EXPERIMENTAL INVESTIGATION OF MRR AND SURFACE ROUGHNESS OF EN-18 STEEL IN ECM

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This is to certify that the thesis entitled, "**EXPERIMENTAL INVESTIGATION OF MRR AND SURFACE ROUGHNESS OF EN-18 STEEL IN ECM"** submitted by Mr. K SAYAN KUMAR in partial fulfillment of the requirements for the award of *Bachelor of Technology* Degree in Mechanical Engineering at National Institute of Technology, Rourkela is an Authentic work carried out by him under my supervision and guidance.

To the best of my knowledge, the matter embodied in this thesis has not been submitted to any other university/ institute for award of any Degree or Diploma.

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ABSTRACT

Electrochemical machining (ECM) is one of the important non-traditional machining process for machining hard materials which are difficult to cut , high strength and heat resistant materials into complex shape. Electrochemical machining has vast application in Automotive, Aircrafts, Aerospace, textile industries etc. Its industrial applications has extended to drilling, deburring, grinding and polishing so studies on Material Removal Rate (MRR) and surface roughness is extremely important. Use of optimal process parameters can significantly reduce the ECM operating, tooling and maintenance cost and will produce components of higher accuracy. This paper investigates the effect and parametric optimization of process parameters for ECM of EN-18 steel alloy. The process parameter considered are applied voltage and Feed rate are optimized for getting high MRR and good surface finish by using Taguchi approach.

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CHAPTER 1

INTRODUCTION

Electrochemical machining (ECM) is one of the important non-traditional machining process for machining hard conductive materials which are difficult to cut , high strength and heat resistant materials into complex shape. ECM can cut small or odd-shaped angles, intricate contours or cavities in hard and exotic metals, such as Titanium aluminides , Inconel, Waspaloy , and high Nickel, Cobalt, and Rhenium alloys. Both external and internal geometries can be machined. Electrical current passes through an electrolyte solution between a cathode (tool) and an anode (workpiece). The workpiece is eroded in accordance with Faraday's law of electrolysis.

1.1 PRINCIPLE OF ECM :-

Electrochemical machining removes material from the work piece by electrochemical process. The working principle is anodic dissolution in which the work piece as anode and the tool as cathode. Both anode and cathode are immersed in the electrolyte and electrical applied to these electrodes. The electric conduction is obtained by the movements of ions between the anode and the cathode through the electrolyte. The current is passing through the system of arrangements which will cause the dissolution of anode. This process of electrolysis is working based on Faradays law of electrolysis. The principal of ECM for steel is shown in Figures 1.1 generally brine solution or solution of sodium chloride ($NaCl$+ H_2O) is taken as the electrolyte.

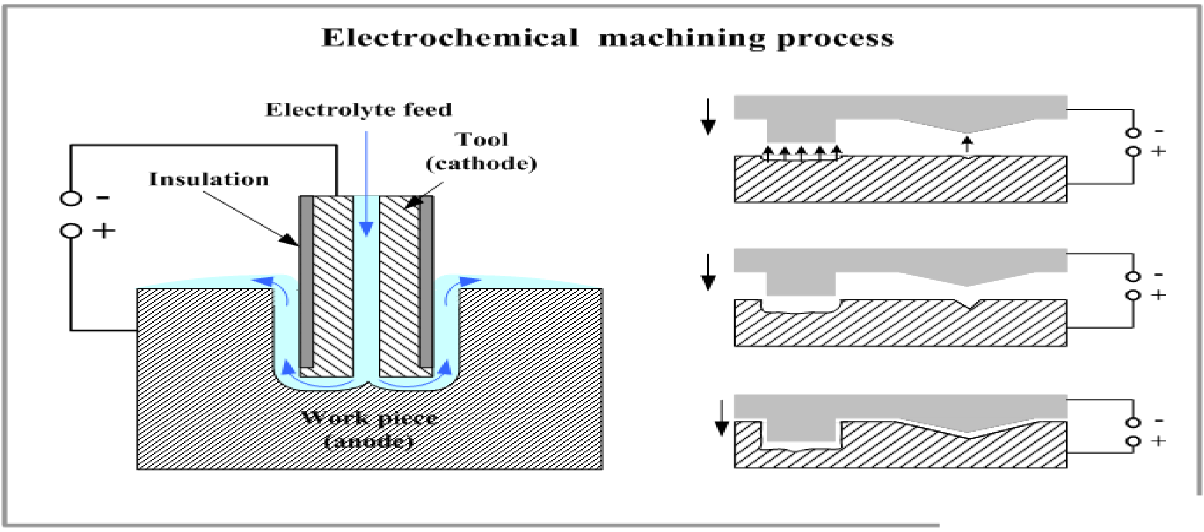

Fig. 1.1: Principle of Electrochemical Machining

Electrolyte breaks as:

$$\uparrow Na^{+} + e^{-} \leftrightarrow Na$$

$$Na + H_2O \leftrightarrow NaOH + H^{+} \uparrow$$
$$2H^{+} + 2e^{-} \leftrightarrow H_2$$

At anode:

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

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

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

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

$$Cl^{-} \leftrightarrow Cl_2 \uparrow +2e^{-}$$

$$2FeCl_2 + Cl_2 \leftrightarrow 2FeCl_3 \downarrow$$

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

$$2Fe(OH)_2 + H_2 + O_2 \leftrightarrow 2Fe(OH)_3 \downarrow$$

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

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

The metal thus dissolved as sludge.

1.2 ADVANTAGES OF ECM:-

- There is no need to use expensive alloys to make tool tougher than workpiece.
- Less tool wear.
- Less heat and stress are produced during processing that can damage the workpiece.
- MRR do not depend on hardness or toughness of workpiece.

1.3DISADVANTAGES OF ECM:-

- High tooling cost of ECM
- Electrolyte poses the risk of corrosion to tool, workpiece and equipment.
- It is not fit for machining non-conducting materials.

1.4APPLICATION:-

- Die-sinking operations
- Drilling jet engine turbine blades
- Multiple hole drilling
- Machining steam turbine blades within close limits

CHAPTER 2

LITERATURE REVIEW

In this chapter some of the selected research papers have been discussed relating to Electrochemical Machining. The studies carried out in this papers are concerned with ECM parameters such as Voltage, Feed rate, current etc and how these affects the machining characteristics like MRR, overcut, surface roughness etc.

I. Strode et al.[4] investigated the effect of ECM on the specimen made of cast and wrought steel where $NaNO_3$ is used as electrolyte. Here it is observed that the surface structure and surface finish are dependent on current density used during machining. Hardness and Tensile strength is little effected but fatigue strength is affected and it is related to current density. When machining occurs at an acceptable current density reduction in fatigue is same as it has undergone a stress-reliving heat treatment but light shot peening after ECM results in increase in fatigue strength due to reintroduction of surface compressive stress, low current density further deteriorates the surface but with modest reduction in fatigue strength.

T.A.El-Taweel et al.[5] presented an analytical approach to establish mathematical model to asses the mechanism of MRR. They used hybridization technique i.e combination of ECM and USM. This enhances the mechanical advantages and minimizes the potential disadvantage accompanied with individual technique. The effect of input parameters and machining conditions on the effectiveness of tool vibration during ECM has been investigated, Low frequency tool vibration gives beneficial effect by changing conditions in inter electrode gap. The variation in gap helps in removal of sludge and allows renewal of electrolyte in the machining gap. It also increases MRR and good surface finish is obtained.

M.S.Hewidy et al.[6] developed a technique to utilize a simultaneously moving and rotating electrode to remove a specific amount of material from pre-machined holes and rods of hardened steel specimens. One of the electrodes was provided with two simultaneous movements, traverse speed and rotational speed. Mathematical model has been proposed. The accuracy and productivity of ECM process with rotating electrodes are not only influenced by average electrolyte flow rate but also by cross-section of inter electrode gap. This technique has given good finish to outer and inner surface providing high surface quality by low cost operation. Here experimental results revealed that this technique could lead to super finishing process.

D.Chakradhar et al.[2] investigated the effect and parametric optimization of process parameters for ECM of EN 31 using grey relation analysis. Voltage, feed rate and electrolyte concentration were considered as a process parameter and are optimized with considerations of MPCI including MRR , overcut, cylindricity error and surface roughness. ANOVA is performed to get contribution of each parameter on the performance characteristics and it was observed that Feed rate is the significant parameter which affects the ECM robustness.

Aim Of The Present Work:

The main aim of this thesis is to investigate MRR and surface roughness on EN-18 steel as work piece in brine solution using Taguchi approach.

CHAPTER 3

EXPERIMENTATION

In this chapter experimentation is discussed which includes work piece and Machine specification, formation of L-9 orthogonal array using Taguchi design, calculation of MRR and surface roughness.

3.1 EXPERIMENTAL SET UP :-

Experiments were conducted on ECM set up from Meta-tech Industry It has input supply of 415V ± 10%, 3 phase AC, 50 HZ and output supply is 0-300A DC. Polarity of work piece is set as negative and the electrode as positive, It has servo motorized vertical up/down movement of tool, electrolyte supplying arrangement, it also consists of work piece and tool holder and X-Y working table.

Fig. 3.1 ECM setup.[8]

3.1.2 CONTROL PANEL

On control panel we set required parameters i.e. voltage(V), feed rate(F) and time(T).

Fig. 3.2 Control panel[8]

3.2 Specification Of Workpiece :-

EN-18 alloy is selected for experiment workpiece and is circular in shape 5 pieces of EN-18 steel is used to conduct 9 experiment.

3.1 Chemical composition :-

Element	**C**	**Mn**	**Si**	**S**	**P**	**Cr**
Weight%	.35 - .45	.60 - .95	.10 - .35	.040	.040	.85 - 1.15

Density= 7.84g/cm^3

3.3 MRR

Electrolysis is the basis of removal of material in ECM process. It occurs due to anodic dissolution of metal. It can be calculated as the ratio of the difference in weight of workpiece to machining time and density of material.

$$MRR = \frac{W_i - W_f}{T x \rho}$$

Where

W_i = initial weight before machining
W_f = final weight after machining
T = machining time (15 min)
ρ is the density of EN-18 steel = 7.84g/cm^3

3.4 Evaluation of Surface Roughness

Surface roughness was measured using

Talysurf profilometer (Model: Taylor Hobson, Surtronic 3+)

It is measured in μm.

Arithmatic mean of three reading was taken.

3.5 Selection of machining parameter and there levels:-

In this experimental plan it has two controllable variables namely, feed rate and applied voltage. In this machining parameter design three levels of cutting parameter were selected

Table 3.2 ECM process parameters

	Process parameter	Level1	Level2	Level3
A	Feed rate(mm/min)	0.10	0.20	0.30
B	Voltage(v)	10	12	14

Experimental layout using L_9 orthogonal array using MINTAB

Table 3.3 **L_9 orthogonal array**

StdOrder	RunOrder	PtType	Blocks	Voltage (v)	F (mm/min)
9	1	1	1	14	0.3
4	2	1	1	12	0.1
5	3	1	1	12	0.2
3	4	1	1	10	0.3
6	5	1	1	12	0.3
7	6	1	1	14	0.1
1	7	1	1	10	0.1
2	8	1	1	10	0.2
8	9	1	1	14	0.2

3.6 Experimental procedure:-

- Initial weight of the workpiece was measured before starting the experiment.
- Workpiece and tool was fixed in the chamber
- After setting the control parameter experiment was conducted for 15 min.
- Final weight of workpiece was measured
- MRR was calculated
- Surface roughness was measured using talysurf profilometer.

3.7 Observation:-

Table 3.4 Observation

Run	Initial weight	Final weight	voltage	Feed rate	MRR	Surface roughness
1	59.549	54.471	10	0.1	43.18	2.6
2	84.56	81.412	10	0.2	26.77	6.73
3	88.144	82.266	10	0.3	49.98	4.2
4	68.859	66.377	12	0.1	21.1	2.87
5	91.234	87.793	12	0.2	29.26	4.2
6	87.793	81.232	12	0.3	55.79	7.0
7	66.377	62.759	14	0.1	30.765	2.6
8	82.265	76.404	14	0.2	49.838	4.2
9	81.412	77.183	14	0.3	35.96	6.73

3.8 Sample calculation:-

$$MRR = \frac{W_i - W_f}{Tx\rho}$$

$$MRR = \frac{59.549 - 54.471}{15x0.00784}$$

So, MRR= 43.18 mm^3/min

3.8 Conclusion:-

Experiments were conducted in Taguchi method, control factors voltage and feed rate were varied for above 9 experiments after that MRR and surface roughness were measured.

CHAPTER 4

RESULT AND DISCUSSION

In this chapter analysis and discussion of responses which are surface roughness and MRR are discussed

Table 4.1 Observation table

StdOrder	RunOrder	PtType	Blocks	V	F	MRR	SR
9	1	1	1	14	0.3	35.96	6.73
4	2	1	1	12	0.1	21.1	2.87
5	3	1	1	12	0.2	29.26	4.2
3	4	1	1	10	0.3	49.98	4.2
6	5	1	1	12	0.3	55.79	7
7	6	1	1	14	0.1	30.765	2.6
1	7	1	1	10	0.1	43.18	2.6
2	8	1	1	10	0.2	26.77	6.73
8	9	1	1	14	0.2	49.838	4.2

4.1 Analysis and discussion of MRR

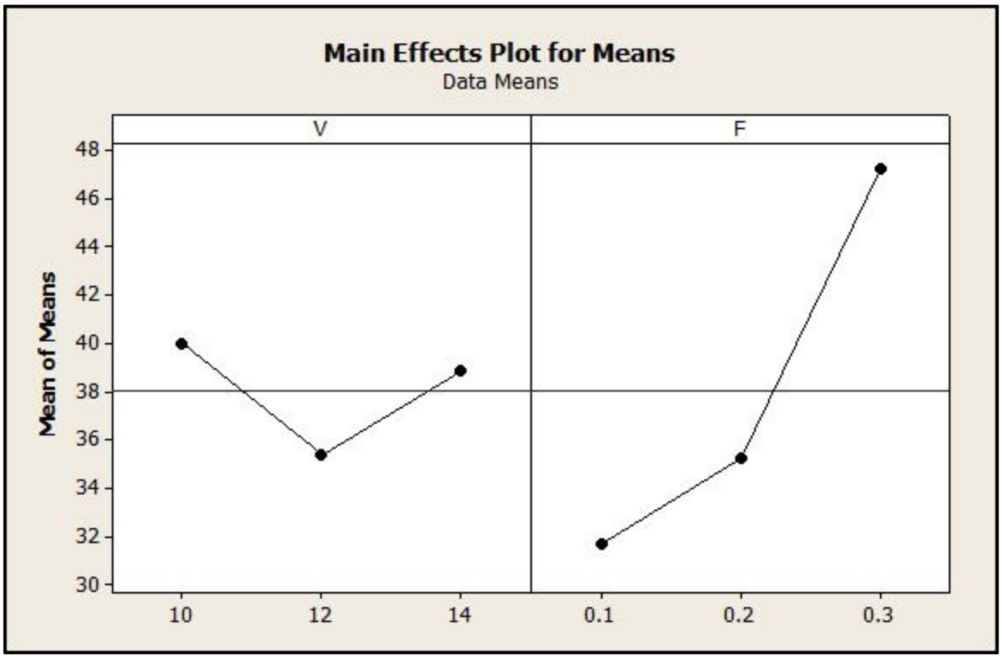

Figure 4.1 Main Effects Plot for MRR

MRR increases as feed rate increases from 0.1 to 0.2 and MRR becomes even higher from 0.2 to 0.3. There is decrease in MRR when voltage changes from 10 to 12 and increases from 12 to 14 but theoretically MRR should increase with increase in voltage.

Table 4.2 **Estimated Model Coefficients for Means**

Term	**Coef**	**SE Coef**	**T**	**P**
Constant	38.071	4.531	8.403	**0.001**
V 10	1.905	6.408	0.297	0.781
V 12	-2.688	6.408	-0.420	0.696
F 0.1	-6.390	6.408	-0.997	0.375
F 0.2	-2.782	6.408	-0.434	0.687

S = 13.59 R-Sq = 36.9% R-Sq(adj) = 0.0%

Table 4.3 **Analysis of Variance for Means**

Source	**DF**	**Seq SS**	**Adj SS**	**Adj MS**	**F**	**P**
V	2	34.41	34.41	17.20	0.09	0.913
F	2	398.08	398.08	199.04	1.08	**0.422**
Residual Error	4	739.06	739.06	184.77		
Total	8	1171.55				

In Table 4.1.2 column 1 represent variable sources such as voltage, feed rate and interaction between these two factors. In next columns degree of freedom (DF), sum of squares (Seq SS), adjusted sum of square (Adj SS), adjusted mean of square (Adj MS), distribution (F) and probability (P) are calculated respectively. The standard deviation of errors in modelling, S= **13.59,** R^2 =36.9% which indicates that model is not capable of predicting response with higher accuracy. Since no factor gives $p<0.05$ neither voltage or feed rate is significant factor.

Table 4.4 **Response Table for Means**

level	**V**	**F**
1	39.98	31.68
2	35.38	35.29
3	38.85	47.24
Delta	4.59	15.56
Rank	2	1

In Table 4.13, the main effect of voltage and tool feed rate on MRR are Voltage (V=4.59) and tool feed rate (F=15.56) is in order of importance tool feed rate is more significant and voltage is less significant as they are ranked.

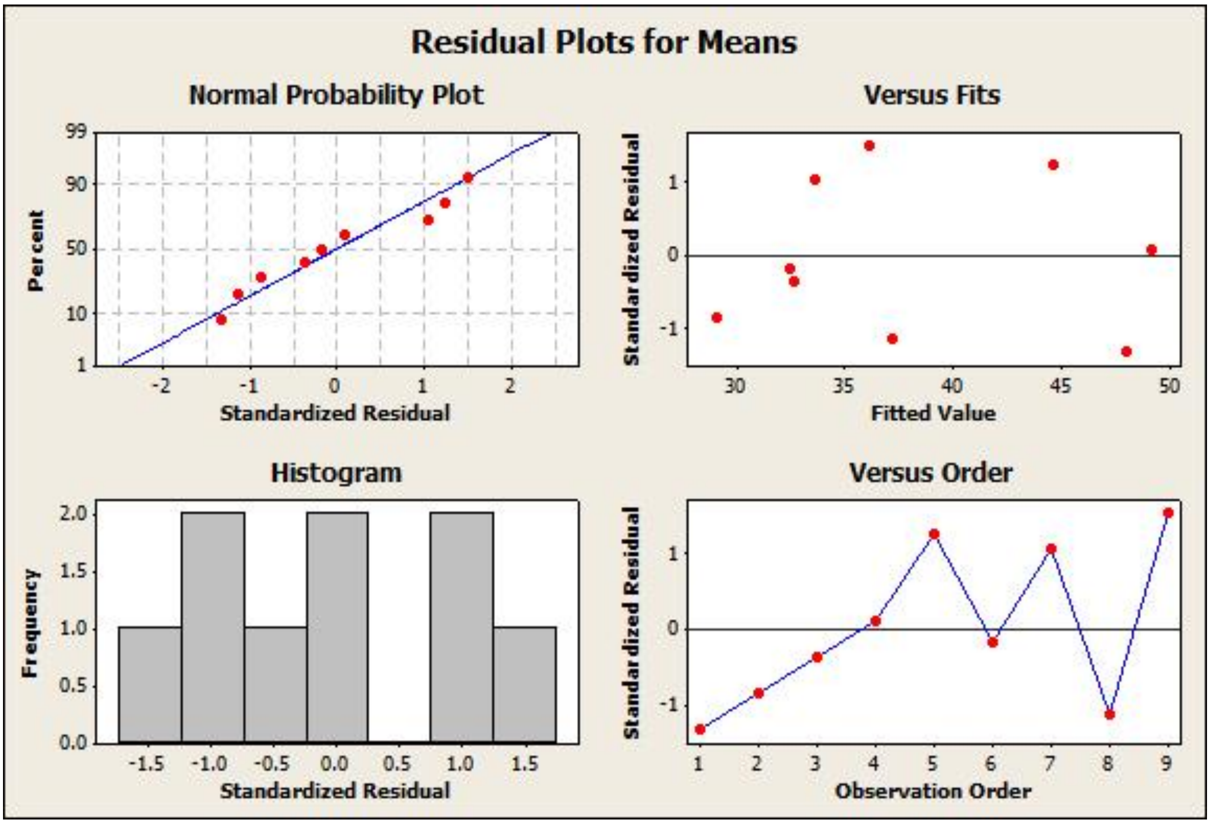

Figure 4.2 **Residual plot for means (MRR)**

The residual plot of MRR is shown in above figure 4.2. The interpretation of this figure as follows:

- Normal probability plot is distributed normally.
- Standard residues versus fits point is fluctuating randomly around zero showing no specific pattern.
- Histogram of data forms a desired skew shape.
- Standard residues versus observation order have increasing pattern form 1-4, but it is fluctuating randomly around zero showing no specific pattern hence forth.

4.2 Analysis and Discussion of surface roughness

Taguchi Analysis: SR versus V, F

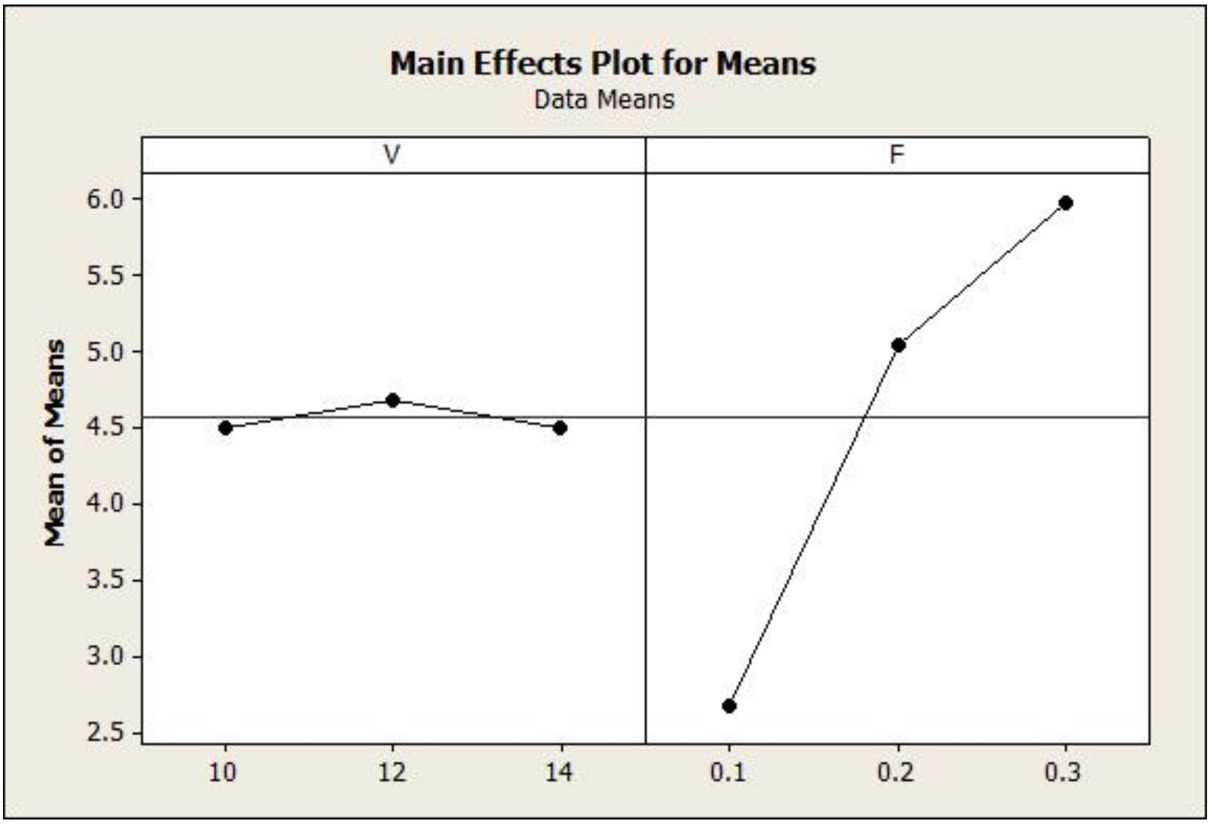

FIG 4.3 Main effect plot for SR

Surface roughness increases as voltage increases from 10 to 12 and then decreases. Surface roughness increases as feed rate increases from 0.1 to 0.3.

Table 4.5 **Estimated Model Coefficients for Means**

Term	Coef	SE Coef	T	P
Constant	4.57000	0.5006	9.129	0.001
V 10	-0.06000	0.7080	-0.085	0.937
V 12	0.12000	0.7080	0.169	0.874
F 0.1	-1.88000	0.7080	-2.655	0.057
F 0.2	0.47333	0.7080	0.669	0.540

S = 1.502 R-Sq = 65.7% R-Sq(adj) = 31.4%

Table 4.6 **Analysis of Variance for Means**

Source	DF	**Seq SS**	**Adj SS**	**Adj MS**	**F**	**P**
V	2	0.0648	0.0648	0.03240	0.01	0.986
F	2	17.2115	17.2115	8.60573	3.82	0.118
Residual error	4	9.0223	9.0223	2.25558		
Total	8	26.2986				

In Table 4.2.2 column 1 represent variable sources such as voltage, feed rate and interaction between these two factors. In next columns degree of freedom (DF), sum of squares (Seq SS), adjusted sum of square (Adj SS), adjusted mean of square (Adj MS), distribution (F) and probability (P) are calculated respectively. The standard deviation of errors in modelling, S=1.502 R^2 =65.7% which indicates that model is not capable of predicting response with higher accuracy. Since no factor gives $p<0.05$ neither voltage or feed rate is significant factor.

Table 4.7 **Response Table for Means**

Level	**V**	**F**
1	4.510	2.690
2	4.690	5.043
3	4.510	5.977
Delta	0.180	3.287
Rank	2	1

In Table 4.2.3, the main effect of voltage and tool feed rate on surface roughness are Voltage (V=0.180) and tool feed rate (F=3.287) is in order of importance tool feed rate is most significant and voltage is less significant as they are ranked.

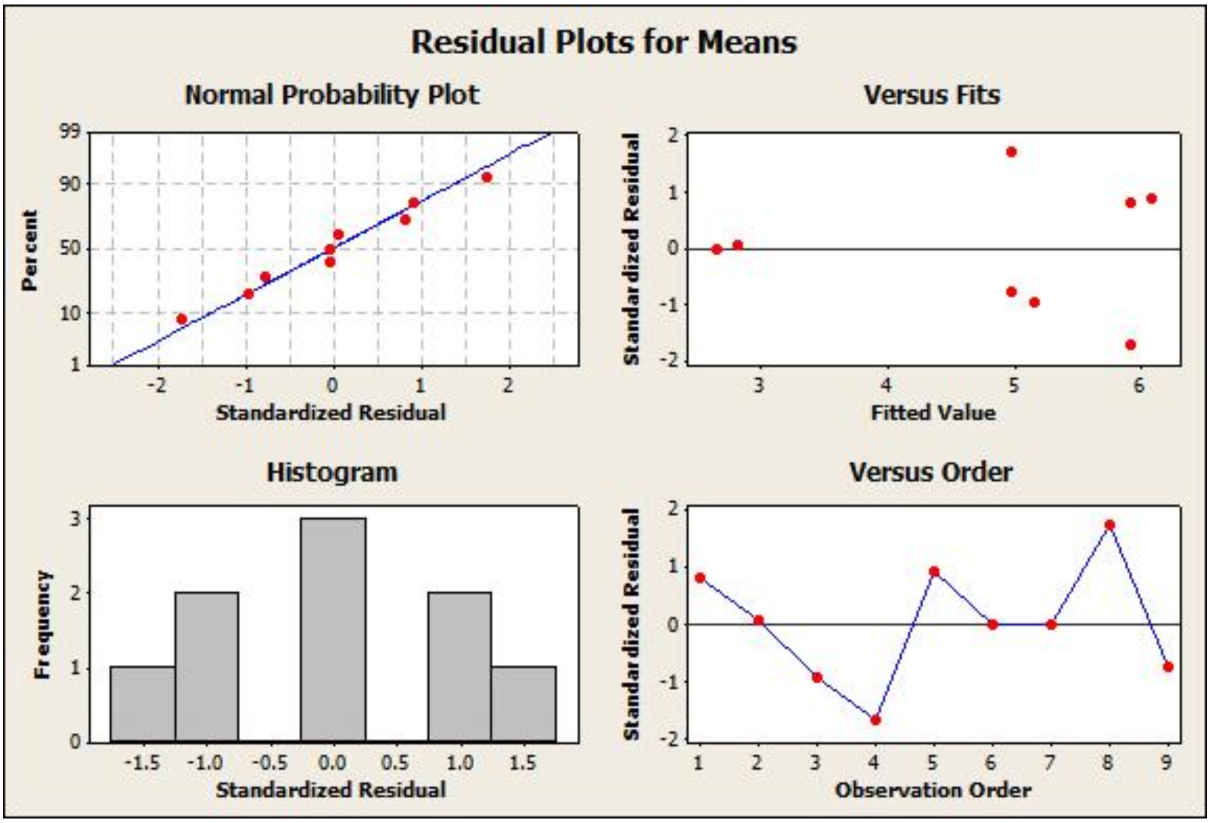

Fig 4.4 Residual plot for means(SR)

The residual plot of SR is shown in above figure. The interpretation of this figure as follows:

- Normal probability plot is distributed normally.
- Versus fits point is fluctuating with a specific pattern around zero.
- Histogram of data forms a desired skew shape.
- Standard residues versus observation order have decreasing pattern form 1-4, but it is fluctuating randomly around zero showing no specific pattern hence forth.

CHAPTER 5

CONCLUSION

In this study of ECM process experiments were conducted considering variable parameters voltage and feed rate on EN-18 alloy steel by considering Taguchi design. Nine experiments were conducted to obtain high MRR and low surface roughness. Although I didn't get any factor as significant from ANOVA table, for both MRR and surface roughness, but by looking at the response table, it was quite clear that tool feed rate was effecting most to obtain high MRR and low surface roughness. Run no 1 gives the best possible combination of process parameter i.e for f=0.10mm/min gives low SR=2.6 μm, and high MRR of 55.79 is achieved for f=0.3mm/min and 12 volts.

CHAPTER 6

APPENDIX

In this machine and equipment used will be discussed

6.1 ECM setup specification:-

Sl. No	Parameters	Specifications
1	Working gap	0.05-0.8 mm
2	Current density	5-100 A/cm^2
3	Voltage	5-30 V
4	Current	50-40,000 amp
5	Temperature	30-80 ^{0}C
6	Velocity	5-50 m/s
7	Maximum material removal rate	15×10^3 mm^3/min
8	Inlet Pressure	0.15-3MPa
9	Outlet Pressure	0.1-0.3MPa
10	Feed Rate	0.1-20mm/min
11	Electrolyte Used	Brine solution, Sodium nitrate
12	Specific power consumption	7w/mm^3/min
13	Accuracy and surface finish	0.02 mm, 0.4µm

6.2 Weight balance specification[8]:-

model	DJ 300S
Brand	SHINKO DENSHI co. LTD
Accuracy	0.001g
Capacity	300g

6.3 Talysurf profilometer[8]

Model :-Talor Hobson, Surtronic 3^{+}

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