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Performance measurement of EDM parameters on high carbon-chromium steel

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Abstract:- Electrical discharge machining (EDM) is an advance machining process primarily used for hard metals which are not possible to machine. In die Sinking EDM process, two metal parts are submerged in an insulating liquid and areconnected to a source of current which is switched on and off automatically. Parametric analysis has been done by conducting a set of experiments on high carbon-chromium steel with copper and graphite as electrodes and high carbon oil as the dielectric medium. This study focuses on the influence of process parameter such as pulse on time, duty cycle, current, voltage gap and pressure on EDM and effect of this process parameter on MRR, EWR and surface roughness has been studied.CCD was used for conducting the experiment and developing empirical models for MRR, surface roughness and EWR with the help of Minitab software.

Key terms:- CCD, ANOVA analysis and Material removal rate, Surface Roughness

I. INTRODUCTION

Electrical discharge machining is an advance machining process primarily used for hard and difficult metals which are difficult to machine with traditional techniques. Only electrical conducting materials are machined by this process. Material is removed from the work piece by a series of rapidly recurring current discharge between two electrodes, separated by a dielectric fluid and subject to an electric voltage [1]. The EDM process is best suited for making intricate cavities and contours which would be difficult to produce with normal machine. At the present time EDM is a widespread technique used in industry for high – precision machining of all type of conductive materials such as: metallic alloys, graphite, or even some ceramic materials of whatsoever hardness. Regression analysis is a stabilized relationship between variables. Usually, the investigator seeks to ascertain the causal effect of one variable upon another variable [2].

Petropoulos et al. [3] used statistical multi – parameter analysis to model surface finish in EDM process. Multiple statistical regression models were developed and closed correlation was observed between surface roughness and EDM input variables. Modelling of die-sinking EDM process for MRR, EWR and SR was carried out by puertas et al. [4] using a factorial design of experiments and multiple regression analysis. Significant variable were identified for each of the responses. Palanikumar [5] in his research using surface responses methodologymodelled the surface roughness in machining of Glass Fibber reinforced plastic composite materials. He employed four factors five levels central composite, rotatable design matrix for experimental investigation and used ANOVA for validation of the model. Kanagarajan et al. [6] applied response surface methodology along with multiple linear regression analysis to obtain second order response equations for MRR and Ra in EDM machining WC/30%Co composite. The most influential parameters aiming at maximizing MRR and minimizing surface roughness were identified by carefully examining surface and contour plots of the response versus different combination of inputs parameters. S Gopalakannan et al. [7]they are applied central composite design and analysis of variance to investigate the influence of process parameters and their interaction on material removal rate, electrode wear rate and surface roughness and identified the significant process parameters that affect the output characteristics.

In this work, the study is focused on the die-sinking EDM of high carbon high chromium steel with electrodes of copper. Consequently, an analysis of the influence of process parameters such as pulse on time, duty cycle, current, voltage gap and pressure over response variables such as material removal rate (MRR), surface roughness and electrode wear rate (EWR) was performed. This was done using the techniques of surface response methodology (CCD) for conducting series of experiment and analysis of variance (ANOVA) used for analysis the data. The combined use of these techniques has allowed us to create the second- order models which make it possible to explain the variability associated with each of the response variables studied.

II. EXPERIMENTAL DETAIL

In this section, there will be brief description of equipment used to carry out the EDM experiment. Also the design factors used in this work will be outlined.

2.1 EQUIPMENT USED IN THE EXPERIMENTS

The equipment used in order to carry out the EDM machine of high carbon high chromium steel was a die – sinking EDM machine fig. 1 shows the photograph of this equipment.

Fig. 1 Die sinking EDM machine

Surface roughness is measure of the texture of the surface in µm. Roughness is fine irregularities that are produced during a machining process. Surface roughness measurement was carried out using a surtronic 3+ fig. 2 show the figure surtronic 3+.

Fig. 2 Subtonic 3+

2.2 MATERIAL USED IN THE EXPERIMENTS

Work piece material used for experiments was high carbon high chromium steel. Table-1 shows the description of chemical composition of high carbon high chromium steel. Copper used as an electrode and high carbon oil used as a die electric fluid medium during the machining.fig.3 show the work piece material.

Fig. 3 work piece

Table – 1 chemical composition of high carbon high chromium steel (%)[8]

C	Mn	Si	Co	Cr	Mo	V	P	Ni	Cu	S
1.4-1.6	0.60	0.60	1.0	11.00-13.00	7.00-1.20	1.10	0.03	0.30	0.25	0.03

2.3 Process Parameters and Their Levels

Table – 2process parameters and their levels

Parameters (unit)	Notation	Levels /coded				
		-2	-1	0	1	2
Pulse on time (μs)	Ton	100	825	1550	2275	300
Duty cycle (%)	Dc	1	8.75	16.5	24.25	32
Current (amp.)	Ip	5	16.25	27.5	38.75	50
Voltage gap (volt)	Vg	10	37.5	65	92.5	120
Pressure (N)	F	0.1	0.2	0.3	0.4	0.5

There are various process parameters to be considered, but in this work we have considered five process parameters such as pulse on time, duty cycle, current, voltage gap and pressure. The material removal rate (MRR), surface roughness and electrode wear rate (EWR) selected as response variables.

Material removal rate is the volume of material removed from the work piece in one minute.

$$MRR = \frac{\text{volume of material removed from work piece}}{\text{time of machining}} \text{Mm}^3/\text{min} \ldots\ldots\ldots [9]$$

EWR is the ratio of the difference of weight of the total before and after machining to the machining time.

$$EWR = \frac{W_{ta} - W_{tb}}{t} \frac{mm^3}{min} \ldots\ldots\ldots [10]$$

Where,

w_{ta} = weight of the tool before machining

w_{tb} = weight of the tool after machining

t = machining time

1.4 METHODOLOGY

Design of experiment: experiments were designed by using Minitab software. Response surface methodology was used as a tool for development of a prediction model of MRR and surface roughness.

RESPONSE SURFACE METHODOLOGY:

RSM was developed to model experimental responses and then migrated into the modelling of numerical experiments [9]. The difference is in the type of error generated by the response. The application of RSM to design optimization is aimed at reducing the cost of expensive analysis methods and their associated numerical noise. Central composite design is generally used for fitting a second – order response surface model. CCD contains an imbedded factorial or fractional factorial design with central points that is augmented with a group of “star points” that a low estimation of curvature. Any central composite design can be built up from an initial 2^k or 2^{k-p} design by adding axial points and centre points to the two level designs (Ref 9).

Table – 3 Experimental data analysis

Run	Ton	Duty Cycle	Ip	Vgap	Fp	Ra copper	MRR Cu	EWR Cu
1	0	0	0	0	0	4.8	66.66667	0.666667
2	-1	-1	1	-1	-1	5.4	34.78261	0.347826
3	-1	1	-1	-1	-1	7.2	88.88889	0.444444
4	-1	-1	-1	-1	1	3.8	32	0.32
5	0	0	0	0	0	9.8	57.14286	0.857143
6	0	0	0	-2	0	5	22.22222	0.222222
7	1	1	-1	1	-1	4.2	40	0.6
8	1	-1	-1	1	1	7	30.76923	-1106.92
9	-1	-1	1	1	1	10.6	100	3603
10	1	1	1	-1	-1	14.2	133.3333	1.333333
11	2	0	0	0	0	7	100	1
12	0	0	0	2	0	5.2	33.33333	0.666667
13	0	0	2	0	0	7.6	160	4
14	0	0	0	0	0	6	100	1.5
15	0	0	0	0	-2	6.8	114.2857	3.428571
16	-1	1	1	-1	1	6.4	160	3.2
17	-1	1	1	1	-1	10.2	133.3333	2.666667
18	-1	1	-1	1	1	7.4	50	1.25
19	0	0	0	0	2	6.6	114.2857	3.428571
20	0	0	0	0	0	8.2	100	2.5
21	1	1	1	1	1	6.8	114.2857	2.857143
22	-2	0	0	0	0	6	133.3333	0.666667
23	1	-1	-1	-1	-1	2	29.62963	0.296296
24	1	-1	1	1	-1	5.8	53.33333	1.866667
25	0	-2	0	0	0	10.2	57.14286	2.857143
26	-1	-1	-1	1	-1	4.6	34.78261	0.347826
27	1	1	-1	-1	1	9.4	40	0.2
28	0	0	0	0	0	6	100	0.5
29	1	-1	1	-1	1	7.1	72.72727	0.363636
30	0	0	0	0	0	6.1	30.76923	0.307692
31	0	2	0	0	0	7.3	36.36364	0.181818
32	0	0	-2	0	0	8.4	61.53846	0.923077

III. RESULTS AND DISCUSSION

In this study, model as well as experimental results of the responses have been analyzed. Model analysis of the MRR, EWR and surface roughness was carried out in a line with the behaviour of the machining parameters on the responses. The analysis of variance is carried out on all the fitted models for a confidence level of 95%.

3.1 MATERIAL REMOVAL RATE (MRR)

Model fitted for material removal rate is represented by Eq. (1) and its variance analysis is given in Table 4

MRR = 78.1960 – 7.7656*Ton + 13.7608*dc +27.1937*amp – 0.5265*Vg + 2.1541*press + 7.793*Ton*Ton – 9.6853*dc*dc + 6.3187*amp*amp – 14.4296*Vg*Vg + 7.1978*press*press – 5.5936*Ton*dc + 0.6773*Ton*amp – 2.4841*Ton*Vg – 3.0454*Ton*press + 11.7751*dc*amp– 8.3968*dc*Vg – 7.1399*dc*press + 2.1922*amp*Vg + 8.2976*amp*press + 0.9696*Vg*press. (1)

Table – 4ANOVA for MRR

Source	DF	Seq SS	Adj SS	Adj MS	F	P
Regression	**20**	**44496**	**44496**	**2224.8**	**2.55**	**0.059**
Linear	**5**	**23858**	**23858**	**4771.6**	**5.48**	**0.009**
Square	**5**	**14527**	**14527**	**2905.5**	**3.34**	**0.045**
Interaction	**10**	**6111**	**6111**	**611.1**	**0.70**	**0.708**
Residual Error	**11**	**9580**	**9580**	**870.9**		
Lack of fit	**6**	**5363**	**5363**	**893.9**	**1.06**	**0.485**
Pure Error	**5**	**4216**	**4216**	**843.2**		
Total	**31**	**54076**				

R- sq= 88.89% , R- sq (adj) = 86.0%

Table -4 Represent ANOVA for material removal rate which is come from Minitab. In table 4 linear square and two factor interaction were compared to see the best fitted model as indicated by F value (Ref 9) The F values can beconverted into the p value by using the F probability distribution curve. The model significance can be tested either by comparing the F value to a threshold F value or by comparing the corresponding p value to the threshold p value. On the basis of P value linear model is best fitted model for material removal rate. Adjusted R^2 is a measure of the amount of variation about the mean which is explained by the model. A value of 0.86 indicates that 86% of the observed variation in the response can be explained by the model.

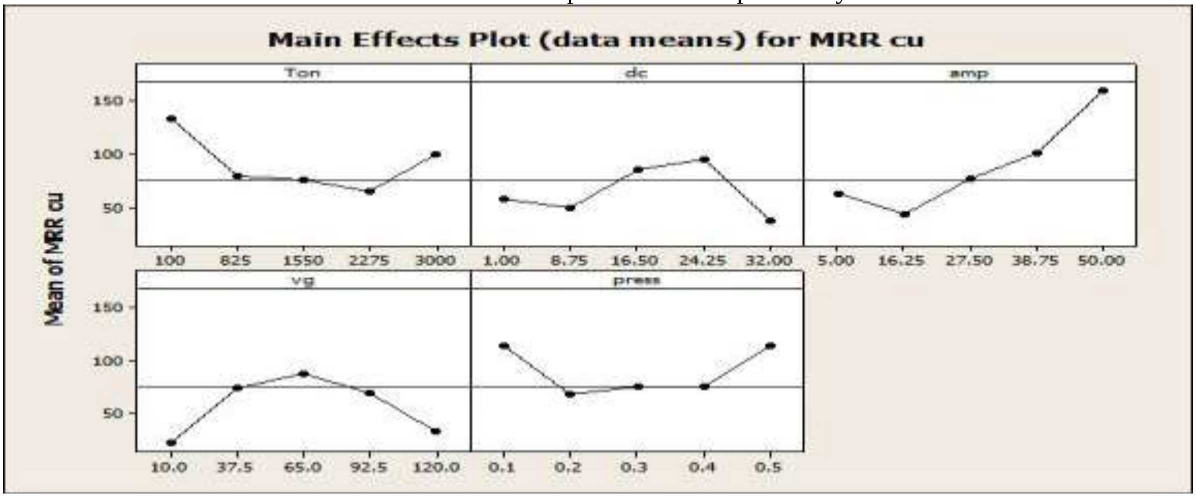

Fig.4: Effect of input process parameters on MRR

Figure 4 represent the main effects of input process parameters on material removal rate. Material removal rate decreases with increasing pulse on time up to 825µm than MRR almost constant to 1552µm further decrease the MRR to 2275µm then increase with pulse on time. In case of duty cycle the material removal rate firstly decrease up to 8.75 then MRR increase from 8.75 to 16.50 after then MRR slightly increase to 24.25 and finally MRR is reduced. Material removal rate decrease as increase the discharge current up to 16.25 then material removal rate increase with discharge current. Firstly MRR increase with voltage gap in case of voltage gap up to 37.5volt then slightly increase to 65 volt after that MRR decrease. In the case pressure material removal rate decrease up to 0.2 then slightly increase between 0.2 to0.3 after than almost constant to 0.4 then finally MRR increase with pressure.

3.2 ELECTRODE WEAR RATE (EWR)

The fitted model of electrode wear rate is given by Eq. (2) and its analysis of variance is given in Table 5

EWR = -1515.28 + 1.57*Ton + 106.03*dc – 37.06*amp – 4.44*Vg - 227.81*press +0.058*Ton*dc – 0.02*Ton*amp – 0.01*Ton*Vg – 4.06*Ton*press – 3.37*dc*amp – 0.73*dc*Vg - 200.92*dc*press +0.95*amp*Vg + 261.63*amp*press +56.66*Vg*press (2)

Table – 5 ANOVA for EWR

Source	DF	Seq SS	Adj SS	Adj MS	F	P
Regression	20	12589351	12589351	629468	4.89	0.005
Linear	5	2633721	1014671	202934	1.58	0.246
Square	5	88553	88553	17711	0.14	0.980
Interaction	10	9867067	9867076	986708	7.66	0.001
Residual Error	11	1416665	1416665	128788		
Lack of fit	6	1416662	1416662	236110	353194.84	0.0000
Pure Error	5	3	3	1		
Total	31	14006016				

R- sq= 89.89% , R- sq (adj) = 71.0%

I can say that from table -5 interaction linear model is best fitted model for electrode wear rate. Lack of fit in this case is so high means there are some input process parameters which is much effected of model.

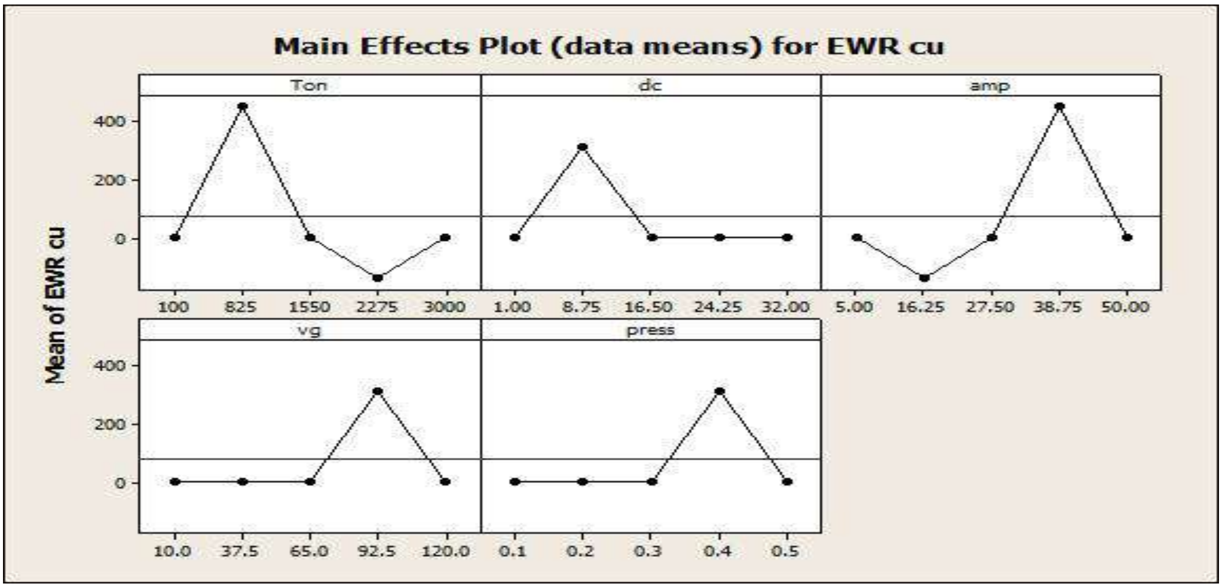

Fig.5: Effect of input process parameters on EWR

First graph represent the variation of electrode wear rate (EWR) with pulse on time. Firstly EWR increases with pulse on time up to 825µm then decrease to 2275µm after than increase as increase pulse on time. Second graph show the variation of electrode wear rate with duty cycle. In this case firstly increase the EWR with duty cycle up to 8.75 then decrease to 16.5 after then electrode wear rate is constant. In case of discharge current electrode wear rate decrease up to 16.25 amp then increase to 38.75 after then finally decrease with increase discharge current. The voltage gap and pressure are same effect on electrode wear rate as shown in above figure.

3.3 SURFACE ROUGHNESS

Model fitted for surface roughness is represented by Eq. (3) and its analysis of variance is given in Table 6

Ra = 1.295 - 0.0012*Ton+ 0.3693*dc- 0.0116*amp- 0.140*Vg+ 30.888*press- 0.0012*Ton*press+ 0.0202*dc*amp- 0.0041*dc*Vg- 2.4452*dc*press- 0.0032*amp*Vg- 0.7711*amp*press+ 0.49*Vg*press (3)

Table – 6 ANOVA for Surface Roughness

Source	DF	Seq SS	Adj SS	Adj MS	F	P
Regression	20	221.28	221.28	11.064	2.85	0.015
Linear	5	22.12	13.28	2.656	0.62	0.688
Square	5	20.85	20.85	4.169	0.97	0.475
Interaction	10	178.31	178.31	17.831	4.17	0.005
Residual Error	11	47.09	47.09	4.281		
Lack of fit	6	27.81	27.81	4.363	1.20	0.429
Pure Error	5	19.28	19.28	3.855		
Total	31	268.37				

R- sq= 86.89% , R- sq (adj) = 71.50

Linear interaction fitted model is best fitted model for surface roughness. The "Lack of Fit F-value" of 1.2 implies that the lack of fit is not significant relative to the pure error. It is good for model because lack of fit is not significant means there are not such type of input process parameters which is much effected of model.

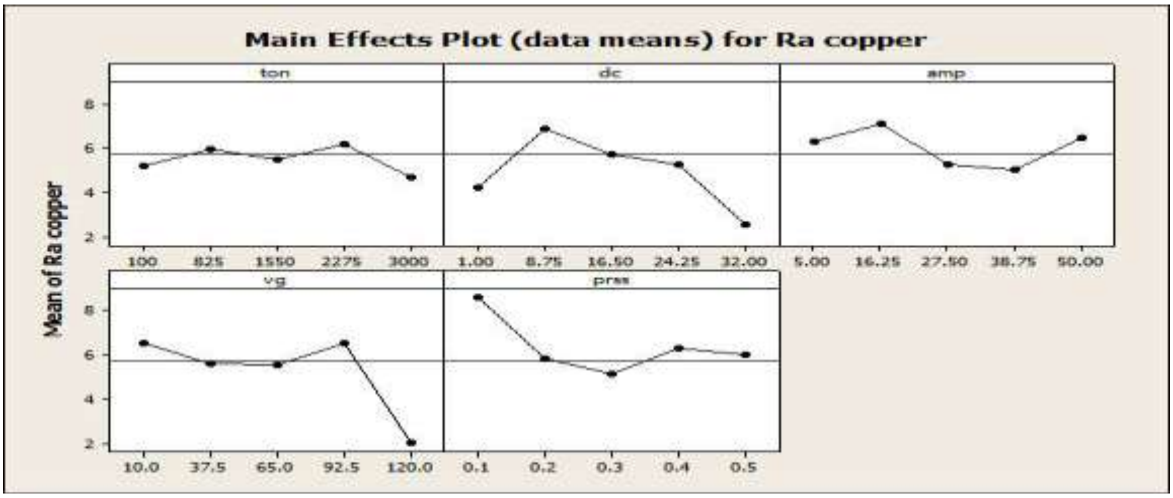

Fig.6: Effect of input process parameters on surface roughness

Fig. 6 Represent the effect of input process parameters on surface roughness.Surface roughness remains almost same with the change in pulse on time. In case of duty cycle surface roughness increase up to 8075µm then finally decrease. Surface roughness slightly increases with discharge current up to 16.25amp then decrease to 38.75amp after then increase the surface roughness. voltage gap does not much effective from 10-92.5 volt on surface roughness bur after that surface roughness decrease with voltage gap. Last graph represent variation of surface roughness with respect to pressure in the above mention figure.

IV. CONCLUSION

In the present work parametric analysis of die- sinking EDM process has been done based on experimental results. Experiments based on the central composite design were conducted to develop empirical models of the process.

Influence of input current and duty cycle is prominent over other machining parameters such as pressure, voltage gap on material removal rate with copper electrode. Pulse on time and duty cycle is most significant in the case of electrode wear rate with copper electrode. Duty cycle and pressure are mostsignificant factor in the case of surface roughness over others operating parameters like pulse on time, voltage gap and discharge current.

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