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An Experimental Study on the Influence of Machining Parameters When Machining Tool Steel Using Die-Sinking EDM

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Abstract

Copper tungsten electrode of 14 mm diameter was used in electrical discharge machining (EDM) of P 20 tool steel at different current, pulse-on time and pulse-off time settings with the objective of determining possible correlation between EDM parameters and the machinability factors. Experiments were conducted using Taguchi method. Each test was performed for 15 mins and EDF-K diamond oil was used as the dielectric fluid. The material removal rate of the workpiece was obtained based on the calculation of mass loss per machining time and surface roughness was obtained based on the average of readings. It was found that material removal rate as well as surface roughness was dependent on peak current, pulse-on time and pulse-off time. High peak current, low pulse-on time and high pulse-off time was found suitable for minimum surface roughness. High peak current, high pulse-on time and low pulse-off time was found suitable for maximum material removal rate.

Keywords: Sinking EDM, Peak current, Pulse-on time, Pulse-off time, Taguchi method, Material removal rate, Surface roughness

I INTRODUCTION

Recently, many researchers have done their work in the field of electrical discharge machining by machining various combinations of workpieces and tool materials in order to reduce the wear of electrode and to increase the material removal rate in the workpiece [3]. From the researches, it is observed that by manufacturing composite electrode, it is possible to reduce wear and to increase the material removal rate. In this paper, it is decided to use copper tungsten electrode and P20 tool steel [11] to find the maximum material removal rate and minimum surface roughness. EDM is successfully used in the field of tool and die making. Pure electrode materials find considerable advantage in the EDM process because of their electrical conductivity. But wear in those electrodes will be more.

Hence, to reduce the wear electrodes are being manufactured in polymer, composite materials and in alloy materials like copper tungsten, silver tungsten. But copper tungsten electrode is economical compared to other alloy electrodes and is being used in the industries world wide. Hence, as wear is less in copper tungsten [1] electrodes this study is focused on material removal rate and surface roughness in workpiece when machining tool steel using copper tungsten electrode.

II EXPERIMENTAL DETAILS

A. *Working principle of EDM*

EDM is the non-conventional method of machining the workpiece using current as a tool. This method is used to cut very hardened workpieces of HRC 62 or more(any hardness). Dielectric oil such as Diamond EDF K oil is used to decrease the arc area so that uniform machining takes place. Machining parameters such as pulse-on time, pulse-off time, gap current [2] should be carefully controlled to obtain precise machining. Hence it is necessary to choose optimum electrode material which provide better surface finish. Polarity of the electrode, servo voltage, gap, machining time, gain are kept constant in this experiment

The electrode was clamped in the electrode holder which has capacity to hold 25 Kg of electrode weight. The workpiece was kept on the machine table and the electrode surface was made to touch the workpiece ground surface. The centre of the workpiece was measured by measuring four sides of rectangular workpiece by setting the work coordinates. Depth was set using Z axis on the machine. Immediately the beep sound was heard, flushing should be switched on. The machine is ready for machining. For this application depth of 1 mm was selected and machining time was set as 15 mins [4].

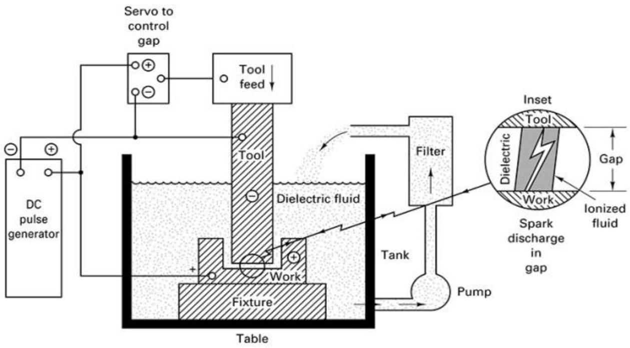

Fig. 1. EDM Process Diagram

The suitable combinations of input parameters such as peak current, pulse-on time and pulse-off time produce stationary MRR and surface roughness.

Moreover the anode melts faster than the cathode due to the absorption of fast moving electrons at the starty of pulse, then begins to resolidify after few micro seconds. The process creates small craters on the material surface, their size and shape depends on the discharge of the energy (as well as the pulse shapes), electrode material thermal properties and heat conduction pattern.

B. *Specifications of the machine*

- Machine : Mitsubishi CNC EDM
- Axis stroke : 300 x 250 x 250 mm
- Workpiece : 740 mm x 470 mm x 150 mm
- Max. electrode weight : 25 Kg
- Max. workpiece weight : 550 Kg
- EDM Oil : Diamond EDF-K

From the above specifications and based on the weight measurements workpiece size of 28 x 27 x 8 mm is chosen and 14 mm electrode is chosen. In this study two assumptions were made:

(a) EDM oil temperature and pressure was maintained as constant throughout the experiment (b) Voltage was assumed to be constant [4].

C. *Workpiece and Electrode material*

- Workpiece size : 28 x 27 x 8 mm
- Material : P20 Toolsteel
- Composition : 40crMnNiMo864
- Electrode size : 14 mm
- Depth of cut : 1 mm
- Electrode material : Cu-W (30 % - 70 %)
- Flushing : Emission flushing

In order to have less electrode wear, better surface roughness and higher machining rates it was proposed to use copper tungsten electrode of above combination. The dielectric fluid has four main functions electrical insulation, spark conductor, flushing medium and coolant. Since, flushing plays the main role in EDM emission flushing in which the coolant (or) dielectric will point in the inter electrode gap so that the spherical debris will be removed with ease.

D. *Material removal rate (MRR)*

Material removal rate is related to the amount of mass loss [4] in work piece after machining 15 minutes in EDM machine. In EDM, material removal rate increases with increase in the peak current and pulse-on time which leaves rough surface quality. Researches are going on in EDM machine to increase machining speed and to reduce surface roughness value. Higher amounts of material removal rate settings can be best utilized in rough machining conditions. Material removal rate can be increased by increasing di-electric flushing pressure and different combinations of parameter settings. MRR can be improved by delivering additional discharges using multiple electrodes. MRR can be improved using tubular electrodes in which air is supplied in the centre micro holes of the electrode. The simultaneous rotation of the electrode with air removes lot of material and can be used very well for rough machining conditions. This experiment focuses on highest material removal rate with less surface roughness with 25 no. of possible experiments.

Hence, material removal rate increases with increased peak current, pulse-on time, flushing pressure, no. of holes in the electrode, by increasing no. of electrodes and by attaching additional mechanism for contouring.

E. *Surface roughness*

This project is focused on lesser surface roughness by setting the lower pulse-off time and higher (or) lower current and less dielectric flushing pressure. Surface roughness decreases with higher pulse-off time and less peak current. In order to achieve the minimum surface roughness, it is necessary to reduce the pulse-on time, increase the pulse-off time, increase (or) decrease the peak current according to the pulse-off time setting with super finished electrode.

III PROBLEM DEFINITION

As seen from the literature surveys, researchers have found techniques to detect electrode wear and material removal rate using conventional electrode materials such as copper and graphite and have done researches on large number of tool steels (DC 53, P20, Ceramics etc.). In this study, EDM machining of AISI P20 material using copper tungsten composite electrode will be carried out and the responses such as material removal rate, surface roughness and tool wear rate will be discussed in detail.

During the machining of conductive materials, electrode wear occurs due to which electrode losses it's shape and consequently, workpiece cannot be machined to a specific shape mentioned in the drawing which is the problem frequently encountered in electrodes like copper, graphite. In this experiment one electrode is used from rough to finish machining stages in order to predict tool wear. Tungsten is blended with copper in order to resist wear which is used to machine P20 toolsteel used in many mold industries.

IV OBJECTIVES

1. Machining the workpieces for each trial of experiment.
2. Measurement of material removal rate and surface roughness for the experiments.
3. Validation of results with ANOVA and Genetic algorithm using matlab.

V DESIGN OF EXPERIMENTS

A. *Orthogonal array*

The selection of orthogonal array to use predominantly depends on number of factors and interactions of interest, number of levels for the factors of interest, desired experimental resolution and cost limitations. The first two items determine the smallest orthogonal array which is possible to use.

B. *Array selection*

There are two basic kinds of orthogonal arrays which are two level arrays (L4, L8, L12, L16, L32) and three level arrays (L9, L18, L27). The number in the array designation indicates the number of trials in the array. An L8 has eight trials and an L27 has 27 trials. The number of levels used in the factors should be used to select either two-level or three level types of orthogonal arrays. Orthogonal array selection should also be made using degrees of freedom for main factors and for interactions. This strategy will minimize the total number of tests to be conducted yet will yield meaningful information at the same time. Once, the appropriate orthogonal array has been selected, the factors can be assigned to various columns of the array and subsequent interaction columns located [20].

C. *Degrees of freedom*

A degree of freedom in a statistical sense is associated with each piece of information that is estimated from the data. Degree of freedom is one of the main criteria in deciding orthogonal arrays. In this project, main effects of factors are considered and for each factor, degree of freedom is number of levels for each factor minus one. Hence, using the above criteria for selection of orthogonal arrays, in this project 12 degrees of freedom arrived and for the above degrees of freedom, L25 orthogonal array is selected in order to have higher resolution. Another criterion in deciding orthogonal array for the experiment is number of runs should be greater than or equal to chosen degrees of freedom.

D. *L 25 Orthogonal array*

The design which was finally chosen was L 25 orthogonal array due to higher amount of resolution. This orthogonal matrix has 6 columns which can be used for input parameters. Basically this orthogonal array is designated as L 25 (5^6). For this experimentation work first three columns have been chosen.

Table 1

Factors and levels selected for the experiment

		Levels				
Sl. No	**Parameters**	**1**	**2**	**3**	**4**	**5**
1	Peak current, **I_p(A)**	0.2	1.2	2.2	3.2	4.2
2	Pulse-on time, **t_{on} (µs)**	2.6	3.6	4.6	5.6	6.6
3	Pulse-off time, **t_{off} (µs)**	4.2	5.2	6.2	7.2	8.2

Table 1 presents the relationship between the design factors and their corresponding selected variation levels taking into account that the study wanted to focus on material removal rate and surface roughness.

Table 2

Design of experiment matrix

Runs	**I_p(A)**	**t_{on} (µs)**	**t_{off} (µs)**
1	1	1	1
2	1	2	2
3	1	3	3
4	1	4	4
5	1	5	5
6	2	1	2
7	2	2	3
8	2	3	4
9	2	4	5
10	2	5	1
11	3	1	3
12	3	2	4
13	3	3	5
14	3	4	1
15	3	5	2
16	4	1	4
17	4	2	5
18	4	3	1
19	4	4	2
20	4	5	3
21	5	1	5
22	5	2	1
23	5	3	2
24	5	4	3

25	5	5	4

Runs	Material removal rate (g/min.)	S/N ratio for MRR
1	1.20×10^{-3}	-58.416
2	6.0×10^{-4}	-64.437
3	1.23×10^{-3}	-58.202

Table 2 shows the design matrix resulting from the type of experiment selected. The importance of the input parameters in the EDM process was determined. The possible influential machining parameters were selected according to literature review. There are three input parameters that affect the EDM performance. Some of these parameters are likely to have a more significant effect on electrical discharge machining performance than others. The levels of input parameters were selected considering rough cut and finish cut conditions.

VI RESULTS AND DISCUSSION

A. *Material removal rate (MRR) results*

Table 3

Material removal rate results

4	2.0×10^{-4}	-73.979
5	4.666×10^{-4}	-66.621
6	1.333×10^{-4}	-77.503
7	1.466×10^{-3}	-56.677
8	1.533×10^{-3}	-56.289
9	6.666×10^{-4}	-63.523
10	1.666×10^{-3}	-55.567
11	2.20×10^{-3}	-53.152
12	1.466×10^{-3}	-56.677
13	1.466×10^{-3}	-56.677
14	0.02746	-31.226
15	0.02333	-32.642
16	4.133×10^{-3}	-47.675
17	3.4×10^{-3}	-49.370
18	0.0622	-24.124
19	0.0566	-24.944
20	0.0559	-25.052
21	1.4×10^{-3}	-57.077
22	0.0698	-23.123
23	0.0699	-23.111
24	0.0754	-22.453
25	0.0750	-22.499

Table 3 presents the results for material removal rate and signal to noise ratio. Material removal rate was calculated by subtracting weight of workpiece before and after machining for 15 mins. From the above table, it is clearly seen that for runs 14, 15, 18, 19, 20, 22, 23, 24, 25 signal to noise ratio had increased compared to other runs.

B. *Analysis of material removal rate*

Table 4

ANOVA table for material removal rate

Source	DF	Seq SS	Adj SS	Adj MS	F	P
I_p	4	4936.2	4936.2	1234.04	29.94	0.000
T_{on}	4	1076.5	1076.5	269.12	6.53	0.005
T_{off}	4	1243.8	1243.8	310.95	7.54	0.003
Residual Error	12	494.6	494.6	41.22		
Total	24	7751.0				

Table 4 clearly shows that P value for peak current and Pulse-off time are in higher influence than Pulse-on time and hence is considered as the most influential parameter in the experimentation process and higher the peak current, higher the material removal rate. The regression equation for material removal rate is obtained and is given by

MRR = 0.0005 + 0.0150 I_p + 0.00756 t_{on} - 0.00756 t_{off}………………... (1)

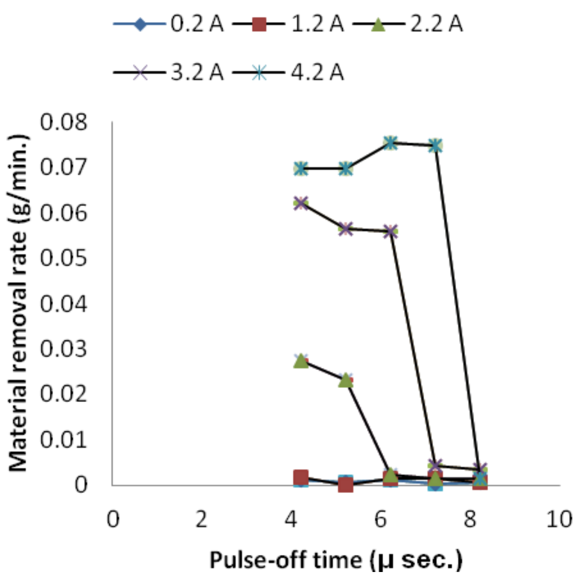

Fig . 2. Material removal rate Vs Pulse-off time

Fig. 2 clearly shows the relation between material removal rate and pulse-off time at different current settings (0.2 A, 1.2 A, 2.2 A, 3.2 A, 4.2 A) and it is clearly seen that at 4.2 μ sec. material removal rate is higher. Since, 4.2 μ sec. is the first level of pulse-off time, peak current and pulse-on time dominates and the material removal rate is increased. The material removal rate starts decreasing at higher levels of pulse-off time and surface roughness at higher levels of pulse-off time is lesser.

VII CONCLUSION

The experimental study of the EDM of AISI P20 tool steel provided important quantitative results for obtaining machining outputs as follows:

a. Material removal rate increases with increased peak current (I_p) and decreased pulse-off time (t_{off}).

b. From ANOVA table, it is found that peak current and pulse-off time are the most influencing parameters for EDMing P20 tool steel with copper tungsten electrodes.

c. From the graph of material removal rate versus pulse-off time, it is found that for lesser pulse-off time in all current settings material removal rate is higher.

d. Since, lesser pulse-off time reduces the time for dielectric flushing in the inter electrode gap (IEG), material removal rate is higher.

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