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Optimization of Process Parameters in EDM during Machining Of En41 Steel Using Response Surface Methodology and ANOVA Analysis

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ABSTRACT

In today's changing world, quality plays an important role in any manufacturing/ production process, Material Removal Rate and Surface Roughness are the main quality functions during working of EN41 steel in Die-sinking electric discharge machining (EDM), this research paper presents work on investigation of Surface Roughness and Material Removal Rate in hole making in by EDM in EN41 steel, Copper has been used as an electrode material to study the effects of input parameters to get minimum Surface Roughness and maximum Material Removal Rate, for this the best optimal level of parameters has to be chosen carefully, This paper represents the application of Response Surface Methodology in optimization of Surface Roughness and Material Removal Rate during working with EDM on EN41 steel. The experimental study is conducted using RSM (Central Composite Rotatable Design) for which there are three input parameters such as Pulse On-time (T_{on}), Sp. Current (I_D), Gap Voltage (V) selected at two levels, ANOVA (Analysis of Variance) is used for analysis the results and further optimization is done by using software Design Expert, the complete experimental results are discussed and presented in this paper.

Keywords: Electric Discharge Machine (EDM), EN41 steel, copper electrode, Surface Roughness, Material Removal Rate, Response Surface Methodology, CCRD, ANOVA.

1. Introduction

EDM is one of the most common machine tool and widely used as the replacement of non-conventional machines in many industries because of its efficient and precise working on materials, it is used to remove material from the surface of work piece, which is electrically conductive in nature by using tool electrode, which also has to be conductive and , electrolyte which may be oil of grade A or mixture of kerosene and water must be used between tool and work-piece, so that the circuit completes and current starts flowing in the circuit and ultimately the metal starts removing due to production of spark between the gap provided in between tool and work-piece, the quantity of material removed from the surface is controlled by up-word and down-word motion of tool at point where cutting is required, this is how machine works.

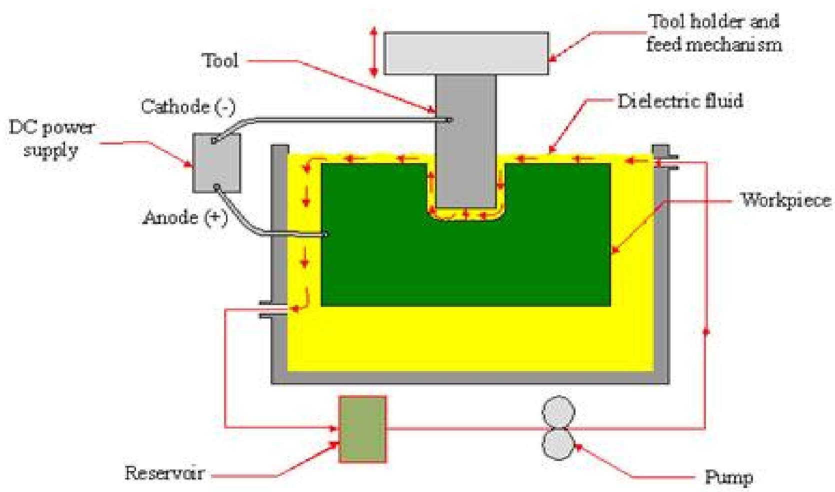


Figure 1: Working principle of EDM

2. Research Gap

After complete literature review one thing can be understand that EDM is a machine tool which is widely used in almost every production industry, i.e. Aviation industry, Auto-mobile industries etc. after literature survey, one thing can be found that a lot of work has been already carried out on machining of AISI steel, but a few work has been done on EN series of high grades, so keeping in mind the literature review, effect of process parameters and their optimization for improved Surface Roughness and Maximum Productivity while working on EN41 steel using RSM (CCRD) and ANOVA analysis will be quite useful.

3. Objective

- Experimental study of effect of Sparking Current, Pulse On-time and Gap Voltage on Productivity and Surface Finish.
- Development of Mathematical Model for Both S.R. and M.R.R.
- Optimization of machining parameters for only better Surface Finish (min. S.R.)
- Optimization of machining parameters for better Surface Finish (min. S.R.) as well as better Productivity (max. M.R.R.)

4. Experimental SETUP

All the work has been performed on Die-sinking EDM model "**ELEKTRA R-50 ZNC"** machine. It is a flexible machine with high power, accuracy and performance. That is the reason we selected this machine for our experimental work and i.e. Accuracy, It works on three axis i.e. X-axis, Y-axis and Z-axis, in which X and Y-axis are manually controlled and Z-axis is computer controlled. This machine is capable of producing spark of 10000^{o}c which is required for metal removal.

ELEMENT	C	Mn	Si	Cr	Mo	Al
CONTENT %	0.35-0.45	0.50-0.60	.10-.35	1.50-1.80	0.10-0.25	0.90-1.20

Figure 2: EDM Machine

In order to find out optimal surface finish and material removal rate, EN41 steel has been used as work-piece material, it is cast steel made up of basically three materials i.e. chromium, molybdenum and aluminium, it is economical and widely used steel in several manufacturing industries.

Table 1 Chemical Composition of EN41

Elements	Percentage composition
Carbon (C)	0.35-0.45%
Manganese (Mn)	0.50-0.60%
Silicon (Si)	0.10-0.35%
Chromium (Cr)	1.50-1.80%
Molybdenum (Mo)	0.10-0.25%
Aluminum (Al)	0.90-1.20%

5. Design of Experiment

5.1 Response Surface Methodology

The main idea behind the use of RSM is to use a series of experiments and from them optimum response is obtained. RSM is a combined structure of both mathematical tools and statistical techniques for building an empirical model. The concept of RSM is become useful:

1. When we focused on optimization of process parameters of any machining operations.
2. In reducing the number of experiments conducted in order to reduce time as well as cost of experiment as compared to other mathematical models available.
3. It represents better pictures of variations in response variables w.r.t. process variables by approaches like, 3D curves, Contour plots etc. helps in improving optimization process.

An important expects of RSM is Design of experiment, which is commonly abbreviate as D.O.E. its objective is to select the points where the response value should be evaluated. The selection of D.O.E. can have large influence on the accuracy of approximation selected and the cost involved in the construction of response surface.

There are many second order designs were provided in Response Surface Methodology, but we study EDM process with one of the best efficient RSM design of second order called Central Composite Rotatable Design (CCRD). A model of order second can be constructed efficiently with central composite design. CCRD involves Factorial runs (2^N), axial runs (2N) and centre run (n_c), where N is the no. of process or input variables in our case it is three, i.e. Pulse on-time (T_{on}), Sparking current (I_p) and Voltage (V), The run is our case are as follows:

- **Factorial Runs (2^N) = 2^3 = 8 Runs**
- **Axial Runs (2N) = 2x3 = 6 Runs**
- **Centre Runs (n_c) = 6 Runs**

Thus we have to perform a total of 20 runs or experiments and all of them are performed on EDM machine and then optimization and analysis part was perform on software known as Design Expert.

SELECTED PROCESS PARAMETERS WITH THEIR LEVELS

Table 2 Machining Parameters and their Levels used for Experimentation

Input parameters selected	Unit	Range (as provide)	Levels and values		
			I	II	III
Pulse-on Time	µsec	1 to 2000 µsec	250	500	750
Sparking Current	Amp	0 to 50 A	12	18	24
Voltage Gap	V	20 to 100 V	34	55	76

5.2 Design Matrix for M.R.R. AND S.R.

Table 3 Design Matrix for MRR and SR

Std	Run	Coded Values			Actual Values			MRR (mm^3/s)	R_a (µm)
		µsec	Amp	V	µsec	Amp	V		
1	7	-1	-1	-1	250	12	34	**31.174**	**3.20**
2	6	1	-1	-1	750	12	34	**40.052**	**2.326**
3	3	-1	1	-1	250	24	34	**72.513**	**4.27**
4	10	1	1	-1	750	24	34	**106.395**	**3.10**
5	8	-1	-1	1	250	12	76	**85.785**	**2.92**
6	12	1	-1	1	750	12	76	**129.291**	**1.664**
7	4	-1	1	1	250	24	76	**199.452**	**3.624**
8	9	1	1	1	750	24	76	**298.706**	**1.388**

9	1	0	0	0	500	18	55	**123.124**	**3.34**
10	3	0	0	0	500	18	55	**120.733**	**2.98**
11	11	0	0	0	500	18	55	**125.609**	**2.95**
12	5	0	0	0	500	18	55	**126.90**	**2.982**
13	17	-1.68	0	0	79.55	18	55	**85.03**	**3.75**
14	19	1.68	0	0	920.45	18	55	**170.934**	**1.336**
15	14	0	-1.68	0	500	7.91	55	**48.530**	**2.727**
16	16	0	1.68	0	500	28.09	55	**205.828**	**3.951**
17	18	0	0	-1.68	500	18	19.68	**21.545**	**3.557**
18	15	0	0	1.68	500	18	90.32	**212.77**	**1.820**
19	20	0	0	0	500	18	55	**119.48**	**2.911**
20	13	0	0	0	500	18	55	**130.728**	**3.01**

5.3 Experimental Procedure

First of all work piece material was purchased from the market and worked of CNC lathe to get better surface regularity, Copper tool is also purchased and its size has been reduced from 10mm to 8mm so that it may firmly fits into tool holder, electrolyte is filled in between the free space provided between work piece and tool, the machine was set to its minimum level, the purpose was to perform 20 runs with different Sp. Current, Pulse on-time and Gap Voltage Combinations, for this tool was held in the tool holder and work-piece was held at the base provided for it, the runs are performed according to the combination generated by software Design Expert.

Figure 3: Experimental Procedure

5.4 ANOVA Table for MRR

The mathematical model suggested for this analysis of MRR is 2FI (Two Factor Interaction) model, from the ANOVA table provided below we found that Lack of fit is 0.2667 which is not significant, Hence the data which have been collected by us fit to the model and useful for further optimization, the value of adjusted R-square and predicted R-square is near about 1 and the difference between the two is very less, hence the suggested model is significant

Table 5.2 ANOVA Table for MRR

Response 1 : MRR						
ANOVA for Response Surface 2FI Model						
Source	**Sum Of Square**	**dof**	**Mean Square**	**F-Value**	**P-Value Prob. > F**	
Model	90433.71	6	15072.29	426.56	< 0.0001	**Significant**
A (N)	7973.84	1	7973.84	225.67	< 0.0001	**Significant**
B (*f*)	31444.40	1	31444.40	889.91	< 0.0001	**Significant**
C (a_p)	45104.85	1	45104.85	1276.52	< 0.0001	**Significant**

AB	815.11	1	815.11	23.07	0.0004	**Significant**
AC	1249.95	1	1249.95	35.38	< 0.0001	**Significant**
BC	3845.56	1	3845.56	108.83	< 0.0001	**Significant**
Residual	424.01	12	35.33			
Lack Of Fit	338.38	8	42.30	1.98	0.2667	**Not Significant**
Pure Error	85.63	4	21.41			
Cor Total	90892.71	19				
Std. Dev.	5.94		**R-Squared**	0.9953		
Mean	122.72		**Adj. R-Squared**	0.9930		
C.V. %	4.84		**Pred. R-Squared**	0.9789		
PRESS	1915.25		**Adeq. Precision**	71.310		

For this response our model is at best possible R-squared values and it is good enough for further analysis, hence no need to apply any elimination step in improved ANOVA.

5.5 ANOVA Table for SR

The mathematical model suggested for the analysis of Surface Roughness is quadratic model, which is better model than 2FI or liner model of analysis, because in quadratic analysis we found more precise and more accurate reading then the others. From the ANOVA table for surface roughness provided below, we found that value of Lack of fit is 0.4720 which is not significant, Hence the collected data is fit for the model.

Table 5.3 ANOVA Table for SR

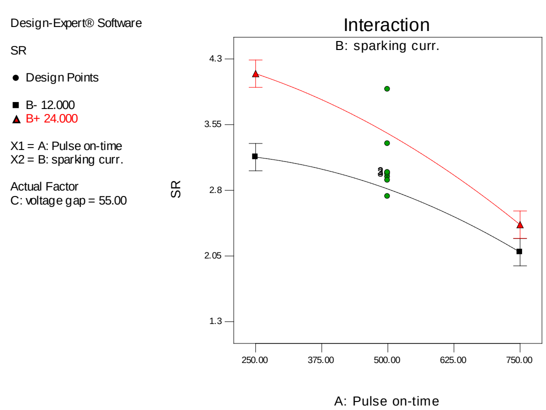
Response : Surface Roughness						
ANOVA for Response Surface Quadratic Model						
Source	**Sum of Square**	**Dof**	**Mean Square**	**F-Value**	**P-Value Prob. > F**	
Model	12.54	9	1.39	53.14	< 0.0001	**Significant**
A (N)	6.74	1	6.74	256.85	< 0.0001	**Significant**
B (f)	1.37	1	1.37	52.30	< 0.0001	**Significant**
C (a_p)	2.83	1	2.83	108.04	< 0.0001	**Significant**

AB	0.20	1	0.20	7.78	0.0148	**Significant**
AC	0.26	1	0.26	9.99	0.0076	**Significant**
BC	0.25	1	0.25	9.56	< 0.0001	**Significant**
A^2	0.46	1	0.46	17.56	0.0013	**Significant**
B^2	0.15	1	0.15	5.76	0.0300	**Significant**
C^2	0.23	1	0.23	8.93	0.0152	**Significant**
Residual	0.24	9	0.026			
Lack Of Fit	0.14	5	0.027	1.11	0.4720	**Not Significant**
Pure Error	0.099	4	0.025			
Cor Total	12.78	19				
Std. Dev.	0.16	**R-Squared**			0.9815	
Mean	2.89	**Adj. R-Squared**			0.9631	
C.V. %	5.60	**Pred. R-Squared**			0.8802	
PRESS	1.53	**Adeq. Precision**			25.975	

The value of Adjusted R-Squared is 0.9631 and value of Predicted R-Squared is 0.8802 which is near about 1 and the difference between the two values is less than 0.2 hence the suggested model is Significant for further analysis. Hence there is no need for omit any step for improved ANOVA.

6. Results and Discussion

6.1 For Surface Roughness



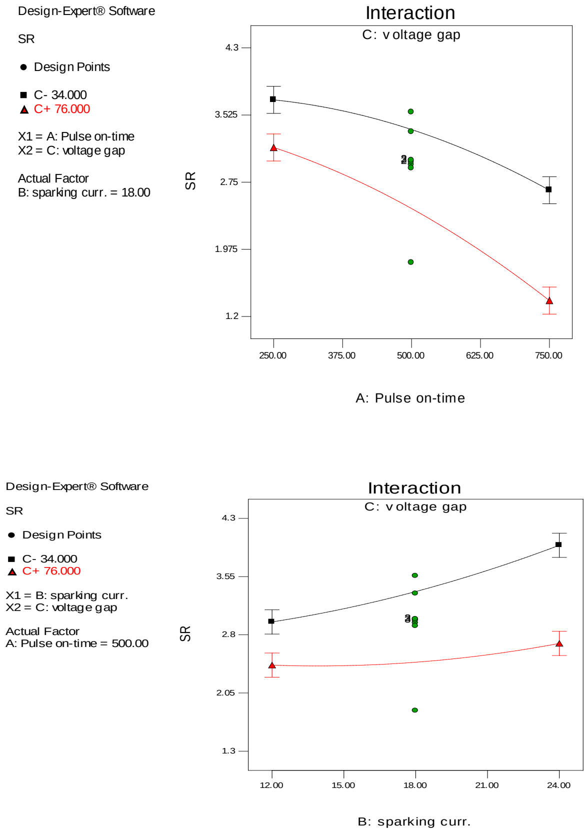
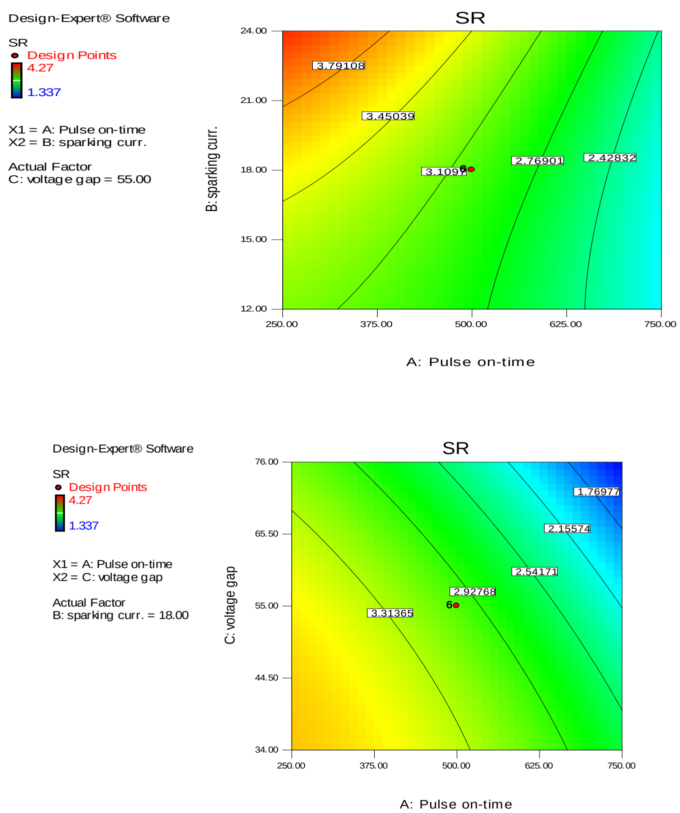


Figure 4: Interaction plots for Surface Roughness



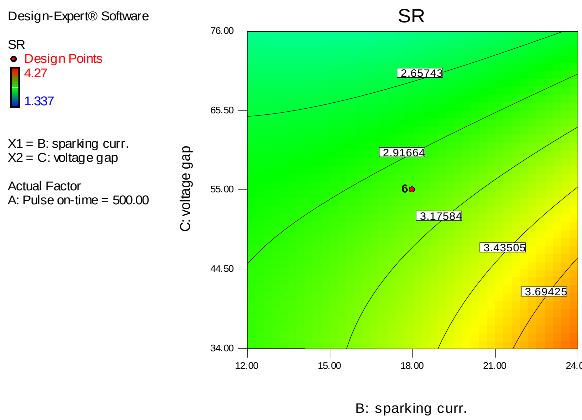


Figure 5: Contour Curves for Surface Roughness 6.2 for MRR

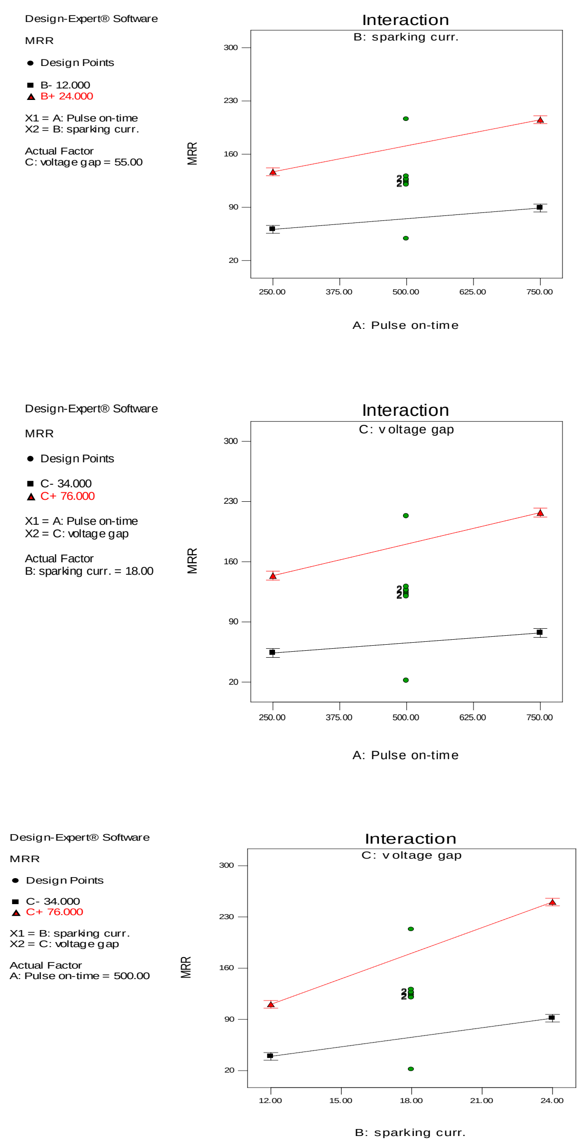


Figure 6: Interaction Plots for MRR

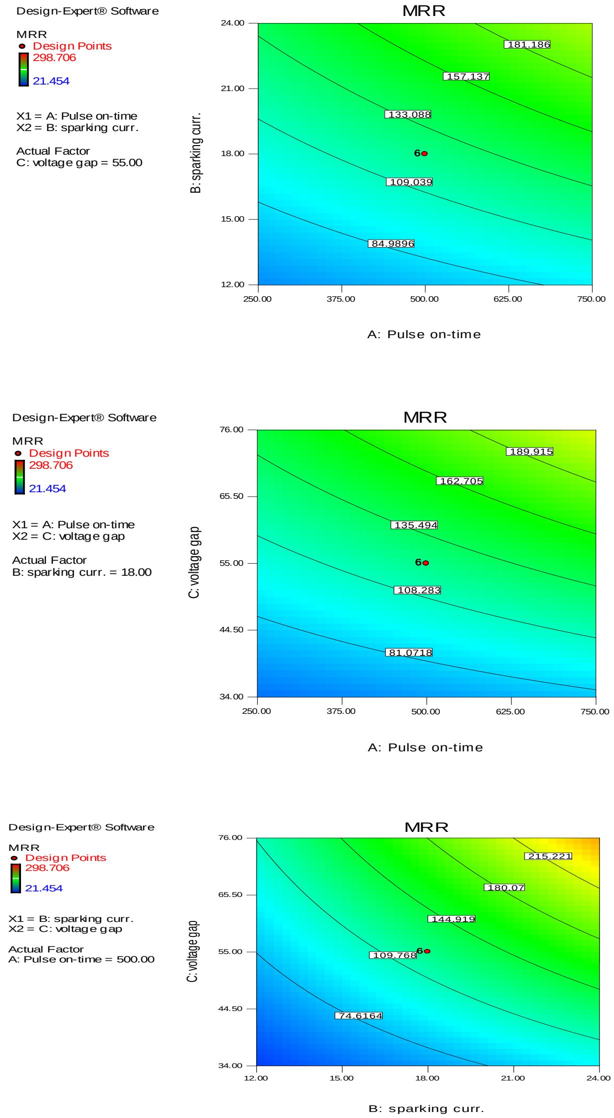


Figure 7: Contour Curves for MRR

7. Conclusions

In this paper, the research has been done to find out the best optimal conditions for MRR and SR on EN$1 steel while working on EDM machine, the analysis results shows the effect of factors over the responses in various forms like one way or interaction plots, Now we have the following conclusions from our research studies:

- Pulse on-time is the most effective factor and SR decreases for every increased value of Pulse on-time.
- Surface roughness behaves linearly with voltage gap, so it should keep low for getting minimum SR which is required.
- The most influencing factors include both Pulse On-time as well as Sparking Current.
- MRR increases directly with increase of Pulse on-time, so Pulse on-time should kept at maximum for Max. Material removal rate and Min. Surface roughness.
- Small change in Sp. Current resulting in great change in MRR.
- All three factors are most effective parameter and MRR increases linearly with each of them, but higher values of these factors may result in overheating, Hazards and tool wear etc.

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