

# Study on the Influence of Process Parameters on Surface Roughness and MRR of AISI 420 Stainless Steel Machined by EDM

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**Abstract**— AISI 420 stainless steel is a martensitic stainless steel which has good corrosion and magnetic properties. It is used widely in rotors of actuator motors due to its magnetic property. Surface Roughness is one of the prominent factors that need to be optimised in this high precision work. The present work is aimed at characterizing the electric discharge machining of AISI 420 stainless steel. Taguchi's L9 orthogonal array was chosen to conduct the experiments by varying EDM parameters like current, pulse on time and pulse off time. The surface roughness and Material removal rate are taken as the output responses. Signal to noise ratio and ANOVA is used to analyze the effect of parameters on surface roughness and also to identify the optimum machining parameters.

**Keywords**— Orthogonal array, Electric discharge machining, Surface roughness, Material removal rate.

## I. INTRODUCTION

EDM is the thermal erosion process in which metal is removed by a series of recurring electrical discharges between a cutting tool acting as an electrode and a conductive workpiece in the presence of a dielectric fluid. Heat from the discharge vaporizes minute particles of workpiece material, which are then washed from the gap by continuously flushing dielectric fluid. A preshaped or formed electrode (tool), usually made from graphite or copper, is machined to the form of the cavity it is to reproduce. The formed electrode is fed vertically down and the reverse shape of the electrode is eroded (burned) into the solid workpiece. A servomechanism maintains a space of about the thickness of a human hair between the electrode and the work, preventing them from contacting each other. Application of voltage pulses causes electrical breakdown to the dielectric in a channel of radius 10  $\mu\text{m}$ . The electrical discharges generate impulsive pressure by dielectric explosion to remove the melted material. The incompletely flushed melted particle resolidifies to form discharge craters which are responsible for the microcracks in the machined surface.

Surface quality of the machined surface is very important in the case of all machining processes especially in the case of non conventional machining like EDM. Extensive study is happening in this field. Selection of appropriate machining parameters for any particular material in EDM is difficult, and relies heavily on operators' experience [1]. This

paper presents the optimization of surface roughness of AISI 420 Stainless Steel by varying process parameters.

## II. LITERATURE SURVEY

Electric discharge machining (EDM) is a widely used unconventional manufacturing process that uses thermal energy of the spark to machine electrically conductive as well as non-conductive parts regardless of the hardness of the work material. EDM can cut intricate contours or cavities in pre-hardened steel or metal without the need for heat treatment to soften and re-harden the materials [2]. S.H Lee [3] analyzed the influence of electrical parameters on tungsten carbide and effectiveness of EDM process is evaluated in terms of surface quality and Material Removal Rate (MRR). He found that MRR increases with increase in open voltage but Tool Wear Rate (TWR) and surface roughness increases with increase in open circuit voltage. Puertas[4] studied the influence of current intensity, pulse time and duty cycle over output responses such as Surface Roughness(SR) and MRR. In the case of Surface roughness, the most influencing parameters were current followed by pulse on time.

Kiyak [5] studied the influence of EDM parameters on surface roughness for machining AISI P20 tool steel. Electrical Parameters selected for study were current, pulse time and pulse off time. It has been observed that the surface roughness increases with increase in current and pulse on time. Palanikumar [6] conducted the study on the 304 stainless steel and investigated the influence of pulse on time, pulse off time, voltage and current affecting MRR. The current and pulse off time are the significant factor affecting MRR in EDM. Ayesta [7] analysed the influence of EDM parameters on slot machining in C1023 aeronautical alloy. Results reveal that discharge current as well as the time pulse, are the most influencing process parameters. The present work is concentrated on AISI 420 Stainless steel which belong to the martensitic Stainless steel group. Hardly any studies on the Electric Discharge Machining of this group are done earlier.

## III. EXPERIMENTAL DETAILS

Investigation was carried out in the following sequence for effective planning and design of experiments to achieve the desirable characteristics.

A. Selection of Workpiece Material and Electrode Material

The work piece material used for the study is AISI 420 stainless steel and tool electrode chosen is copper. The chemical composition of AISI 420 is given in Table I. Copper was selected because it is highly conductive and gives high surface finish. The electrode is prepared in square shape of dimension 10 x 10 mm. The electrode is machined using high precision milling and grinding operations to give maximum finish to electrode.

TABLE I. CHEMICAL COMPOSITION OF AISI 420 STAINLESS STEEL

C %	Si %	Mn %	P %	S %	Cr %	Fe %
0.15	Max 1.00	Max 1.00	Max 0.04	Max 0.03	12.0 - 14.0	Bal

B. EDM Process Parameters and their Levels

Based on the literature survey and previous work experience, the machining parameters which are selected as inputs of the experiment are current, pulse on time and pulse off time. The working range of process parameters selected is shown in Table II.

TABLE II. PROCESS PARAMETERS AND LEVELS SELECTED

Parameters	Unit	Levels			Response
		1	2	3	
Current	A	1	2	3	1. Surface Roughness
Pulse on time	μs	1.5	3.5	5.5	
Pulse off time	μs	8	16	24	2. Material Removal rate

C. Selection of Orthogonal Array

Taguchi's orthogonal array method is a very effective method to deal with responses influenced by multi-variables. Compared to the conventional approach to experimentation, this method reduces drastically the number of experiments that are required to model the response functions. The selection of Orthogonal array (OA) is based upon the number of factors and levels that are considered for doing the experiment. The degree of freedom (dof) for each of the factor is 2 (dof for a factor = number of levels minus 1) and therefore the total dof obtained is 8 (i.e., 4x2=8). The selected OA's degree of freedom must be greater than the total dof of all the factors. The dof for an OA is given by number of experiments minus 1. Hence L9 is considered for the study which has 8 degrees of freedom which is the smallest array that can be selected with the 3 level 4 factor experiment. The selected OA is presented on the following Table III.

TABLE III. L9 ORTHOGONAL ARRAY

Experiment No.	Current (A)	Pulse on time (μs)	Pulse off time (μs)
1	1	1.5	8
2	1	3.5	16
3	1	5.5	24
4	2	1.5	24
5	2	3.5	8
6	2	5.5	16
7	3	1.5	16
8	3	3.5	24
9	3	5.5	8

D. Experimentation

A rod of 350 mm length and 40 mm diameter is taken as workpiece material. The surface is flattened using milling operation to give a breadth of 35 mm. The electrode used for the experiment is copper of square shape with dimension 10 x 10 mm which is shown in Fig.1. The Agie Charmilles EDM machine of SA 20 model is used for the study of EDM parameters affecting the surface roughness. The work piece is mounted on the fixture and flooded with the dielectric fluid during machining which is shown in Fig.2. EDM-30 is used as die-electric fluid.



Fig. 1. Copper electrode

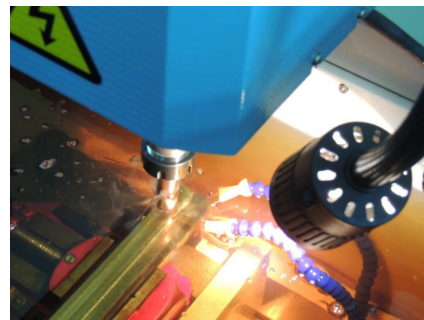


Fig. 2. Workpiece during machining

E. Surface Roughness Measurement

Surface roughness is one of the performance characteristic that is to be evaluated. It is referred as roughness or smoothness of a given surface. Average surface roughness(Ra)

which is measured in this study is an arithmetic average of peaks and valleys of a work piece surface measured from the centreline of evaluation length. It was measured by TALYSURF CLI 2000 surface roughness tester.

F. Material Removal Rate Measurement

Material Removal Rate (MRR) is defined as the volume of material removed from the work piece in unit time. It can be calculated using the formula given below.

$$MRR = \frac{\text{Volume of material removed from workpiece}}{\text{Time taken for machining}} \quad (1)$$

IV. RESULTS AND DISCUSSIONS

After the experimentation, surface roughness and MRR of each experiment is found and tabulated. Statistical analysis was performed using MINITAB 16 software and the signal to noise ratio values of surface roughness and MRR are tabulated. Analysis of S/N ratio is used to find the optimum parameter combination for the surface roughness and MRR that can be achieved.

A. Surface Roughness

Taguchi experiments often use a 2-step optimization process. Step 1 is the identification of control factors that reduce variability using S/N ratio. Identification of control factors that move the mean to target and have a small or no effect on the signal-to-noise ratio is considered as step 2. The signal-to-noise ratio measures how the response varies relative to the nominal or target value under different noise conditions. The performance characteristic for the surface roughness is chosen as the smaller the better.

$$S/N = -10 \log \left[ \frac{1}{n} \sum_{i=1}^n (y_i)^2 \right] \quad (2)$$

Where 'n' is the number of measurements in a trial and 'yi' is the measured value in the trial. In this experiment the desired characteristic for the surface roughness is lower the better. Using equation (2), the S/N ratios of surface roughness for each experiment of L9 Orthogonal array can be calculated which is given in Table IV.

TABLE IV. S/N RATIO FOR SURFACE ROUGHNESS

Experiment	Parameters			Ra (µm)	S/N ratio for Surface roughness (db)
	I	T <sub>on</sub>	T <sub>off</sub>		
1	1	1.5	8	0.5570	5.08199
2	1	3.5	16	0.6330	3.97040
3	1	5.5	24	0.6863	3.26884
4	2	1.5	24	0.6517	3.71880

5	2	3.5	8	0.7153	2.90901
6	2	5.5	16	0.8023	1.91211
7	3	1.5	16	0.7493	2.50627
8	3	3.5	24	0.8537	1.37380
9	3	5.5	8	0.8963	0.94987

Each of selected EDM parameters have different influence on surface roughness. The analysis of variance was used to establish statistically significant machining parameters and the percentage contribution of these parameters on the surface roughness. The significant parameters are found by the analysis of variance (ANOVA) and the optimal machining parameters are obtained using main effect plots.

TABLE V. RESPONSE TABLE FOR SIGNAL TO NOISE RATIOS

Level	Current	Pulse on time	Pulse off time
1	4.107	3.769	2.789
2	2.847	2.751	2.880
3	1.497	2.044	2.895
Optimum	1	1	3
Delta	2.497	1.725	0.105
Rank	1	2	3

The main effect values are plotted in Fig. 3 for the Current, pulse on time and pulse off time respectively. The main effects plot shows the influence of each level of factors and the SN ratio with maximum value is taken as the optimum value for surface roughness. The optimal level of the machining parameters is the level with the highest S/N ratio value which is shown in Table V. Based on the analysis of S/N ratio, the optimal machining performance for the surface roughness is obtained at a current of 1A (level 1) and pulse on time of 1.5µs (level 1) and pulse off time of 24 µs(level 3).

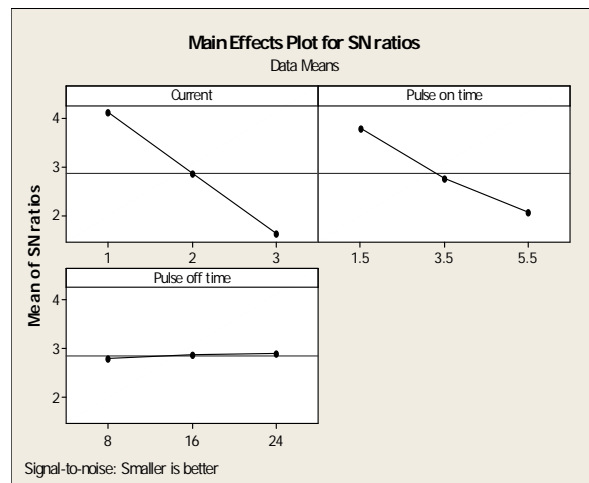


Fig. 3. SN ratio plot for surface roughness

The ANOVA is a statistically based, objective decision making tool for detecting any difference in the average performance of groups of items tested. ANOVA helps in formally testing the significance of all main factors and their interactions by comparing the mean square against an estimate of experiment at specific confidence levels. The P value is defined as the significance rate of process parameters on the output responses which is shown in percentage. It can be observed from Table VI that current and pulse off time are the two significant factors that affect surface roughness. Pulse off time has no significant effect on surface roughness. The percentage contribution of current and pulse on time are 67.01 % and 32.34 % respectively.

TABLE VI. ANALYSIS OF VARIANCE FOR SURFACE ROUGHNESS

Source	Degrees of freedom	Sum of squares	Mean of squares	F	P	% contribution
Current	2	9.3535	4.6768	131.26	0.008	67.01
Pulse On time	2	4.5138	2.2569	63.34	0.016	32.34
Pulse off time	2	0.0195	0.0098	0.27	0.785	0.14
Error	2	0.0713	0.0356			0.51
Total	8	13.9581				100

Regression Equation

The regression equation is also found out for predicting the surface roughness with a different combination of the process parameters

$$\text{Surface Roughness} = 0.416 + 0.104 \text{ Current} + 0.0356 \text{ Pulse on time} - 0.00129 \text{ Pulse off time}$$

B. Material Removal Rate

In this experiment, the desired characteristic for MRR is larger the better. The equation for S/N ratio is given in equation (3).

$$S/N = -10 \log \left[ \frac{1}{n} \sum_{i=1}^n \left( \frac{1}{y_i^2} \right) \right] \tag{3}$$

Where 'n' is the number of measurements in a trial and 'yi' is the measured value in the trial. Using equation (3), the S/N ratios of MRR for each experiment of L9 Orthogonal array can be calculated which is given in Table VII.

TABLE VII. S/N RATIO FOR MRR

Experiment	Parameters			MRR (mm <sup>3</sup> /min)	S/N ratio for MRR (db)
	I	T <sub>on</sub>	T <sub>off</sub>		
1	1	1.5	8	0.143	-16.8933

2	1	3.5	16	0.179	-14.9429
3	1	5.5	24	0.134	-17.4579
4	2	1.5	24	0.188	-14.5168
5	2	3.5	8	0.162	-15.8097
6	2	5.5	16	0.165	-15.6503
7	3	1.5	16	0.177	-15.0405
8	3	3.5	24	0.227	-12.8795
9	3	5.5	8	0.219	-13.1911

The significant parameters are found by the analysis of variance (ANOVA) and the optimal machining parameters are obtained using main effect plots. The optimal level of the machining parameters for larger MRR is the level with the highest S/N ratio value which is shown in Table VIII.

TABLE VIII. RESPONSE TABLE FOR S/N RATIO FOR MRR

Level	Current	Pulse on time	Pulse off time
1	-16.43	-15.48	-15.14
2	-15.33	-14.54	-14.22
3	-13.70	-15.43	-16.10
<b>Optimum</b>	3	2	2
<b>Delta</b>	2.73	0.94	1.89
<b>Rank</b>	1	3	2

The main effect values are plotted in Fig. 4 for the Current, pulse on time and pulse off time respectively.

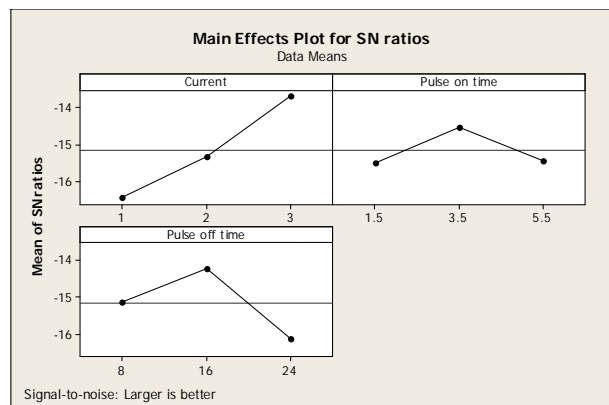


Fig. 4. SN ratio plot for MRR

Based on the analysis of S/N ratio, the optimal machining performance for MRR is obtained at a current of 3A (level 3) and pulse on time of 3.5µs (level 2) and pulse off time of 16 µs (level 2).

It can be observed from Table IX that current and pulse off time are the two significant factors that affect MRR. Pulse on

time has no significant effect on MRR. The percentage contribution of current and pulse off time are 61.05 % and 28.84 % respectively.

TABLE IX. ANALYSIS OF VARIANCE FOR MRR

Source	Degrees of freedom	Sum of squares	Mean of squares	F	P	% contribution
Current	2	11.2934	5.6467	57.86	0.017	61.05
Pulse On time	2	1.6757	0.8378	8.58	0.104	9.06
Pulse off time	2	5.3348	5.3348	27.33	0.035	28.84
Error	2	0.1952	0.1952			1.05
Total	8	18.4991				100

*Regression Equation*

The regression equation is also found out for predicting the MRR with a different combination of the process parameters

$$MRR = 0.139 + 0.0278 \text{ Current} + 0.00083 \text{ Pulse on time} - 0.00129 \text{ Pulse off time}$$

V. CONCLUSION

In this study the influence of the process parameters on surface roughness of AISI 420 stainless steel in the die sinking EDM was studied by using Taguchi L9 orthogonal array method. From the results, it is found that, current and pulse on

time play a significant role in EDM operation related to surface roughness. Pulse off time has no significant effect on surface roughness. Also it is found that, for the lower surface roughness the optimum levels for current, pulse on time and pulse off time are 1A (level 1), 1.5 μs (level 1) and 24 μs (level 3) respectively. The significance of the machining parameters and their individual contributions on the surface roughness is determined by using analysis of variance (ANOVA). Current is found to be the most influencing parameter on surface roughness with 67% contribution followed by the pulse on time with 32 % contribution.

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