Study the Effect of Machining Parameters in Electric Discharge Machining of EN 31 Die Steel

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***Abstract*—Electric discharge machining (EDM) is a non-conventional machining process extensively used to manufacturer complex and intricate geometries of hard materials. This paper presents an experimental investigation of EN 31 die steel using the EDM process. The machining parameters such as peak current, pulse-on-time and pulse-off-time were chosen to study their effects on machining performance. The experiments were planned using L9 orthogonal array of Taguchi methodology. The output responses measured were material removal rate (MRR), tool wear rate (TWR) and surface roughness (SR). The observed results revealed EDM performance is greatly influenced by peak current followed by pulse-on-time.**

Keywords—Electric discharge machining; Taguchi method; ANOVA; MRR; TWR; SR

I. INTRODUCTION

In 1770, Joseph Priestly, first discovered the erosive effect of electric sparks on metals [1-2]. However, in 1943, two Soviet Scientists took advantage of the electric sparks for constructive use *i.e.* machining. EDM is one of the most popular machining processes used in manufacturing industries to produce complex and intricate shapes of parts in small batches or even on the job - shop basis, especially dies and molds. The mechanism of metal removal from workpiece surface primarily makes use of electrical energy and turns it into thermal energy through a series of electrical sparks generating between the electrode and workpiece immersed in a dielectric fluid [1-3]. The thermal energy generates a plasma channel between the cathode and anode at a temperature in the range of 8000 to 12,000 °C initializing a substantial amount of heating and melting of material at the surface of each electrode [3].

There are many process parameters which when varied in the EDM process have certain effect on machining performance namely material removal rate (MRR), tool wear rate (TWR) and surface roughness (SR) of the machined components. Jeswani (1978) measured the SR value of Tungsten Carbide (WC), High Speed Steel (HSS) tool, High Carbon Steel (HCS) and Mild Steel (MS) after EDM process. The experimental results revealed that SR increases with increase in pulse energy for particular work piece-tool combinations [4]. Mohri et al. (1993) attempted to improve the surface properties of Carbon Steel and Al work piece with Cu, Al, WC and Ti electrodes submerged in hydrocarbon dielectric oil [5]. Singh et al. (2004) reported the effects of pulsed current on MRR, SR, overcut and tool wear when hardened and tempered EN-31 tool steel was machined by using Cu, Cu-W, Al and brass as electrode materials [6]. Lin et al. (2006) investigated the effect of different process variables during machining of SKH 57 high-speed steel on various output parameters namely MRR, EWR and SR. A well known L_{18} OA was used to design the experimentation matrix. The significant control factors were identified from the ANOVA results that affected the machining performance [7]. Dvivedi et al. (2008, 2010) experimentally observed that MRR increases with increase in current and on-time up to a certain optimal range and after that it start to decrease during EDM of cast Al 6063 SiCp composite [8-9]. Patel et al. (2010) developed the ceramic (Al_2O_3–SiC_w–TiC) and machining was performed by varied the values of discharge current, pulse-on time, duty cycle and gap voltage to investigate its machinability *i.e.* MRR and SR [10]. Rahman et al. (2011) presented the experimental results to evaluate the effectiveness of process in terms of MRR, TWR and SR during EDM of austenitic stainless steel (grade 304) with positive polarity Cu electrode [11]. Zhang et al. (2013) proposed a new type of sinking EDM in which water-in-oil emulsion dielectric was used, and the performance measures were investigated by comparing results with kerosene dielectric [12]. Mohanty et al. (2014) experimentally investigated the machining characteristics of Inconel 825 material, used in the highly corrosive environment [13]. Sindhia et al. (2015) studied the effect of three different electrode materials such as copper, brass and aluminum in EDM of EN 24 alloy steel material on machining characteristics namely MRR, TWR and surface roughness. Better results were observed with copper electrode than brass and aluminum [14]. The present study has been carried out to study the effect of some input parameters such as peak current, pulse-on-time and pulse-off-time on output responses in EDM of EN 31 die steel.

II. METHODOLOGY

A. Workpiece and electrode material

Selection of workpiece and electrode material is the important step because both have significant effect on responses. EN 31 die steel was used as workpiece material in the present experimental study. The electrode material used was copper (Cu) of 15 mm diameter. The chemical compositions of workpiece and electrode material are given in Table I.

B. Experimental Setup

The experiments were performed on the die sinking EDM machine; model OSCARMAX S 645 CMAX, available at Central Institute of Hand Tools, Jalandhar, Punjab. The pictorial view of EDM machine is shown in Figure 1.

TABLE I: CHEMICAL COMPOSITION OF EN 31 and Cu

Workpiece Material (EN 31)		**Electrode Material (Copper)**	
Element	Percentage	Element	Percentage
C	0.285	Zn	0.165
Si	1.05	Cr	<0.001
Mn	0.47	Pb	0.0385
P	0.035	Sn	0.0405
Cr	0.57	Fe	0.0825
V	0.95	Ni	<0.0050
Fe	Balance	Cu	99.4

Fig. 1: Pictorial view of EDM machine

C. Experimental design

Taguchi's experimental design of experiment was used for designing the experiments. Three factors (i) peak current, (ii) pulse-on-time and (iii) pulse of time were used during the experiments. Each factor was varied at three levels. Therefore, standard L9 orthogonal array was used for designing the experiments. The control factors with units and their respective levels are listed in Table II. The L9 orthogonal array with actual values of each control factors is shown in Table III.

TABLE II: FACTORS OF INTEREST AND THEIR LEVELS

Control Factors	**Levels**		
	Level-1	**Level-2**	**Level-3**
Peak Current (Amp), A	10	15	20
Pulse-on-time (µs), B	30	60	90
Pulse-off-time (µs), C	15	30	45

D. Measuring and test equipment

To calculate the MRR and TWR, weight of workpiece and electrode were measured using a digital weighing machine with least count 0.001 gram as shown in Figure 2. The weight of each workpiece sample and electrode were taken before and after the machining of experiment. The MRR and TWR of each experiment were calculated using the difference in weight of workpiece and electrode. The MRR and TWR were calculated using equation (1) and (2) respectively. The surface roughness of all the samples were measured with MITUTOYO Surface Roughness Tester (Model: Surf test SJ-400) at a cut of length of 0.8 mm.

$$MRR(mm^3/\min) = \frac{(wi - wf)\times 1000}{\rho \times t} \qquad (1)$$

$$TWR(mm^3/\min) = \frac{(wi - wf)\times 1000}{\rho \times t} \qquad (2)$$

Where wi = initial weight of workpiece/ tool (gm)
wf = final weight of workpiece/tool (gm)
ρ = density of workpiece/tool material (gm/cm^3)

TABLE III: L9 EXPERIMENTAL DESIGN

Experiment Number	Control Factors with their Actual Values		
	Peak Current	Pulse-on-time	Pulse-off-time
1.	10	30	15
2.	10	60	30
3.	10	90	45
4.	15	30	30
5.	15	60	45
6.	15	90	15
7.	20	30	45
8.	20	60	15
9.	20	90	30

Fig. 2: Pictorial view of weighing machine

III. RESULTS AND DISCUSSION

A. Material Removal Rate (MRR)

The MRR is defined as the removal of material per unit machining time. The mean values of MRR for 09 experiments are listed in Table IV. The analysis of variance (ANOVA) for S/N ratios is given in Table V. ANOVA table shows the percent contribution (PC) of each control factors. From ANOVA Table V, peak current was observed to be most significant factors with a contribution of 86.42% followed by pulse-on-time 6.32% and pulse-off-time 5.86%.

TABLE IV: AVERAGE RESULTS FOR MRR, TWR AND SR

Experiment Number	MRR (mm3/min)	TWR (mm3/min)	SR (Ra)
1.	3.542	0.1475	5.50
2.	5.725	0.1205	4.20
3.	7.245	0.1385	5.15
4.	10.265	0.1615	7.85
5.	12.565	0.2305	5.55
6.	11.345	0.3460	7.25
7.	15.545	0.2410	7.45
8.	14.782	0.3440	8.00
9.	16.508	0.4610	7.50

TABLE V: ANOVA TABLE FOR MRR, TWR AND SR

Factors	DOF	MRR		TWR		SR	
		Seq SS	PC (%)	Seq SS	PC (%)	Seq SS	PC (%)
A	2	140.5	86.42	95.90	70.85	23.69	74.30
B	2	10.27	6.32	23.28	17.20	4.038	12.67
C	2	9.53	5.86	9.675	7.15	2.101	6.30
Error	2	2.27		6.50		2.056	
Total	8	162.6		135.4		31.88	

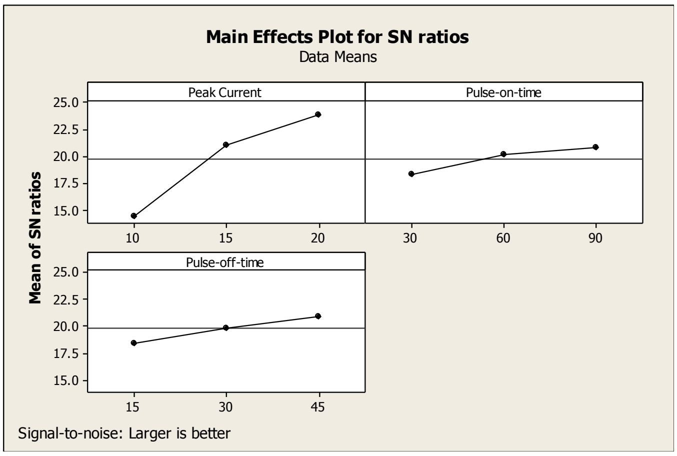

Fig. 3: Main effects plot for MRR

From Figure 3, it was observed that MRR was increased as peak current increases from 10 Amp to 15Amp sharply. Thereafter, MRR declines in the range of 15Amp to 20 Amp current. The higher MRR was observed at higher peak current 20Amp as shown in Figure 3. It was happened because discharge energy in EDM increased as the value of current increases. Pulse-on-time also affected the material removal rate as indicated in Figure 3. Longer pulse duration resulted in higher MRR, because discharge energy was supplied for longer duration, which increases the rate of melting and vaporization of material and material was eroded in the larger size of craters. Thus, MRR was increased. Pulse-off-time had smaller effect on MRR as shown in Figure 3 and ANOVA Table V. During the experiments, arcing was also observed when machining was carried out with higher value of current and pulse-on-time and shorter pulse-off-time. Hence, MRR was decreased due to unstable machining. From Figure 3, it was concluded that maximum MRR was obtained at higher value of current (20 Amp), higher value of pulse-on-time (90µs) and higher value of pulse-off-time (45 µs).

B. Tool Wear Rate (TWR)

TWR is the reduction in weight of tool material per unit machining time. Volumetric TWR was calculated using equation (2). The observed mean values of TWR are listed in Table IV. The TWR was observed in the range of 0.1205 mm^3/min to 0.4610 mm^3/min. The higher TWR was observed at higher current 20Amp for trial 9 as indicated in Table IV. ANOVA table shows the percent contribution (PC) of each control factors affected the TWR. From ANOVA Table V, peak current was observed to be most significant factors with a contribution of 70.85% followed by pulse-on-time 17.20% and pulse-off-time 7.15%. For better machining performance, less TWR is the important quality of tool material. Thus, selection of tool material is the important factor in EDM process.

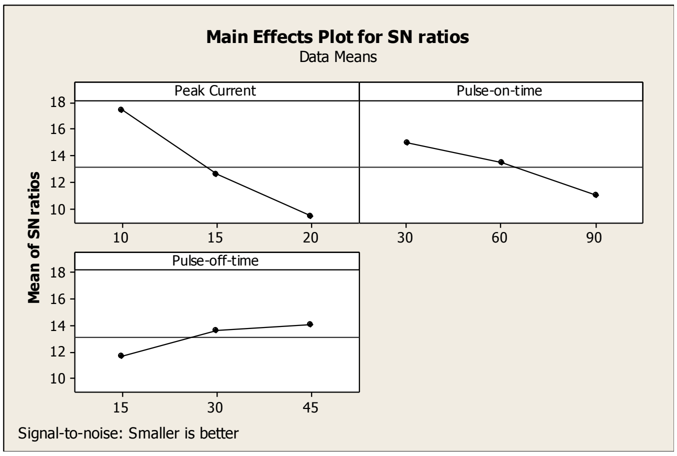

Fig. 4: Main effects plot for TWR

From Figure 4, it was concluded that lower TWR was obtained at lower value of current (10 Amp), smaller value of pulse-on-time (30µs) and higher value of pulse-off-time (45 µs). At lower value of current and pulse-on-time, available discharge energy was less for shorter duration of time, thus, reduces the TWR.

C. Surface Roughness (SR)

The surface roughness of the workpiece can be expressed in different ways such as; arithmetic average (*R*a), average peak to valley height (*RZ*), etc. Generally, the surface roughness is measured in terms of arithmetic mean (*R*a) which is defined as the arithmetic average roughness of the deviations of the roughness profile from the central line along the measurement. It is shown in equation (3):

$$R_a = \frac{1}{l}\int_{l}^{0}\left|h(x)dx\right| \quad (3)$$

Where *h(x)* is the value of roughness profile and *'l'* is the evaluation length.

The observed mean values of SR are listed in Table IV. The SR was observed in the range of 4.20 Ra to 8.0Ra. The higher SR was observed at higher current 20Amp for trial 8 as indicated in Table IV. ANOVA table shows the contribution of each control factors affected the SR. From ANOVA Table V, peak current was observed to be most significant factors with a contribution of 74.30% followed by pulse-on-time 12.67% and pulse-off-time 6.30%.

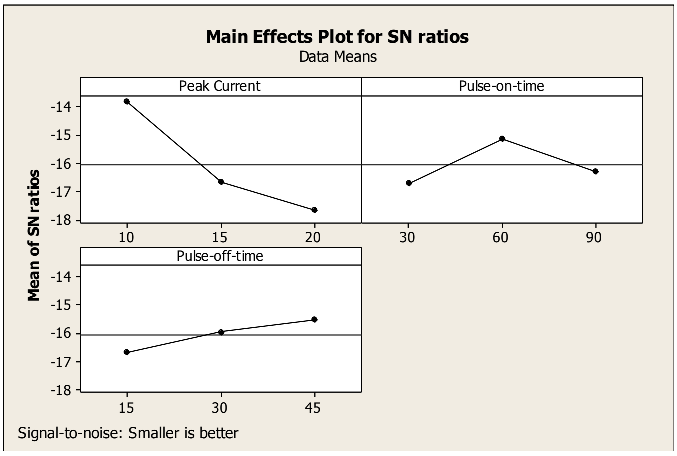

Fig. 5: Main effects plot for SR

From Figure 5, it was concluded that lower SR was obtained at lower value of current (10 Amp), average value of pulse-on-time (60µs) and higher value of pulse-off-time (45 µs). At lower value of current and pulse-on-time, available discharge energy was less for shorter duration of time, resulting in removal of materials in the form of shallow craters, thus, improves the surface finish.

IV. CONCLUSIONS

On the basis of present experimental study, the following conclusions can be drawn:

I. Taguchi methodology was used for designing the experiments.

II. Peak current was observed the most significant input parameters that highly affected the response parameters such as MRR, TWR and SR.

III. Higher MRR was observed at higher current and pulse-on-time.

IV. Low TWR and better surface finish can be obtained at low current value.

V. Pulse-off-time had smaller effect on response parameters as compared to pulse-on-time.

VI. Arcing wad observed when machining was done at higher current, longer pulse-on-time and shorter pulse-off-time.

VII. Optimum combination of input parameters which gives the maximum MRR, less TWR and better surface finish are listed in Table VI.

TABLE VI: OPTIMUM COMBINATION OF INPUT PARAMETERS

Response	Input Parameters		
Parameters	Peak Current	Pulse-on-time	Pulse-off-time
MRR	Level-3 (20Amp)	Level-3 (90µs)	Level-3 (45µs)
TWR	Level-1 (10Amp)	Level-1 (30µs)	Level-3 (45µs)
SR	Level-1 (10Amp)	Level-2 (60µs)	Level-3 (45µs)

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