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ORIGINAL CONTRIBUTION

PARAMETRIC OPTIMIZATION OF EDM PROCESS ON MILD STEEL WITH COPPER TOOL USING STATISTICAL TECHNIQUES

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ABSTRACT

With the advent of coming of age materials (such as super alloys, ceramics and composites) with properties such as high hardness, brittleness; the demand for a machining process arises with which those new age materials can be machined conveniently and accurately, while keeping the machining process economic and competitive. Electrical Discharge Machining (EDM) is such a nontraditional manufacturing process which fulfills all the above criterion stated above. EDM technology is increasingly being used in tool, die and mold making industries, for machining of tool materials with heat treatment and advanced materials (super alloys, ceramics, and metal matrix composites) requiring highly precise dimensions, complex shapes and very good surface finish.

Electrical Discharge Machining (EDM) is controlled by a number of process parameters such as Pulse on Time (POT), pulse off time (POF), Duty factor, spark gap, Input current for different cutting operations. In this paper, two responses- Material removal rate (MRR), and overcut are considered. Experimentation is planned as per Taguchi's L9 orthogonal array (OA). Copper tool (cylindrical shape) with and length of 16.2 mm and diameter 26.1mmMild Steel blocks of 12 mm thickness were used as work piece, Paraffin oil was used as dielectric. Multi response characteristics was used to optimize machining parameters applying response surface methodology (RSM)

KEYWORDS—EDM, Material removal rate, Overcut, RSM, ANOVA, L9 OA

1. INTRODUCTION

Electrical Discharge Machining (EDM) is an electro-thermal process based on the eroding effect of an electric spark on both the electrode and work piece. In EDM metal removal takes place by a series of recurring electrical discharges between a tool acting as an electrode and a electrically conductive work piece, in the presence of a dielectric fluid. This discharge occurs in a voltage gap between the electrode and work piece, which causes localized temperatures (estimated at around 10,000◦C) high enough to melt and vaporize the metal in the immediate vicinity of the discharge. The dielectric fluid is continuously supplied to the machining zone to flush out the eroded particles (chip) and heat. Although the individual discharges remove metal at localized points, they occur thousands of times per second so that a gradual erosion of the entire surface takes place in the area of the gap. To achieve desired contours or 3-d geometry on work piece the shaped tool's movements are computer numerically controlled via a servomotor (3-axis).

This process is best suited for parts with materials of low mach inability, having intricate profile details, needing close tolerances, which need high repeatability, and material having high temperature strength.

Due to its versatility in machining electrically conducting materials, EDM process holds a major share in non-traditional manufacturing sector and is employed in manufacturing of dies, molds, aerospace, automobile and other industries.

A brief literature review on EDM is presented here. Kumar Sandeep (2013) investigated and reviewed the effect of five process variables namely- Pulse time, Pause time, Spark Gap, Duty cycle, Current and voltage on MRR, surface roughness on D2 die steel as work material. Patel et.al (2013) studied the optimization of material removal rate in wire-cut EDM process. Nipanikar (2012) studied optimization of MRR, Electrode wear rate and overcut in EDM process by Taguchi method. The process variables used were Pulse on time, Peak current, Duty factor, and Gap voltage. L9 array was constructed and significant test were carried out for independent variables. The workpiece used was of AISI D3 steel material, and tool was made of copper.Modi et.al (2015) reviewed optimization of process parameters (MRR and surface roughness) of EDM for air hardening tool steel. Patil et.al (2014) studied the optimization of process parameters in wire-edm using response surface methodology. AISI D2 cold work steel was used as workpiece and brass was used as tool material. They found out the optimized values of process parameters and conclude that MRR increases as peak current increases. Ghodsiyeh et.al (2012) experimentally studied the behavior of WEDM process selection of three important control parameters such as Pulse ON Time, Pulse OFF Time and Peak Current on machining performance, to optimize Material Removal Rate (MRR) and Surface Roughness (SR) of titanium alloy (Ti6Al4V) using Analysis of Variance (ANOVA).Pallela et.al (2014) studied the Optimization of machining parameters in electric discharge machining using response surface methodology. Response Surface Methodology (RSM) was used to investigate relationships and parametric interactions between the four controllable variables on the material removal rate (MRR). Experiments were conducted on a SS304 work piece with copper electrode and four process variables. The variables used were: duty-cycle, gap voltage, current and quill lift time. The experimentation plan was designed using Box-Behnken Design (BBD) of response surface method.Abulais (2014) reviewed the current Research trends in Electric Discharge Machining (EDM). Different types of EDM process were explained with different stages of development and pro and cons of same. Huang et. al (2003) studied the optimization of maximum metal removal rate and minimum surface roughness of SKD11 alloy steel in Wire-EDM process applying Grey relational analysis as well as statistical techniques. Singh et. al (2014) studied and reviewed the optimisation of parameters like MRR, wear ratio, and surface roughness in EDM process, using tools like Taguchi's method and RSM. Mir et. al (2012) did modelling and analysis of machining parameters for surface roughness in powder mixed EDM using RSM approach. The work piece was made of H11 steel. Chaudhary et. al (2013) studied optimisation of MRR for W-EDM in EN-5 steel using RSM. The effects of various process parameters on MRR were noted.

In the present experimental work, parametric optimization of EDM process using MS workpiece and Copper tool is done. To identify the significant process parameters, Analysis of Variance (ANOVA) is applied using L9 orthogonal array. The present experimental study focuses to yield a reasonably high metal removal rate (MRR) along with low overcut (OC), further the paper is aimed at studying the effects of the process variables, Response surface methodology (RSM).Regression equations are developed for the responses final the response surfaces are studied to investigate the prominence of the process variables and their levels so as to optimize their responses. The objective of present research work is to determine a single set of process variable which will optimize both the conflicting nature of responses simultaneously. In the present work response optimizer technique through RSM is applied to establish the multi objective optimization effectively.

2. PLANNING AND EXPERIMENTATION

In this paper an experimental study has been carried out on specimen of MS material to optimize the machining parameters of EDM for maximum MRR and minimum OC, using TAGUCHI methodology following RSM. MRR and OC are conflicting responses which require different level settings of machining parameters for their optimization. So, proper machining parameters setup for simultaneous optimization of responses is critical. Three different process parameter levels as shown in table 1, are varied in conformance with L9 orthogonal array.

Table 1: process parameter levels

Parameters	Symbols	Units	Levels		
			L1	L2	L3
Pulse on time	POT	μ-sec	1500	2000	3000
Current	I	Amps	20	25	30
Duty factor	DF	-	20	26	32
Spark gap	SG	Mm	0.2	0.28	0.355

The shaped tool used for present experimental investigation is cylindrical shaped copper tool, having a diameter of 26.1 mm and a length of 16.2 mm which is shown in figure 1 below.
The general properties of tool material (Copper) are shown in table 2 below:

Table 2: The general Properties of tool material (tool electrode)

1.	Name, symbol, number	Copper ,Cu, 29
2.	Density	8.94 g.cm-3
3.	Liquid density atm. p.	8.02 g.cm-3
4.	Melting point	1357.77 K
5.	Boiling point	28335 K
6.	Heat of vaporization	300.4 KJ.mol-1
7.	Electro negativity	1.90 (Pauling scale)
8.	Electrical resistivity	(20 C) 16.78 nΩ.m
9.	Thermal conductivity	(300 K) 401 W.m-1. K-1
10.	Thermal expansion	(25 C) 16.5 µm.m-1 .K-1
11	Young's modulus	110 – 128 Gpa
12.	Shear modulus	48 Gpa
13.	Bulk modulus	140 Gpa
14.	Poisson ratio	0.34
15.	Mohs hardness	3.0
16.	Vickers hardness	369 MPa

Figure 1: Tool and work piece

Mild steel(MS) is most common form of steel as it is relatively cheap compared to other steel varieties and it provides material properties such as high malleability, ductility, which favors it's use in processes where large amounts of metal is required such as in structural steel. The general properties of MS are shown in table 3 below. Machining setup and working of EDM is shown in figure 2.

Table 3: The general Properties of work material (mild steel)

1.	Density	7800 – 7900 kgm-3
2.	Modulus of Elasticity	200 – 250 Gpa
3.	Yield Strength	250 – 395 Mpa
4.	Tensile Strength	345 – 580 Mpa
5.	Elongation	26% - 47%
6.	Hardness	107.5 –172.5 HV

(a)

(b)

Figure 2: (a) and (b) Machining setup and working

3. ANALYSIS USING ANOVA RESULT

The Analysis of Variance (ANOVA) is required for estimating the error variance for the factors effects and variance of prediction error. First the total summation of squared deviations SST from the total mean S/N ratio n_m can be calculated.

$$SS_t = \sum_{i=1}^{n}(n_i - n_m)^2 \quad \dots (1)$$

Where, n is the number of experimental run in the orthogonal array and ηi is the mean signal-to-noise ratio for the ith experiment.

The percentage contribution P is calculated as:

$$P = \frac{SS_d}{SS_t} \quad \dots \quad (2)$$

Where, SS_d is the sum of the squared deviations.

The experimental results are investigated to analyse the role of different control variables on various responses by using S/N ratio n_m and ANOVA.

S/N ratio measures the variation of different process. The objective is to find out an optimal combination of control parameter settings that achieve robustness against noise factors.

S/N ratio analysis for MRR is carried out on the basis of larger is the better and the related S/N ratio is expressed as follows:

$$n_1 = -10\log_{10}\left[\frac{1}{n}\sum_{i=1}^{n}\frac{1}{MRR^2}\right] \dots \quad (3)$$

S/N ratio analysis for OC is modeled on the basis of smaller is the better and corresponding equation is

$$n_2 = -10\log_{10}\left[\frac{1}{n}\sum_{i=1}^{n} OC^2\right] \quad \dots \quad (4)$$

The S/N plot for MRR and OC are shown in figure 3 and figure 4 respectively

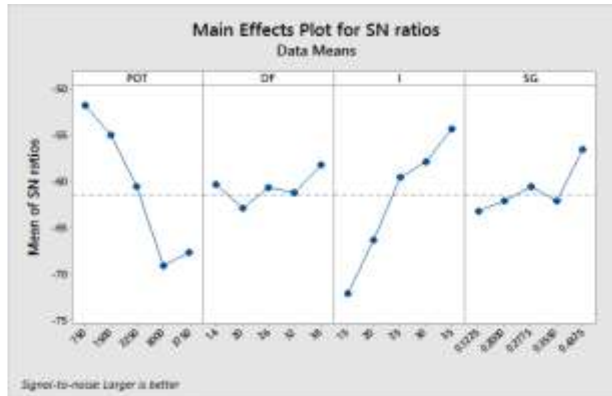

Figure 3: S/N plot for MRR

It is evident from the figure 3 as POT increases, MRR decreases this can be explained as with increase in POT the charging time of the circuit increases and due to this MRR decreases because for the same spark time required is more. With increase in current (I), MRR increases because due to increase in current the energy per spark increases and greater amount of material is removed per spark. With increase in DF, MRR increases because the effective spark time increases and it also sometimes decreases because of improper flushing of eroded material. With increase in SG, MRR increases because at lower SG the spark is localized and proper sparking does not take place and with increase in SG proper sparking takes place.

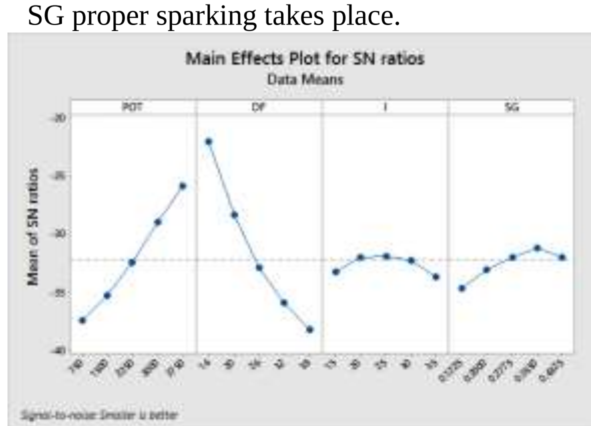

Figure 4: S/N plot for OC

It is evident from the figure 4 as POT increases, OC increases because with increase in POT, energy per spark increases so crater is formed resulting in greater OC.With increase in DF, OC decreases because as duty factor(DF) increases POT increases and hence OC increases.With increase in current(I), OC increases because spark energy increases and cause more material removal per spark causing higher OC.With increase in SG, OC increases because at higher at lower SG spark is localized and less material is removed per spark.From the S/N ratio Plot of Taguchi Design maximum MRR is obtained at combination of POT (750), DF (38), I (6), SG (0.4325) and minimum OC is obtained at combination of POT (3750), DF (14), I (25), SG (0.3550).

4. RESULTS ANALYSIS USING RESPONSE SURFACE METHODOLOGY (RSM)

A. Response Surface Methodology:

Response surface methodology (RSM) is a collection of mathematical and statistical techniques for empirical model building. Response surface methodology (RSM) is useful for modeling and analysis of problems in which response (output variable) is influenced by several independent process variables (input parameters) and the objective is to find the correlation between the output variable and the input variable. It can be used for optimizing the response, also RSM can be used for the approximation of both numerical and experimental responses. There are two steps necessary, to define an approximation function and the design of the experimental plan. At present this method is applied for various experimental analysis ofa complex process like EDM. The main objective of RSM is to determine an optimal response with the help of a set of designed experiments. In the present research work RSM is utilized for determining the relations between the various EDM controllable process parameters with the various machining criteria and finding the effect of these process parameters on the output responses i.e. MRR and overcut. The purpose of using RSM is also to locate the region of interest at which the responses reaches its optimum or near value.

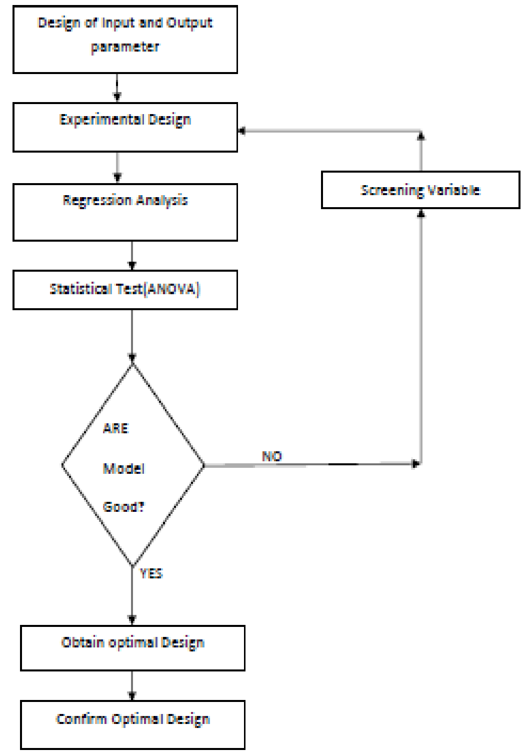

Figure 5: Flow chart for procedure of Response surface methodology

Analysis of test results for Material Removal Rate (MRR)

The regression equation for MRR is

$$MRR = 0.000399 - 0.000001\,POT + 0.000009\,DF + 0.000075\,I + 0.001989\,SG \quad \text{.......}\ (5)$$

Where,

POT="Pulse on time (µsec)"

SG= "Spark gap (mm)"

I= "Current (amps)"

D.F= "Duty factor"

The details of regression analysis is shown in the table 4 below, the values of R-sq and R-sq(adj) comes to be 94.43% and 93.58% respectively.

Table 4: Estimated regression coefficients for MRR

Term	Coef	SECoef	T	P
Constant	0.000399	0.000292	1.36	0.184
Pulse Of Time	-0.000001	0.000000	-17.67	0.000
Duty Factor	0.000009	0.000006	1.53	0.137
I	0.000075	0.000007	10.39	0.000
SG	0.001989	0.000463	4.30	0.000
S=0.0001757 R-sq=94.43% R-sq(adj)=93.58% R-sq(pred)=91.42%				

It is evident from the above table that the most significant parameter affecting MRR is I, followed by SG. In surface plots two control parameters are varied simultaneously while keeping the other two constant to study their effect on MRR.

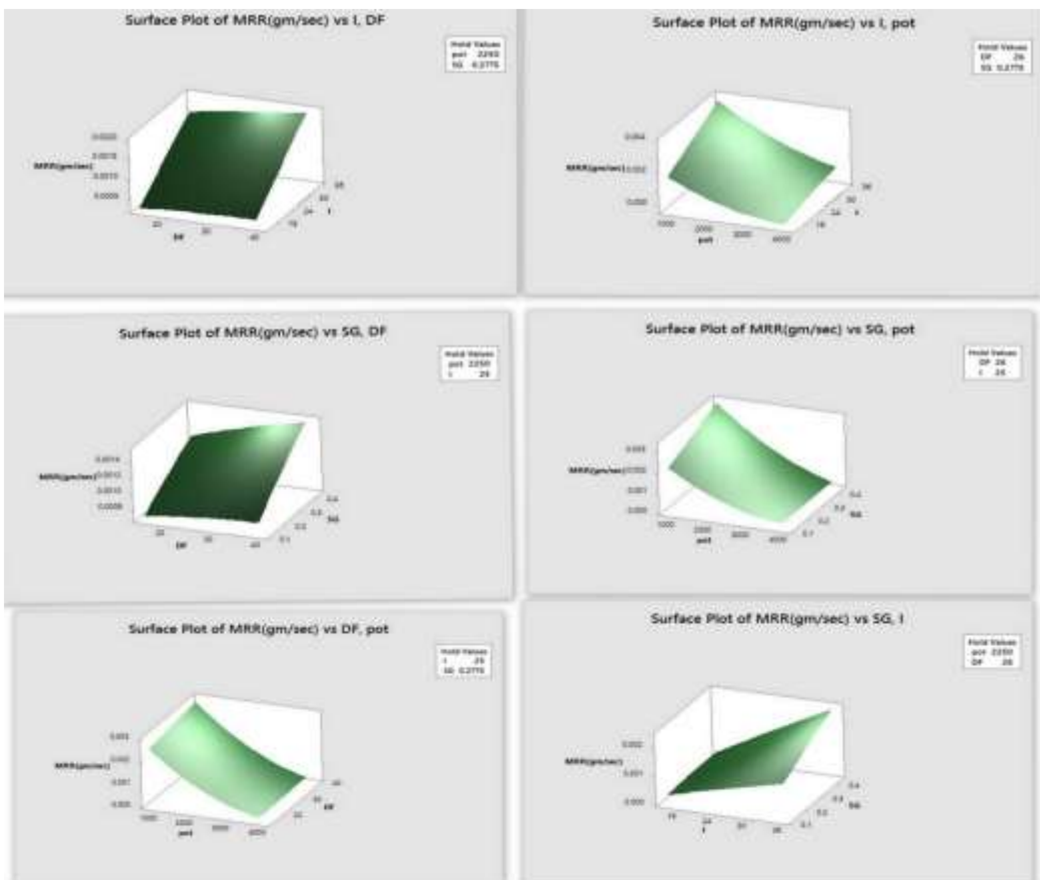

Figure 6: Surface plot of MRR

From figure 6 it is evident that with increase in I, MRR increases rapidly as compared to DF. It can be seen that with increase in I, DF and SG MRR increases and with POT MRR decreases.

Analysis of test results for OVER CUT (OC)

The regression equation for OC is

$$OC = 23.50 - 0.01840\,pot + 2.880\,DF + 0.1200\,I - 46.00\,SG \quad \ldots\ldots. (6)$$

Where,

POT="Pulse on time (µsec)"

SG= "Spark gap (mm)"

I= "Current (amps)"

D.F= “Duty factor”
The details of regression analysis is shown in the table below, the values of R-sq and R-sq(adj) comes to be 100% and 1000% respectively.

Table 5: Estimated regression coefficients for OC

Term	Coef	SECoef	T	P
Constant	23.50	0.00	-	-
Pulse Of Time	- 0.0184	0.00000	-	-
Duty Factor	2.80	0.00000	-	-
I	0.120	0.00000	-	-
SG	-46.00	0.00	-	-
S=0.000 R-sq=100% R-sq(adj)=100% R-sq(pred)=100%				

Similarly, in case of overcut the surface plots are drawn by varying two control parameters are simultaneously while keeping the other two constant.

From figure 7 it is evident that with increase in DF, OC increases rapidly as compared to I. It can be seen that with increase in I, DF and SG, OC increases and with POT, OC decreases.

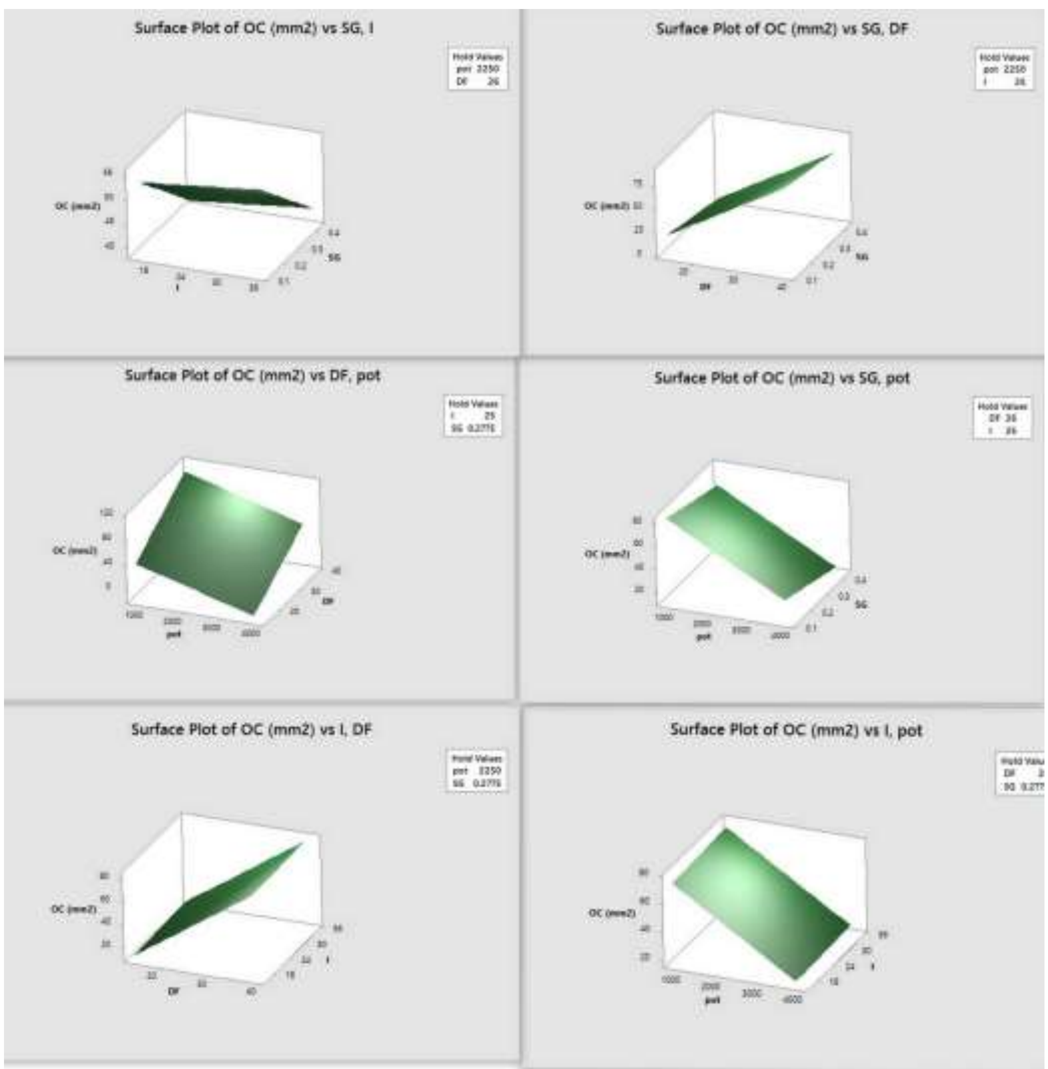

Figure 7: Surface plot of OC

5. MULTI RESPONSE OPTIMIZATION

A. OVERLAID CONTOUR PLOT

With reference to present experimental investigation, two characteristics were considered- MRR, which is desired as high as possible and overcut which is desired to attain lowest possible value. Those two attributes are incongruous with each other, hence they are achievable in a range of values applicable as per the specifications of product demands and viability of the process. Multi response optimization is carried out in this section to find reasonable ranges for previously stated attributes. Overlay contour plots were plotted to review the range of operating parameters that satisfy the need for MRR (high) and overcut (low). Overcut in range of 11.97mm^2 to 82.46 mm^2 has been found to meet the acceptance criterion for most of applications. MRR has been set between a lower bound of 0.0000530 gm/sec and upper bound of 0.0025875 gm/sec.

Thus constrained equation becomes:

$$11.97<OC<82.46 \quad (7)$$

$$0.000053<MRR<0.0025875 \quad (8)$$

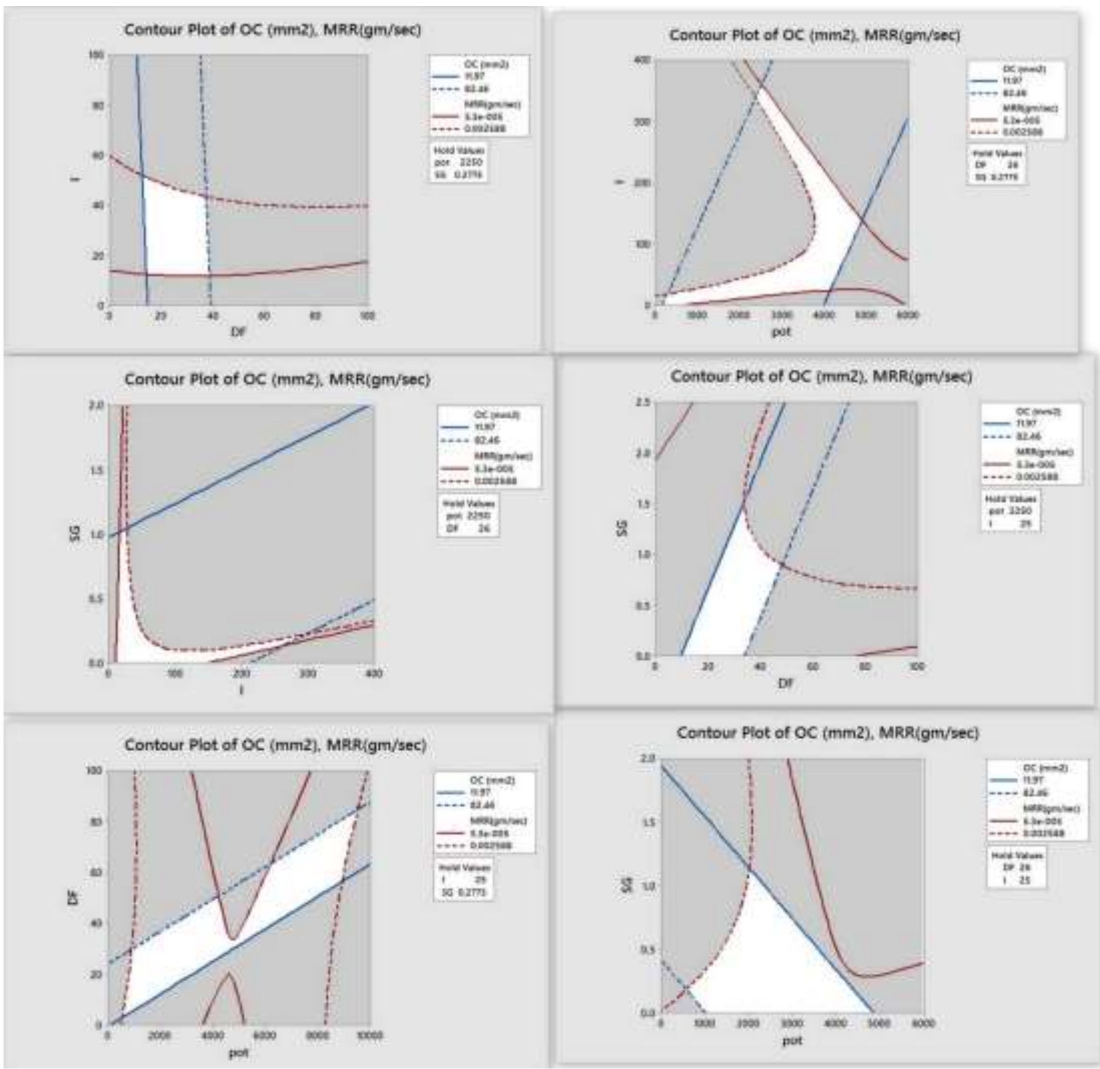

Figure 8: overlaid contour plots for MRR and Overcut (OC)

The overlaid contour plot of MRR, OC (overcut) with respect to Duty factor (DF), Current (I) and Spark gap (SG) has been illustrated above. The bounded white areas between dotted lines(maximum values) and solid lines (minimum values) are regions that satisfy the criterion of high MRR and low overcut along with possible combinations of process variables. From the plots it can be inferred that combination of moderate to high duty factor and low spark gap help achieve the target. The white areas in the figure 8 highlights the conditions for optimum MRR, overcut and corresponding values of process variables can be obtained from graph.

B. DESIRABILITY FUNCTIONS

Response optimizer helps to detect the parameter setting that optimize a single or a group of responses. All the requirement for responses must be fulfilled for multiple responses optimization.

It is done by converting responses into individual desirability function that varies from 0 to 1.

The characteristics of desirability function are goal, upper limit, target, lower limit and weightage of responses.

The important parameters decide how desirability functions are combined into single optimized desirability.

Starting Point: POT= 750, DF= 14.00, I= 15.00, SG= 0.1225

From the S/N ratio Plot of Taguchi Design we get highest MRR at combination of POT (750), DF (38), I (6), SG (0.4325) & Lowest OC at combination of POT (3750), DF (14), I (25), SG (0.3550) Hence an optimized combination of POT (750), DF(14), I (15), SG (0.1225) can be taken as starting point

The response optimization is shown in Table 6

Table 6: Desirability Function Result

<table>
<tr><td>Parameter</td><td>Goal</td><td>Lower</td><td>Target</td><td>Upper</td><td>Weight</td><td>Import</td></tr>
<tr><td>MRR</td><td>Maximum</td><td>0.0000530</td><td>0.0025</td><td>0.0025875</td><td>1</td><td>1</td></tr>
<tr><td>OC</td><td>Minimum</td><td>11.97</td><td>12</td><td>82.46</td><td>1</td><td>1</td></tr>
<tr><td colspan="4">Predicted Response
OC=12.4086;Desirability=0.99378(99.38%)
MRR=0.0025; Desirability=0.99998(99.99%)
Composite Desirability=0.9969(99.69%)</td><td colspan="3">Global Solution
POT=1941.1113
DF=14.0
I=35
SG=0.4325</td></tr>
</table>

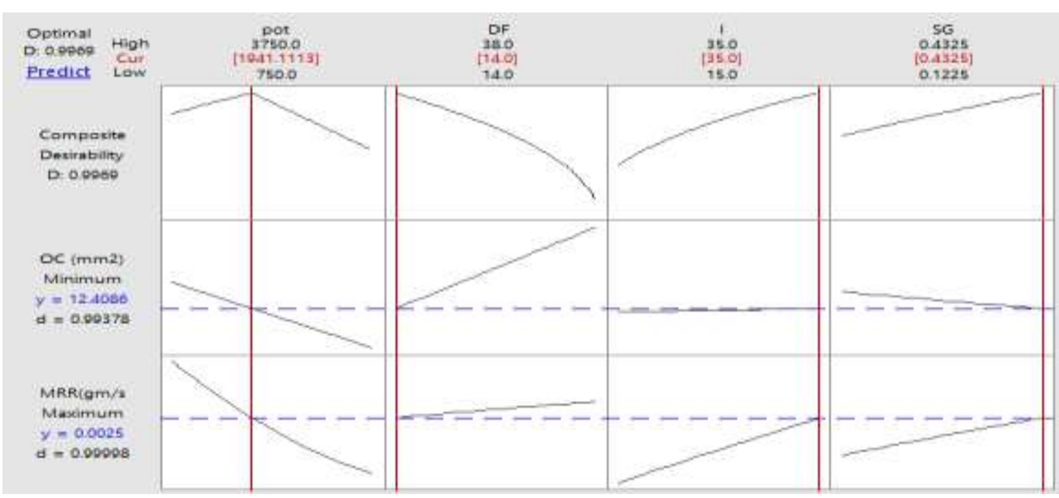

Figure 9: Optimization Plot of Responses With Process Variables

The figure 9 shows the objective for response and predicted response is shown on Y axis, at current factor settings and individual desirability. The composite desirability D is also shown in graph at upper left corner.

From the graph we get optimized value of dual objective as MRR=0.0025 with desirability =0.99998, and OC=12.4086 with desirability=0.99378.

Finally, the dual desirability is 0.99969 having POT=1941.1113, DF=14, I=35, SG=0.4325 is the near optimal combination.

6. CONCLUSION

The experimental investigation of EDM process using MS work piece using copper tool is successfully accomplished. The parameters considered for experimentation affect the responses in a significant manner. Initially the effect of the control parameters on the responses is studied. Finally multi objective optimization is done to determine the plausible parametric combination which will satisfy the contradictory responses simultaneously. The Material Removal Rate (MRR) in Electric Discharge Machining (EDM) are greatly influenced by the various dominant process parameters. The Material Removal Rate (MRR) increases with an increase of spark gap and current (I), also MRR increases with decrease in pulse on time (POT). As MRR increases if both spark gap and current (I) increases simultaneously, this has been proved in the present study. From the present study, it is found that machining parameters like duty cycle, spark gap and current (I) and some of their interactions have significant effect on MRR.

From the research work, we also find that, with an increase of duty factor (DF) and current (I), overcut (OC) increases. Also with a decrease of spark gap (SG) and pulse on time (POT), overcut increases.

In the present study, an attempt has been made to find the optimum machining conditions to produce the best possible MRR within the experimental constraints. We also done multi-objective optimization to simultaneously increase MRR and decrease OC, we find that at POT=1941.1113, DF=14, I=35, SG=0.4325 our both objectives are simultaneously satisfied, i.e high MRR and low OC.

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