Optimization of CNC Die-Sinking EDM Process Parameters Based on MRR and EWR by Taguchi Method Using Copper Electrode on P20 Tool Steel

Mehul Prajapati and Sowmin Trivedi

Abstract Optimization using Taguchi methodology is one of the techniques for industries by which manufacturing for quality products at lower cost is achieved. The process parameters, such as current, pulse-ON and pulse-OFF time in electrical discharge machining (EDM) process, give variations in the performance characteristics, such as material removal rate (MRR) on workpiece and electrode wear rate (EWR) on tool while machining P20 tool steel using copper electrode. By conducting Taguchi design of experiments using L9 orthogonal array, the analysis had been carried out. Using Minitab, its response tables and graphs were observed to find out the optimal levels of parameters in the EDM process. Thus, the process parameters for EDM were optimized during machining of P20 steel for achieving the combined objectives of higher rate of material removal and lower wear rate on tool. The obtained results helped to identify the major and minor parameters affecting MRR and EWR.

Keywords EDM process · MRR · EWR · Taguchi method

1 Introduction

Electrical discharge machining is a type of an unconventional machining technique where the electrical energy is directly used to remove or cut the metals. It is also called as spark erosion machining or electro-erosion machining [4]. The metal is removed by electrical spark discharge between electrode tool (cathode) and workpiece (anode). Electrical discharge machining is used in mould and die-making industries, automobile industries and also making of aerospace components. In die and mould making, a die-sinking EDM is especially used for machining intricate and unique patterns and shapes which otherwise are difficult to machine or time-consuming using conventional CNC milling machines. The paper describes an investigation of EDM process

M. Prajapati (✉) · S. Trivedi
Department of Production Engineering, Dwarkadas J. Sanghvi College of Engineering, Vile Parle, Mumbai, India
e-mail: mehul.prajapati@djsce.ac.in

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parameters and its optimization using Taguchi method and determining the major and minor parameters affecting MRR and EWR as well as finding optimized values based on the values considered for this experiment [1].

2 Literature Survey

Optimization of EDM process parameters using Taguchi method with copper electrode by Niraj Kumar Ohdar, Babuli Kumar Jena, Saumya Kanta Sethi discusses optimizing process parameters that are current, pulse-ON time, pulse-OFF time and flushing pressure using Taguchi method with copper electrode based on MRR and EWR with corresponding S/N ratio and then finding out mean of their S/N ratios with 'larger the better' for MRR and 'smaller the better' for EWR and then finding their residual plots and respectively the major and minor parameters were identified for both MRR and EWR.

The implementation of Taguchi method on EDM process of tungsten carbide by Mohd Amri Lajis, H. C. D. Mohd Radzi and A. K. M. Nurul Amin discusses using Taguchi method with graphite as an electrode and tungsten carbide as workpiece and accordingly finding optimized values for the parameters, i.e. current, pulse-ON time, pulse-OFF time and voltage, and similarly, the major and minor parameters based on its effects on MRR, EWR and surface roughness are determined with its optimized values from the graph plotted.

Optimization of EDM process parameters using Taguchi method with graphite electrode by Vishal J. Nadpara and Prof. Ashok Choudhary discusses optimizing process parameters that are current, pulse-ON time and pulse-OFF time by Taguchi method with graphite as electrode and AISI D3 Steel as workpiece. The MRR and EWR are respectively found based on machining time and weight loss, and the S/N ratio is founded for each values. The mean of S/N ratio graph is plotted based on 'smaller the better' for EWR and 'larger the better' for MRR for finding again the major and minor parameters affecting them and similarly finding the optimized values.

3 Experimental Set-Up

The experiments were conducted using a CNC die-sinking EDM machine manufactured by HCM Taiwan as shown in Fig. 1. The copper electrode is fed downwards into the workpiece under servo control in this EDM machine. The workpiece material used for this experiment was P20 tool steel. In this experiment, Taguchi design of experiments with L9 orthogonal array, the analysis had been carried out [2]. Using this, the proposed process parameters were arranged accordingly and corresponding MRR and EWR along with their signal-to-noise ratio based on 'higher the better'

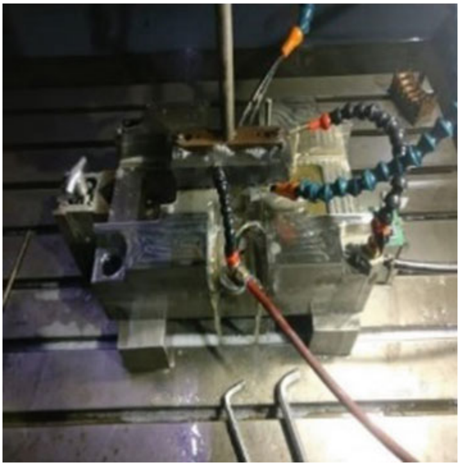

Fig. 1 CNC die-sinking EDM machine setup

and 'smaller the better', respectively. With the help of Minitab software, the mean of S/N ratio graph is plotted, and accordingly, the values and the ranking of each parameter based on importance are found.

4 Material Properties

The workpiece is P20 tool steel for this experiment with the following physical properties (Table 2) and Chemical Composition (Table 1) [5].

5 Experiment Data

The parameters considered for this experiment are current, pulse-ON time and pulse-OFF time [3]. The duration of time (in μs) when the current is passed gives pulse-ON time (td) to flow per cycle. The duration of time (in μs) in between two consecutive sparks and current (I) is current flowing through the whole cycle (in AMP) is pulse-OFF time (to).

5.1 Experiment Procedure

During the experiment, 3 levels (Table 3) were taken for each parameter and then arranged in a L9 orthogonal array (Table 4) in Taguchi method. During the readings, all the weight loss and machining time are taken for calculating MRR and EWR for

Table 1 Chemical composition of ‘P20’

Components	Percentages (%)
C	0.378
Mn	1.412
Si	0.300
P	0.014
S	0.0001
Cr	1.8600
Ni	0.230
Mo	0.188
Al	0.020
Cu	0.220
Nb	0.0030
V	0.005
Ti	0.003
N (ppm)	83

Table 2 Physical properties of ‘P20’

Properties of ‘P20’	Metric
Hardness, Brinell (typical)	300
Hardness, Rockwell C (typical)	30
Tensile strength, ultimate	965–1030 MPa
Tensile strength, yield	827–862 MPa
Compressive strength	862 MPa
Elastic modulus	190–210 GPa
Thermal expansion	12.8×10^{-6}/°C at 20–425 °C

Table 3 Levels for process parameters

Parameters	Levels		
	1	2	3
Current (*I*)	4	5	6
Pulse-ON time (T-ON)	80	100	120
Pulse-ON time (T-OFF)	40	50	60

each of the 9 readings. These values are input in Minitab 19 software and then under DOE and analysis of Taguchi method, S/N ratio and mean table were calculated, and based on the values, graph was plotted accordingly for MRR and EWR, respectively, where the optimized values were then determined from the graph [2].

For calculating MRR, the formula:

Table 4 L9 orthogonal array for Taguchi method

Experiment levels	Current (I)	Pulse-ON time (T-ON)	Pulse-OFF time (T-OFF)	MRR	EWR
1	4	80	40	2.11	2.05
2	4	100	50	2.72	2.64
3	4	120	60	3.24	3.13
4	5	80	50	4.50	4.85
5	5	100	60	5.18	5.58
6	5	120	40	2.92	9.13
7	6	80	60	3.22	11.16
8	6	100	40	9.60	8.58
9	6	120	50	6.66	10.30

$$\frac{W_b - W_a}{d * t} \text{ mm}^3/\text{min}$$

where

W_b—Workpiece weight before machining (g)
W_a—Workpiece weight after machining (g)
d—Density of P20 tool steel (g/cc)
t—Machining Time (in mins)
The density of P20 tool steel is 7.85 g/cc.

For calculating EWR, the formula:

$$\frac{E_b - E_a}{d * t} \text{ mm}^3/\text{min}$$

where

E_b—Electrode weight before machining (g)
E_a—Electrode weight after machining (g)
d—Density of electrode (g/cc)
t—Machining Time (in mins)
The density of copper electrode is 8.96 g/cc.

5.2 Results and Analysis

After putting the MRR values in Minitab software, for ‘larger the better’ option to get S/N ratio values, Table 5 represents the S/N ratio for MRR. Accordingly, the response table (Table 6) and graph (Figs. 2 and 3) for mean of S/N ratio along with

Table 5 S/N ratio

MRR	S/N ratio
2.11	6.4856
2.72	8.6914
3.24	10.2109
4.50	13.0643
5.18	14.2866
2.92	9.3077
3.22	10.1571
9.60	19.6454
6.66	16.4695

Table 6 Response table for signal-to-noise ratios

Level	*I*	T-ON	T-OFF
1	8.463	9.902	11.813
2	12.220	14.208	12.742
3	15.424	11.996	11.552
Delta	6.961	4.305	1.190
Rank	1	2	3

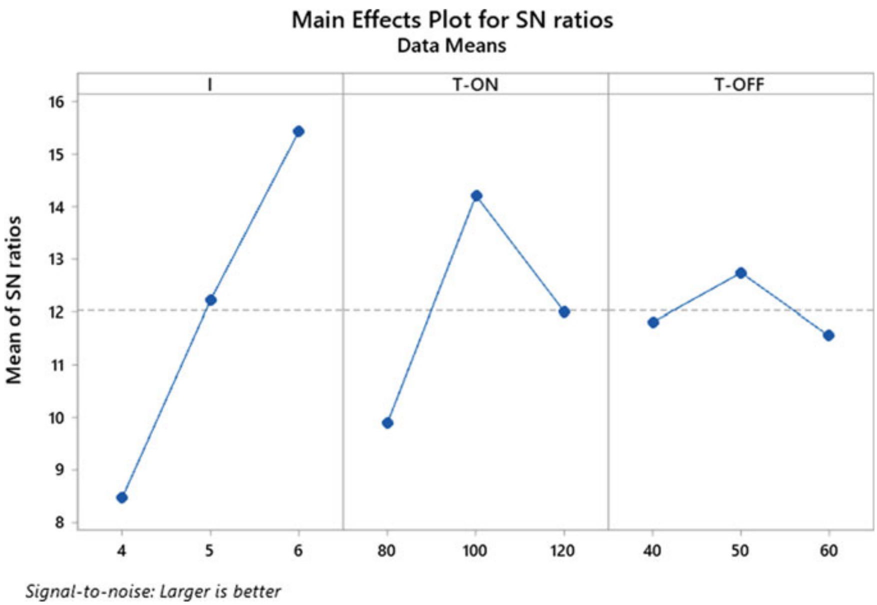

Fig. 2 Signal to noise ratios for MRR

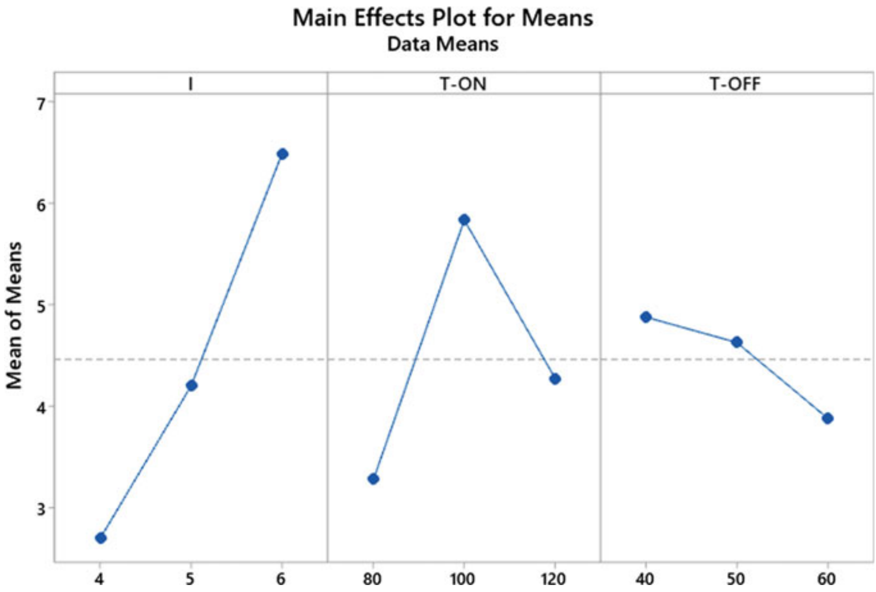

Fig. 3 Mean for MRR

a significance of each of the process parameters were ranked based on delta value from high to low (Table 7).

So accordingly, MRR is most affected by current followed by current, pulse-ON time and then pulse-OFF time. The parameters where MRR is said to be maximum are: current (6 A), pulse-ON time (100 µs) and pulse-OFF time (40 µs).

Similarly, for EWR for ‘smaller the better’ option is selected in Minitab software for obtaining S/N values, Table 8 represents the S/N ratio for EWR. Accordingly, the response table (Table 9) and graph (Figs. 4 and 5) for mean of S/N ratio along with significance of each of the process parameters were ranked based on delta value from high to low (Table 10).

So accordingly, the EWR is most affected by current followed by current, pulse-ON time and then pulse-OFF time. The parameters where EWR is said to be minimum are: current (4 A), pulse-ON time (100 µs) and pulse-OFF time (50 µs).

Table 7 Response table for means

Level	*I*	T-ON	T-OFF
1	2.690	3.277	4.877
2	4.200	5.833	4.627
3	6.493	4.273	3.880
Delta	3.803	2.557	0.997
Rank	1	2	3

Table 8 S/N ratio

EWR	S/N ratio
2.05	−6.2351
2.64	−8.4321
3.13	−9.9109
4.85	−13.7148
5.58	−14.9327
9.13	−19.2094
11.16	−20.9533
8.58	−18.6697
10.30	−20.2567

Table 9 Response table for signal-to-noise ratios

Level	*I*	T-ON	T-OFF
1	−8.193	−13.634	−14.705
2	−15.952	−14.012	−14.135
3	−19.960	−16.459	−15.266
Delta	11.767	2.825	1.131
Rank	1	2	3

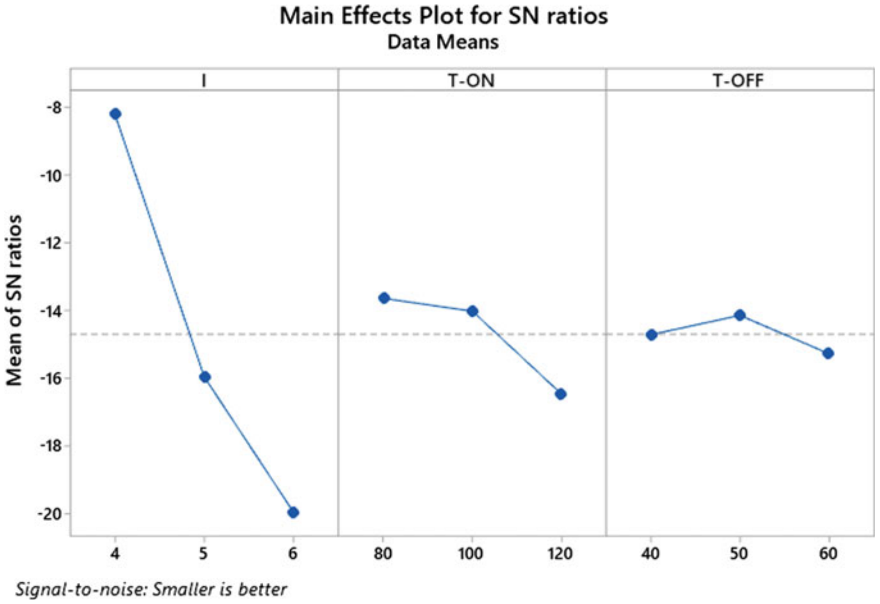

Fig. 4 Signal to noise ratios for EWR

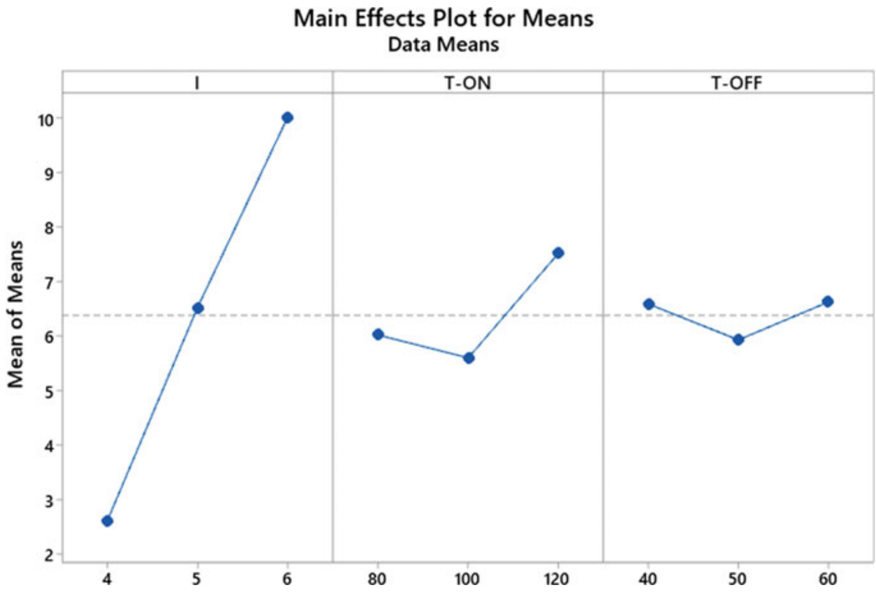

Fig. 5 Mean for EWR

Table 10 Response table for means

Level	I	T-ON	T-OFF
1	2.607	6.020	6.587
2	6.520	5.600	5.930
3	10.013	7.520	6.623
Delta	7.407	1.920	0.693
Rank	1	2	3

6 Conclusion

It was found that MRR is most affected by current followed by pulse-ON time and pulse-OFF time and is maximized at current (6 A); pulse-ON time (100 μs) and pulse-OFF time (40 μs).

As far as EWR is concerned, it is most affected again by current followed by pulse-ON time and pulse-OFF time, and further, EWR is minimized at current (4 A); pulse-ON time (100 μs) and pulse-OFF time (50 μs).

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