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Optimization of Quality and Accuracy in ECM Process with Hybrid Method

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Abstract: ***Quality and accuracy are two important characteristics have become excessive concerns in today's industries. Every manufacturing unit essentially concentrations on these areas in relation to the process as well as production developed. Achieving high quality necessarily requires higher degree of skill, with machine/tools, advanced technology, immense and considerable time. Improvement of quality results as well as improved the accuracy also. Thus, optimality must be maintained between quality as well as accuracy. The study of Electrochemical machining (ECM) has invested himself as one of the major other possible way to conventional methods for machining hard materials and complicated outlines not having the residual stresses and tool wear for improved the quality and accuracy. The present work is to investigate the surface roughness and overcut on ECM process. The surface roughness i.e. (Ra value) of the machine surface has been chosen as surface quality evaluation with the necessity to minimize it; whereas overcut of the work-piece surface has been chosen for accuracy estimation with the result to minimize it. These two responses have been simultaneously fulfilled machining parameters with PCA based grey relation analysis this hybrid optimization approach coupled with Taguchi design of experiment techniques.***

Keywords: Electrochemical machining (ECM); Surface Roughness; overcut; Grey relation analysis; Principal component analysis

1. Introduction

Electrochemical machining (ECM) creates approximately the replica image of tool on the work-piece surface. High Benefits of ECM over other machining processes (e.g. grinding and other machining process) include its applicability without any heat generation, residual stress, material hardness, no tool wear, comparably high material removal rate, smooth and positive surface, and production of components with complex geometry having stress-free and crack-free surfaces. ECM is one of the well-established non-traditional manufacturing processes nowadays. ECM is opposite of electrochemical or galvanic coating or deposition process. Thus ECM can be thought of a controlled anodic dissolution at atomic level of the work piece that is electrically conductive by a shaped tool due to flow of high current at relatively low potential difference through an electrolyte which is quite often water based neutral salt solution. It is a good and effective method in machining of complex shapes [1].

ECM is the controlled removal of metal by anodic dissolution in an electrolytic cell in which the work piece is the anode and the tool is cathode. Electrochemical machining is developed on the principle of Faradays law**.** The metal is removed by the controlled anodic dissolution of the anode according to the well-known Faradays law of electrolysis. Since this machining method is achieved by electrochemical reaction, hard and difficult-to-cut materials can be machined. Various variants of ECM like: electrochemical sinking, ECM with numerically controlled tool-electrode movement, electrochemical debarring and electrochemical polishing are used in industrial practice.

In order to obtain high machining accuracy in the electrochemical machining (ECM), an appropriate cathode design is necessary by Zhang et al [2]. Previous cathode employing in radial ECM (called equal-thickness in this paper) leads to considerable distortion of work piece shape at the trailing edge in machining cascade passages. Zhu et al [3] an appropriate flow mode of electrolyte has a positive effect on process efficiency, surface roughness, and machining accuracy in the electrochemical machining (ECM) process. Investigated the effect and parametric optimization of process parameters for ECM of EN 31 using grey relation analysis are given by Dhar et al. [4]. Senthi et al. [5] & Zhu et al [6] has presented an appropriate flow mode of electrolyte has a positive effect on process efficiency, surface roughness, and machining accuracy in the electrochemical machining (ECM) process.

Koyano et al. [7] has shown the new tool electrode having a porous structure is developed for electrochemical machining (ECM), in which electrolyte fluid can be forced through its permeable structure. Jet electrochemical machining is a promising shaping method that has the potential to replace traditional sinking ECM in the industry owing to its flexibility and stability is given by Liu et al. [8]. Jeykrishnan et al [9] has described that the Electro-chemical machining (ECM) is one of the important Non-conventional machining processes, which is used for shaping difficult to machine and electrically conductive materials used in aircrafts, automobiles, medical, petroleum and electronic industries. Sun et al. [10] discuss about hard passive alloys, such as nickel-based super alloys, titanium alloys, and molybdenum alloys, are widely used as engine components, isothermal hot dies and forging tools, die castings, etc. Wang and Zhu [11] has reported that the variation in altitude density function of the surface topography of mild steel during electrochemical polishing.

Aim of the present work is to find the responses, their interaction with input variables, and to find combination of input variables to find optimum value of the response variables using cylindrical electrode on mild steel as work piece in brine solution using Taguchi L_9 OA approach. The input variables selected are voltage; tool feed rate and electrolyte concentration. Find optimum value of surface roughness and overcut of machine surface. After that these responses are converted into single objective that is Optimum quality performance index (OQPI). This calculated OQPI values with the help of PCA based grey relation hybrid optimization techniques. They give the low value of SR and OC simultaneously.

2. Experimentation

Taguchi designs provide a powerful and efficient method for designing products that operate consistently and optimally over a variety of conditions. Taguchi proposed several approaches to experimental designs that are sometimes called "Taguchi Methods." These methods utilize two, three, four, five, and mixed-level fractional factorial designs. Taguchi refers to experimental design as "off-line quality control" because it is a method of ensuring good performance in the design stage of products or processes. In the experiment using three factors and three levels setup the total number of experiments to be conducted is 9. In this study, an L_9 OA based on Taguchi design are used machining parameters like voltage (V), Feed rate (F) and conductivity (C) were varied to conduct 9 different experiments and finding the value of surface roughness and overcut value with the help of profilometer and optical microscope.

The levels of experiment parameters are voltage (V), Feed rate (F) and conductivity (C) shown in Table 1 with their different levels.

Table 1: Machining parameter and their levels

Parameters	Symbols	Unit	Level 1	Level 2	Level 3
voltage	V	V	5	8	11
Tool feed rate	F	mm/min	0.2	0.4	0.6
concentration	C	g/l	20	30	40

3. Proposal of Tool and Work Piece

In this investigate of present work chosen mild steel diameter 75 mm was used as a work piece material with copper electrode which is shown in Fig.1. This mild steel has increasing range of applications like plastic molds, frames for plastic weight dies, hydro founding tools etc.

Figure 1: Mild steel work-piece and tool

4. Result and Discussions

In This section are related about influences of SR and OC and finding the result which factors discharge voltage, feed rate and concentration of Cu tool, is most with mild steel work piece important with help of orthogonal array based on Taguchi design. And the Design with respect to L_9 and responses are presented in table 2.

4.1. Effect on Input Parameters on overcut

The influence of various machining parameters on overcut is shown in Figure 2. The feed rate has enormous effect on width over cut and it increases with increase in feed rate. Overcut-diameter also increases with increase in voltage. The below figure shows if voltage is increases the overcut-diameter is also increases. Trends are shown by the plot of main effects (means) on overcut.

The analysis of variances for the factors is shown in Table 3 which is clearly indicates that the concentration is not important for influencing MRR and V and F are the most influencing factors for OC and other factors are not significant .The delta values are Voltage, Feed rate, Concentration are 0.1133, 0.1267, 0.0233 respectively, depicted in Table 4. The case of OC, it is "lower is better", so from this table it is clearly definite that feed rate is the most important factor then V and concentration of solution.

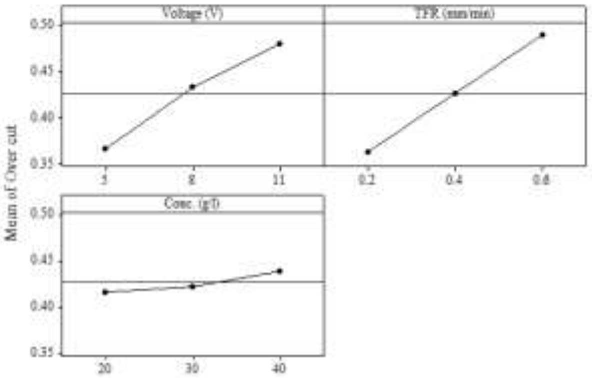

Figure 2: Machining parameters vs. overcut plots

Table 3: Analysis of Variance for overcut

Source	DF	Seq SS	Adj SS	F	P
Voltage (V)	2	0.01946	0.019467	13.90	0.067
TFR (mm/min)	2	0.02406	0.024067	17.19	0.055
Conc. (g/l)	2	0.00086	0.000867	0.62	0.618
Residual Error	2	0.00140	0.001400		
Total	8	0.04580			
S = 0.02646 R-Sq = 96.9% R-Sq(adj) = 87.8%					

Table 4: Response table for overcut

Level	Voltage (V)	TFR (mm/min)	Conc. (g/l)
1	0.3667	0.3633	0.4167
2	0.4333	0.4267	0.4233
3	0.4800	0.4900	0.4400
Delta	0.1133	0.1267	0.0233

4.2. Effect on Input Parameters on SR

The effect of control factors voltage, tool feed rate and concentration on surface roughness are shown in Figure 3.

Surface roughness value increases slightly with increase in voltage value from 5V to 8V and then decreases with increase in value of voltage value from 8V to11V. Surface roughness value increases with increase in feed rate from 0.2mm/min to 0.4mm/min and then decreases with increase in value of feed rate from 0.4-0.6 mm/min. In case of concentration surface roughness decreases with increase in value of concentration from 20-30 g/l and then increases with increase in concentration from 30- 40 g/l. So most effective factor looks to be tool feed rate and then concentration.

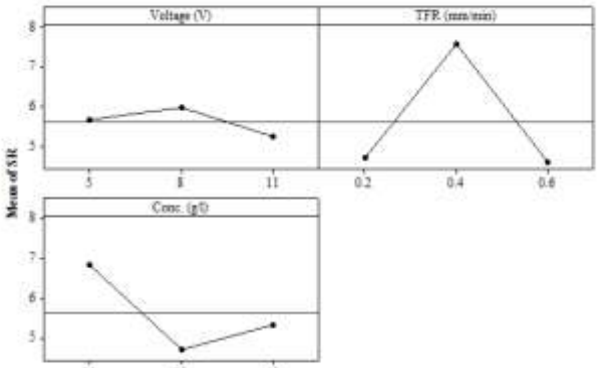

Figure 3: Machining parameters vs. SR (Ra) Plots

The analysis of variances for the factors is shown in Table 5 which is clearly indicates that the on one factor is not important for influencing MRR and V and F.

Table 5: Analysis of Variance for SR

Source	DF	Seq SS	Adj SS	F	P
Voltage (V)	2	0.8556	0.8556	0.50	0.667
TFR (mm/min)	2	16.9678	16.9678	9.92	0.092
Conc. (g/l)	2	7.0983	7.0983	4.15	0.194
Residual Error	2	1.7110	1.7110		
Total	8	26.6327			
S = 0.9249 R-Sq = 93.6% R-Sq(adj) = 74.3%					

Table 6: Response Table for Means of SR

Level	Voltage (V)	TFR (mm/min)	Conc. (g/l)
1	5.660	4.703	6.837
2	5.990	7.570	4.727
3	5.237	4.613	5.323
Delta	0.753	2.957	2.110
Rank	3	1	2

4.3 PCA Based GRA Methods

In the PCA based Grey method is used to convert multiple responses into a single characteristic index known as overall quality performance index (OQPI) value. For calculation of optimal OQPI value by using following steps:

- Convert the experimental data into S/N ratio.
- Calculating the principal component scores (PCS).
- Normalized PCSs.
- Calculating the grey relation coefficient using principal component score.
- Finally OQPI is calculated.

In this procedure at first, the experimental values of SR and OC are converted into S/N ratio. Taguchi method is one of the modest and best solutions for parameter design and experimental planning [1]. According to this method, the three types of S/N ratio are categories lower-the-better (LTB) quality characterized. The S/N ratio with a LTB represented following equation.

LTB response variable $\eta_{ij} = -10\log\left[\frac{1}{n}\sum_{i=1}^{n} y_i^{2}\right]$

$$\eta_{ij} = -10\log\left[\frac{1}{n}\sum_{i=1}^{n} y_i^{-2}\right]$$

Where η_{ij} denotes the S/N ratios i^{th} experiment and j^{th} response) calculated from observed values, yi represents the experimentally observed value of the i^{th} experiment and n=1 is the repeated number of each experiment in L_9 OA is conducted. The value of S/N in response (SR and OC) is tabulated in Table 7.

The second steps conduct PCA on the S/N ratios to obtain uncorrelated PCSs corresponding to each experimental run, in the form of PCS_{il} it can be obtained by follows:

$$PCS_{il} = a_{l1}\eta_{i1} + a_{l2}\eta_{i2} + ... + a_{lj}\eta_{ij}$$

Where $a^2_{l1}+a^2_{l2}........+a^2_{lj} = 1$. The a_{l1}, a_{l2}........a_{lj} are the elements of eigenvector corresponding to the l^{th} eigenvalue of response variables. It can be calculated by MINITAB software. The eigenvalue and eigenvector are shown in Table 8. The third steps normalized the PCSs value by using equation.

$$X_{il} = \frac{PCS_{il} - PCS_{il}^{\min}}{PCS_{il}^{\max} - PCS_{il}^{\min}}$$

Where X_{il} and PCS_{il} the normalized data and observed data, respectively, for i^{th} experiment using l^{th} principal component score. The smallest and largest value of PCS_{il} for the the l^{th} PCS are min PCS_{il}^{min} and max PCS_{il}^{max} respectively. Then next step to calculating the grey relation coefficient (GRC) of normalized PCSs data with the help of equation.

$$\zeta_{ij} = \frac{\Delta_{\min} + \zeta\Delta_{\max}}{\Delta_{il} + \zeta\Delta_{\max}}$$

Where $\Delta_{il} = |1-X_{il}|$. is ζ_{ij} the GRC of i^{th} experiment using j^{th} response, $\Delta_{\max}$ and $\Delta_{\min}$ are the global maximum and global minimum values in the different data series, respectively. The distinguishing coefficient varies between 0 and 1, which is to expand or compress the range of GRC. After calculating the GRCs, for l no. of PCS, the final steps OQPI (γ) can be calculated using equation.

$$\gamma = \frac{1}{n}\sum_{i=1}^{n} W_l \zeta_{ij}$$

Where w_l is the proportion of variance explained by l^{th} principal component. The magnitude of γ imitates the overall degree of standardised deviation of the i^{th} experimental run. In general, a scale item with a high value of γ indicates that the respondents, as a whole, have a high degree of favourable consensus on the particular item. The OQPI values of i^{th} experimental run are tabulated in Table 7.

Table 8: Eigen analysis of the Correlation Matrix

Variable	Eigen vectors		Eigenvalue	Proportion
	PC1	PC2		
SN-SR	-0.707	-0.707	1.0871	0.544
SN-OC	0.707	-0.707	0.9129	0.456

4.4. Analysis of OQPI

The higher value of OQPI means comparability sequence has a stronger correlation to the reference sequence. Fig. 4 represents graphically in main effect plots for OQPI and this graph depiction that the optimal machining parameters setting is Voltage is 8V, TFR is 0.4mm/min and Conc. is 20 g/l. In this figure identifies the effect of ECM parameters on the multi-performance characteristics for minimum SR and OC.

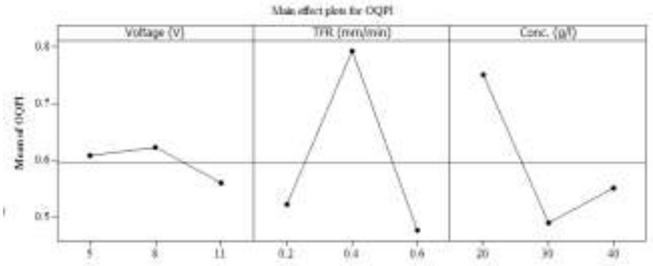

Figure 4: Main effect plots for OQPI

5. Conclusions

PCA based grey method (OQPI) was adopted to optimize the ECM process with multiple performance characteristics, i.e. SR and OC. The optimal ECM parameter settings were found to for minimum SR and OC for Voltage is 8V, TFR is 0.4mm/min and Conc. Is 20 g/l.

In this study of ECM process on Mild steel by round shaped diameter of 75 mm. The considered L_9 OA based on Taguchi design. For surface roughness, feed rate belongings it most then concentration and at latter voltage. Tool feed rate effects maximum to overcut at second rank is voltage and at 3rd rank is concentration which disturbs most to overcut.

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Table 7: Observed PCS value and OQPI

SN	SN (SR)	SN (OC)	PCS 1	PCS 2	GRC 1	GRC 2	OQPI
1	-16.205	10.752	19.058	3.855	1.000	0.466	0.757
2	-16.560	8.404	17.650	5.766	0.712	0.624	0.672
3	-11.573	7.331	13.365	2.999	0.380	0.419	0.398
4	-13.607	7.959	15.247	3.993	0.478	0.475	0.477
5	-18.680	7.744	18.682	7.731	0.903	0.954	0.926
6	-13.236	6.196	13.739	4.977	0.396	0.547	0.465
7	-9.127	7.959	12.080	0.826	0.333	0.333	0.333
8	-17.373	6.196	16.663	7.902	0.593	1.000	0.779
9	-14.744	5.193	14.095	6.753	0.413	0.755	0.569

Table 2: L_9 OA design with responses

Run	Voltage (v)	TFR (mm/min)	Conc. (g/l)	Avg. surface roughness (μm)	Overcut (mm)
1	5	0.2	20	6.46	0.29
2	5	0.4	30	6.73	0.38
3	5	0.6	40	3.79	0.43
4	8	0.2	40	4.79	0.40
5	8	0.4	20	8.59	0.41
6	8	0.6	30	4.59	0.49
7	11	0.2	30	2.86	0.40
8	11	0.4	40	7.39	0.49
9	11	0.6	20	5.46	0.55