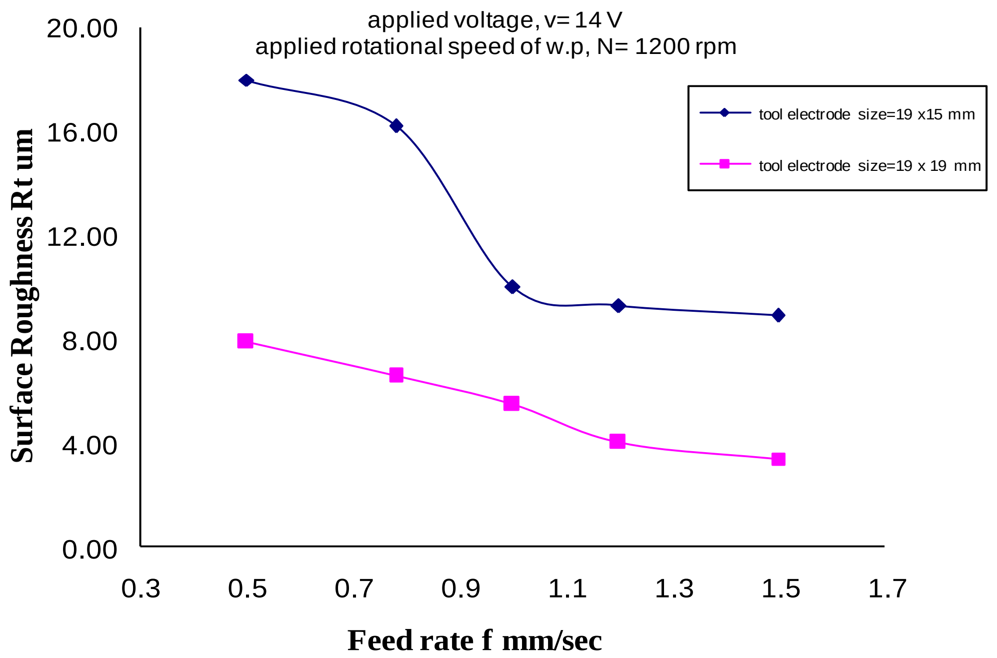


Fig. 4.25 surface roughness Rt vs, feed rate at different tool electrode size

4.5.2 Effect of Applied Voltage on Surface Roughness

The effect of applied voltage on surface roughness is shown in Fig. 4.26, the figure uses five different voltages (7, 9, 11, 13, and 15V), from the figure it is clear that decreasing the applied voltage the surface roghness decreases and the accuract of the surface increase, also it is cleared that from the figure that surface roughness decrease with deacreses the applied feed rate. By increasing the feed rate, stray machining will be less because of small time interval. This will, therefore, result in better surface finish. Further, an increase in feed rate causes an increase in the electrolyte flow rate.

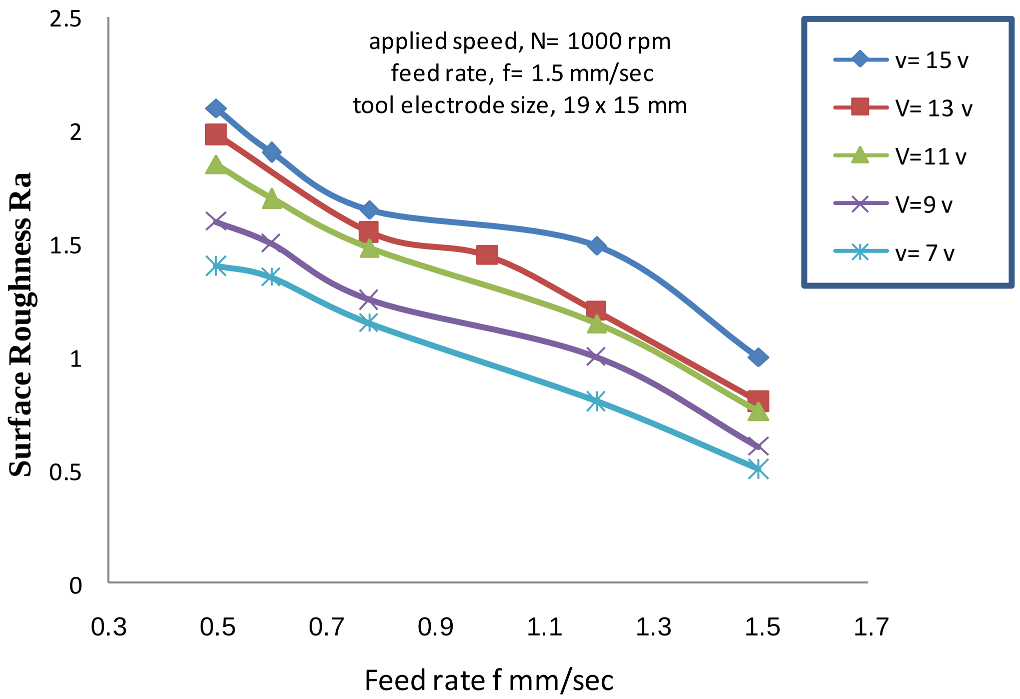


Fig. 4.26 Surface roughness vs, feed rate at different applied voltages

Conclusion

Electrochemical turning was investigated through the experimental consideration of applied voltage, feed rate, rotational speed of workpiece and electrode size. Conclusions drawn from the results obtained are as follows;

1- Material removal (MRR) increases with increasing the applied feed rate of the electrode or velocity of tool electrode displacement. Moreover, material removal rate increases with increasing the applied voltage, as the voltage increases the current density increases and material removal rate increases. Moreover, material removal rate increases with increasing the applied rotational speed of workpiece.

2- Hardness of workpiece decreases with increases the applied feed rate,also hardness of workpiece decreases with increases the applied rotational speed of workpiece and decreases the tool electrode dimension.

3- Surface roughness decreases with decreasing applied voltage, increasing feed rate and increasing tool electrode area, By increasing the feed rate, stray machining will be less because of small time interval. This will, therefore, result in better surface finish. Further, an increase in feed rate causes an increase in the electrolyte flow rate, surface roughness decreases as the rotational speed of workpiece increases, High rotational speed of the workpiece produces better surface finish, since the rotational energy provides better discharge mobility by inducing more turbulent flow of electrolyte.

4- Making an experimental design using response surface methodology of matlab software to produce a mathematical predicted model related between material removal rate, surface roughness and working parameter of (feed rate, applied voltage and rotational workpiece speed) .

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Appendix A

Theoretical removal rates for a current of 1000A [Ref. 1]

Metal	Atomic weight	Ionic charge	Density kg/m^3	Removal rate 10^{-3} kg/s	10^{-6} m^3/s
Aluminum	26.97	3	2.67	0.093	0.035
Beryllium	9.0	2	1.85	0.047	0.025
Chromium	51.99	2	7.19	0.269	0.038
		3		0.180	0.025
		6		0.090	0.013
Cobalt	58.93	2	8.85	0.306	0.035
		3		0.204	0.023
Niobium	92.91	3	9.57	0.321	0.034
Columbium)		4		0.241	0.025
		5		0.193	0.020
Copper	63.57	1	8.96	0.660	0.074
		2		0.329	0.037
Iron	55.85	2	7.86	0.289	0.037
		3		0.193	0.025
Magnesium	24.31	2	1.74	0.126	0.072
Manganese	54.94	2	7.43	0.285	0.038
		4		0.142	0.019
		6		0.095	0.013
		7		0.081	0.011
Molybdenum	95.94	3	10.22	0.331	0.032
		4		0.248	0.024
		6		0.166	0.016
Nickel	58.71	2	8.90	0.304	0.034

		3		0.203	0.023
Silicon	28.09	4	2.33	0.073	0.031
Tin	118.69	2	7.30	0.615	0.084
		4		0.307	0.042
Titanium	47.9	3	4.51	0.165	0.037
		4		0.124	0.028
Tungsten	183.85	6	19.3	0.317	0.016
		8		0.238	0.012
Uranium	238.03	4	19.1	0.618	0.032

Appendix B

The matlab program of material removal rate (MRR)

```
clc, clear, close all;

load machining

alpha = 0.01; % Significance level

rstool(predictors,MRR,'quadratic',alpha,xn,yn2)

stats = regstats(MRR,predictors,'quadratic','beta');

b = stats.beta; % Model coefficients

X1 = predictors(:,1);

X2 = predictors(:,2);

X3 = predictors(:,3);

MRR_stat = b(1) + b(2)*X1 + b(3)*X2 + b(4)*X3 + ...

b(5)*X1.*X2 + b(6)*X1.*X3 + b(7)*X2.*X3 + ...

b(8)*X1.^2 + b(9)*X2.^2 + b(10)*X3.^2;

e_MRR=abs(MRR-MRR_stat);

plot(e_MRR,'r*--'), grid
```

Response surface regression: response versus X_1, X_2, X_3

The analysis was done using coded units.

Estimated Regression Coefficients for response

Term	Coeff β
Constant	32.9345
X1	-23.1989
X2	0.0199
X3	-7.3638
X1X2	0.0102
X1X3	1.8569
X2X3	0.0011
X_1^2	1.9966
X_2^2	-1.180×10^{-5}
X^2_3	0.2833

Maximum error is 0.071

Appendix B continued

The matlab program of surface roughness Ra

```
clc,clear close all;

load machining_m

alpha = 0.01;%significance level

rstool(predictors,Ra,'quadratic',alpha,xn,yn3)

stats = regstats(Ra,predictors,'quadratic','beta');

b = stats.beta; % Model coefficients

X1 = predictors(:,1);

X2 = predictors(:,2);

X3 = predictors(:,3);

Ra_stat = b(1) + b(2)*X1 + b(3)*X2 + b(4)*X3 + ...

b(5)*X1.*X2 + b(6)*X1.*X3 + b(7)*X2.*X3 + ...

b(8)*X1.^2 + b(9)*X2.^2 + b(10)*X3.^2;

e_Ra=(Ra-Ra_stat);

plot(e_Ra,'r*--'), grid
```

from the program the output regression coefficient from program is:

Response Surface Regression: response versus X_1, X_2, X_3

The analysis was done using coded units.

Estimated Regression Coefficients for response

Term	Coeff β
Constant	1.9087
X1	-4.0258
X2	-0.0032
X3	0.5688
X1X2	7.7031×10^{-4}
X1X3	0.0447
X2X3	-1.9549×10^{-5}
X_1^2	0.9756
X_2^2	5.8644×10^{-7}
X^2_3	-0.0191

Maximum error is 0.08836

الملخص العربى

تعتبر عملية الخراطة الكهروكيميائية من أهم طرق التشغيل غيرالتقليديه ومن اهم مزاياها انتاج سطح خال من الاجهادات بالاضافة الى امكانية تشغيل اشكال هندسية معقدة ذات دقة عالية وايضا عدم حدوث تآكل لآداة القطع المستخدمة فى عملية الخراطة بطريقة التشغيل غير التقليديه ولكن العيب الوحيد هو صعوبة التحكم فى دقة ابعاد الشغلة وتكلفتها العالية.

تعتبر عملية الخراطة بطريقة التشغيل غيرالتقليدي عملية اكثر تعقيدا من الخراطة التقليدية ومعظم الابحاث التى اجريت فى مجال التشغيل الكهروكيميائى اغلبها على عملية الثقب ولكن القليل من الابحاث اجريت على الخراطة الخارجية

اهتم البحث بعمل نموذج مصغر لماكينة تشغيل كهروكيميائية لاجراء عملية الخراطة الخارجية عليها ويدرس البحث نتائج التجارب التى اجريت على أداء عملية الخراطة الكهروكيميائية ECT.

يدرس البحث تاثير معدل التغذية وفرق الجهد ومساحة مقطع الالكترود وسرعة دوران العمود الدوار على كل من معدل ازالة المعدن وصلادتة وايضا درجة خشونة السطح وذلك على نموذج مصغر لماكينة خراطة مثبت بها الكترود من النحاس على عينات من الصلب الطرى باستخدام ملح نتريت الصوديوم نسبة تركيزة 25% بمعدل تدفق 27 لتر/دقيقة تحت ظروف تشغيل مختلفة. ايضا البحث يدرس كيفية التحكم فى المدخلات او المتغيرات كمعدل التغذية عن طريق التحكم فى سرعة المحرك ذو التيار المستمر وايضا التحكم فى السرعة الدورانية للشغلة عن طريق استخدام محول بترددات مختلفة كى تعطى سرعات مختلفة للمحرك المركب عليه العينة وايضا التحكم فى الفجوة الموجودة بين الالكترود والعينة عن طريق المحرك الخطوى وذلك عن طريق التحكم فى عدد الخطوات الخارجة من دائرة المؤائمه.

كما تهدف الدراسة الى فهم اداء عملية الخراطة الكهروكيميائية وايضا تحديد شروط التشغيل اللازمه لإنتاج سطح ذو جودة معينة وذلك باستخدام معادلات تم استنتاجها من النتائج العملية عن طريق استخدام برنامج الماتلاب باستخدام طريقة سطح الإستجابة باستخدام صندوق الادوات (rstool) واقتراح معادلة تحتوى على جميع المتغيرات معتمدة على النتائج العملية.

جامعة بنها

كلية الهندسة بشبرا

التحكم فى عملية التشغيل الكهروكيميائيه

رسالة مقدمة للحصول على درجة

الماجستير فى الهندسة الميكانيكية

من

المهندسة/ رشا محمد السيد عفيفى

بكالوريوس هندسة ميكانيكية (انتاج)

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<table>
<tr><td>ا.م.د. صابرمحمود عبد ربه
استاذ مساعد بقسم
الهندسة الميكانيكية
هندسة شبرا</td><td>ا.م.د. تامر سمير محمود
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هندسة شبرا</td></tr>
</table>

د. رؤوف توفيق فهمى

مدرس بقسم الهندسة الميكانيكية

هندسة شبرا

(2011)