International Journal of Computer Communication and Information System (IJCCIS)
– Vol2. No1. ISSN: 0976–1349 July – Dec 2010

Enhancement of surface finish of Pulse Electrochemically Machined (PECM) surface using rotating electrode

Dr. D. S. Bilgi[1,] Mr. P. V. Jadhav[2]

[1]Principal, B. V. Women's College of Engineering, Pune, India, Pin: 411043
[2]Research Scholar, Department of Mechanical Engineering,
B. V. U., College of Engineering, Pune, Maharashtra, India, Pin: 411043
E-mail: pvjadhav_19@rediffmail.com

Abstract - **The Electrochemical Machining (ECM) is widely used in machining variety of components used in aerospace, automotive, defense, and medical applications. Due to low machining accuracy ECM is yet to be a best alternative process. ECM with pulse current offers an enhanced accuracy control. This paper presents experimental investigation of PECM parameters such as Voltage, Pulse on time and duty cycle on surface enhancement by rotating electrode (cathode tool) arrangement. This results shows PECM with rotating tool has enhanced surface by 50 % as compared to stationary tool in PECM. (1.2 to 0.7 micron). The design of experiments was done by 2^k factorial designs. The experimental results were analyzed by analysis of variance (ANOVA) method and by plotting various graphs**.

Keywords - ANOVA, Design of Experiment, PECM, Rotating tool movement, surface roughness.

I. INTRODUCTION

Electrochemical machining (ECM) process is generally used for machining complex shape and hard materials, ECM generates no burrs, no internal stress, has a long tool life, higher material removal rate and surface quality.

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 [1].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'd products. Electrochemical machining is an anodic dissolution process with employ, low D.C voltage across pre-shaped cathode tool and anode workpiece.ECM with pulse current yield higher accuracy, control [4]. Many attempts have made to improve machining quality with limited success.

The progress has been slow because of the complex nature of the ECM process.

Therefore, this study addresses the improvement of quality of surface finish 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 surface finish is observed.

II. ANALYSIS OF EXISTING PROBLEMS

The Machining accuracy in ECM largely depends on the electrolyte flow field distribution. The low field distribution [3] sometimes results in abnormal dissolution (such as striated dissolution). The machined surface of hole wall often shows evidence of the striation flow due to sharp divergent flow in IEG. And even sparking causing cavitation and striation. Additionally, these phenomena are often unstable and random, and therefore, further deteriorate the uniformity of ECM products and the process stability.

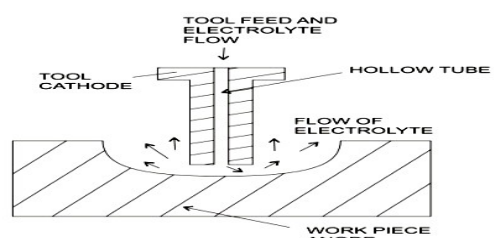


Fig. (1)ECM Process with stationary tool

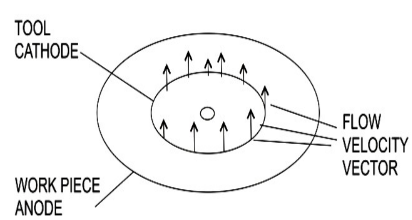


Fig. 1(b) Uneven Velocity Distribution of Electrolyte during ECM

III. PROPOSED ROTATING ELECTRODE IN PECM

This study attempts to reduce the effects of the flow field variations to achieve higher process accuracy and uniformity by rotating cathode(tool) and employing ECM with pulse current(PECM). Rotating electrode (cathode tool) fig.2. Yields shifting of cavitation region due to continuously varying flow field distribution in IEG and eliminates dead dissolution region and striation so produces uniform anode dissolution at both frontal area and side wall stabilizing machining process; the rotating electrode movement forces a constant change of the electrolyte flow and so improves the uniformity of the machined surfaces and reduces sparking actions [3].

Pulse power generator to supply working voltage across the gap between the cathode and anode. By applying voltage pulses, having short pulse on time, all the experiments were conducted. It uses small initial electrode gap of 0.1mm for all experiments. Electrochemical dissolution takes place during on time (t_{on}), [5, 6] while no dissolution takes place during off-time (t_{off}) pulse t_{off} allow the electrolyte to carry away the reaction products of anodic dissolution from the gap.

Drilling was carried out with a constant tool feed rate as shown in fig (2). Experimental results were used to verify the feasibility of the rotating electrode in ECM and to compare the corresponding machining accuracy results.

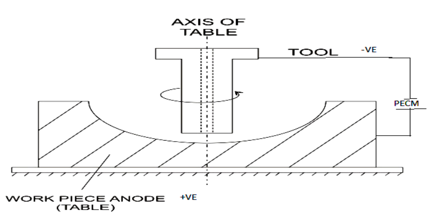


Fig.2. Rotating tool movement PECM & Gap distribution.

IV. EXPERIMENTAL SET UP

The experimental set-up used for small hole drilling (2-3mm diameter) is as shown in the fig.3.It consists of (i) tool feed arrangement (Rotating tool/ stationary tool), 2) Machining chamber, 3) Electrolyte flow system and 4)Pulse power supply. Experiment where conducted using mixed electrolyte (170 gm/lit) 10% by Wt HNO3/ NaNo3 to avoid wild corrosion and sludge formation during the process [].Current sensing comparator was incorporated into the tool feed arrangement to avoid short circuiting between tool and work piece, stepper motor controls the tool feed arrangement along z axis. Servo motor rotates about z axis. Machining chamber consist of table, work holding device, blow off system. Electrolyte flow system used anticorrosive submersible pump, electrolyte filter, electrolyte tank, pressure gauge and constant discharge flow control valve. Pulse power supply with constant voltage (CV) made of rectangular pulsed shape was chosen. PECM provides smaller IEG without boiling of electrolyte in gap,(3) 1995 R, That necessitate limiting the valve of IEG across tool and work piece. Pilot experiments with smaller IEG (0.1mm) suffered due to short circuiting between work piece and tool, because of cavitation and sludge formation. The limiting current, to avoid short circuiting, was compute for controllable IEG, electrolyte conductivity and are of tool, and of operating voltage. [5] Using stationary and rotating tool feed arrangement. The sufficient electrolyte (Q=12lit/min) was maintained and hole (10 to 15mm) drilled using stainless steel work piece.

Using full factorial design (2^3) all the experiments were conducted for stationary and rotating tool arrangement.

After machining, the surface roughness value was 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”.

Specification of Machine

PECM power supply technical specifications; Power rating 3 kva, Working voltage 415 v/ 3 phase, Vertical travel of electrode: 120 mm, table travel: 120 mm, Pump capacity:12 liters per min Electrolyte tank capacity: 175liters,Machining chamber: 25 liters, Electrode sizes: To be selected depending upon dimensions of work piece. Most of components are fabricated using stainless steel material or anticorrosive material.

Cathode Tool

The tool dimension is slightly i.e. 30% smaller than the size of cavity to allow the overcut (front machining gap) 1.5 times the front gap.

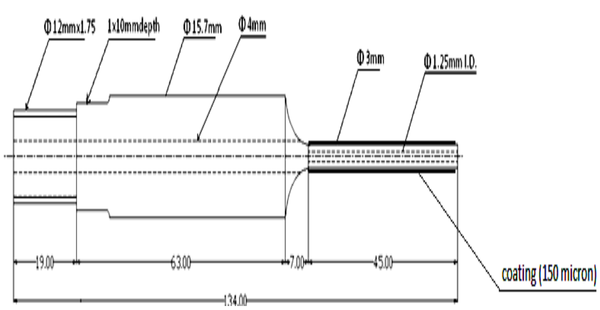


Fig. 3. Tool

IV DESIGN OF EXPERIMENTS

Experiments were planned using full factorial design of experiments for three variables. Experiments where planned using $2^{k=3}$ factorial design multiple linear regression to investigate, effect of 'K' factor with smallest number of (08) runs for factor screening experiments [09].

Generalized process model can be expressed as:

Y= f(x_1, x_2, ------x_k) where y= response and f= response function and x_1, x_2-----x_k are controllable variables

A regression model was fitted to the experimental data and the response surface is given by equation (1)

$y=b_0+b_1x_1+b_2x_2+b_3x_3+b_{12}x_1x_2+b_{13}x_1x_3+b_{23}x_{23}+b_{123}x_1x_2x_3$ --------------------------------1)

Where y is response, the β's are parameters constants whose values are to be determined. Various process variables represented A, B, C as shown in table no (1).

The response surface equation for evaluating surface roughness are obtained separately by calculating the coefficients of equation 1 and they are given table (4, 5) respectively.

Table 1: coded levels and actual values of different parameters

Parameters	Unit	Nomen clature	Low (-1)	High (+1)
Voltage (v)	V	A	12	16
Pulse on time(t_{on}),	µs	B	500	50
Duty Cycle (%)	%	C	48	80

The plane of experiment is given the table to all the experiments where conducted stationary tool, rotating tool randomly and surface roughness was recorded for each experiment.

Table2. RESULTS for Stationary and Rotating electrode

Sr. No.	Voltage (v)	Pulse on time (µs)	Duty cycle (%)	Surface roughness (µm) Stationary Electrode	Rotating Electrode
1	+1(16)	+1(500)	-1(48)	1.15	0.78
2	+1	-1	+1	1	0.7
3	-1	+1	-1	1.2	0.82
4	-1(12)	-1(50)	+1(80)	1.1	0.74
5	-1	-1	-1	1.4	0.98
6	-1	+1	+1	1.25	0.84
7	+1	+1	+1	1.18	0.8
8	+1	-1	-1	1.34	0.93

VI ANALYSIS OF EXPRIMENTS

To know the significance of the regression equation ANOVA was conducted. It significantly establishes between response surface and controllable parameter through f test analysis equation (2)

$$F_o = \frac{SS_A/V_A}{SS_E/V_E} = \frac{MS_A}{MS_E} \quad (2)$$

Where SS_A stands for sum of square of A, SSE stands for sum of square due to error, VA and VE stands for variance and error respectively. ANOVA with 95%confidance interval for stationary tool and rotating tool is given in the table (3ab).

Table 3a: FINAL ANOVA TABLE (stationary Electrode)

Sr. No.	Factor	Sum of Squares	Degre es of Freed om	Variance or Mean Square	Fo
1	A	0.0098	1	0.0098	196.00
2	C	0.039	1	0.039	784.00
3	BC	0.065	1	0.065	1296.00
5	Pooled error	0.005100	4	0.00012	

Table 3b: FINAL ANOVA TABLE (Rotary Electrode)

Sr. No.	Factor	Sum of Squares	Degrees of Freedom	Variance or Mean Square	Fo
1	A	0.00281	1	0.00281	225.00
2	C	0.025	1	0.025	2025.00
3	BC	0.033	1	0.033	2601.00
5	Pooled error	0.001251	4	0.00031	

From F distribution at 95% confidence level we find that $F_{0.05,1,4}$ = 7.71i.e. F_{limit} = 7.71 F0 values for stationary and rotating tool are given in the table ()if critical F value (7.71) it implies factor effects of A, C and AC are significant since F0 >F. The regression equation can be written below

$Y=b_o+b_1x_1+b_3x_3+b_{23}x_2x_3$---**(3)**

Therefore final regression equation in terms of coded factors for stationary electrode and rotating electrode is given equation (4, 5) respectively

Surface Roughness (Ra) = +1.20 - 0.035 * A- 0.070 * C + 0.090 * B *C---(4)

Surface Roughness(Ra) = +0.83-0.019*A-0.056*C+0.064*B*C------------------(5)

VII RESULTS AND DISCUSSIONS

Effect of parameters on surface roughness:

The multiple linear regression equation model equation (4, 6) include significant factor that affects in prediction of surface roughness. Using these models main effects of factors namely A (voltage), C (duty cycle), and interaction between BC (pulse on time and duty cycle). The given in fig (4). For stationary and rotating tool respectively.

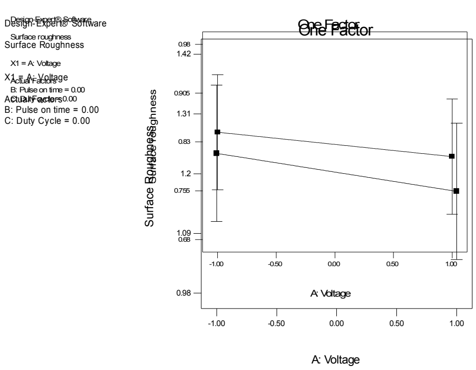


Fig 4: Voltage vs. Surface Roughness

Effect of voltage on surface roughness:

Fig 4: shows the effect of voltage on surface roughness value for both a) stationary electrode and rotating electrode in PECM. As voltage increased from (12 to 16 volts), surface roughness decreased by about 50% and so (1.2µm to 0.7µm).

Anodic dissolution takes place in PECM from the work piece, since work piece consist of different

At low voltage rough surface is produced as current density being low cause eatching effect and highly rough surface is produced ( ). At higher voltages difference in electrode potential of the constituents deminish that lead to incresing dissolution resulting decresing surface roughness value.

As shown in fig .(9) as compare to stationary electrode over rotary elecrtode, to improve the surface roughness value by %. Also gain boundary attact at lower voltage may also contribute to some extend to the increase in surface value (Ra). As voltage increases further difference in electrode potential of the constituents is reduced which leads to increase in dissolution of the constituents [5,7]. Therefore surface value (Ra) decreasees as voltage increases.

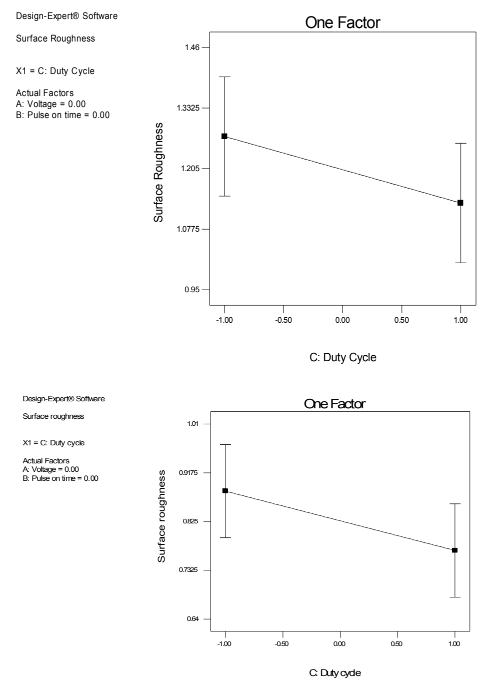
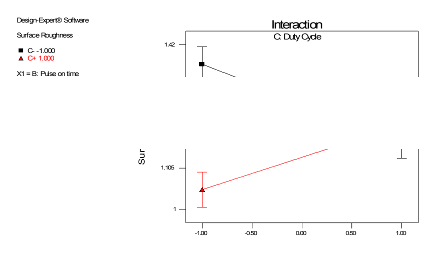


Fig 5: Duty cycle vs surface roughness

Fig 5: ECM removal rates are greater than that of DC and PC , and the surface roughness is also lower due to the elimination of oxide film reheating during the cathodic cycle. For given pulse on time as duty cycle increases pulse frequency decreases.

Interpretation plot for interaction between Pulse on time and Duty cycle:



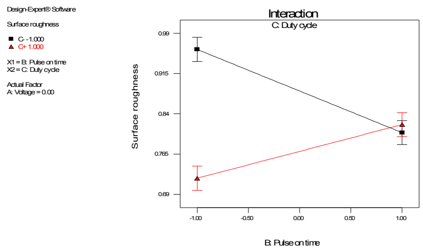
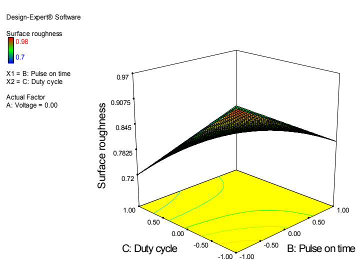


Fig: 6: Interpretation plot for interaction BC

Fig 6: shows the interaction between pulse on time and duty cycle (BC). The two level factorial reveled the powerful interaction between duty cycle and pulse on time.

Surface Response Plots

Combine effect of various process parameters can be better visualized with the help of three dimensional response surface plots. A response surface is a plane Combined effects of various process parameters can be better visualized with the help of three dimensional response surface plots. Plane of y – values (response variable values) generated by various combinations of x_1 and x_2. These plots for various combinations. Surface response of interaction BC



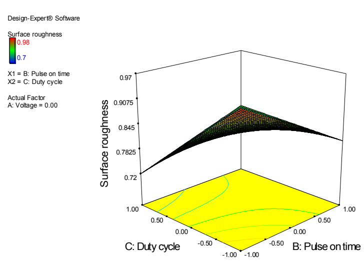
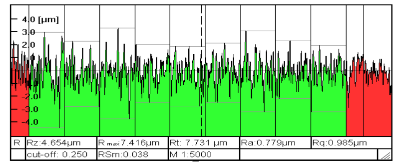
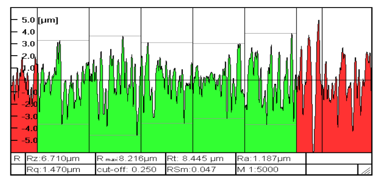


Fig. 7: surface for Electrode diameter vs. duty cycle



Sr. no. 7 , voltage= 16v, f=0.8mm/min, Pulse on time= 500µs, pulse on =500µs,duty cycle=80%,speed =60rpm,pressure=0.9kg/cm²

(Stationary electrode)



Sr. no. 7, voltage= 16v, f=0.8mm/min, Pulse on time= 500µs, pulse on =500µs,duty cycle=80%,speed =60rpm,pressure=0.9kg/cm²

Fig: 8 surface roughness profiles of hole during pecm

Surface Roughness profile obtained for two holes with stationary electrode and rotary electrode arrangement during PECM. For the experimental Sr. no 7 parameters of above experiments are given in the respective caption (0.8*3=2.4mm). Surface was measured from top face of the hole with cut off length is 0.25 mm and sampling size is '3'. The surface roughness value improved from (1.18 to 0.77µm). Hence Enhancement of surface finishes ware improved by % value of (34.75%) with PECM using Rotating electrode.

VIII. CONCLUSION

Improvement of surface finish of Electrochemical machining using rotating electrode taking input parameters as Voltage, Pulse on time, Duty Cycle and output parameters as surface roughness following facts can be concluded.

When the Voltage & duty cycle increases the surface roughness value is decreased. Keeping Electrolyte concentration and feedrate constant and electrode gap (0.1mm).

When stationary electrode is compare to the rotating electrode. The rotating electrode gives better

we move in depth study via response surface methods (RSM) and central composite rotatable design (CCRD) can be performed [5].

Comparison of Stationary & Rotating Electrode:-

(Rotating electrode)

roughness value (decreased).

The interaction between B (pulse on time) and C (Duty cycle) is important for the response of surface roughness.

From ANOVA analysis, it is found that A, C, and BC are more important factors of surface roughness performance. While the compare between rotating & stationary electrode the rotating electrode is better surface finish.

Design of experiments and analysis of variance-helped in –Identifying the significant factors affecting response factors. Developing regression models.

ACKNOWLEDGEMENT

The authors acknowledge the financial support provided by the department of science and Technology, New Delhi, to the project no DST.SR/S3/MERC-64/2005, entitled Enhancement of Surface finish of electrochemically drilled deep hole”

REFERENCES

[1] 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)

[2] 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).

[3] 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).

[4] K.P. Rajurkar,et al “New development in electrochemical machining” annuls of the CIRP vol.48/2,pp No.567-1999

[5] 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).

[6] D.S.Bilgi, V.K.Jain and Shekhar, Predicting radial over cut in deep holes drilled by shaped tube electrochemical machining, journal of adv Manuf Technology, pp1185,2007.

[7] Li Yong, Zheng Yunfel, Yang Gaung, Localized electrochemical micromachining with gap control.

[8] Douglas C. Montgomery, “Design and Analysis of Experiments”, John Wiley and Sons, Prentice Hall Publication,2001.

[9] Mishra,P.K.,1997,non conventional machining, the institute (India) text book series, Narosa publishing house, New Delhi

[10] D. Zhu, H. Y. Xu , Improvement of electrochemical machining accuracy by using dual pole tool Journal of Materials Processing Technology, Volume 129, Issues 1-3, 11 October 2002.

[11] Li Yong, Zheng Yunfel, Yang Gaung, Localized electrochemical micromachining with gap control.