Optimization of EDM Parameters for Minimum Surface Roughness During Electric Discharge Machining using Two Level Full Factorial Design

Sunil Kumar
M. Tech Scholar
Department of Mechanical Engineering
YIT Jaipur

Amit Kumar Bansal
Reader
Department of Mechanical Engineering
SKIT Jaipur

Suman Anand
Lecturer
Department of Mechanical Engineering
SKIT Jaipur

Chandan Kumar
Lecturer
Department of Mechanical Engineering
SKIT Jaipur

Bhaskar Srivastava
Associate Professor
Department of Mechanical Engineering
YIT Jaipur

Abstract

During electric discharge machining the main output parameters are the material removal rate (MRR), tool wear and surface finish. To increase the productivity, it is desirable to obtain the maximum MRR with minimum surface roughness .Therefore the surface roughness is considered to be a measure of the technological quality of a product. Surface roughness is the one of the critical performance parameter that has an appreciable effect on several mechanical properties of machined parts like friction, wear, light reflection, heat transmission, lubrication, electrical conductivity, etc. Hence, achieving the desired surface quality is of great importance for the functional behavior of the mechanical parts. The quality of the machined work piece is greatly influenced by the cutting conditions. In order to produce parts with the desired surface finish using EDM, EDM parameters should be selected properly. During non-traditional machining, it has long been recognized that the machining conditions affect the performance of the operation to a greater extent. These machining conditions should be selected to optimize the economics of machining operations. So it can be achieved by empirical modeling of performance as a function of machining conditions using design of experiments (DOE). The proposed work will be employed for investigation of the effect of EDM parameters on surface roughness and development of surface roughness and MRR prediction models using two level full factorial design.
Keywords: DOE ,Two Level Full Factorial Design, Surface Roughness (ra),ANOVA

I. INTRODUCTION

During non-traditional machining, it has long been recognized that the machining conditions affect the performance of the operation to a greater extent. These machining conditions should be selected to optimize the economics of machining operations. So it can be achieved by empirical modeling of performance as a function of machining conditions using design of experiments (DOE). The proposed work will be employed for investigating the effect of EDM parameters on surface roughness using response surface methodology based on two level full factorial design.. Due to demands for alloy materials having high hardness, toughness and impact in aerospace and automotive industries, electrical discharge machining (EDM) technology has grown tremendously. The EDM provides the best alternative or sometimes the only alternative for machining conductive, exotic, high strength and temperature resistive materials, conductive engineering ceramics with the scope of generating intricate shapes and profiles with high dimensional accuracy and good surface finish. A number of studies have been carried out to investigate the effect of machining conditions on surface roughness during electric discharge machining. Also, number of attempt have also been made by the previous researchers to optimize the EDM parameters for minimize surface roughness.

A. *Design of Experiments:*

Design of experiment procedure is a powerful approach to improve product design or improve process performance. This procedure constitutes a systematic method concerning the planning of experiments, collection and analysis of data with near-optimum use of available resources. It is possible to identify the process conditions that influence product quality and costs, which in turn enhance the product manufacturability, quality, reliability and productivity.
The advantages of design of experiments are as follows:

1) Number of trials are significantly reduced.
2) Important decision variables which control and improve the performance of the product or the process can be identified.
3) The optimal setting of the parameters can be found out.
4) Experimental error can be estimated.

On the basis of planning of experiments, design of experiment includes number of techniques like factorial design, Taguchi method, centre composite design etc.

In the present work, 2 level full factorial design has been used to plan the experiments and subsequent analysis of the data collected

II. LITERATURE REVIEW

A number of studies have been carried out to investigate and formulate the effect of machining condition for prediction of surface roughness and selection of optimal machining parameters during electric discharge machining. Some of research studies are presented below.

Zhixin et al. (1995) proposed a technique (mechanical pulse electric discharge machining) to produce holes in the conductive hard and brittle materials. The ultrasonic vibration has been used to generate the spark in place of the conventional special pulse generator between the tool and workpiece in mechanical pulse electric discharge machining (MPEDM). Ultrasonic vibration of the tool also acted as gap-flushing method. Pecas and Henriques, (2003) investigated the effect of addition of powder particles in the dielectric fluid on the surface roughness of machined parts during the electrical discharge machining (EDM). The analysis is carried out varying the silicon powder concentration and the flushing flow rate over a set of different processing areas. The evaluation of process is done by surface morphologic analysis. Liao et. al. (2003) used the modified traditional circuit using low power for ignition for WEDM. With the assistance of Taguchi quality design, ANOVA and *F*-test, machining voltage, current-limiting resistance, type of pulse-generating circuit and capacitance have been identified as the significant parameters affecting the surface roughness in finishing process. It has been found that a low conductivity of dielectric should be incorporated for the discharge spark to take place. After analyzing the effect of each relevant factor on surface roughness, appropriate values of all parameters were chosen and a fine surface of roughness R_a = 0.22 μm was achieved. Kansal et al. (2007) studied the effect of Sic powder mixed EDM on machining rate of AISI D2 Die steel using Taguchi and ANOVA. Pradhan and Biswas (2009) investigate the effect of EDM parameters on surface roughness using response surface methodology pulse duration, pulse off time and applied voltage have been considered as EDM parameters. The discharge current, pulse duration and pulse off time and their interactions have been found significant parameters that affect the surface roughness.

III. EXPERIMENTAL WORK

The experimental work which includes selection of EDM parameters, selection of range of EDM parameters, formation of design matrix using two level full factorial design, selection of work-piece material, experimental set-up, measurement of surface roughness. The process parameters that were chosen for experimentation are given as under:

1) Peak current
2) Pulse on time (μs_n)
3) Pulse off time (μs_f)
4) Voltage
5) Kerosene

The levels of each input parameter were decided by studying the literature in detailed and according to machine limitations. Table 3.1 shows the levels of EDM parameters according to two level full factorial design.

Table – 1
EDM Parameters and Their Levels

Factor	*Name*	*Units*	*Type*	*Subtype*	*Minimum (+1)*	*Maximum (-1)*
A	*Voltage*	*Volts*	*Numeric*	*Continuous*	*30*	*45*
B	*Current*	*Ampere*	*Numeric*	*Continuous*	*6*	*25*
C	*Pulse on*	*Microsecond*	*Numeric*	*Continuous*	*6*	*200*
D	*Pulse off*	*Microsecond*	*Numeric*	*Continuous*	*12*	*100*

B. *Surface Roughness Measurement:*

Surface roughness is defined as the finer irregularities of the surface texture that usually result from the inherent action of the machining process or material condition. The constants for surface roughness tester for all the measurements of work pieces were standard ISO 97R, 0.8 mm cut-off, least count of 0.001μm. The measurements were repeated at three different locations of the finish work piece in the direction of the tool movement. Finally, the mean of surface roughness values were considered for the particular trial. Technical specifications of the surface roughness tester are summarized in table 3.2 and the results obtain after measurements of surface roughness indicators of machined work pieces have been shown in tables 3.3

Table - 2
Technical Specification of Surface Roughness Tester (Surf Coder TR210)

Model	*TR 210*
Roughness Parameter	*Ra, Rq, Rz, Rt*
Unit	*mm , inch*
Weight	*440 g*
Dimension	*141 mm x 56 mm x 48 mm*
Power	*Li-ion battery rechargeable, AC adapter 8.4V,800mA*
Display resolution	*0.01 µ m*
Accuracy	*≤±10%*
Reparability	*<6%*
Data output	*RS232*
Measuring Range	*Ra: 0.025~12.5µ m*
Cutoff length (L)	*0.25mm/0.8mm/2.5mm/Auto*
Evaluation length	*5L (selectable)*
Tracing length	*5L + 2 L*
Digital filter	*RC, PC-RC, Gauss, D-P*
Max. driving length	*17.5mm/0.71inch*
Min. driving length	*1.8mm/0.071*
Pick-up	*Standard pickup TS100, inductive, Diamond stylus radius 5µm, angle of stylus 90°*

Table - 3
Measurement Results

S.No.	*A:Voltage (volts)*	*B:Current (Ampere)*	*C:Pulse on (Microsecond)*	*D:Pulse off (Microsecond)*	*E:type of dielectric*	*Surface roughness (Microns)*
1	30	6	6	12	kero	3.481
2	45	6	6	12	kero	3.215
3	30	25	6	12	kero	3.865
4	45	25	6	12	kero	3.348
5	30	6	200	12	kero	7.012
6	45	6	200	12	kero	5.886
7	30	25	200	12	kero	7.199
8	45	25	200	12	kero	6.641
9	30	6	6	100	kero	3.422
10	45	6	6	100	kero	2.105
11	30	25	6	100	kero	3.998
12	45	25	6	100	kero	2.602
13	30	6	200	100	kero	5.717
14	45	6	200	100	kero	4.342
15	30	25	200	100	kero	6.127
16	45	25	200	100	kero	4.672

17	*37.5*	*15.5*	*103*	*56*	*kero*	*4.201*
18	*37.5*	*15.5*	*103*	*56*	*kero*	*3.898*
19	*37.5*	*15.5*	*103*	*56*	*kero*	*4.381*
20	*37.5*	*15.5*	*103*	*56*	*kero*	*4.111*

IV. DEVELOPMENT OF SURFACE ROUGHNESS PREDICTION MODEL

The complete results of the 20 experiments performed as per the experimental plan were input into the Design Expert 8.0.4.7 software for further analysis.

A. ANOVA for Surface Roughness Prediction Model:

The analysis of variance (ANOVA) is based on two assumptions: (1) the variables are normally distributed and (2) homogeneity of variance. Significant violation of either assumption can increase the chances of error.

To check the assumption of normal distribution, the normal probability plot of the residuals is shown in figure.4.1.The normal probability plot indicates whether the residuals follow a normal distribution or not, if the residuals follow a normal distribution majority of points will follow a straight line except some moderate scatter even with normal data. The figure displays that the residuals generally fall on a straight line implying that the errors are distributed normally.The figure.4.2 represents residuals versus the predicted response plot for surface roughness. It tests the assumption of constant variance. The plot should be a random scatter. The figure shows that there is no obvious pattern and it shows unusual structure. This implies that there is no reason to suspect any violation of the independence or constant variance assumption.

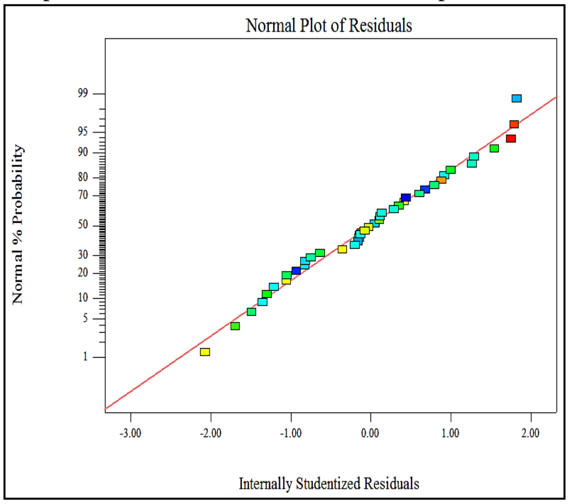

Fig. 1: Normal Plot of Residuals

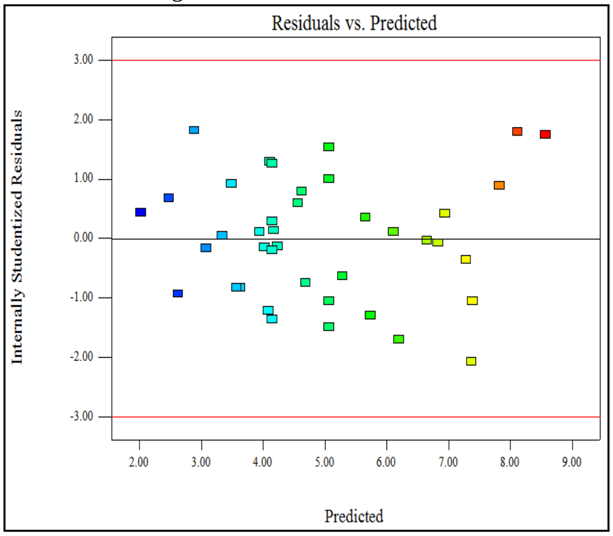

Fig. 2: Residuals vs. Predicted

B. ANOVA Analysis:

The ANOVA was carried out for a significance level of α = 0.05, i.e. for a confidence level of 95%. The ANOVA for surface roughness is summarized in Table 4.1.

The table 4.1, shows that the value of "Prob. > *F*" for model is less than 0.0001 which is less than 0.05, that indicates the model is significant, which is desirable as it indicates that the terms in the model have a significant effect on the surface roughness. In the same manner, the value of "Prob. > *F*" for main effect of voltage, current, pulse on, pulse off, type of dielectric and two-level interaction of voltage and pulse off, pulse off and pulse on, pulse on and type of dielectric are less than 0.05 so these terms are significant model terms.

Table – 4
Resulting ANOVA Table for Surface Roughness

Source	Sum of squares	Degree of freedom	Mean square	F-Value	p-value Prob > F
Model	105.2975	8	13.16218	159.8787	< 0.0001S
A-Voltage	10.48133	1	10.48133	127.3149	< 0.0001
B-Current	1.646205	1	1.646205	19.99616	< 0.0001
C-Pulse on	71.06108	1	71.06108	863.1664	< 0.0001
D-Pulse off	9.182755	1	9.182755	111.5413	< 0.0001
E-type of dielectric	7.999514	1	7.999514	97.16868	< 0.0001
AD	1.282401	1	1.282401	15.5771	0.0004
CD	2.992681	1	2.992681	36.35157	< 0.0001
CE	0.651511	1	0.651511	7.91379	0.0084
Residual	2.552108	31	0.082326		
Lack of Fit	2.20243	25	0.088097	1.511631	0.3190NS
Pure Error	0.349678	6	0.05828		
Cor Total	107.8496	39			
Std. Dev.	0.286925		R-Squared		0.976336
Mean	4.95835		Adj R-Squared		0.97023
C.V. %	5.786707		Pred R-Squared		0.965185
PRESS	3.754819		Adeq Precision		48.08503

The value of "Prob. > *F*" for lack-of-fit is 0.3190 which is greater than 0.05 and it indicates the insignificant lack of fit. If the model does not fit the data well, this will be significant. The insignificant lack of fit is desirable.

The R^2 value is equal to 0.976 or close to 1, which is desirable. The adjusted R^2 value is equal to 0.970; it is particularly useful when comparing models with different number of terms. The result shows that the adjusted R^2 value is very close to the ordinary R^2 value. Adequate precision value is equal to 48.08; a ratio greater than 4 is desirable which indicates adequate model discrimination. Adequate precision value compares the range of the predicted values at the design points to the average prediction error.

1) Surface Roughness Prediction Mode:

The regression model for surface roughness in terms of coded factors is shown as follows:

$$Surface\ roughness = 4.96 - 0.57 * A + 0.23 * B + 1.49 * C - 0.54 * D + 0.45 * E - 0.20 * A * D - 0.31 * C * D + 0.14 * C * E \quad (4.1)$$

The empirical models in terms of actual factors are shown by equation 4.2. Equation 4.2 represented the relation between the EDM parameters and surface roughness with kerosene.

$$Surface\ roughness = 4.57 - 0.042 * Voltage + 0.024 * Current + 0.0179 * Pulse\ on + 0.01795 * Pulse\ off - 0.0006 * Voltage * Pulse\ off - 0.000071 * Pulse\ on * Pulse\ off \quad (4.2)$$

V. EFFECT OF EDM PARAMETERS ON SURFACE ROUGHNESS

To examine the effect of EDM parameters on surface roughness and MRR, different curves have been plotted between the EDM parameters and responses.

The effect of voltage on surface roughness at constant current (15.5 A), constant pulse on time (103 microseconds) and constant pulse off time (56 microseconds) is shown in figure 5.1

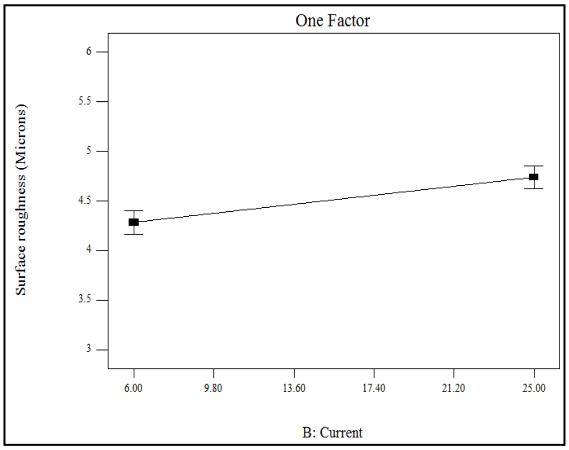

Fig. 3: The Surface Roughness Decreases as the Voltage Increases.

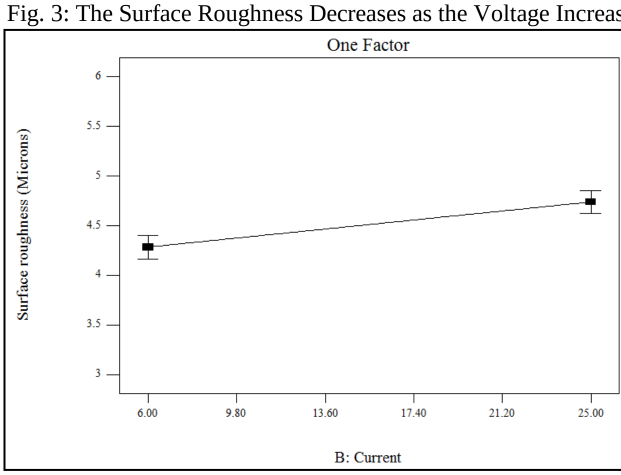

Fig. 4: The Effect of Current on Surface Roughness at Constant Voltage

The result shows that the surface roughness decreases as the voltage increases. With the higher voltage, the discharge time gets longer. This will lead to a wider average discharge gap. Therefore, the discharge condition becomes more stable but the number of discharge cycles decreases within a given period. Owing to this stable machining, surface accuracy becomes better and surface roughness value decreases.

Figure 5.2 shows the effect of current on surface roughness at constant voltage (37.50 Volts), constant pulse on time (103 microseconds) and constant pulse off time (56 microseconds). The surface roughness increases as the current increases. The higher is the peak current, the larger is the discharge energy. Large discharge energy creates craters, this leads to increase in surface roughness.

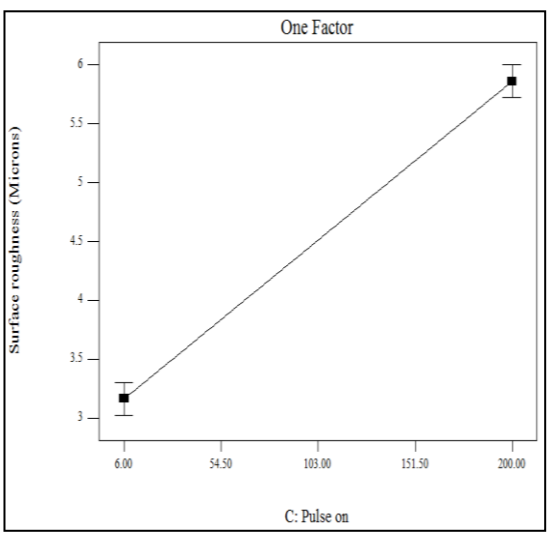

Fig. 5:

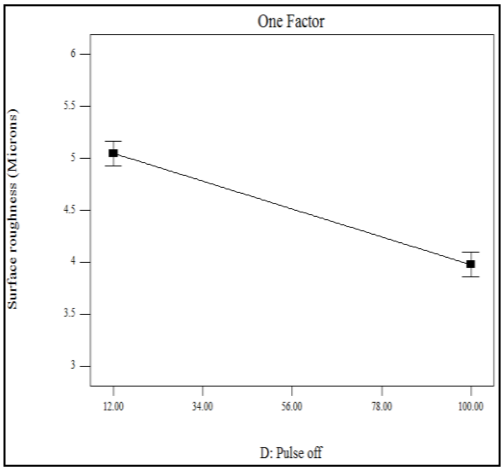

Fig. 6

It is clear from the plot that as the pulse on time increases from 6 microseconds to 200 microseconds, the value of surface roughness also increases. The surface roughness is most affected by the amount of discharge energy which increases with increase in pulse on-time. The Influence of pulse off time on surface roughness at constant voltage (37.50 Volts), constant current (15.5 A) and constant pulse on time (103 microseconds) is shown in figure 5.4. The amount of discharge energy decreases with increase in pulse off-time. Further as the discharge energy decrease, the roughness also decreases.

The figure 5.5 shows the contour plot for surface roughness at constant current 15.5 A and pulse on time 103 microsecond, its shows the cumulative effect of voltage and pulse off time on surface roughness. From the contour plot it is clear that as the voltage increases the surface roughness decreases for any value of pulse off time. It is also visible that as the pulse off time increases the surface roughness decreases for any value

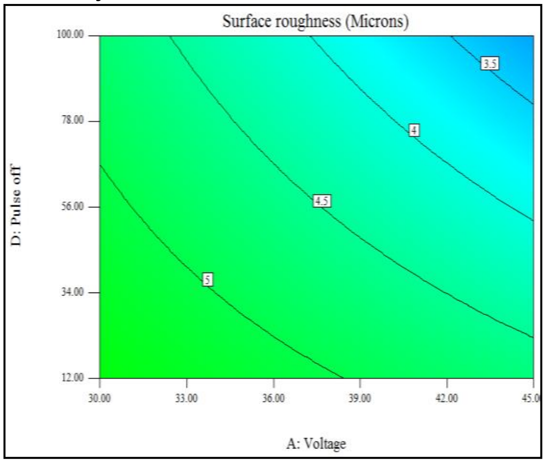

Fig. 7: Shows the Contour Plot for Surface Roughness at Constant Current

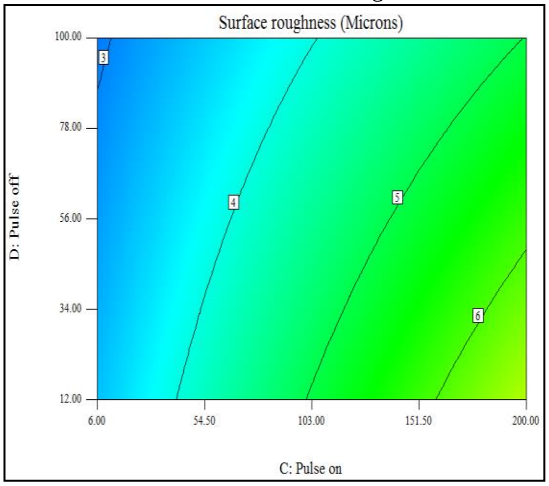

Fig. 8

VI. OPTIMIZATION OF EDM PARAMETERS FOR MINIMUM SURFACE ROUGHNESS

In the present study, the aim is to obtain the optimal values of EDM parameters for minimum surface roughness The constraints used during the optimization process are summarized in Table 6.1.The optimal solutions are reported in table 6.2

Table – 5
Constraints for Optimization of EDM Parameters

Condition	*Units*	*Goal*	*Lower limit*	*Upper limit*
A:Voltage	*Volts*	*Is in range*	*30*	*45*
B:Current	*Ampere*	*Is in range*	*6*	*25*
C:Pulse on	*Microseconds*	*Is in range*	*6*	*200*
D:Pulse off	*Microseconds*	*Is in range*	*12*	*100*
E:type of dielectric		*Is in range*	*Kerosene*	
Surface roughness	*Microns*	*Minimize*	*2.105*	*8.88*

Table – 7
Optimization Results for Surface Roughness

Solution No.	*A:Voltage (Volts)*	*B:Current (Ampere)*	*C:Pulse on (Microseconds)*	*D:Pulse off (Microseconds)*	*Surface roughness (Microns)*
1	*45.00*	*6.00*	*6.00*	*100.00*	*1.934*

VII. CONCLUSION AND FUTURE SCOPE

The important conclusions drawn from the present work are summarized as follows:

1) The minimum surface roughness 1.934 microns has been obtained at voltage 45 V, current 6 A, pulse on time 6 microseconds pulse off time 100 microseconds and with kerosene as dielectric medium .
2) All the five independent parameters (Current, Voltage, Pulse on time Pulse off time and type of dielectric medium) seem to be the influential EDM parameters that affect the surface roughness .
3) The surface roughness prediction model clearly shows that the pulse on seems to be the most significant factor that affect the surface roughness.
4) Surface roughness decreases as pulse off increases, voltage increases, current decreases and pulse on decreases.

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