

STUDY OF SURFACE ROUGHNESS FOR DISCONTINUOUS ULTRASONIC VIBRATION ASSISTED ELECTRIC DISCHARGE MACHINING USING RSM

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Abstract

The objective of this paper is to study the effects of response parameters on the performance characteristics in the Ultrasonic vibration Assisted Electric Discharge Machining (UEDM) Process. Response Surface Methodology (RSM) is used to investigate the effect of amplitude of vibration, peak current, pulse on-time, machining time and flushing pressure. To study the proposed second order polynomial model for surface roughness (SR), a Central Composite Design (CCD) is used for the estimation of the model coefficients of five factors, which are believed to influence the SR in UEDM process. Experiments are conducted on Aluminum alloy 6063 with copper electrode. The response is modeled on experimental data by using RSM. The separable influence of individual machining parameters and the interaction between these parameters are also investigated by using analysis of variance (ANOVA). It is found that amplitude of vibration, peak current; pulse-on time, flushing pressure and most of their interactions have significant affect on SR.

Keywords: Central Composite Design, SR, UEDM, RSM, Aluminum alloy (Al6063)

1. INTRODUCTION

In today's world, there is an essential requirement of advance materials such as high strength alloys, ceramics, fiber-reinforced composites etc. These materials are very hard in nature and are difficult to machine. To get rid from this machining problem, Electric Discharge Machining (EDM) was invented. EDM works on the principle of spark erosion, which removes the material by eroding the work piece. The main equipments of the Electric Discharge Machine are D.C. supply unit, EDM circuit, servomechanism, dielectric unit etc. There is a gap between the tool (electrode) and the work piece, which is known as spark gap. To complete the circuit the current is passed through the tool and the work piece through dielectric fluid. The current tends to break the dielectric fluid into ions, which start moving from work piece to tool. The movement of ions and electrons between tool and work piece occurs at such a high speed that it seems as a spark. This transfer of ions and electrons increases the temperature, which melts the work piece. The spark melts a small material volume on each of the electrodes. The dielectric fluid that fills the gap between the electrodes removes part of this material.

The circulation of dielectric fluid and the removal of machined-debris is very difficult, especially when the hole or the cavity becomes deep, which reduces the machining

efficiency due to poor circulation of the dielectric fluid from working gap. This poor flushing ends up with stagnation of dielectric and builds-up machining residues which apart from low material removal rate (MRR) also lead to short circuits and arcs. To improve the machining performance of EDM, a combined method of ultrasonic vibration and Electric Discharge Machining has been developed by some researchers. Response-surface methodology comprises a body of methods for exploring for optimum operating conditions through experimental methods. Typically, this involves doing several experiments, using the results of one experiment to provide direction for what to do next. This next action could be to focus the experiment around a different set of conditions, or to collect more data in the current experimental region in order to fit a higher-order model [1]. Shabgard et al. concluded that the regression technique is an important tool for representing the relation between machining characteristic and EDM process input parameters. The results show, that the CCD is a powerful tool for providing experimental diagrams and statistical-mathematical models, to perform the experiments appropriately and economically [2]. Asif and Khan used RSM to investigate the relationships and parametric interactions between three controllable variables on the material removal rate (MRR), electrode wear rate (EWR) and SR in EDM milling of AISI 304 steel. Developed models can be used to get the desired responses within the experimental

range[3]. Sahoo et al. demonstrated the effect of most influencing parameters on SR using RSM for different work piece materials in EDM [4]. Kanagarajan et al. developed models for the MRR and SR over the most influencing process parameters in EDM of WC/30% Co composites. The RSM methodology is used to identify the most influential parameters for maximizing metal removal rate and for minimizing the SR[5]. Shabgard and Shotorbani suggested mathematical models for relating the MRR, TWR and SR to machining parameters. RSM approach is used to determine the relationship between various process parameters and machining criteria of FW4 welded steel[6]. Pradhan et al. used RSM method to investigate the effect of input parameters on SR in EDM of AISI D2 tool steel. It was found that the developed models can be used effectively in prediction of responses. In this work, mathematical models have been developed for relating the SR to machining parameters like discharge current, pulse-on time and pulse-off time which varied over wide range from roughing region to nearly finishing conditions[7]. Kuppan et al. derived mathematical model for MRR and average SR of deep hole drilling of Inconel 718. The experiments were planned using CCD and RSM was used to model the same. It revealed that MRR is more influenced by peak current and duty factor, and the parameters were optimized for maximum MRR with the desired SR value using desirability function approach [8]. Jaharah et al. investigated the machining performance such as SR, electrode wear rate and MRR with copper electrode and AISI H3 tool steel work piece and the input parameters taken are I_p , T_{on} , and T_{off} . The optimum condition for SR was obtained at low I_p , low T_{on} , and T_{off} and concluded that the I_p was the major factor effecting both the responses, MRR and SR [9]. Chiang had explained the influences of I_p , T_{on} , duty factor and voltage on the responses; MRR, electrodes wear ratio, and SR. The experiments were planned according to a CCD and the influence of parameters and their interactions were investigated using ANOVA. A mathematical model was developed and claimed to fit and predict MRR accurately with a 95% confidence. Results show that the main two significant factors affecting the response are the I_p and the duty factor[10].

Literature reviewed shows that, the two main significant factors on the value of the SR are the discharge current and the duty factor. Statistical models have been developed using RSM based on experimental results considering the machining parameters, viz., amplitude of vibration (A , μm), peak current (I_p , A), pulse-on time (T_{on} , μs), machining time (M_t , min.) and flushing pressure (P_f , kgf/cm^2) as independent variables. Finally, an attempt has been made to obtain optimum machining conditions with respect to SR parameter considered in the present study with the help of response optimization technique.

2. EXPERIMENTATION

The method of assisting EDM process with discontinuous ultrasonic vibrations is designed and developed. The ultrasonic vibrations of 25000 Hz are achieved through developed Piezo-electric transducer. A piezo-electric transducer is attached with EDM machine to give continuous and discontinuous ultrasonic vibrations to work piece at frequency of 25000 Hz with amplitude range of $1\ \mu\text{m}$ to $10\ \mu\text{m}$.

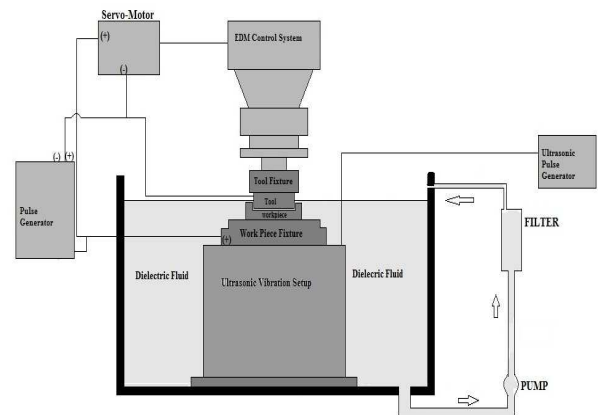


Fig- 1: Line diagram of UEDM set-up

An ultrasonic panel is used to control the amplitude and mode (continuous and discontinuous) of vibration. In case of discontinuous vibrations, the high frequency electrical impulse from the generator to the transducer is discontinuous but interval time is adjusted in terms of frequency-adjustment and finally frequency is maintained at 25000Hz. Figure 1 shows the schematic diagram of the developed UEDM set-up and Figure 2 shows the circuit diagram of discontinuous vibration through piezoelectric transducer. The work piece used for study is Aluminum alloy 6063 with cylindrical shape (Diameter 10mm and Height 30mm). Table 1 shows the chemical composition of work-piece used for study.

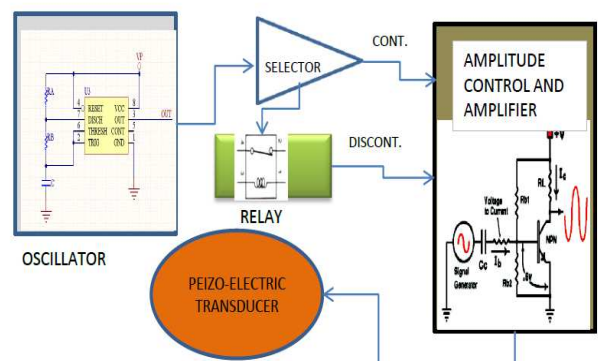


Fig- 2: Circuit diagram of discontinuous vibration

Table -1: Chemical Composition of Al 6063

Element	%
Si	0.3
Fe	0.35
Cu	0.09
Mn	0.1
Mg	0.7
Zn	0.1
Ti	0.1
Cr	0.1
Al	98.16

The experiments are conducted using the commercial Elektra EMS 5535 model Die Sinking Ram EDM. For each experiment, a separate Copper electrode (Diameter 5mm and Height 30mm) has been used.

3. DESIGN OF EXPERIMENTS

The design factors, response variable as well as the methodology employed for the experimentation is described below.

3.1 Design Factor

The design factors considered in the present work were amplitude of vibration, peak current, pulse-on time, machining time and flushing pressure. The selection of these five factors has been made because they are the most important and widely used by researchers in the die sinking EDM field.

3.2 Response Variables

SR is the measure of the fine surface irregularities in the surface texture. These are the results of the EDM process employed to create the surface. SR is related as the arithmetic average deviation of the surface valleys and peaks expressed in micro-meters.

The parameter mostly used for general SR is SR. It measures average roughness by comparing all the peaks and valleys to the mean line, and then averaging them all over the entire cut-off length. Cut-off length is the length for which the stylus is dragged across the surface. A longer cut-off length will give a more average value, and a shorter cut-off length might give a less accurate result over a shorter stretch of surface. In this work, the SR is measured by Mitutoyo surfest SJ-400. The surf test is a shop-floor type SR measuring instrument, which traces the surface of various machine parts and calculates the SR based on roughness standards, and displays the results in μm . The work piece is attached to the detector unit of the SJ-400 which traces the minute irregularities of the work piece surface. The vertical stylus displacement during the trace is processed and digitally displayed on the display of the instrument. The surf test has a resolution varying from 0.01 μm to 0.4 μm depending on the measurement range. The roughness values are taken by averaging at least three measurements per specimen at different locations of specimens.

3.3 Factorial Design Employed

Experiments were designed on the basis of design of experiments. The design finally chosen was a factorial design 24 with six central points, consequently carrying out a total of 32 experiments. Based on the CCD, experiments were conducted to develop empirical models for SR in terms of the five input variables: amplitude of vibration, peak current, pulse-on time, machining time and flushing pressure. Each input variable (factor) was varied over five levels: ± 1 , 0 and $\pm\alpha$. Table 2 shows the relationship between the machining parameters and their corresponding selected variation levels, taking into account the entire range of machine parameters. The experimental data as shown in Table 2 is utilized to obtain the relation between the EDM process parameters and the output SR. RSM utilizes statistical design of experiment technique and least-square fitting method in the model generation phase. An equation consisting of values of a dependent response variable and independent variables is derived for SR characteristics.

Table -2: Process Parameters and their Levels

S. No.	Symbol and Units	Parameters	Levels				
			(-2)	(-1)	(0)	(+1)	(+2)
1	A (μm)	Amplitude of Vibration	0	2	4	6	8
2	IP (A)	Peak Current	5	15	25	35	45
3	Ton (μs)	Pulse-on Time	50	100	150	200	250
4	Mt (Min.)	Machining Time	20	25	30	35	40
5	Pf (Kgf/cm ²)	Flushing Pressure	0.2	0.4	0.6	0.8	1.0

Regression equations are found out using software for statistical analysis called “Design Expert (DX-8)”. ANOVA and Fisher’s statistical test (F-test) is performed to check the adequacy of the model as well as significance of individual parameters.

4. RESPONSE SURFACE METHDOLOGY

Response surface methodology is a collection of mathematical and statistical techniques that are useful for modelling and analysis of problems in which a response of interest is influenced by several variables and the objective is to optimize the response. Response Surface Method adopts both mathematical and statistical techniques [11,12]. RSM helps in analyzing the influence of the independent variables on a specific dependent variable (response) by quantifying the relationships amongst one or more measured responses and the vital input factors. The first step in RSM is to find a suitable approximation for the true functional relationship between response of interest ‘y’ and a set of controllable variables {x1, x2,xn}. Usually when the response function is not known or non-linear, a second order model is utilized [13] in the form:

$$Y = b_0 + \sum_{i=1}^k b_i x_i + \sum_{i=1}^k b_{ii} x_i^2 + \sum_{i < j=2}^2 b_{ij} x_i x_j \pm e_r \dots 1$$

Where, ε represents the noise or error observed in the response y such that the expected response is (y -ε) and b’s are the regression coefficients to be estimated. The least square technique is being used to fit a model equation containing the input variables by minimizing the residual error measured by the sum of square deviations between the actual and estimated responses. The calculated coefficients or the model equations however need to be tested for statistical significance and thus the test is performed.

4.1 Significance Test of the Regression Model

Analysis of Variance (ANOVA) is used to check the adequacy of the model for the responses in the experimentation. ANOVA

calculates the F-ratio, which is the ratio between the regression mean square and the mean square error. The F-ratio, also called the variance ratio, is the ratio of variance due to the effect of a factor (the model) and variance due to the error term. This ratio is used to measure the significance of the model under investigation with respect to the variance of all the terms included in the error term at the desired significance level (α). If the calculated value of F-ratio is higher than the tabulated value of F-ratio for roughness, then the model is adequate at desired α level to represent the relationship between machining response and the machining parameters.

5. EXPERIMENTAL RESULTS

Table 3 shows the design matrix developed for the proposed model as well as the machining characteristics values obtained in the experiments for SR.

5.1 Model Adequacy Test for SR

The ANOVA and Fisher's statistical test (F- test) were performed to check the adequacy of the model as well as the significance of individual parameters. Table 4 shows the pre-ANOVA model summary statistics for SR. It can be seen that standard deviation of quadratic model is 0.49, which is much better as compared with lower order model for R-squared. Hence the quadratic model suggested is most appropriate. Table 5 shows the variance analysis results of the proposed model of SR. The ANOVA Table includes Sum of Squares (SS), Degrees of Freedom (DF), Mean Square (MS), F-value and P- value. The MS was obtained by dividing the SS of each of the sources of variation by the respective DF. The P-value is the smallest level of significance at which the data are significant. The F-value is the ratio of MS of the model terms to the MS of the residual. In this analysis, insignificant model terms were eliminated to adjust the fitted mathematical model. As seen from Table 5, the P-values for developed model of SR is less than 0.0001, which indicates that model is significant at 92% confidence level.

Table -3: Experimental conditions and results of response characteristics for SR

Std. Order	Run order	Factor A		Factor B	Factor C	Factor D	Factor E	Response
		Amplitude of Vibration (µm)	of	Peak Current (A)	Pulse-on time (µs)	Time of Machining (min.)	Flushing Pressure (kg/cm2)	Surface Roughness (µm)
1	15	2		15	100	25	0.8	7.69
2	32	6		15	100	25	0.4	10.63
3	4	2		35	100	25	0.8	10.1
4	6	6		35	100	25	0.4	10
5	26	2		15	200	25	0.8	10.38

6	24	6	15	200	25	0.4	11.85
7	9	2	35	200	25	0.8	9.5
8	20	6	35	200	25	0.4	9.42
9	27	2	15	100	35	0.8	10.89
10	25	6	15	100	35	0.4	9.31
11	22	2	35	100	35	0.8	10.9
12	19	6	35	100	35	0.4	9.97
13	29	2	15	200	35	0.8	9.76
14	10	6	15	200	35	0.4	10.71
15	16	2	35	200	35	0.8	10.37
16	17	6	35	200	35	0.4	12.63
17	5	0	25	150	30	0.6	11.47
18	30	8	25	150	30	0.6	12.67
19	12	4	5	150	30	0.6	6.52
20	11	4	45	150	30	0.6	7.02
21	28	4	25	50	30	0.6	10.95
22	23	4	25	250	30	0.6	11.65
23	21	4	25	150	20	0.6	10.35
24	31	4	25	150	40	0.6	11.13
25	7	4	25	150	30	0.2	10.39
26	18	4	25	150	30	1.0	11.67
27	2	4	25	150	30	0.6	9.37
28	13	4	25	150	30	0.6	9.38
29	3	4	25	150	30	0.6	8.45
30	8	4	25	150	30	0.6	9.67
31	1	4	25	150	30	0.6	9.56
32	14	4	25	150	30	0.6	9.78

Table -4: Model summary Statistics for SR

Model summary Statistics						
Source	Standard Deviation	R-Squared	Adjusted R-Squared	Predicted R-Squared	PRESS	
Linear	1.45	0.1021	-0.0705	-0.3993	85.13	
2FI	1.60	0.3259	-0.3061	-0.5057	91.60	
Quadratic	0.49	0.9558	0.8754	0.3309	40.70	Suggested
Cubic	0.54	0.9710	0.8500	-10.1824	680.29	Aliased

Table -5: ANOVA for quadratic model of Surface roughness

Source	Sum Squares	of	DOF	Mean square	F-Value	P-Value Prob> F	
Model	55.91		16	3.49	10.65	<0.0001	Significant
A-Amplitude of vibration	2.24		1	2.24	6.82	0.0196	
B-Peak Current	0.30		1	0.30	0.91	0.3564	
C-Pulse-on Time	1.78		1	1.78	5.42	0.0344	
D-Machining Time	1.78		1	1.78	5.42	0.0344	

E-Flushing Pressure	0.12	1	0.12	0.38	0.5468	
AD	0.78	1	0.78	2.37	0.1442	
AE	3.02	1	3.02	9.20	0.0084	
BD	1.40	1	1.40	4.26	0.0567	
BE	3.21	1	3.21	9.79	0.0069	
CE	2.68	1	2.68	8.17	0.0120	
DE	0.29	1	0.29	0.88	0.3629	
A2	10.79	1	10.79	32.90	<0.0001	
B2	15.14	1	15.14	46.14	<0.0001	
C2	5.03	1	5.03	15.33	0.0014	
D2	2.20	1	2.20	6.72	0.0204	
E2	3.52	1	3.52	10.74	0.0051	
Residual	2.69	11	0.24			
Lack of Fit	1.55	6	0.26	1.66	0.3006	Not Significant
Pure Error	1.44	5	0.23			
Cor Total	60.84	31				

It was noted that MS of the model (3.49) is many times larger than MS of the residual (0.24), thus the computed F-value of the model ($F=3.49/0.24$) of 14.54 implies that the model is significant.

Table 6 shows the R-Squared (R²), "Adjusted R-Squared (Adj. R²)" and "Predicted R- Squared (Pred. R²)" statistics. The R-Squared is defined as the ratio of variability explained by the model to the total variability in the actual data and is used as a measure of the goodness of fit. The more R² approaches unity, the better the model fits the experimental data. For instance, the obtained value of 0.9191 for R² in the case of SR (Table 6) implies that the model explains variations in the SR to the extent of 91.91% in the current experiment and thus the model is adequate to represent the process.

The "Predicted R²" of 0.5433 is in reasonable agreement with the "Adjusted R²" of 0.8328 because the difference between the adjusted and predicted R² is within 0.28 as recommended for model to be adequate.

The value of Pred. R² of 0.5433 indicates the prediction capability of the regression model. It means that the model explains about 54.33% of the variability in predicting new observations as compared to the 91.91% of the variability in the original data explained by the least square fit. "Adeq

Precision" measures the signal to noise ratio. A ratio greater than 4 is desirable. The ratio of 15.697 indicates an adequate signal. Thus, the overall prediction capability of the model based on these criteria seems very satisfactory.

Table -6: Post ANOVA Model adequacy for SR

R-Squared	0.9191
Adj R-Squared	0.8328
Pred R-Squared	0.5433
Adeq Precision	15.697

6. ANALYSIS AND DISCUSSION OF RESULTS

The set of experiments is designed and conducted by employing RSM using discontinuous nature of vibration. The selection of appropriate model and the development of response surface models have been carried out by using statistical software "Design Expert (DX-8)". The regression equations for the selected model are obtained for the response characteristics, viz., SR. These regression equations are developed using the experimental data presented in Table 3. The response surfaces are plotted to investigate the effect of input process parameters, amplitude of vibration, peak current, pulse-on time, machining time and flushing pressure together

with their second order interaction on the response characteristics. The Analysis of Variance (ANOVA) is performed to statistically analyze the results.

6.1 Selection of Adequate Model

Table 7 displays different tests to select the adequate model to be fit for SR. The “sequential model sum of squares” test in each Table7 shows how the terms of increasing complexity

contribute to the model. It can be observed that for all the responses/characteristics, the quadratic model is appropriate [because Prob>F Value, 0.0001 (Table 7), is less than 0.05]. The addition of cubic terms does not significantly improve the lack of fit because these terms are aliased for CCD (even if these were significant). The “lack of fit” test compares the residual error to the pure error from the replicated design points.

Table -7: Selection of Adequate Model for surface roughness

1 Sequential Model sum of Squares						
Source	Sum of Squares	DOF	Mean Square	F-value	Prob > F	
Mean	3283.34	1	3283.34			
Linear	6.21	5	1.24	0.59	0.7065	
2FI	13.61	10	1.36	0.53	0.8441	
Quadratic	38.32z	5	7.66	31.33	<0.0001	Suggested
Cubic	0.92	5	0.18	0.63	0.6867	Aliased
Residual	1.77	6	0.29			
Total	3344.17	32	104.51			
2 Lack of Fit Tests						
Source	Sum of Squares	DOF	Mean Square	F-Value	Prob > F	
Linear	53.48	21	2.55	11.16	0.0070	
2FI	39.87	11	3.62	15.89	0.0034	
Quadratic	1.55	6	0.26	1.13	0.4555	Suggested
Cubic	0.63	1	0.63	2.74	0.1587	Aliased
Pure Error	1.14	5	0.23			
3 Model summary Statistics						
Source	Standard Deviation	R-Squared	Adjusted R-Squared	Predicted R-Squared	R-PRESS	
Linear	1.45	0.1021	-0.0705	-0.3993	85.13	
2FI	1.60	0.3259	-0.3061	-0.5057	91.60	
Quadratic	0.49	0.9558	0.8754	0.3309	40.70	Suggested
Cubic	0.54	0.9710	0.8500	-10.1824	680.29	Aliased

The Table 7 indicates that the quadratic model in all the response characteristics does not show significant lack of fit, hence the adequacy of quadratic model is confirmed. Another test “model summary statistics” given in the following Table further confirms that the quadratic model is the best to fix as it exhibits low standard deviation, high “R-Squared” values, and a low “PRESS” (Adeq Precision).

$$f_{LN} = N - 1 \quad \dots 2$$

Where,

f_{LN} = Total degrees of freedom of an OA

L_N = OA designation

N = Number of trials

The regression coefficients of the second order equation (Equation 3) are obtained by using the experimental data in Table 3. The regression equations for the response characteristic as a function of five process parameters considered in this experiment are given below. The insignificant coefficients (identified from ANOVA) have been omitted from the equation.

$$\begin{aligned}
 \mathbf{SR} = & +33.28 - 1.24 * A + 0.15 * IP - 0.06 * P_o - 0.73 * M_t - \\
 & 30.15 * P_f - 8.21E-003 * A * IP + 2.66E-003 * A * T_{on} - \\
 & 0.02 * A * M + 1.08 * A * P_f - 4.03E-004 * IP * T_{on} + 5.91E- \\
 & 003 * P * M_t + 0.22 * IP * P_f - 8.25E- \\
 & 005 * T_{on} * M_t + 0.04 * T_{on} * P_f + 0.13 * M_t * P_f + 0.15 * A^2 - \\
 & 7.18E-003 * IP^2 + 1.65E- \\
 & 004 * T_{on}^2 + 0.01 * M_t^2 + 8.66 * P_f^2 \quad 3
 \end{aligned}$$

Where A: Amplitude of vibration, IP: Peak Current, T_{on} : Pulse-on Time, M_t : Machining Time, P_f : Flushing Pressure.

Using this equation, the response surfaces have been plotted to study the effect of process parameters on the performance characteristics.

Figure 3 shows the combined effect of amplitude of vibration and peak current on SR. At the lower value of peak current against amplitude of vibration, the SR is less but it increases with increase in the peak current. SR decreases with increase in the amplitude of vibration with respect to peak current up to a certain level. This happens due to intensity of vibration, as amplitude of vibration at its lower level allows less debris to get removed and at higher level, the ideal time is more which result in increased surface roughness.

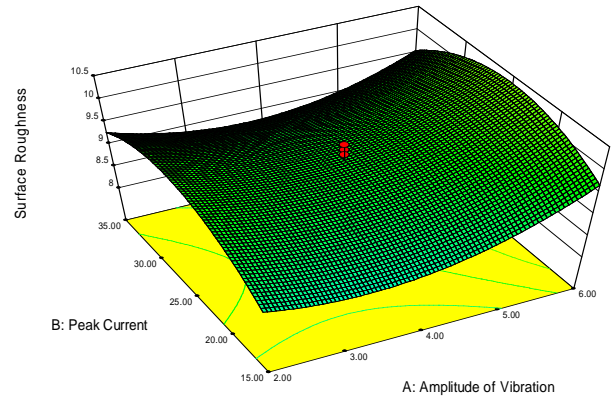


Fig -3: Response Surface for the Combined Effect of Amplitude of Vibration and Peak Current on SR

Figure 4 shows the combined effect of amplitude of vibration and pulse-on time on SR. The amplitude of vibration and pulse-on-time have similar effect on SR..SR is minimum at the average value of both parameter. The response increases when the value of both factors increase, as with the increased amplitude of vibration, more craters are created at the work piece and with increased pulse on time as lesser time is available to eject the eroded material from working zone.

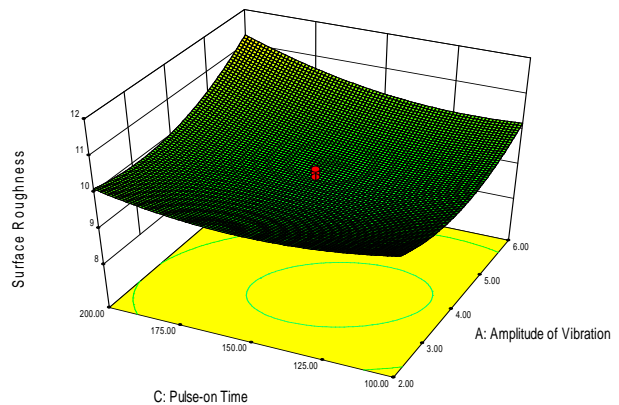


Fig -4: Response Surface for the Combined Effect of Amplitude of Vibration and Pulse-on Time on SR

Figure 5 shows the combined effect of amplitude of vibration and machining time on SR. Lower value of machining time and amplitude of vibration cause lesser SR while SR increases with their increasing values, as the machining time is increased, deeper craters are formed, which result in rougher surfaces. The maximum value of response occurs at the lower value of machining time and higher value of amplitude of vibration.

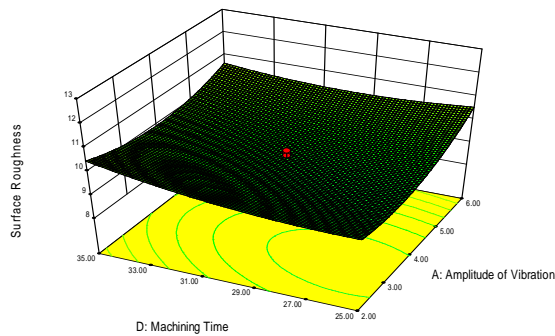


Fig -5: Response Surface for the Combined Effect of Amplitude of Vibration and Machining Time on SR

Figure 6 shows the combined effect of amplitude of vibration and flushing pressure on SR. At higher values of flushing pressure and amplitude of vibration, SR is much more as compared to the any other values.. On the lower value of amplitude of vibration and increasing value of flushing pressure the SR decrease while at the higher value of amplitude of vibration with increasing value of flushing pressure the SR increase. The SR is higher at lower and higher value of amplitude of vibration with respect to flushing pressure, while SR decreases at its average value.

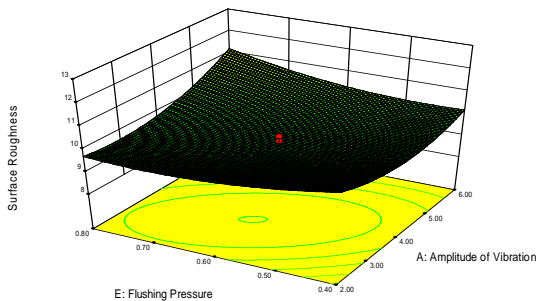


Fig -6: Response Surface for the Combined Effect of Amplitude of Vibration and Flushing Pressure on SR

Figure 7 shows the combined effect of peak current and pulse-on time on SR. With rise in peak current, SR increases up to a certain level and then decreases. At lower value of peak current and increasing value of pulse on time, SR is much lower then any other level. The response is maximum at higher value of pulse on time and average value of peak current. The pulse on-time causes the increased size of spark crater with aid of peak current which results in increased SR.

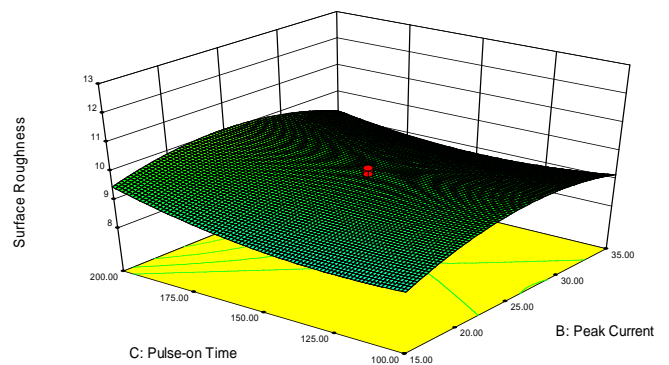


Fig -7: Response Surface for the Combined Effect of Peak Current and Pulse-on Time on SR

Figure 8 shows the combined effect of peak current and machining time on SR. The SR decreases when the machining time is maximum and peak current is minimum or vice versa. The SR is maximum at average value of peak current and higher value of machining time. The higher machining time and peak current gave less time for the removal of debris which results in increase in SR.

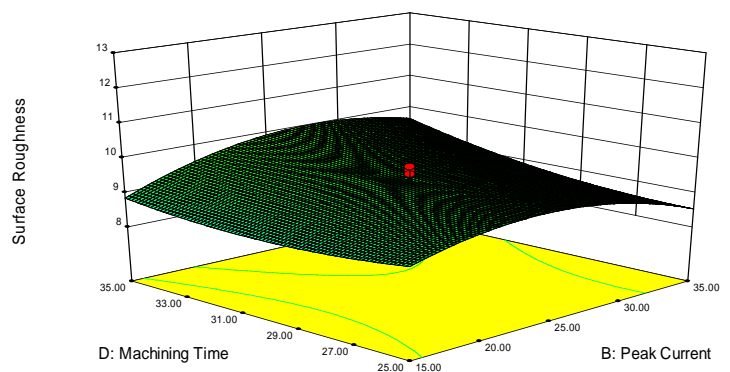


Fig -8: Response Surface for the Combined Effect of Peak Current and Machining Time on SR

Figure 9 shows the combined effect of peak current and flushing pressure on SR. The increase in peak current with respect to flushing pressure increases the SR. The SR is lesser when the flushing pressure is increasing and peak current is minimum. When the peak current increases, the size of crater increases which causes more erosion of the work piece. This eroded work piece can only be removed with higher flushing pressure otherwise the SR would increase.

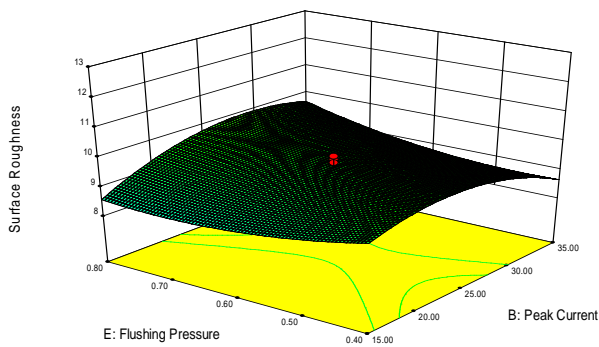


Fig -9: Response Surface for the Combined Effect of Peak Current and Flushing Pressure on SR

Figure 10 shows the combined effect of pulse-on time and machining time on SR. The SR is maximum at higher values of pulse on time and machining time. The response is minimum at the average values of both parameters. The pulse on-time and machining time collectively effect the SR because machining time is totally dependant on pulse on-time.

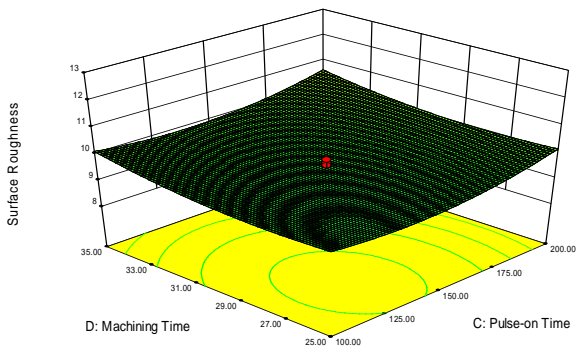


Fig -10: Response Surface for the Combined Effect of Pulse-on Time and Machining Time on SR

Figure 11 shows the effect of pulse-on time and flushing pressure on SR. SR increases at lower and higher levels of both parameters collectively. SR decreases at minimum value of pulse on time and higher value of flushing pressure or vice versa. Pulse on time allows the current to erode the work piece by heating it. The higher flushing pressure quench the work piece while the lower did not remove debris properly, which result higher SR at their higher and lower level.

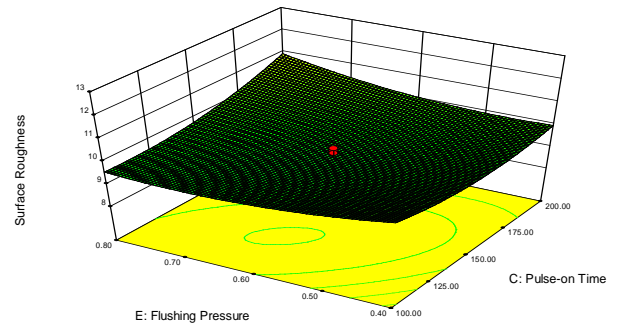


Fig -11: Response Surface for the Combined Effect of Pulse-on Time and Flushing Pressure on SR

Figure 12 shows the combined effect of machining time and flushing pressure on SR. The SR is maximum when the values of both the parameters are at higher level. With increase in flushing pressure with respect to machining time, the SR decreases. The increase in machining time with flushing pressure causes, firstly reduction and then increase in SR. The more flushing pressure with less machining time cause proper elimination of debris which result in lower SR.

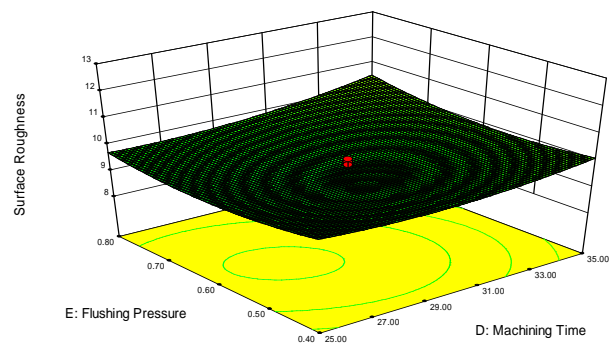


Fig -12: Response Surface for the Combined Effect of Machining Time and Flushing Pressure on SR

CONCLUSIONS

Using Al6063 as work piece, the effects on SR is found by five parameters i.e. amplitude of vibration, pulse-on time, peak current, machining time and flushing pressure by using RSM. It is concluded that all the five parameters have their different effect on SR when used with each other. The intensity of SR may be reduced by increasing flushing pressure as this leads to easy removal of debris. Also, SR increases with increase in amplitude of vibration, peak current and pulse on-time.

So, it is concluded that at lower values of amplitude of vibration, peak current & pulse on-time and higher value of flushing pressure leads to reduction in SR.

REFERENCES

- [1]. Russell V. Lenth, "Response-Surface Methods in R, Using RSM," Journal of Statistical Software, Vol. 32 (7), 2009
- [2]. M.R. Shabgard and R.M. Shotorbani, "Mathematical Modeling of Machining Parameters in Electrical Discharge Machining of FW4 Welded Steel," World Academy of Science, Engineering and Technology, Vol. 52 (63), pp. 403-409, 2009
- [3]. K. M. Iqbal Asif and Ahsan Ali Khan, "Modeling and analysis of MRR, EWR and Surface Roughness in EDM Milling through Response Surface Methodology," American Journal of Engineering and Applied Sciences, Vol. 3 (4), pp. 611-619, 2010
- [4]. P. Sahoo, Routara B.C. and A. Bandyopadhyay, "Roughness modeling and optimization in EDM using response surface method for different work piece materials," International Journal of Machining and Machinability of Materials, Vol. 5, (2-3), pp. 321- 346, 2009.
- [5]. D. Kanagarajan, R. Karthikeyan, K. Palanikumar and P. Sivaraj, "Influence of process parameters on electric discharge machining of WC30%Co composites," Proceedings of the Institution of Mechanical Engineers, Part B: Journal of Engineering Manufacture, Vol. 222, pp. 807-815, 2008.
- [6]. M.R. Shabgard and R.M. Shotorbani, "Mathematical Modeling of Machining Parameters in Electrical Discharge Machining of FW4 Welded Steel" World Academy of Science, Engineering and Technology, Vol. 52 (63), pp. 403-409, 2009.
- [7]. M.K. Pradhan and C.K. Biswas, "Modeling & analysis of process parameters on surface roughness in EDM of AISI D2 tool steel by RSM approach," International Journal of Mathematical, Physical and Engineering Sciences, Vol. 3 (1), pp. 66-71, 2009
- [8]. P. Kuppan, A. Rajadurai, and S. Narayanan, "Influence of EDM process parameters in deep hole drilling of inconel 718," International Journal of Advance Manufacturing Technology, Vol. 38, pp. 74-84, 2007.
- [9]. Jaharah, C. Liang, A. Wahid, S.Z., M. Rahman, and C. Che Hassan, "Performance of copper electrode in electrical discharge machining of AISI H13 harden steel," International Journal of Mechanical and Materials Engineering, Vol. 3 (1), pp. 25-29, 2008.
- [10]. K. Chiang, "Modeling and analysis of the effects of machining parameters on the performance characteristics in the edm process of Al₂O₃+tic mixed ceramic," International Journal of Advanced Manufacturing Technology, Vol. 37 (5-6), pp. 523-533, 2008.
- [11]. D.C.Montgomery, "Design and Analysis of Experiments," Wiley-India, 2007.
- [12]. Myers, D.C. Montgomery and Anderson-Cook, "Response Surface Methodology," John Wiley-New York, 2009.

- [13]. D. C. Montgomery, "Design and analysis of experiments," John Wiley and Sons Inc., 2001.

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