ISSN: 2348 - 2117

Available Online at www.ijetcr.org

International Journal of Engineering Technology and Computer Research (IJETCR) 1 (1) 2013, 36-44

Optimization of Pulse on time and Gap Voltage parameters for Maximum Material Removal Rate (MRR) on D3 Die Steel Using Factorial Design

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ABSTRACT

The electrical discharge machining (EDM), is one of the processing based on non-traditional manufacturing procedures, is gaining increased popularity, since it does not require cutting tools and allows machining involving hard, brittle, thin and complex geometry. EDM process is based on thermoelectric energy between the work piece and an electrode. Material Removal Rate (MRR) is an important performance measure in EDM process. Since long, EDM researchers have explored a number of ways to improve and optimize the MRR including some unique experimental concepts that depart from the traditional EDM sparking phenomenon.

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.

Keywords: EDM, parameters, MRR, dielectric, powder, variations.

INTRODUCTION:

In the manufacturing industries, various machining processes are adopted for removing the material from the work piece to obtain finished product. Due to demands for alloy materials having high hardness, toughness and impact in aerospace and automotive industries, electrical discharge machining (WEDM) 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.

Electric discharge machining (EDM) is a non-traditional machining where material removal takes place by electro thermal process. In which heat is produced by electric spark & then melting and vaporization of tiny particles of work- specimen occurs due to thermal energy. EDM is possible only to electrically conductive material. It is mainly used for hard and high strength material with simple as well as complex geometry with high precision, accuracy & finish in small batches or job shop basis.

2. WORKING PRINCIPLE OF EDM

EDM is electro- thermal machining in which material is removed by erosion with rapid recurring type spark produced between tool & work which results in melting & vaporization of small particles of specimen. In this process a gap of about 0.025 mm is kept between work-piece & tool using servo mechanism. Both tool & work-specimen are submersed in dielectric fluid which is generally EDM oil / kerosene /deionised water.

Tool is made of anode & work-piece is made of cathode & proper gap is maintained. When the voltage across the gap becomes high enough, it discharges spark through the gap. Spark is produced in the pulse duration T_{on}=2-2000 micro second range and during the off time and which results in acceleration of the positive ions and electrons producing a conductive discharge channel. A sudden drop of electric resistance increases current density and creates powerful magnetic field due to increase in ionization. As the spark occurs, sufficient pressure is developed between tool & work, result in high pressure and temperature that removes metal by melting and erosion. This cycle goes on working time and then electrode is raised up for lift time T for good flushing. The parameters which have to be controlled are gap voltage (v), peak current (I_P), pulse duration (T_{ON}).

Important parameters of EDM

1) Spark On-time (Pulse time or Ton): The duration of time (μ s) the current is allowed to flow per cycle. Material removal is directly proportional to the amount of energy applied during this on-time. This energy is really controlled by the peak current and the length of the on-time.

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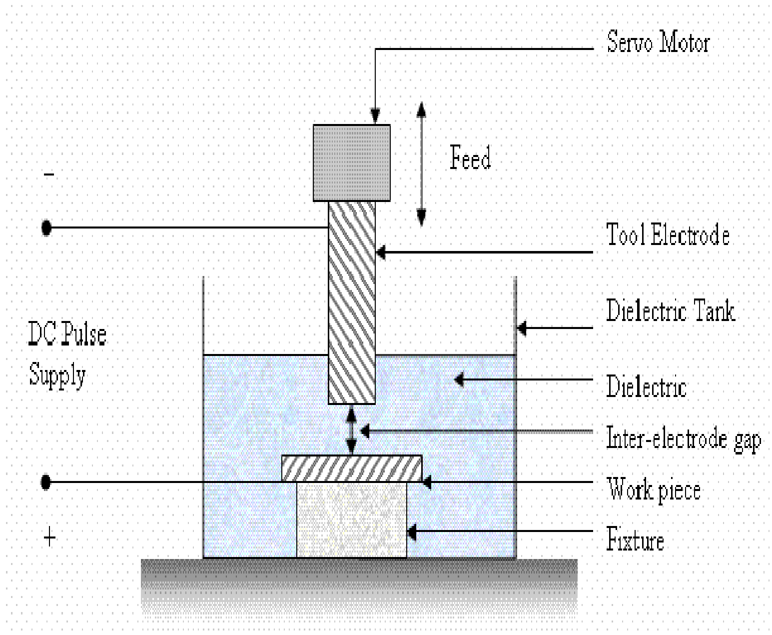

Figure 1: Working principle of EDM

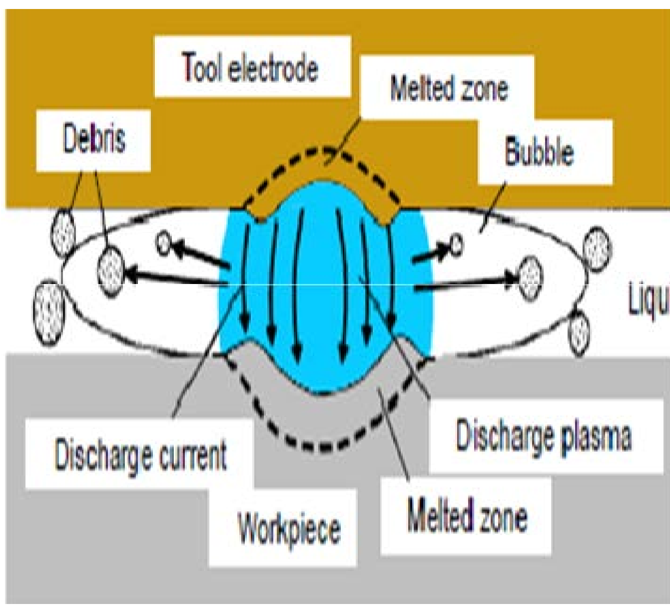

Figure 2: Schematic view of discharge gap

2) Spark Off-time (Pause time or T off): The duration of time (µ s) between the sparks (that is to say, on-time). This time allows the molten material to solidify and to be wash out of the arc gap. This parameter is to affect the speed and the stability of the cut. Thus, if the off-time is too short, it will cause sparks to be unstable.

3) Arc Gap (or gap): The Arc gap is distance between the electrode and work piece during the process of EDM. It may be called as spark gap. Spark gap can be maintained by servo system

4) Discharge Current (Current Ip): Current is measured in amp Allowed to per cycle. Discharge current is directly proportional to the Material removal rate.

5) Duty Cycle (τ): It is a percentage of the on-time relative to the total cycle time. This parameter is calculated by dividing the on-time by the total cycle time (on-time pulse off-time).

τ = (Pulse on time/Pulse off time + Pulse on time).

6) Voltage (V): It is a potential that can be measure by volt it is also effect to the material removal rate and allowed to per cycle.

3. DESIGN FACTORS & THEIR RANGE

Table 3.1: Input parameters and their range

Input parameters	Unit	Range of machine	Levels and values	
			1	2
Pulse-on Time	µsec	1 to 2000 µsec	200	800
Gap Voltage	Volt	20 to 100 V	30	70

3.1 Experimental Procedure

1. Initially, we had the work-piece AISI-D3 die steel of size 160*50*15 mm^3.
2. Then, the piece was grinded from top & bottom to get finish surface of the work-piece so that we could perform electric discharge machining in proper way.
3. The purpose was to drill the hole of diameter 10mm and up to 4mm depth.
4. That was performed using Cu electrode of 12mm diameter and kerosene was taken as a dielectric fluid to drill the hole on to the work-piece by EDM process.
5. For this, tool was hold in the tool holder and work-piece was supported on table.
6. Then, feed was given to the electrode to drill the hole of required size on to the work-piece.
7. Total 20 runs were performed at different level of factors according to design matrix made by Design Expert software.
8. For each of the treatment, time to drill the hole was noted and then MRR (material removal rate) was calculated using the formula required.

3.2 EVALUATION OF MRR

MRR = (volume of the material removed / time taken in minute) mm^3/min

MRR = (Area of hole * depth of hole) / time taken

In our case

Hole diameter =10mm, depth = 4mm

So, volume = $(\pi/4) * d^2 * l = (\pi/4) * 10^2 * 4$ mm^3

3.3 DESIGN MATRIX

Table 3.2: Design matrix for Material Removal Rate (MRR)

	C:Gap Voltage	A:Pulse-on Time	MRR
Exp. No.	Volts	µsec	mm3/min
1	70	800	85.035
2	30	200	58.351
3	70	200	59.944
4	30	800	95.889
5	70	800	69.178
6	50	500	66.674
7	30	200	62.718
8	70	200	68.519
9	70	200	53.068
10	50	500	67.523
11	50	500	65.466
12	70	800	63.200
13	30	800	70.948
14	30	800	90.619
15	30	800	75.952
16	30	200	49.789
17	30	200	73.523
18	70	200	44.281
19	70	800	80.580
20	50	500	67.258

4. ANOVA FOR METAL REMOVAL RATE PREDICTION MODEL

4.1 Diagnosis of assumptions of ANOVA

To check the assumption of normal distribution, the normal probability plot of the residuals is shown in fig.4.1.The figure displays that the residuals generally fall on a straight line implying that the errors are distributed normally.

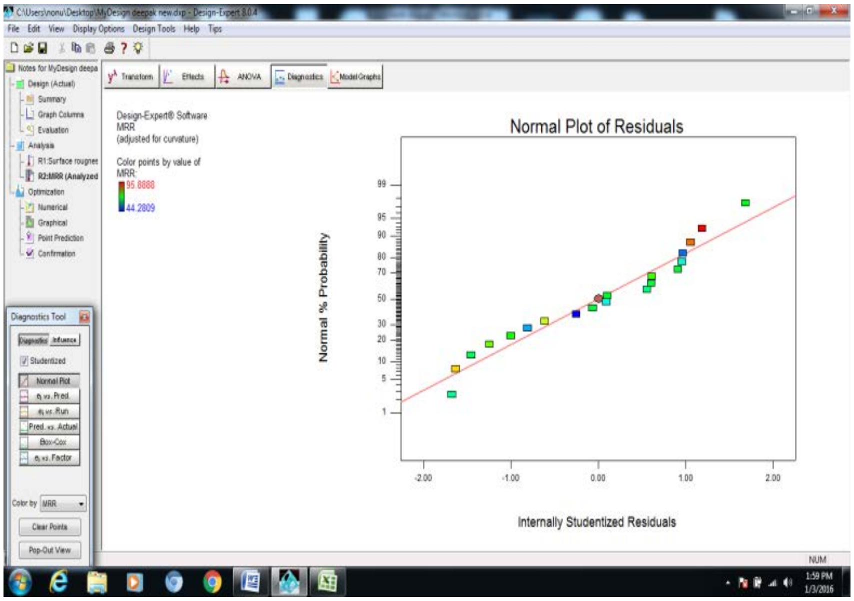

Fig. 4.1 Normal probability plot of residuals

The fig.4.2 represents residuals versus the predicted response plot for surface roughness. 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.

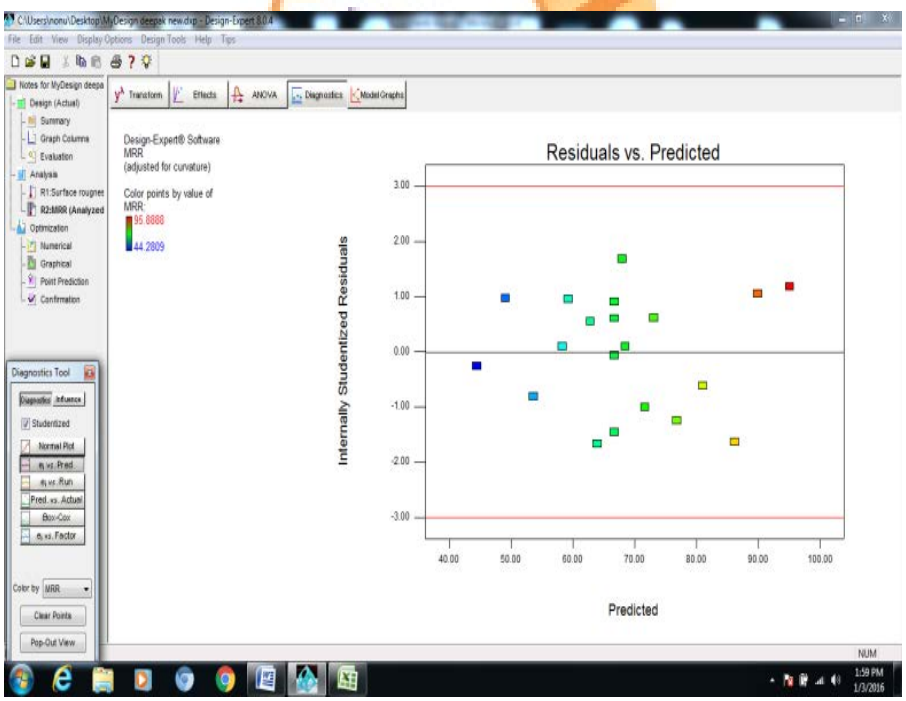

Fig. 4.2 Plot of residuals v/s predicted response

A graph of the actual response values versus the predicted response values is shown in fig.4.3. The figure reveals that all the data points split evenly by the 45 degree line.

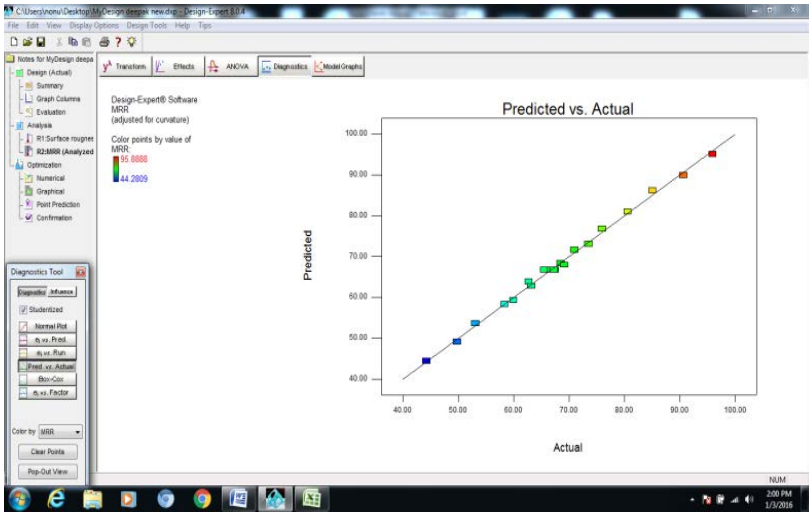

Fig. 4.3 Plot of predicted v/s actual response

4.2 ANOVA analysis and development of metal removal rate prediction model

The ANOVA test for response surface model for metal removal rate is summarized in Table 4.2. This analysis was carried out for a significance level of α = 0.05, i.e. for a confidence level of 95%.

Table 4.2 Resulting ANOVA table for metal removal rate

Source	Sum of squares	df	Mean square	F-Value	p-value Prob > F
Model	1824.127	3	608.042	382.175	0.0001
A-Pulse-on Time	1624.247	1	1624.247	1020.896	0.0001
C-Gap Voltage	182.146	1	182.146	114.485	0.0001
AC	17.734	1	17.734	11.146	0.0136
Residual	25.467	16	1.591		
Lack of Fit	22.958	13	1.766	3.050	0.1945
Pure Error	2.509	3	0.836		
Cor Total	1872.552	19			
Std. Dev.	1.457			R-Squared	0.992
Mean	68.426			Adj R-Squared	0.987
C.V. %	2.129			Pred R-Squared	0.981
PRESS	59.142			Adeq Precision	54.904

Table shows that the value of "Prob. > *F*" for model is 0.0001 which is less than 0.05, that indicates the model is significant. In the same manner, the value of "Prob. > *F*" for main effect of Voltage, Current, Pulse on, Pulse off and two-level interaction of current and Pulse on, Pulse off and Pulse off are less than 0.05 so these terms are significant model terms.

The value of "Prob. > *F*" for lack-of-fit is 0.1945 which is greater than 0.05 and it indicates the insignificant lack of fit.

The R^2 value is equal to 0.992 or close to 1, which is desirable. The adjusted R^2 value is equal to 0.987. The result shows that the adjusted R^2 value is very close to the ordinary R^2 value. Adequate precision value is equal to 54.904. A coefficient of variation (CV) can be calculated and interpreted in two different settings analyzing a single variable and interpreting a model. The standard formulation of the CV, the ratio of the standard deviation to the mean. The higher the CV, greater the dispersion in the variable. The CV for a model aims to describe the model fit in terms of the relative sizes of the squared residuals and outcome values. The lower the CV, smaller the residuals relative to the predicted value.

The regression model for metal removal rate in terms of coded factors is shown as follows:

$$(MRR) = 68.43 + 10.08 * A - 3.37 * C - 1.05 * A * C$$

While, the following equation is the empirical model in terms of actual factors

$$(MRR) = 58.3 + 0.053 * Pulse\ on - 0.081 * Voltage - 0.00017 * Pulse\ on * Voltage$$

4.3 CONTRIBUTION OF EDM PARAMETERS ON METAL REMOVAL RATE

The fig.4.4 shows the half normal plot, the extreme right side factor has the highest effect on the response, however as the dots corresponding to the particular factor comes nearer and nearer to the line, it shows these value affects the least.

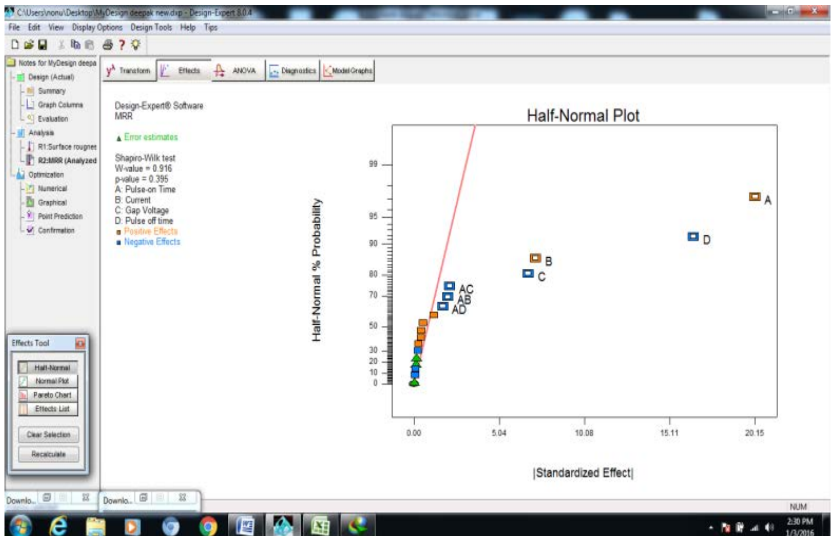

Fig.4.4: A half normal plot shows the effectiveness of the factors

The value at the right extreme has the strongest effect on the metal removal rate and keeps on decreasing as it comes nearer and nearer to the line. It can also be understood in the fig 4.5, which shows the of effectiveness rank wise. The graph is between t-value and rank of factors.

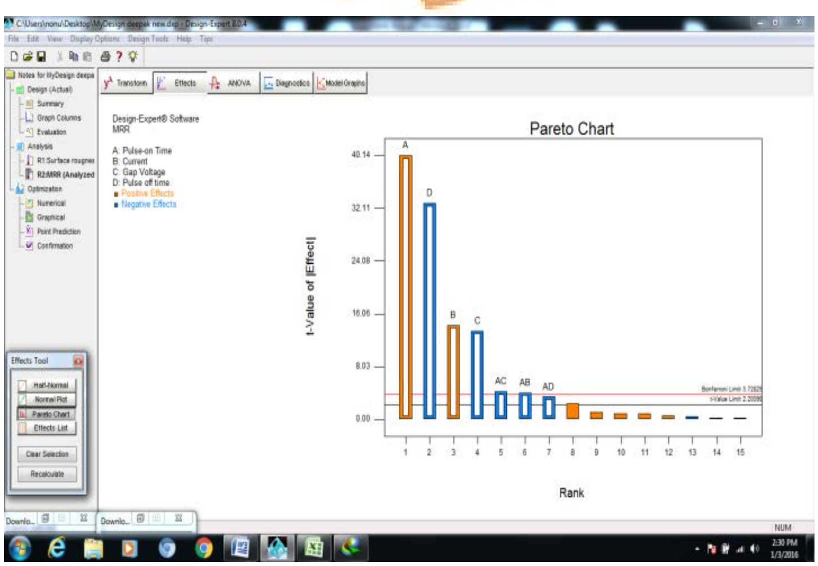

Fig.4.5: Graph between t-value and rank

The t-value here denotes the effectiveness of the factor. As it can be seen from the figure, that the most effective factor is A, followed by D, B, C combination of A&C, A&B than combination of A&D.

5. EFFECT OF EDM PARAMETERS ON METAL REMOVAL RATE

5.1 Effect of voltage on metal removal rate

Influence of voltage on metal removal rate at constant current (25 A), constant pulse on time (500 microseconds) and constant pulse off time (250 microseconds) is shown in fig. 5.1.

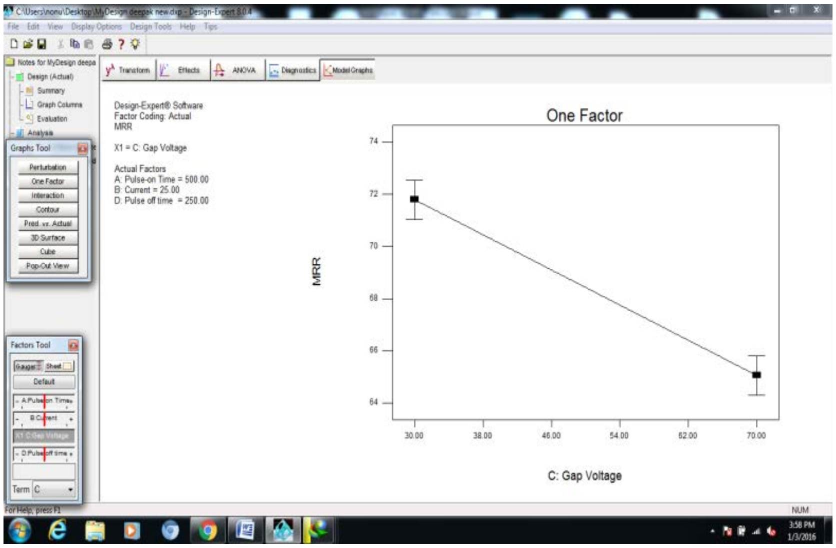

Fig.5.1 Plot between metal removal rate & voltage at current (25 A), pulse on time (500 microseconds) and pulse off time (250 microseconds)

The result shows that the metal removal rate decreases as the voltage increases from 30 V to 70 V. With the higher voltage, the discharge time gets longer. This will lead to a wider average discharge gap. Therefore, MRR decreases as voltage increases.

5.2 Effect of pulse on time on metal removal rate

Influence of pulse on time on metal removal rate at constant voltage (50 Volts), constant current (25 A) and constant pulse off time (250 microseconds) is shown in fig. 5.2. It is clear from the plot that as the pulse on time increases from 200 microseconds to 800 microseconds, the value of metal removal rate also increases. The metal removal rate is most affected by the amount of discharge energy which increases with increase in pulse on-time. Furthermore, greater discharge energy will produce a larger crater, causing a high metal removal rate.

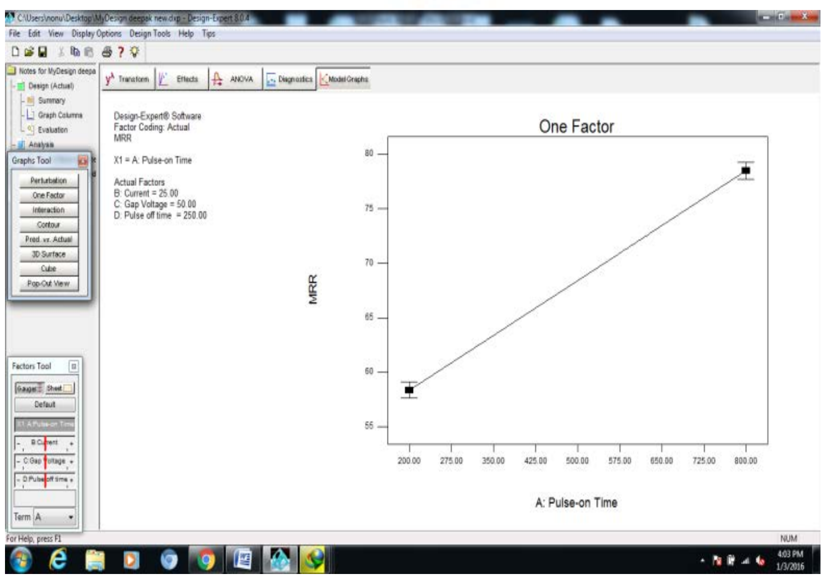

Fig.5.2 Plot between pulse on and metal removal rate at voltage (50 Volts), current (25 A) and pulse off time (250 microseconds)

6. OPTIMIZATION OF EDM PARAMETERS FOR MAXIMUM METAL REMOVAL RATE

In the present study, the aim is to obtain the optimal values of EDM parameters in order to minimize the value of weight loss of AISI D3. The constraints used during the optimization process are summarized in Table3.1The optimal solutions are reported in Table 3.2.

Table 6.1 Constraints for optimization of EDM parameters

Condition	Units	Goal	Lower limit	Upper limit
A:Voltage	Volts	Is in range	30	70
C:Pulse on	Microseconds	Is in range	200	800
MRR	mm3/sec	Maximize	44.28	95.88

Table 6.2 Optimization results for MRR

Sol No	A:Voltage (Volts)	C:Pulse on (Microseconds)	MRR (mm3/sec)	Desirability	Remarks
1	30	800	94.62	0.97	Selected

7. CONCLUSION

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

1) The two relationships between MRR and EDM parameters have been developed. The predicted results are in good agreement with the measured ones. These relationships are applicable within the ranges of tested parameters.

2) All the two independent parameters (Pulse on time and Gap Voltage) seem to be the influential EDM parameters.

3) The MRR prediction model developed clearly shows that the pulse on seems to be the most significant factor.

4) Surface roughness decreases as pulse off increases, voltage increases, current decreases and pulse on decreases.

5) The maximum MRR has been observed to be 94.62 mm^3/sec, corresponding to voltage = 30 V, current = 40 A, pulse on time = 800 microseconds and pulse off time =100 microseconds.

In this study mathematical modeling and optimization has been attempted only for two response variable. The work can be extended to consider more response variables. Also more parameters such as temperature, shape of electrode, type of fluids can be introduced to have a better insight into the process.

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