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Experimental Investigation on Process Responses for Stainless Steel 420 in EDM using Response Surface Methodology

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Abstract— *In present days non-conventional machining process plays a tremendous role in manufacturing industries. To achieve the highly accurate, finished product with good quality and to make the intricate shapes, non-conventional machining like electrical discharge machining (EDM) is used to withstand the competition and to meet the demands in the industry. In electro-thermal non-traditional (or) un-conventional machining process, EDM is one where electrical sparks are generated by creating voltage difference between the electrode and work piece and due to the thermal electric energy of the sparks; the eroding of material takes place. To machine the materials which are difficult to machine in traditional machining and for temperature resistant high strength alloys EDM is applicable. The practical applications include dies in watches, mould cavity with deeper and narrow slots, mould cavity for the injection molding. In present study Martensitic stainless steel (SS) 420 is used to conduct the experiment by varying the control factors such as Discharge current (Ip), Pulse on time (Ton) and Duty cycle (%). Process responses such as material removal rate (MRR) and surface roughness (SR) are determined for every experimental run. With a minimum amount of experimentation Taguchi's L9 orthogonal array (OA) is used to study the response of control factors with varying levels. A mathematical and statistical technique called Response surface methodology (RSM) has been used for the analysis and modeling of the MRR and SR by using the commercial tool Design expert 9.0.3.1.*

Keywords— *EDM,* ***SS 420, L9 OA, RSM, MRR and SR.***

I. INTRODUCTION

The history of EDM begins with Sir Joseph Priestly in 1770[3]. He was observed the erosive effect of electrical discharges, but it is undesirable with failures. Critical materials are needed to be conserved during the world war in 1941. For automotive engines Tungsten was widely used electrical contact material. The engines required maintenance when corrosion takes place. To avoid the problem Professor Dr. Boris Lazarenko developed a spark-machining process with an electrical circuit called R-C (Resistor and Capacitance) circuit. Thus EDM was originally started in 1943. Now a day's some advance materials like super alloys, ceramics and composites are difficult to machine, become more challengeable materials for the manufacturing industries. By using the non-conventional energy sources like mechanical, light, sound, chemical and electrical a new concept of machining was developed. In this machining process there is no contact between electrode and work piece as in traditional machining process. In this process, work piece should possess the electrical conductivity. An electric field is established depending on the applied potential difference and gap between electrode and work piece. This process lead to the eroding of material by continuously melting and evaporating the material with the help of repeated sparks [2]. The erosion process consists of five phases, namely pre breakdown, breakdown, discharge, end of discharge and post discharge. Plasma channel is created with the help of electro thermal energy and temperature ranges are 8000˚c to 12000˚c [1]. With this high temperature of plasma state eroding occurs. In this study spark machining is used to make the ribs on the moulds and to make the threads on the bolt and nut patterns to increase the productivity with less time and cost. The EDM is shown in Figure 1.

There are many researchers have been studied EDM process. Some literature deals with the processing, modeling and analysis of EDM process Parameters are discussed below

Fig 1: ED machine

Shashikanth et al [4] investigated the optimization of input parameters such as pulse on time, pulse off time, discharge current and gap voltage with the consideration of process response such as *SR* by using the Response surface methodology for EN19. It is observed that the most significant factors for *SR* are peak current and pulse on time. With the decrease of peak current and pulse on time, the SR also decreases. Vikas et al [5] investigated the optimization of control factors such as pulse on time, pulse off time, discharge current and gap voltage on EN41 material by considering the process responses of *SR* parameters like *Ra*, *Rq*, *Rsk*, *Rku* and *Rsm* using Grey Taguchi. It is observed that, there is a great impact on the SR with discharge current. Another investigation was carried out by A.K.Roy et al [6] to find out the performance characteristics of various input parameters such as pulse on time, pulse off time, discharge current and gap voltage on *MRR* by using Taguchi single objective optimization approach for EN19 and EN41 materials in EDM. From this study it is noticed that, *MRR* is high for EN41 than EN19 for all combinations of control factors due to high carbon percentage in EN41. Another approach was carried out by P.Balasubramanian et al [7] for EN8 and D3 steel to find out the effect of various input parameters such as peak current, pulse on time, di-electric pressure and tool diameter with the consideration of multiple process parameters such as *MRR*, Tool wear ratio (*TWR*) and *SR* in *EDM* by using *RSM* for cast and sintered copper electrodes. It is observed that, for EN8 steel, cast electrode offers low *TWR* and high *MRR* than that for the sintered electrode and sintered electrode have more smooth finish than cast electrode. For D3 steel, cast electrode gives high *MRR* and low *TWR* than the sintered electrode; sintered electrode give low surface irregularities than the cast electrode. Milan Kumar Das et al [8] investigated the performance characteristics of the input factors such as pulse on time, pulse off time, discharge current and voltage with the consideration of process responses *MRR* and *SR* in EDM for EN31 tool steel by using Artificial bee colony multi objective optimization technique. It is concluded that, the pulse on time and discharge current are proportional to the *MRR* and *SR*. Ayush Poddar et al [9] investigated the optimization of input parameters such as current, spark on time and duty cycle with the consideration of output responses such as *MRR*, *SR* and overcut (OC) using Taguchi approach for SS 304 in EDM. S.Jai Hindus et al [10] investigated the effect of control factors such as current, pulse on time and voltage on process responses which are *MRR* and *TWR* in EDM for SS 316 material using Taguchi technique. From this study, it is concluded that *MRR* is directly proportional to the current; and *TWR* increases more with current then with pulse on time and voltage. Raghuraman S et al [11] investigated on the optimization of EDM parameters using Grey relational analysis for mild Steel 2026.

II. EXPERIMENTAL PROCEDURE

2.1. Experimental setup

Experiments were conducted on the Electronica plus die sinking EDM machine (115/230V and 50-60 Hz) is shown in Figure 1. EDM oil is used as the dielectric medium. EDM is comprised of machine tool, power supply unit and dielectric supply unit. Machine tool comprises of base, column, work table and work head. Work table is mounted inside a work tank. Work piece is mounted and clamped on the work table. Power supply comprises of electric pulse generator motor driver and a logic controller. The machining zone is completely submerged in a dielectric medium while machining. Also the machining zone is cleaned by using the side jet flushing with EDM dielectric oil. In this study, the experiments were conducted with three input variables namely Discharge current, Pulse on time, Duty cycle and the Process response variables like *MRR* and *SR*. *MRR* is evaluated as the ratio of weight difference of work piece before and after machining to the machining time and it was expressed in terms of gm/min. *SR* measurement was done by using a Talysurf (Mitutoyo) Profilmeter as shown in Figure2 and is expressed in micro meter. Experiments were designed with three level control factors at equal difference as shown in Table 1.

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Table1: levels of Design Factors

Design Factors	Units	Symbol	Levels		
			-1	0	1
Discharge current(Ip)	Amp	D	6	8	10
Pulse on time (Ton)	micro sec (µsec)	E	100	150	200
Duty cycle(τ)	Percentage (%)	F	10	11	12

Fig.2: Talysurf equipment

III. NOMENCLATURE AND SELECTION OF MATERIALS

3.1 Nomenclature

RSM Response surface methodology
OA Orthogonal array
MRR Material removal rate, gm/min
SR Surface roughness, micro meter
SS420 Stainless steel 420
EDM Electrical discharge machining
DOE Design of experiments
ANOVA Analysis of variance

3.2. Selection of work piece and tool material

The Martensitic SS 420 plate was used as the work piece material in the experiment as shown in Figure 3. The initial dimensions of the work piece were 155mm×47mm ×16mm plate. By using milling and grinding operations, it was finished to the dimensions of 150mm×45mm× 12mm. The code for material is Din 1.2316. Copper electrode is shown in Figure4 with 9.9mm diameter to make the 10mm diameter blind hole on the work piece. Grade of SS 420 is a high chromium (15.5%-17.5%) alloy steel with high degree of corrosion resistance, strength, hardness and possesses magnetic property. The practical applications of SS420 includes plastic injection molds, moulds for corrosive plastics, mould inserts, dies, shaft sleeves, seats for oil well pumps, nozzles, bolt and nut, ball bearings, bushes, dental and surgical instruments, dies in watches, needle valves and pump shafts. The chemical composition and mechanical properties of SS 420 are shown in Table 2 and Table 3.

Table 2: Chemical composition of stainless steel 420

%	C	Cr	Fe	Mn	P	Si	S	Mo
Min	0.33	15.5	Balance	-	-	-	-	0.8
Max	0.45	17.5		1.5	0.04	1	0.03	1.3

Table 3: Mechanical properties of stainless steel 420

Property	Value
Specific gravity	7.73
Density	7800 Kg/m³
Brinel hardness	205
Rockwell hardness	50-55
Ultimate tensile strength	760 to 1700 Mpa
Tensile strength yield	515 to 1380 Mpa
elastic modulus	200 Gpa
Thermal conductivity	24.9 W/m-k

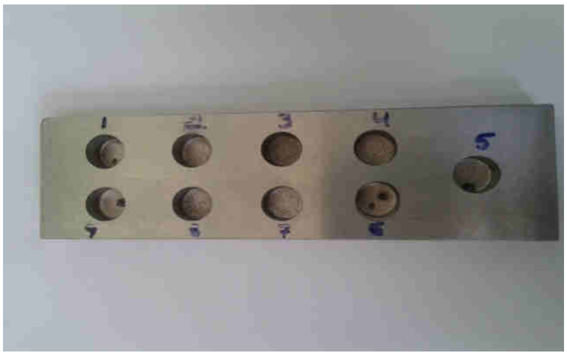

Fig 3: Work piece with blind holes after machining

Fig 4: copper round shaped electrode and different shaped electrode.

3.3. Design of Experiments (DOE)

To study the effect of different control factors on different process responses and for obtaining the relation between them. DOE reduces machining time, power consumption and machining cost for the experimental investigation. For finding the optimum machining process parameters, an OA is used in Taguchi's method. The selection of OA depends on the total degree of freedom (DOF). In this Study, L9 OA is selected having 8 DOF with three input factors and three levels are tabulated in Table 1. The DOF for three levels test is 3(3-1) =6. Hence as per Taguchi, OA of L9 is selected.

Table 4: design of experiment with experimental results

Exp no.	Ip (amp)	Ton (μsec)	τ (%)	MRR (gm/sec)	SR Ra (μm)
1	6	100	10	0.05028	4.138
2	6	150	11	0.04678	5.0208
3	6	200	12	0.07925	5.3846
4	8	100	11	0.06845	4.1918
5	8	150	12	0.09025	6.2469
6	8	200	10	0.0844	5.94
7	10	100	12	0.1137	6.35
8	10	150	10	0.12215	6.5818
9	10	200	11	0.13789	7.38

IV. RESPONSE SURFACE METHODOLOGY (RSM)

RSM is a group of mathematical and statistical methods that are suitable for applications such as modeling and analysis. RSM creates the optimum region, in which operating conditions are satisfied. Here output is influenced by the number of input factors. So in this method, the main goal is, to reduce the expensive analysis cost and optimize the output responses that are influenced by various input parameters. For the visualization of the response, contour and surface plots [M.M.Noor.et.al] are used. It gives the relation between the control factors and output responses.

4.1. Experimental results and discussions

Process responses such as *MRR* and *SR* values are presented in table 4.

4.2. Analysis of variance (ANOVA)

By using design expert tool, a complete analysis can be carried out in RSM, when the *MRR* and *SR* values are obtained.

ANOVA for Response Surface Linear Model

Analysis of variance table [Partial sum of squares - Type III]

Source	Sum of Squares	df	Mean Square	F Value	p-value Prob > F	
Model	7.408E-003	3	2.469E-003	24.41	0.0021	significant
A-A	6.496E-003	1	6.496E-003	64.21	0.0005	
B-B	7.960E-004	1	7.960E-004	7.87	0.0378	
C-C	1.159E-004	1	1.159E-004	1.15	0.3334	
Residual	5.059E-004	5	1.012E-004			
Cor Total	7.914E-003	8				

R-Squared	0.9361
Adj R-Squared	0.8977
Pred R-Squared	0.7374

Fig 5: Analysis of MRR.

Analysis of *MRR* is obtained using RSM as shown in Figure 5. The important factor to note here is the P-value where it denotes the significant of control factor. The P-value i.e. probability for *MRR* is 0.0021. The parameter which having less than 0.05 is considers being important. Out of these three input parameters it can be observed that, for *MRR* the Discharge current and Pulse on time have the lowest p-value of 0.0005 and 0.0378 respectively. This shows that both of these parameters have more effect on the *MRR*. The R-Sq. value is given as 93.61%. The difference between Adj R-Squared and Pred R-Square is 0.16< 0.2. So that the model is fit.

ANOVA for Response Surface Linear Model

Analysis of variance table [Partial sum of squares - Type III]

Source	Sum of Squares	df	Mean Square	F Value	p-value Prob > F	
Model	7.89	3	2.63	10.64	0.0131	significant
A-A	5.21	1	5.21	21.06	0.0059	
B-B	2.47	1	2.47	9.98	0.0251	
C-C	0.22	1	0.22	0.87	0.3927	
Residual	1.24	5	0.25			
Cor Total	9.12	8				

R-Squared	0.8646
Adj R-Squared	0.7833
Pred R-Squared	0.6206

Fig 6: Analysis of SR.

Analysis of *SR* is obtained using RSM as shown in Figure5. The P-value for model is 0.0131. It shows that, the error in the experimental values is less than five percent. It can be observed that for *SR*, the Discharge current and Pulse on time have the lowest P-value of 0.043 and 0.059. This shows that Discharge current has more effect on SR. The R-sq. value is given as 86.46%. The difference between Adj R-Squared and Pred R-Square is 0.16< 0.2. So that the model is fit.

4.3. EFFECTS OF CONTROL FACTORS ON PROCESS RESPONSES

4.3.1 Influence of Discharge current on *MRR*:

MRR values are investigated on the various levels of Discharge current. The influence of Discharge current on *MRR* is shown in Figure7. From the graph it is clear that, *MRR* increases rapidly with increase of Discharge current. The reason for this is, when the current increases more heat is supplied to the work material so that material melts easily.

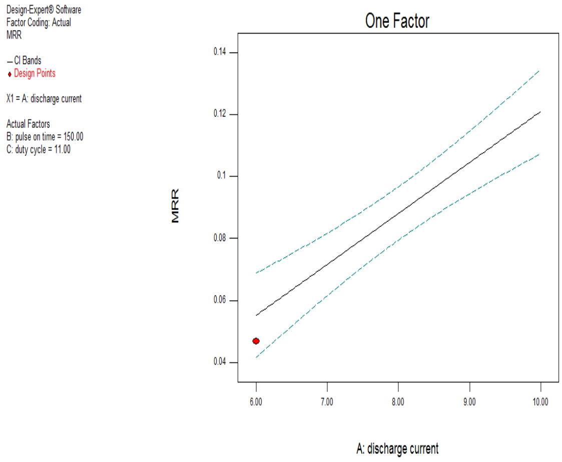

Fig 7: the Relationship between discharge current and MRR

4.3.2 Influence of Pulse on time on *MRR*

The influence of Pulse on time on *MRR* is shown in Figure 8. From the graph it is clear that, with the increasing of Pulse on time *MRR* increases. From this, it is observed that Pulse on time shows less effect than Discharge current. Reason here for increasing of *MRR* is that, when Pulse on time increases the sparking width increases which cause big craters on the work material which results higher *MRR*.

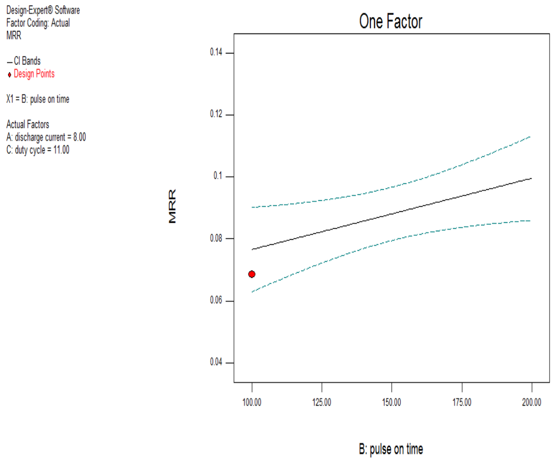

Fig 8: the Relationship between pulse on time and MRR

4.3.3 Influence of duty cycle on *MRR*:

The influence of Duty cycle on *MRR* is shown in Figure 9. From the graph it is observed that with increase of Duty cycle, *MRR* increases slightly. From this it is clear that, Duty cycle has less effect on *MRR* compared to the Discharge current and Pulse on time.

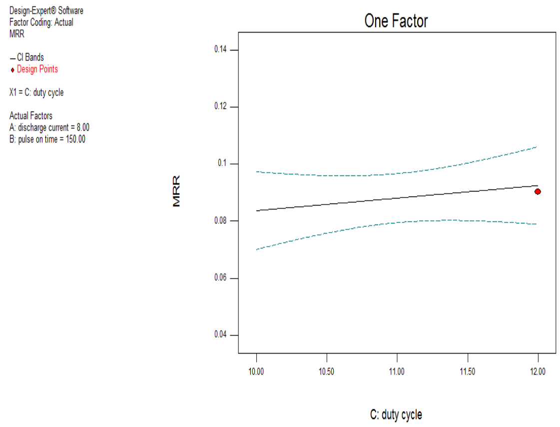

Fig 9: the relationship between duty cycle and MRR.

4.3.4 Influence of Discharge current on *SR*:

The *SR* values are investigated on the various levels of Discharge current conditions. The influence of Discharge current on *SR* is shown in Figure 10. From the graph, it is clear that with increase of Discharge current *SR* increases. The reason for this is, when the Discharge current increases sparking energy increases. This causes big craters on the work surface.

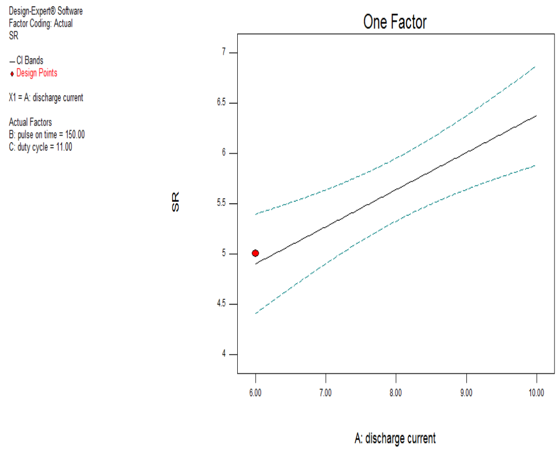

Fig 10: the relationship between discharge current and SR.

4.3.5 Influence of Pulse on time on *SR*:

The influence of Pulse on time on *SR* is shown in Figure11. From the graph it is clear that with increase of Pulse on time the *SR* increases. The reason for this is with the increase of pulse on time; pulse width increases and forms the big crater on the work surface i.e. surface irregularities increases. But compared to Discharge current, Pulse on time shows less effect on *SR*.

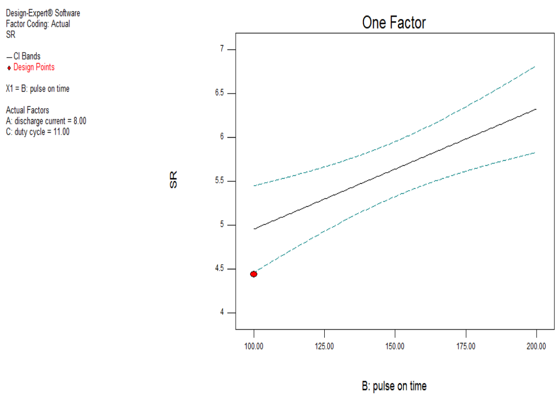

Fig 11: the relationship between pulse on time and SR.

4.3.6 Influence of Duty cycle on *SR*:

The influence of Duty cycle on *SR* is shown in Figure12. From the graph it is clear that with increase of Duty cycle the SR slowly. It shows less effect compared to the Discharge current and Pulse on time on *SR*.

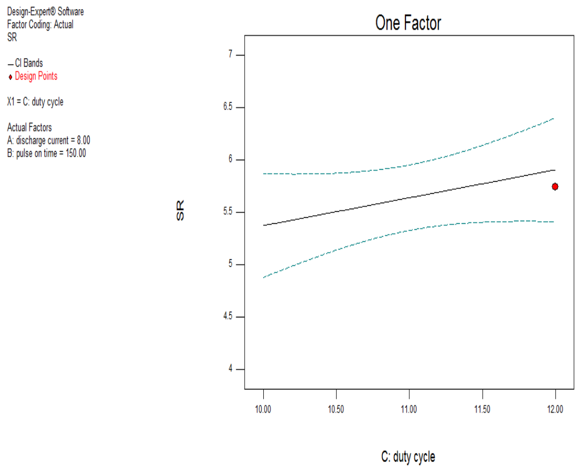

Fig 12: the relationship between duty cycle and SR.

4.4. Development of a mathematical model

The Regression equation for the MRR and SR are obtained by using RSM. The regression equations for the MRR and SR are the function of three process parameters and equations are developed by using Experimental data (Table 4) is given below. The regression equations are used to predict the results of process responses within the range of experimental conditions.

MRR = −0.12639 + 0.016452×Discharge current + 2.30367E−004×Pulse on time + 4.39500E-003×Duty cycle.

SR = −2.02413+0.46570×Discharge current+ 0.012826 ×Pulse on time + 0.18978×Duty cycle.

V. CONCLUSION

This paper present the RSM, which is used to investigate the relationship between EDM input factors with output factors. The control factors used here are Discharge current, Pulse on time and Duty cycle. The importance of the study is to find out the effect of control factors on output responses such as *MRR* and *SR*. From the analysis of *MRR* and *SR* it is found that, Discharge current is the more affecting factor.

The regression equation for *MRR* and *SR* are:

MRR = −0.12639+0.016452×Discharge current+ 2.30367E−004× Pulse on time + 4.39500E-003 ×Duty cycle

SR = −2.02413+0.46570×Discharge current+ 0.012826 ×Pulse on time + 0.18978 ×Duty cycle.

From this investigation it can be observed that

a. The analysis shows that a high *MRR* is obtained by Discharge current and Pulse on time regardless Duty cycle used.

b. *SR* is highly affected by Discharge current and Pulse on time. Duty cycle shows less effect on *SR*.

c. RSM models reveals that Discharge current is the most significant design variable on *MRR* and *SR* as compared to the other variables.

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