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Optimization of process parameters of ECM by RSM on AISI 202 steel

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Abstract: The machining of complex shaped designs was difficult earlier, but with the advent of the newer machining processes incorporating in it electrical, chemical & mechanical processes, manufacturing has redefined itself. Especially, the Electrochemical Machining (ECM) process is used to machine the hard to cut materials without producing heat and friction. Hence, in this work, the ECM process has been chosen to machine SS AISI 202 steel. This study establishes the effect of process parameters such as voltage, current and concentration of electrolyte on the responses on material removal rate (MRR). In this work, second-order quadratic models were developed for MRR, considering the electrolyte concentration, voltage and current as the machining parameters, using central composite design. The developed models were used for Response Surface Methodology (RSM) optimization by desirability function approach to determine the optimum machining parameters.

Keywords: ECM, MRR, AISI 202 Steel, RSM, Desirability Function, Interaction Graph.

1 Introduction: Electrochemical Machining (ECM), a nontraditional process for machining **[1,2]** has been recognized in these days for performing numerous machining operations. New materials which have high strength to weight ratio, heat resistance, hardness and complex shapes needing greater accuracy demands the development of newer type of machining processes **[3]**. The new and improved machining processes are often referred to as unconventional machining processes. For e.g ECM removes material without producing heat. Almost all types of metals can be machined by this machining process. In today's high precision scenario, ECM has wide scope of applications **[4, 5]**. More importantly, ECM is a process based on the controlled anodic dissolution of the workpiece as anode **[6]**, with the tool as the cathode, in the electrolytic solution. The electrolytic solution flows between electrodes and carries away the dissolved metal **[11]**. Since the introduction of ECM in 1929 by Gusseff, its industrial applications have been extended to electrochemical drilling, electrochemical deburring, electrochemical grinding and electrochemical polishing.**[13]** More specifically, ECM was found more advantageous for high-strength alloys. Today, ECM has been increasingly recognized for its potential for machining **[7, 8]**, while the precision of the machined profile is a concern of its application. During the ECM process, electrical current passes through an electrolyte solution between a cathode tool and an anode work piece. The work piece is eroded in accordance with Faraday's law of electrolysis **[9, 10]**. ECM processes find wide applicability in areas such as aerospace and electronic industries for shaping and finishing operations of a variety of parts that are a few microns in diameter **[12]**. Furthermore, it has been reported that the accuracy of machining can be improved by the use of pulsed electrical current and controlling various process parameters **[13]**. Amongst the often considered parameters are electrolyte concentration, voltage, current and inter electrode gap. Though there is a possibility of improving the precision of work, the dependency of accuracy on numerous parameters demand that a thorough investigation should be carried out to ascertain the causality to different parameters **[14]**. In the backdrop of above information, this study was carried out to assess the best conditions (with respect to different process parameters) for improving the accuracy of ECM process. In this paper, a quadratic model of electrochemical machining is proposed to predict the Material Removal Rate (MRR). The study envisaged an empirical data obtained from the experiments carried out to assess effect of operating parameter variations on MRR for Stainless steel (AISI 202) **[15 - 20]**.

2 Proposed Methodology

2.1 Response surface methodology: RSM is a collection of statistical and mathematical techniques useful for developing, improving and optimizing the process. It is a technique for determining and representing the cause and effect relationship between the responses and input control variables influencing the responses as a two- or three-dimensional hyper surface. The accuracy and effectiveness of an experimental design depends on careful planning and execution. The steps involved in this research work for the experimental investigation include the following:

1. Identifying the important process control variables.
2. Finding the upper and lower limits of the control variables, viz., electrolyte concentration, voltage and current.
3. Development of design matrix using Central Composite Design (CCD) and conducting the experiments as per the design matrix.
4. Recording the responses of MRR.
5. Development of second-order quadratic model.
6. Determining the coefficients of the second-order polynomials.
7. Checking the adequacy of the models developed.
8. Testing the significance of the regression coefficients.
9. Presenting the main effects and the significant interaction effects of the process parameters on the responses in two- (contour) and three-dimensional (surface) graphical form.
10. Determination of optimized machining process parameters for responses.

2.2 Central Composite Design: CCD is the most popular second-order design which was introduced by Box and Wilson. It is a factorial or fractional factorial design with centre points and star points. The star points are added to estimate the curvature. The factorial design points in CCD contribute to the estimation of the interaction terms. The axial points contribute in a large way to the estimation of quadratic terms. Without the axial points, only the sum of the quadratic terms can be estimated. The factorial points do not contribute to the estimation of quadratic terms. The centre runs provide an internal estimate of error (pure error) and contribute toward the estimation of quadratic terms. The areas of flexibility in the use of CCD reside in the selection of axial distance (α) and the number of centre runs (nc). The choices of these parameters are very important. The choice of α depends to a greater extent on the region of operability and region of interest. The choice of nc often has an influence on the distribution of variance in the region of interest. The axial distance value α is chosen to maintain rotatability and it depends on the number of experimental runs in the factorial portion of the CCD. In this work, 20 experimental design points were considered including five centre points.

3 Experimental procedures: In this experiment, the entire work has been carried out by electrochemical machining set up (METATECH-Industry, Pune) available at Nitesh Engineering Works, Chennai, which is having input Supply of - 415 V+/- 10%, 3φ AC, 50 HZ. Output supply is 0-300 A-DC at any voltage from 0-25 V and efficiency is better than 80% at partial and full load condition. The insulation resistance is not less than 10 Mega ohms with 500V DC. Stainless steel of grade AISI 202 is selected as a workpiece for ECM machining. RSM design is made by considering three factors such as Electrolyte Concentration, Voltage and Current. Material removal rate is calculated by taking initial and final weight of work piece before and after the experiment. AISI 202 steel specimens are prepared according to the required dimensions of electrochemical machine fixtures. The dimensions of the workpiece are length 125 mm, breadth 65 mm and thickness 6mm. Three input parameters have been varied according to L27 orthogonal array to analyze the MRR of the AISI 202 Steel. The control parameters are selected according to the feasible parameters and working condition of electrochemical machine. Based on the experimental results of the response (MRR), second-order quadratic model is developed using design expert software for 95% level of confidence as shown in below equation. These equations are in the form of coded factors.

$$MRR = 4.29 + 0.59A + 0.44B + 0.21C + 0.55AB - 0.024\,BC + 0.50\,A^2 - 0.40\,B^2$$

Table (1): Selected machining parameter levels.

FACTORS	**LEVELS**		
	-1	**0**	**1**
Electrolyte Concentration (A) in %	5	10	15
Voltage (B) in volt	8V	12V	18V
Current (C) in amphere	125	150	175

Table (2): Experimental design and the measured responses.

Sl. No.	**A**	**B**	**C**	**MRR**
1	5	8	125	4.134
2	5	8	150	3.647
3	5	8	175	4.276
4	5	12	125	3.875
5	5	12	150	3.758
6	5	12	175	4.429
7	5	18	125	3.647
8	5	18	150	3.352
9	5	18	175	4.429
10	10	8	125	4.770
11	10	8	150	3.352
12	10	8	175	5.167
13	10	12	125	4.134
14	10	12	150	4.429
15	10	12	175	4.429
16	10	18	125	4.593
17	10	18	150	4.000
18	15	18	175	4.961
19	15	8	125	3.758
20	15	8	150	4.961
21	15	8	175	4.593
22	15	12	125	3.445
23	15	12	150	5.392
24	15	12	175	5.167
25	15	18	125	6.201
26	15	18	150	5.906
27	15	18	175	6.201

3.1 Analysis of Variance (ANOVA): The analysis of variance of the experimental data has been done to statistically analyse the relative significance of the parameters: electrolyte concentration, voltage and current on the response variable, MRR. The detailed ANOVA of the experimental data shows the statistical significance of parameters and its effect by means of comparison of mean squares (MS) with an estimation of the experimental error as shown in Table 3. In this table, SS represents sum of squares while DOF represents the number of degrees of freedom. The column corresponding to Mean Square (MS) is obtained by dividing SS by its corresponding degrees of freedom. The F column value is the quotient of MS of each effect

3.2 ANOVA for MRR: The developed model for MRR is tested for its significance using ANOVA analysis. The model F value of 12.17 implies that the model is significant. There is only 0.01% chance for the noise in this model. From the F and P values, it is clearly seen that factors A, B, C and AB are most influential on MRR. The P value of each of these factors indicates that the confidence level is more than 99%. The F value for the lack of fit implies that the lack of fit is not significant relative to the pure error. The high P value of lack of it, 96.36% indicates that the model is fit, while the very low P value of the model, 0.01% indicates that the model is significant.

Source	**Sum of squares**	**Dof**	**Mean square**	**F value**	**P-Value**
Model	9.42	9	1.05	12.17	0.0003
A	3.48	1	3.48	40.49	< 0.0001
B	1.91	1	1.91	22.15	0.0008
C	0.42	1	0.42	4.91	0.0511
AB	2.40	1	2.40	27.95	0.0004
BC	4.753E-003	1	4.753E-003	0.055	0.8189
A^2	0.69	1	0.69	8.07	0.0175
B^2	0.43	1	0.43	5.03	0.0488

Table (3): Analysis of variance for main and interaction effects of parameters on MRR

4 Results and discussion: The quadratic model was suggested based on F test for MRR. From this model, the interaction effect of electrolyte concentration - voltage on MRR is shown in the contour plot as in Figure 1. It is clearly noted that, at moderate electrolyte concentration and voltage, the MRR value gets improved. Furthermore, the developed model was used for response optimizations by desirability function approach to obtain maximum MRR. The maximum desirability is found to be 100%. The optimum machining conditions for the electrolyte concentration, voltage and current are determined as 10.06 %, 8.14 v and 173.56 amp respectively. The optimum response value of MRR is 6.361 mg/min respectively, as shown in Figure 2.

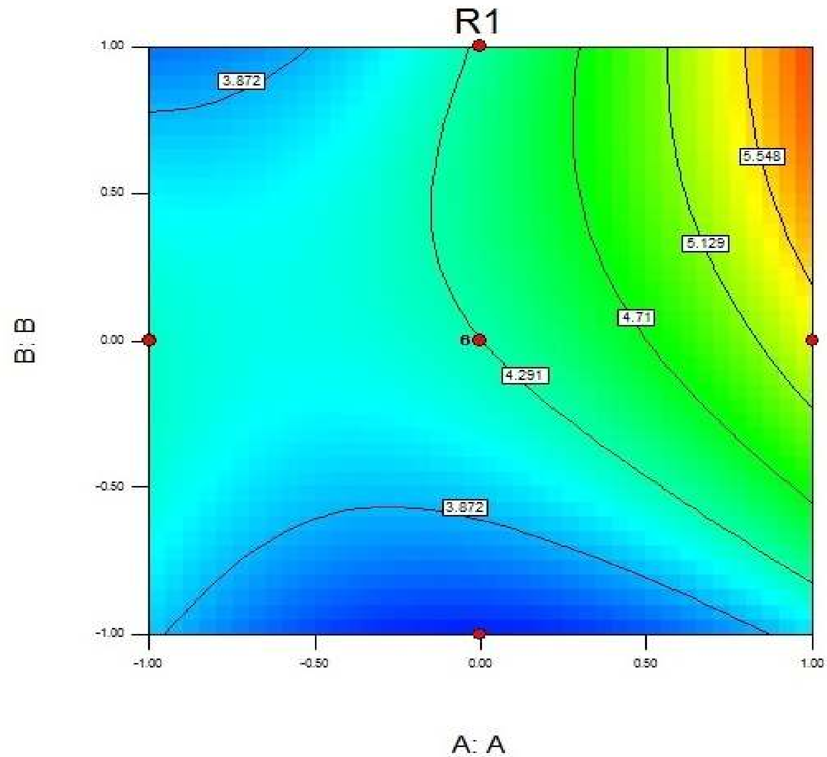

Figure (1): Contour plots showing the effect electrolyte concentration, voltage on MRR.

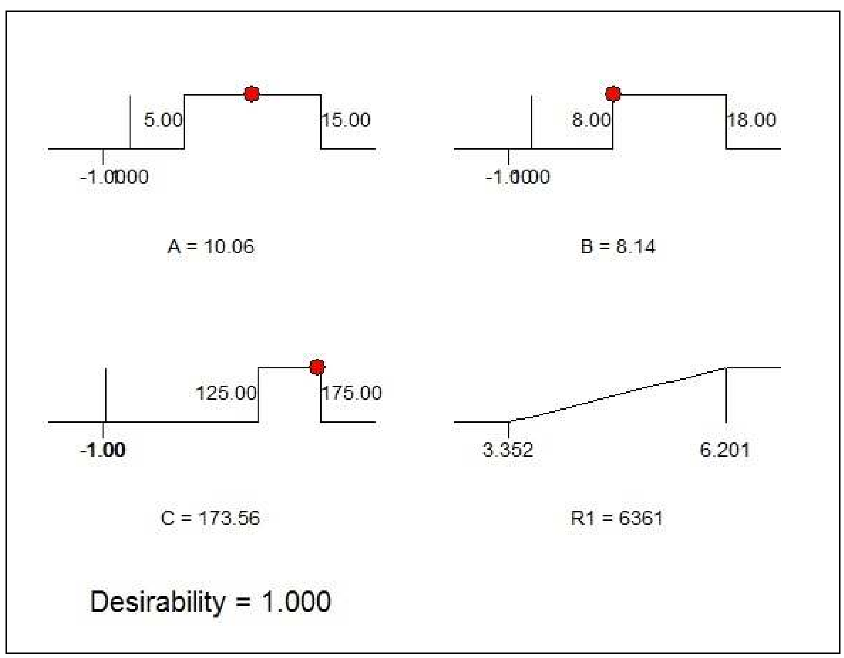

Figure (2): Ramp diagram with optimized machining parameters and predicted responses.

5 Conclusions: In this study, response surface methodology for the optimization of machining parameters has been proposed. Statistical model has been developed for the MRR using central composite design with three level factors. The optimum machining parameters are determined using the model for the response to achieve maximum MRR. It is concluded that at moderate electrolyte concentration and voltage, the MRR gets improved.

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