Effect of Parameters on the Surface Roughness of Electrochemically Drilled Deep Hole Using Rotating Electrode and Stationary Electrode

D.S. Bilgi and P.V. Jadhav

Abstract:

Today, demand for the deep hole drilling is steadily increasing. As the ratio of depth to diameter increases it become extremely difficult to produce such holes. The improvement in machining accuracy of electrochemical machining (ECM) continues to be a major challenge for user industries. This study focuses on the development of a precision ECM. Process which uses rotating electrode (anode) movement with the traditional ECM. The feasibility of the proposed process has been experimentally verified. Attempts are being made to investigate optimum process parameters such as conductivity, pressure, electrode diameter etc. keeping voltage, feedrate, & rpm constant in the experimental proposed set up.

Keywords: Design of Experiment, ANOVA, surface roughness, ECM.

I INTRODUCTION

Electrochemical machining (ECM) is often used for machining complex shape and hard materials, because electrochemical dissolution process is independent of the material hardness and toughness. Additionally ECM generates no burrs, no stress, has a long tool life, high material removal rate and good surface quality. ECM process is originally designed for manufacturing complex shape components in defense and aerospace industries has been extended to many other industries such as automotive, weaponry, electrical and medical equipments.

[1] However, due to its relatively low machining accuracy, difficulties in tool design and electrolyte disposal ECM is not a commonly used technology. Hydrogen gas bubbles and Joule heat generated in the interelectrode gap (IEG) causes varying local electrolyte conductivity and hence non-uniform distribution of the gap .The stray removal in ECM adversely affects dimensional accuracy and surface quality of machined components [2]. Some flow field disrupting phenomena such as cavitations and striation in electrolyte flow worsen accuracy and the uniformity of the ECM machined products. Many attempts have made to improve machining accuracy with limited success. The progress has been slow because of the complex nature of the ECM process.

Therefore, this study addresses the improvement of machining accuracy in ECM by modifying the electrolyte flow distribution. An ECM with Rotating electrode movement is proposed to enhance the uniformity of electrolyte flow and to reduce or eliminate the flow field disrupting processes. A significant improvement in machining accuracy is observed.

II ANALYSIS OF EXISTING PROBLEMS.

An electrolytic cell consists of electrolyte, an anode work piece, and a pre-shaped cathode tool (Fig.1a). A low DC voltage is applied across the gap between the work piece and tool, resulting in high current passing through the electrolyte. The anode material is electrochemically dissolved and then flushed away by rapidly flowing electrolyte. As the dissolution process continues, the work piece becomes an approximate negative mirror image of the tool.

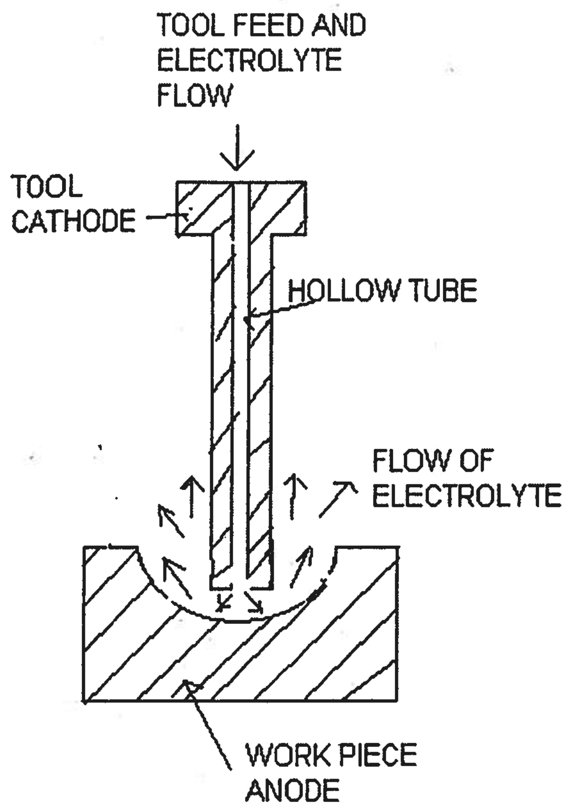


Fig.1(a): ECM Process with Stationary Tool

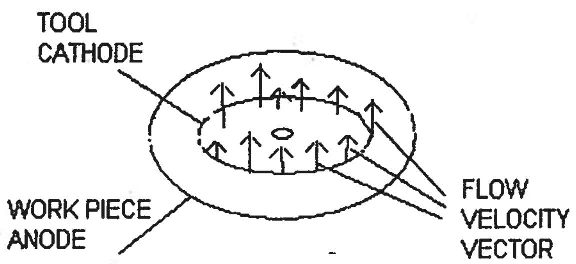


Fig.1(b) Uneven Velocity Distribution of Electrolyte during ECM

Machining accuracy in ECM critically depends on the electrolyte flow field distribution. The flow field distribution [1,3] sometimes results in abnormal dissolution (such as striated dissolution) and even sparking. In order to develop a better understanding, the electrolyte flows in the frontal machining area of ECM with forward flow as shown in Fig.b. As a first approximation, in this study assumes a constant gap, constant feed rate, speed in rpm, voltage etc

The results indicate that the electrolyte flow is subject to unusual phenomenon-cavitations. Energy stored in flowing

electrolyte is pressure energy or kinetic energy. In addition to abnormal dissolution caused by cavitations, the striated dissolution is often found in ECM of holes and cavities. This may be due to an uneven distribution of the electrolyte flow. The flow in rapid divergence spreads out radically from the center hole under the tool face. Many streams of flow develop in the direction of flow along both the front gap and the side gap. Consequently, the striated flow with different flow velocity. Takes place and causes significant non-uniform dissolution (Fig 2a&2b).

The machined surface of hole wall often shows evidence of the striation flow as observed in previous reports therefore a sharp divergent flow in ECM with a forward flow causes cavition and striation, leading to an abnormal dissolution and hence significant inaccuracy and even harmful sparking. Additionally, these phenomena are often unstable and random, and therefore, further deteriorate the uniformity of ECM products and the process stability.

III PROPOSED ROTATING ELECTRODE IN ECM AND EXPRIMENTAL SET- UP.

This study attempts to eliminate or reduce the effects of the flow field variations on machining accuracy and to improvement the process accuracy and uniformity. This study employs a rotating electrode movement of electrode to obtain uniform and stable electrolyte flow. As the electrolyte supply adversely affects the smoothness of the tool, a work piece movement instead of tool movement is used.

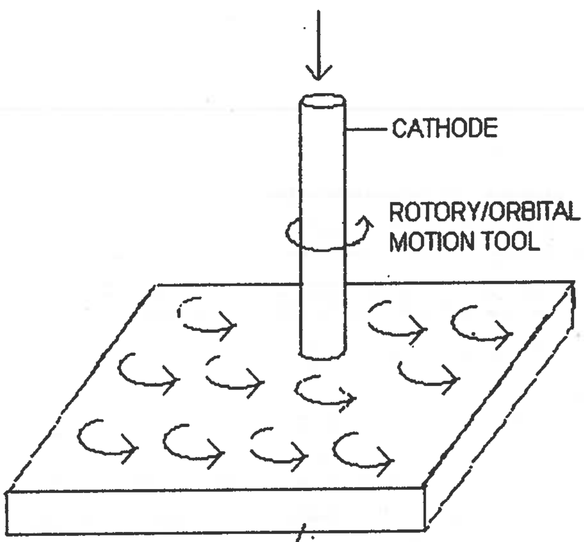


Fig 2(a): Rotational and orbital motion to ECM tooling

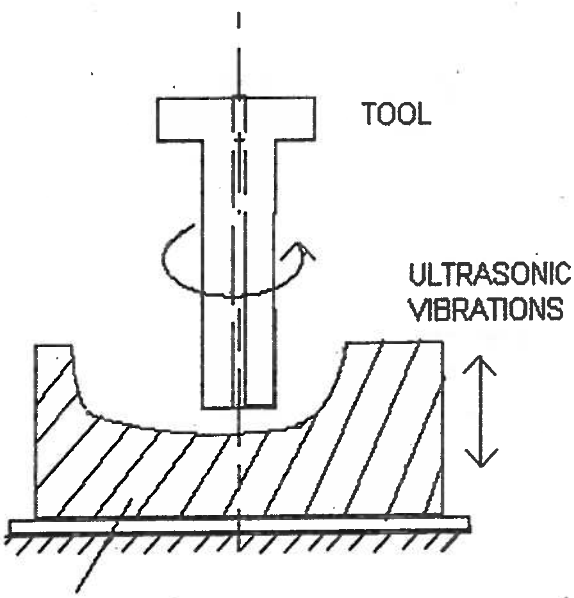


Fig 2(b): ECM tooling with ultrasonic motion

In this process, (fig.3) rotating anode movement in a, perpendicular plane to tool feed direction is provided by a specially designed horizontal rotating movement unit. Resulting in a controlled periodic variation of electrolyte flow field. The expected benefits of rotating movement of work piece are (a) shifting cavitation region; the varying flow field distribution with time and location periodically shifts cavitation region and so eliminates the dead dissolution region, (b) eliminating striated dissolution; the periodic change in flow field leads to an even distribution of electrolyte flow and eliminates striated flow and so produces uniform anode dissolution at both frontal area and side wall, (c) stabilizing machining process; the rotating electrode movement forces a constant change of the electrolyte flow instead of random fluctuations and so improves the uniformity of the machined products and minimizes the conditions leading to sparking.

Experiments on ECM drilling with and without rotating movement of anode work piece have been conducted. Experimental results were used to verify the feasibility of the rotating electrode in ECM and to compare the corresponding machining accuracy results. The experimental system (Fig.3) consists of electrolytic cell, electrolyte unit, rotating electrode movement unit, control panel unit, and power supply. The cathode tool is made of copper tube without an outer insulated coating. Its diameter is 12.5mm & maximum electrode diameter is 23.5mm. The anode work piece is mild steel; Electrolyte of Sodium Nitrate (160 g/1) was kept at 30 degree Centigrade. Continuous Direct current power supply was used. ECM drilling occurs at the centerline of the work piece. After machining, the surface roughness value is measured with the help of surf test equipment. Surface roughness produced on the work pieces by using the rotating electrode & stationary electrode was measured with "Surface Roughness Tester SJ 201P with cut off length of 0.8 x 3 (i.e. 2.4 mm evaluation length).

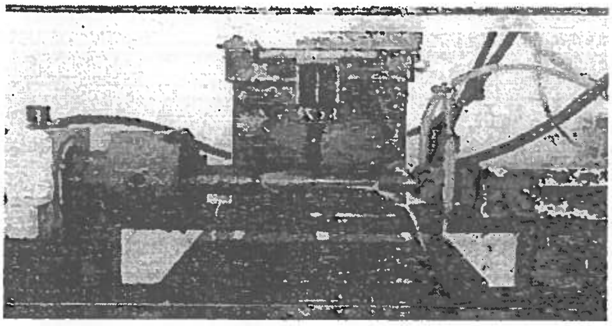


Fig. (3) Experimental set-up of ECM

The rotating movement is implemented by using a electric motor. The stepping motor provides a rotational movement. The output of the rotational unit is connected with a work piece holder. All parts of the rotational device in contact with electrolyte are made corrosion resistant materials such as stainless steel or plastic.

The experiments were conducted on an industrial ECM system (14V, horizontal feed). During experiments, constant machining voltage 14V and constant feed rate 0.75 mm/min were used. Work piece rotating movement is 150rpm. In order to minimize the initial transition time of machining process, the initial gap was set equal to the theoretical equilibrium-machining gap. The machining depth was about 3-4 mm. More than 16 experiments of rotating movement of electrode & stationary electrode in ECM and traditional ECM have been conducted to verify the feasibility of the proposed rotating electrode in ECM and assess the effect of the process on machining accuracy in terms of surface roughness using ANOVA method.

IV EXPERIMENTATION.

Specifications of Machine Tool:

Electro Chemical machining unit PDS-100 A make by sparkonix Engg. Work, Pune.

Technical specifications; Power rating 3 kva, Working voltage 415 v/ 3 phase, T slot area: 220x 180 mm, Vertical travel of electrode: 100 mm, Horizontal travel of electrode: 100 mm, Chuck: 125 mm, Coolant pump capacity: 20 liters per min Electrolyte tank capacity: 175 liters, Settling tank capacity: 125 liters, Electrode sizes: To be selected depending upon dimensions of work piece

ECM Tooling

The ECM tooling is approximately the mirror image of the machined area of the completed part. The tool dimensions are slightly different to allow for over cut (side and front machining gaps) which can range from 0.025 to 0.5 mm depending upon the feed rate; electrolyte flow etc. The side over cut is about 1.5 times the front gap. The size correction of a die-sinking ECM tool is more complex than in a simple, generating ECM tool (for example drilling. trepanning or similar operations.)

Surface Roughness Measurement.

Surface roughness produced on the work pieces by using the rotating electrode was measured with "Surface Roughness Tester SJ 201P with cut off length of 0.8 x 3

a) Electrode diameter- A (mm)

b) Pressure - B (kg/cm^2.)

c) Conductivity C (mho/mm)

Table 1 Experimental Condition

Parameters	Nomenclature	High (+1)	Low (-1)
Electrode diameter (mm)	A	23.5	12.5
Pressure (kg/cm^2.)	B	3.0	2.5
Conductivity (Mho/mm)	C	91	84.6

By considering these three parameters A, B and C are variables. Now, we consider that the surface roughness is a function of above all three parameters.

ANALYSIS OF EXPRIMENTS.

Table2. RESULTS (Stationary Electrode)

Sr. No.	Electrode diameter (mm)	Pressure (Kg/cm^2)	Conductivity (Mho/mm)	Surface Roughness (μm)
	A	B	C	R_a
1	-1(12.5)	-1(2.5)	-1(84.6)	2.45
2	-1	-1	+1(91)	2.14
3	-1	+1(3.0)	-1	2.20
4	-1	+1	+1	2.10
5	+1(23.5)	-1	-1	2.33
6	+1	-1	+1	2.11
7	+1	+1	-1	2.02
8	+1	+1	+1	2.00

Table 3. RESULTS (Rotary Electrode)

Sr. No.	Electrode diameter (mm)	Pressure (Kg/cm^2)	Conductivity (Mho/mm)	Surface Roughness (μm)
	A	B	C	R_a
1	-1(12.5)	-1(2.5)	-1(84.6)	0.99
2	-1	-1	+1(91)	0.82
3	-1	+1(3.0)	-1	0.92
4	-1	+1	+1	0.84
5	+1(23.5)	-1	-1	0.80
6	+1	-1	+1	0.79
7	+1	+1	-1	0.82
8	+1	+1	+1	0.80

The response was analyzed using F- test of ANOVA (Analysis of variance) at 95 % level of confidence. The final table of ANOVA is shown below.

Table 4: FINAL ANOVA TABLE (Rotary Electrode)

Sr. No.	Factor	Sum of Squares	Degrees of Freedom	Variance or Mean Square	F_o
1	A	0.0162	1	0.0162	22.34
2	C	0.0098	1	0.0098	13.51
3	AC	0.00605	1	0.0060	8.34
5	Pooled Error	0.0029	4	0.0007	

V (variance) or MS (mean square), v is degrees of freedom, and F_o is F ratio. Now, in calculation of F ratio;

$$\frac{SS_A / v_{factor}}{SS_E / v_{Error}} = \frac{MS_{factor}}{MS_{Error}} \quad \text{.......} \quad (a)$$

Degrees of Freedom for numerator =1, Degrees of Freedom for denominator = 4 Therefore F - distribution Table, for 95% Level of Confidence we find that F value is $F_{0.05,1,4} = 7.71$ i.e. $F_{limit} = 7.71$ since all the F values in the Table 4 are greater than the limiting value of F ratio, we reject the Null Hypothesis at 5 % Level of Significance and conclude that, surface roughness parameters.

1. A Electrode diameter,
2. C Conductivity,
3. AC Interaction between electrode diameter and conductivity

Have significant effect on surface roughness (at 5 % Level of Significance)

Final Equation in terms of coded factors

Therefore final equation in terms of coded factors can be given as for stationary electrode

Surface Roughness = 2.17 + (-0.11) x A + (-0.081) x C + (0.029) x AC.................(b)

Final Equation in Terms of Actual Factors

Therefore final equation in terms of coded factors can be given as:

Surface Roughness = +2.16625 0.11375 x A -0.081250 x C + 0.028750 x A x ....(c)

Final Equation in terms of coded factors for (Rotary electrode)

Therefore final equation in terms of coded factors can be given as:

Surface Roughness = +0.8475 + (-0.045) x A + (-0.035) x C +(0.027) x AC...............(d)

Final Equation in Terms of Actual Factors

Therefore final equation in terms of actual factors can be given as:

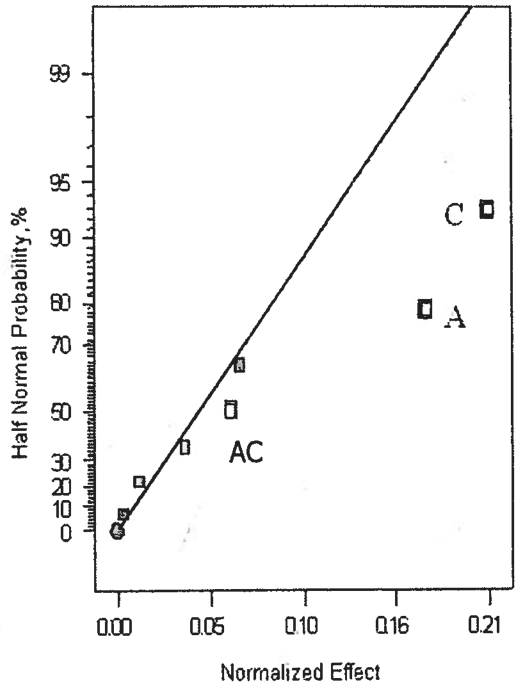
Surface Roughness = +0.84750 0.045000 x A -0.03500 x C + 0.027500 x A x C..............(e)

V RESULTS AND DISCUSSION

As stated previously, the surface roughness can be related to many factors such as electrode diameter, pressure & conductivity. A DoE (design of experiment) based study conducted in the present work that includes above-mentioned three important factors has come up with many important results. A multiple linear regression model that includes some of the very important factors in predicting surface roughness has been developed. Using the model presented here, one can select the optimum combination of electrode diameter & conductivity parameters for better performance of surface roughness

Selecting the Factors for Mathematical Modeling

A Normal Probability plot of the estimates of the effects can be used in selecting the most influential factors. The effects that are negligible are normally distributed, with mean zero and variance σ^2 and tend to lie along a straight line on this plot, whereas significant effects will have non-zero means and will not lie along the straight line. Thus the mathematical model will be specified to contain those effects that are apparently non-zero, based on the Normal Probability plot.



A: Electrode Diameter
B: Pressure
C: Conductivity

Fig. 4.: Half Normal Probability Plot for Effect Estimates.

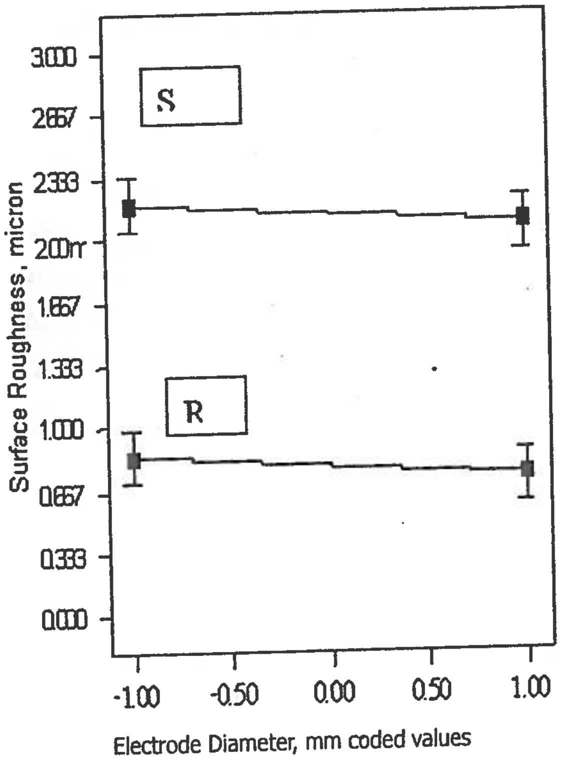
From the data obtained for this study, the normal probability plot as shown in Fig. 4 can be constructed to pick the significant effects. After examining the Fig. 4 the factors selected for the mathematical modeling are main factors A, B & C and interaction between A & C. A multiple linear regression model developed considering these factors is presented.

Model Adequacy Checking By Checking The Normality Assumption:

During ANOVA while testing the appropriate hypothesis about treatment means, the model errors are assumed to be normally and independently distributed random variables with mean zero and variance σ^2, implying that the observations are from normal population and are mutually independent. If these assumptions are valid, the ANOVA procedure is an exact test of hypothesis of no differences in treatment means. This normality assumption can be checked using the Normal plot of Residuals. 'Residual or Error' for each experiment is the difference between the practical or actual value of response variable and predicted value of the response variable. If the NID $(0, \sigma^2)$ assumption on errors is satisfied, this plot resembles a straight line. we can get the normal plot of Residuals as below.

Main Effects and Interaction Plots

Fig. 5 to Fig. 6 gives the main factor effects for factors A, B & C and interaction between factors A and C.



S: Stationary Electrode
R: Rotating Electrode

Fig. 5 : Electrode diameter vs. surface roughness

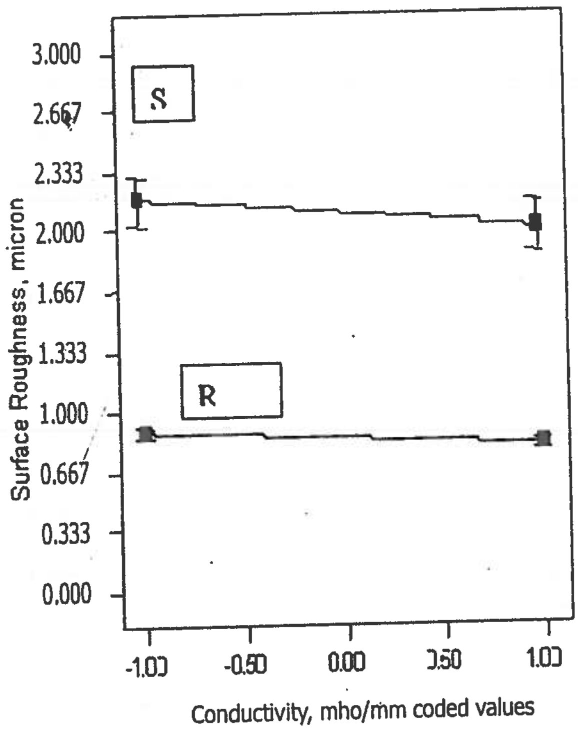


Fig. 6 : Conductivity vs. Surface Roughness
S: Stationary, R: Rotating

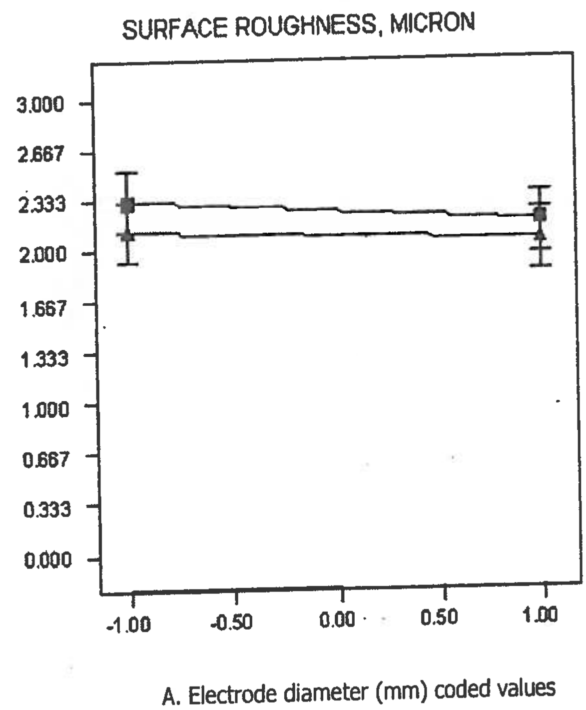


Fig. 7 Conductivity vs. Surface Roughness

-1 = Coded value of Conductivity (84.6 Mho/mm)
+1 = Coded value of Conductivity (91. Mho/mm)

Interaction Graph

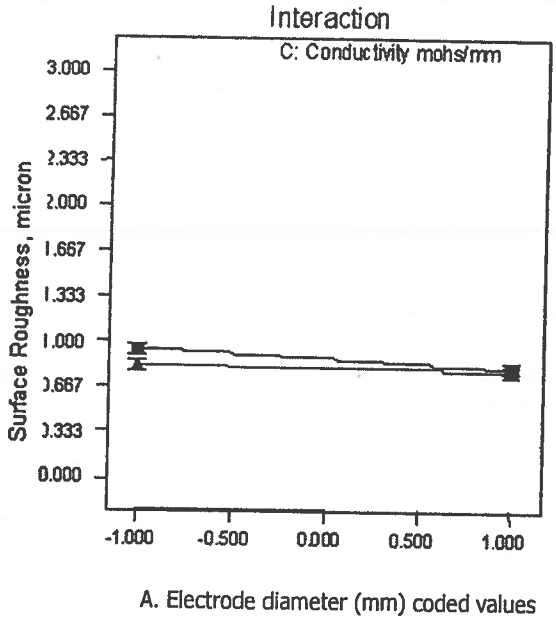


Fig. 5 : Electrode diameter vs. Ra
(Stationary Electrode)

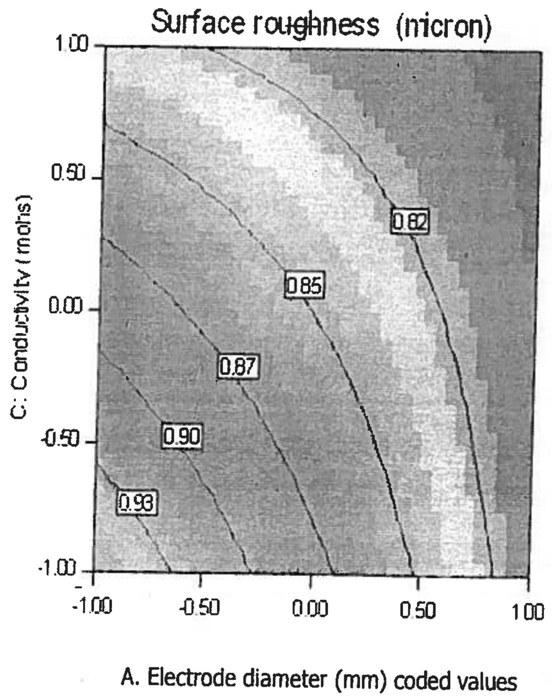


Fig. 6 : Electrode diameter vs. conductivity

Combined Effect of Various Parameters:

Graph 6 & 7 gives the contour lines of constant response variable - y (surface roughness) in the x_1, x_2 plane. From these contours, we can select a proper combination of process parameters for obtaining the required surface finish. Contour Plot of Interaction AC.

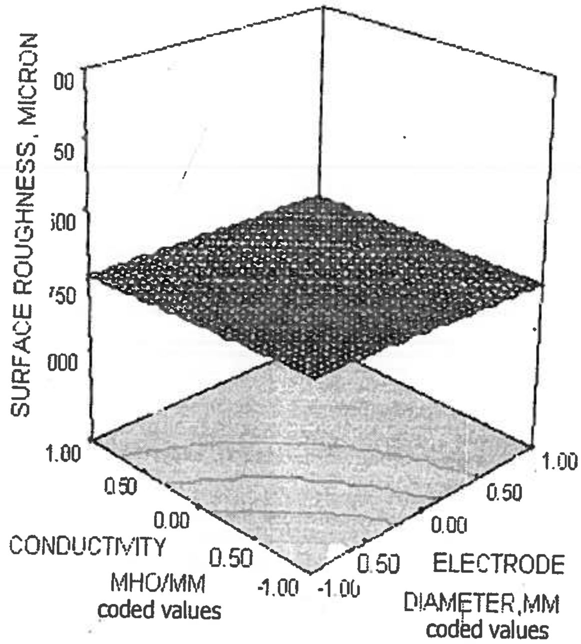
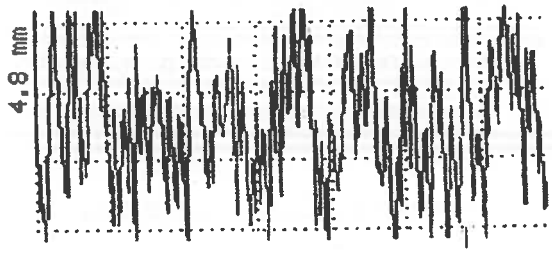


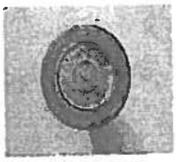
Fig. : 7 Electrode diameter vs. conductivity (Stationary electrode)

Surface Response Plots

Similar to contours plots, combined effects of various process parameters can be better visualized with the help of three dimensional response surface plots. A response surface is a plane of y values (response variable values) generated by various combinations of x_1 and x_2. Fig. 7 gives these plots for various combinations. Surface response of interaction AC

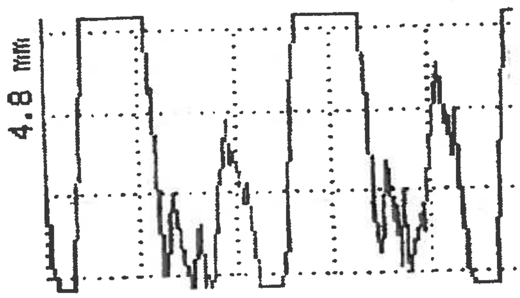
Comparison of Stationary & Rotating Electrode

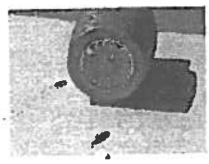




(Rotating electrode work piece)

COMMENTS: ACTUAL OBSERVED Ra = 0.79 MICRON (rotating electrode, surface roughness value as shown in above graph)





(Stationary Electrode work piece)

COMMENTS: ACTUAL OBSERVED Ra = 2.00 MICRON (stationary electrode, surface roughness value as shown in above graph.)

CONCLUSION

'Enhancement of surface finish of electrochemically (EC) drilled deep hole using rotating electrode" taking input parameters as electrode diameter, pressure & conductivity and output parameters as surface roughness following facts can be concluded.

1] When the Electrode diameter & conductivity increases the surface roughness value is decreased. Keeping Voltage, rpm, and feedrate constant.

2] When stationary electrode is compare to the rotating electrode. The rotating electrode gives better Surface finish than the stationary electrode.

3] Increase in pressure (B) has no effect on surface roughness value.

4] The interaction between A (electrode diameter) and C (conductivity) is important for the response of surface roughness. Regression analysis shows that % contribution of this interaction for electrode diameter is 35.59% while that for conductivity is 41.02%.

5] From ANOVA analysis, it is found that A, C, and AC are more important factors of surface roughness performance. Author does not claim that pressure is a neglected factor. While the compare between rotating & stationary electrode the rotating electrode is better surface finish.

REFERENCES

[1] J. F. Wilson, Practice and theory of Electrochemical Machining, johns Wiley & Sons Inc.1971.

[2] O.V. KRISHNALAL CHETTY, Dr. V. RADHAKRISHANAN. "A study of surface production in electrochemical machining." Proceedings of the 8th AIMTDR conformance IIT Bombay, pp.no.562 (1978)

[3] K.P.RAJURKAR, D. ZHU, B. WEI. "Minimization of machining allowance in electrochemical machining" Annals of the CIRP volume 47/1, pp. no. 165 (1998).

[4] K.P.RAJURKAR, D. ZHU. "Improvement of electrochemical machining accuracy by using orbital Electrode movement" Annals of the CIRP volume 48/1, pp. no. 139 (1999).

[5] D.S Bilgi,. (PhD thesis) "ECM deep drilling IIT Kanpur. (2004)

[6] D.S.Bilgi, V.K.Jain, Sekhar R., Mehrotra. S., "Electrochemical deep hole drilling in super alloy for turbine rotor, Journal of material process technology" vol. 149 .pp 445 (2004).

[7] S. K. MUKHERJEE, S. KUMAR, P.K.SHRIVASTAV. "Effect of electrolyte on current carrying process in electrochemical machining." AMTEG 2 national conference in advertising in manufacturing tech. In the Era of globalization, PIET Pune & I.I.P.E. Pune. Pp. no. 349 (2005).

[8] DOUGLAS C. MONTGOMERY, "Design and Analysis of Experiments", John Wiley and Sons, Prentice Hall Publication.

NOMENCLATURE

A	Electrode diameter (mm)
B	Pressure (kg/cm^2)
C	Conductivity (Mho/mm)
ó^2	Population variance,
N	Total number of observations,
y_i	ith observation or response data, i = $1,2,3,\ldots\ldots N$
i	Number of levels for each factor,
A_i	Sum of observations under ith level,
$\bar{A}_i$	average of observations under level, Average of all observations,
T	sum of all observations,
$\bar{T}$	Average of all observations,
n_{Ai}	number of observations under A_i level,
k_A	number of levels or treatments for factor
k_B	number of levels or treatments for factor
SS_A	Sum of square for factor A.
í	Degrees of freedom
CF	Correction factor
Ra	Surface roughness

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