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Experimental Investigations of EDM Process Parameters for Tool Wear Rate Based on Orthogonal Array

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ABSTRACT

The global utilization of electric discharge machining is proving as a smart machining process among the tool makers for the production of molds and dies. In the Industrial tool room survey it is observed that the critical aspect of the EDM technology is the availability of machining data in terms of tuned process parameter as on needed basis. As the electrode undergoes wear continuously in spark phenomenon, therefore detailed knowledge with regards to optimization on tool wear is essential in order to improve accuracy in designing the electrodes and surface quality. In this paper experimental investigation is carried out to improve performance measures in terms of tool wear rate by optimizing the process variables, particularly in ram electric discharge machining. Design of experimentation and ANOVA for optimization of process parameters is investigated in order to improve the responses of the machining in terms of lowering tool wear rate within work interval of semi finish machining.

Keywords: Electric Discharge Machining (EDM), Tool Wear Rate (TWR), Orthogonal Array.

I. INTRODUCTION

The electrical discharge machining is a non-traditional manufacturing process based on removing material from a part by means of a series of repeated electrical discharges (created by electric pulse generators at short intervals) between a tool, called electrode, and the part being machined in the presence of a dielectric fluid [1]. At the present time, EDM is a widespread technique used in industry for high-precision machining of all types of conductive materials such as metals and metallic alloys of whatsoever hardness. This process is well suited for machining of forging dies, injection molds and automobile parts.

Among the non-traditional methods of material removal processes, electrical discharge machining has drawn a great a deal of researchers attention because of its broad industrial applications. Puertas and Luis carried out the influence of the factors of intensity, pulse time and duty cycle to select the optimal machining conditions. Therefore, in order to obtain a good surface finish the use of high values of intensity and low values of pulse time were considered within work interval. [1] Initial parametric studies of MRR and Ra have been made by Dastagiri and Hemantha Kumar considering one variable at a time approach. One variable at a time was varied and its effect on metal removal rate and surface roughness observed by keeping all other entities at fixed average values. Although this analysis does not give a clear idea of the phenomena over the entire range of the input parameters, it can highlight some of the important characteristics of EDM process. [2] Rajmohan and prabhu reported that even though EDM is a common process but no standard data on optimizing the machining parameter is readily available for reference to get maximum metal removal rate considering 304 stainless steel. Based on minimum number of trails conducted they arrived at optimum cutting parameters with conclusion that Ip and Toff are most significant machining parameter for metal removal rate. [3]

EDM has a high capability of machining the accurate cavities in dies and molds. Nevertheless, improper electrode wear occurs during EDM process owing to the lack of availability of machinability data in terms of tuned process parameters. Furthermore, electrode wear imposes high costs on manufacturers to substitute the eroded complicated electrodes by new ones for die making. In order to increase the machining efficiency, erosion of the workpiece must be maximized and that of the electrode to be minimized in EDM process [1]. Therefore, optimize the tool wear rate in correlation with depth of cut (Z-axis) machining characteristics would be effective to enhance the machining productivity and process reliability.

II. METHODS AND MATERIAL

A. Experimental Planning

The equipment used to perform the experiments is a die-sinking EDM machine of type Electronica E-20, which has pulse generator, as shown in figure 1. In this case, due to its simplicity shallow machining is carried out in these experiments. The pressure used for the dielectric fluid is 0.2 kg/cm^2, under jet flushing.

Figure 1: Experimental die sink EDM

The workpiece material used in experimentation is EN 31 alloy steel which achieves a high degree of hardness with compressive strength and shock resistance properties. Furthermore, the copper tool is selected in a prismatic form with a transverse area of 12.5mm × 12.5mm and 50 mm in height. The copper rods with 99% purity and 8.98 g/cc density were machined with good surface finish and exact dimensions as tool electrodes. Both electrodes and workpieces were ground carefully to provide stable machining conditions in EDM process.

B. Design of Experiments

The nature of variation of response with respect to a particular factor helps in deciding the level of the factor. There are a large number of factors to be consider within the EDM process, but in this work the level of the generator current pulse intensity (*Ip*), pulse time (*Tp*), gap voltage (*Vg*) have only been taken into account as design factors for L16 orthogonal array as mentioned in table 1.

Table 1: Machining parameters with levels

Symbols	**Machining Parameters**	**Level 1**	**Level 2**	**Level 3**	**Level 4**
A (Ip)	Pulse Current (amps)	3	5	7	10
B (Tp)	Pulse Time (μsec)	110	170	290	380
C (Vg)	Gap Voltage (volt)	130	135	140	145

C. Response Variable - Tool Wear Rate

Tool wear rate (TWR) is expressed as volumetric material removal (mm³/min) for tool. It is the difference of weight of the copper electrode before and after machining to the product of workpiece density and machining time.

$$\text{TWR} = \frac{(\text{Wtb} - \text{Wta})}{(\rho\text{t x T})} \qquad ..1.1$$

where Wtb and Wta are weights of the Cu-tool before and after machining measured with accurate digital weighing machine and T is the machining time as 20 minutes experimental run.

For the semifinish tool wear analysis, lower the better phenomenon is followed in design of experiments. The S/N ratio statistics can be obtained by evaluating the largest variance in the process as,

$$\text{TWR S/N Ratio} = -10\log_{10}\left(\frac{1}{\text{n}}\sum_{i=1}^{n}\text{y}_\text{i}^2\right) \qquad ..1.2$$

where y_i is the i^{th} observation of a treatment combination and n is the number of replications.

III. RESULTS AND DISCUSSION

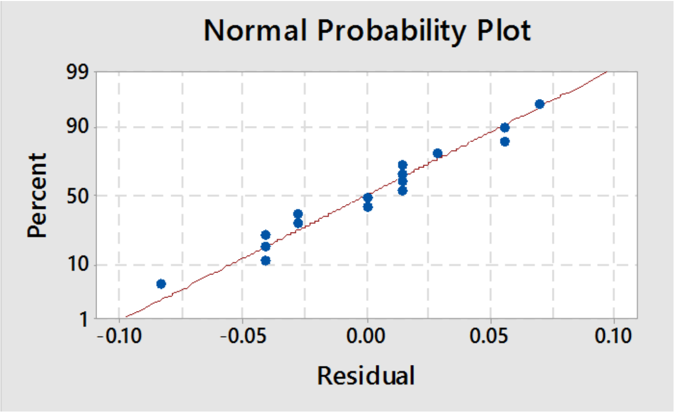
Table 2 shows the experimental results for pulse current intensity (Ip), pulse time (Tp) and gap voltage (Vg),where the behaviour of each parameter significantly affect the tool wear rate in semifinish machining of EN 31 alloy steel. Therefore the array like L16 with 4 numbers of levels of parameters is implemented to find out better tune up parameter with the help of Minitab16 version.

Table 2 : Orthogonal array L16 based experimental results for TWR

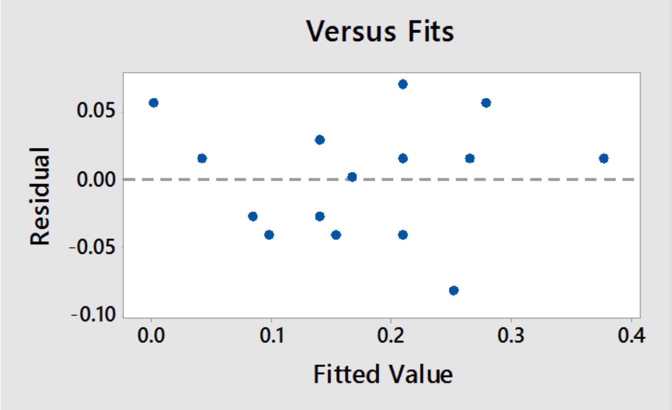
Expt No.	Pulse Current Ip (amps)	Pulse Time Ton (μsec)	Gap Voltage Vg (volt)	Tool wear rate TWR (mm³/min)	Depth of Cut (mm)
1	3	110	130	0.056	0.725
2	3	170	135	0.056	1.035
3	3	290	140	0.056	1.015
4	3	380	145	0.056	0.805
5	5	110	135	0.167	1.110
6	5	170	130	0.167	1.325
7	5	290	145	0.167	2.275
8	5	380	140	0.223	2.015
9	7	110	140	0.167	2.005
10	7	170	145	0.278	3.300
11	7	290	130	0.111	2.600
12	7	380	135	0.111	2.525
13	10	110	145	0.167	3.540
14	10	170	140	0.390	4.375
15	10	290	135	0.334	4.005
16	10	380	130	0.278	2.875

A. Experimental Run Validation through Residual Plot Analysis

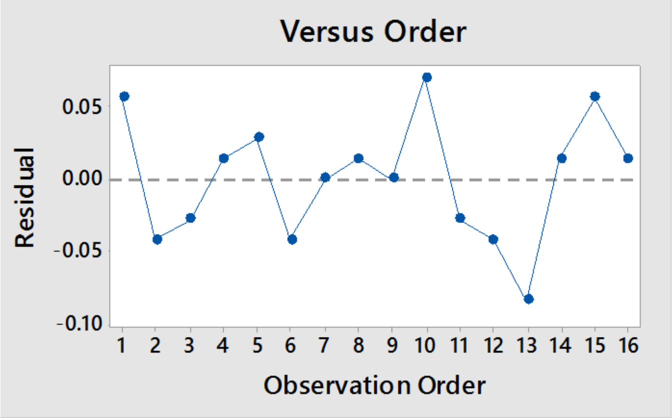
Experimental data confirmation is carried through the residual plot analysis for tool wear rate. In the plots of residual there are three assumptions for experimental run adequacy checking i.e. normality, constant variance and independence. All these three assumptions are validated by the residual plots with the intention of particular response factor, which in this case is tool wear rate. Figure 2 (a, b, c) visibly implies that TWR residual have constant variance and are independent of one another. Therefore it is concluded that the experimental data obtained through orthogonal array L16 is appropriate for TWR.



a) Normality residual plot



b) Constant varience residual plot



c) Independence residual plot

Figure 2 : Residual plot analysis for tool wear rate

B. The Analysis of Tool Wear Rate

Figure 3 shows the main effects plot for tool wear rate and S/N ratio. The main effect plot for S/N ratio is followed according to lower the better analysis because in the machining lower tool wear rate is treated utility. For the performance characteristic of the tool wear rate, the levels A1B1C1 including discharge current of 3amp, pulse duration of 110μsec and open voltage of 130V leads to optimal tuned process parameters as shown in figure 4.

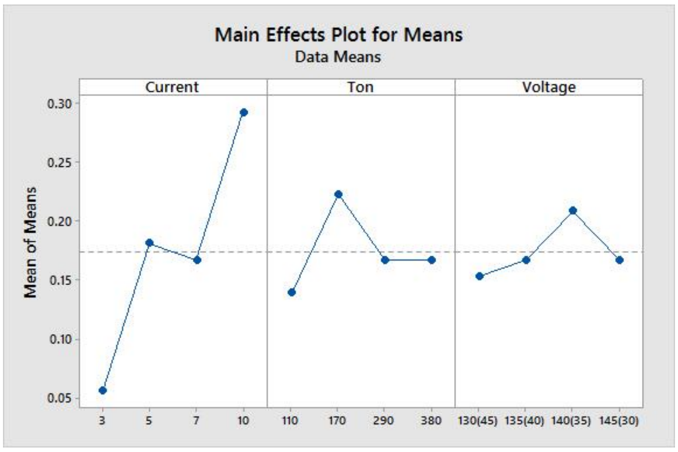


Figure 3: Main effects plot of means for TWR

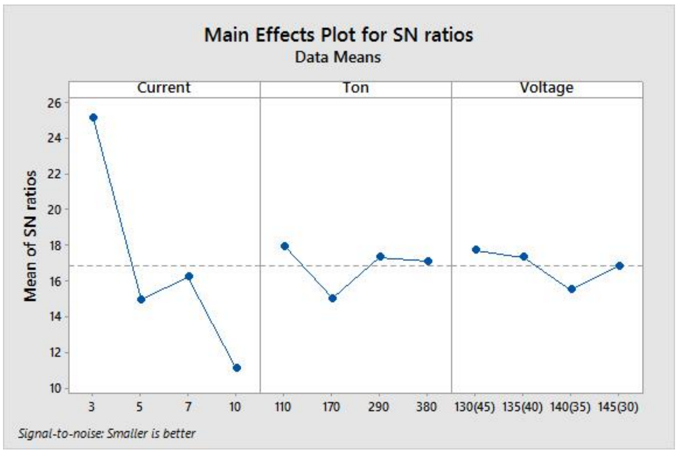


Figure 4: Main effects plot of S/N ratios for TWR

The table 3 shows the signal to noise ratios responses for levels of parameters related to tool wear rate. The pulse current is the highest ranked parameter with maximum difference among the levels for tool wear rate followed by pulse time and gap voltage. As can be seen in this table the pulse current significantly dominates other factors in terms of the response variable tool wear rate.

Table 3: Signal to noise ratios response table for TWR

Parameter Level	Pulse Current Ip (amps)	Pulse Time Ton (μsec)	Gap Voltage Vg (volt)
1	25.09	17.93	17.70
2	14.92	14.98	17.30
3	16.20	17.30	15.46
4	11.09	17.08	16.82
Delta	14.00	2.95	2.24
Rank	1	2	3

C. Analysis of Variance for Tool Wear Rate

Table 4 illustrates the corresponding ANOVA results, where the contribution ratio of each machining parameter is estimated. It can be seen that the discharge current plays vital role for the tool wear rate with about 64.6% of the contribution ratio followed by gap voltage as 20.3% and pulse on time 15.1% respectively.

Table 4: ANOVA for tool wear rate

Source	DoF	Adj SS	Adj MS	P Value	Contribution %
Linear Model	9	0.134	0.015	0.075	
Current	3	0.112	0.037	0.014	64.6 %
Ton	3	0.015	0.005	0.413	15.1 %
Voltage	3	0.007	0.002	0.678	20.3 %
Error	6	0.026	0.004		
Total	15	0.160			

IV. CONCLUSION

Implementation of semifinish EDM machining work interval to improve the performance characteristics of tool wear rate has been reported in the present work. Orthogonal array L16 experimentation and ANOVA for determining the optimal tuned process parameters has been carried out. According to main effect plot it is found that discharge current, pulse duration and gap voltage have found a clear effect on the ram EDM performance for tool wear rate characteristics.

1) On the basis of experimental results the discharge current has been found to play a significant role with about 64.6 % in semifinish tool wear rate responses.
2) The A1B1C1 parameters including the discharge current 3amp, pulse duration of 110μsec and open voltage of 130V respectively, are the optimum favorable performance characteristic for the tool wear rate
3) Based on the experimentation conducted lower levels than discharge current 5amp, pulse duration 290μsec may considered as transition phase levels from semifinish to finish stages for efficient EDM machining.

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