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Investigations on Material Removal Rate of AISI D2 Die Steel in EDM using Taguchi Methods

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Abstract
Electrical discharge machining (EDM) process is one of the most commonly used non conventional precise material removal & world class standard non contacting machining processes. The work piece must be a conductive electricity material which is submerged into the dielectric fluid for better erosion. This process widely used for machining of hard, brittle, component material, complex geometry, intricate shapes, making moulds & deep holes by arc erosion in all kinds of electro conductive materials. The workpiece material selected in this study is AISI D2 Die Steel. The input parameters are voltage, current, pulse on time and pulse off time. L_9 orthogonal array was selected as per the Taguchi method. The data have been analyzed using Minitab15 Software. The effect of above mentioned parameters upon machining performance characteristics such as Material Removal Rate (MRR) is studied and investigated on the machine model C-3822 with PSR-20 Electric Discharge Machine. The copper alloy was used as tool material.
Keywords: EDM, MRR, ANOVA, Taguchi method, AISI D2 Die steel, copper electrode

1-Introduction

That present manufacturing industries are facing challenges from these advanced materials viz. super alloys, ceramics, and composites, that are hard and difficult to machine, requiring high precision, surface quality which increases machining cost. To meet these challenges, non-conventional machining processes are being employed to achieve higher metal removal rate, better surface finish and greater dimensional accuracy, with less tool wear. Electric Discharge Machining (EDM), a non-conventional process, has a wide applications in automotive, defense, aerospace and micro systems industries plays an excellent role in the development of least cost products with more reliable quality assurance. Electrical Discharge Machining (EDM) is nontraditional, high precision metal removal process using thermal energy by generating a spark to erode the workpiece. Material is remove from the workpiece by series of rapidly recurring discharge between two electrode separated by dielectric liquid subjected to an electric voltage. The workpiece must be a conductive electricity material which is submerged into the dielectric fluid for better erosion. EDM process showing in the figure-1

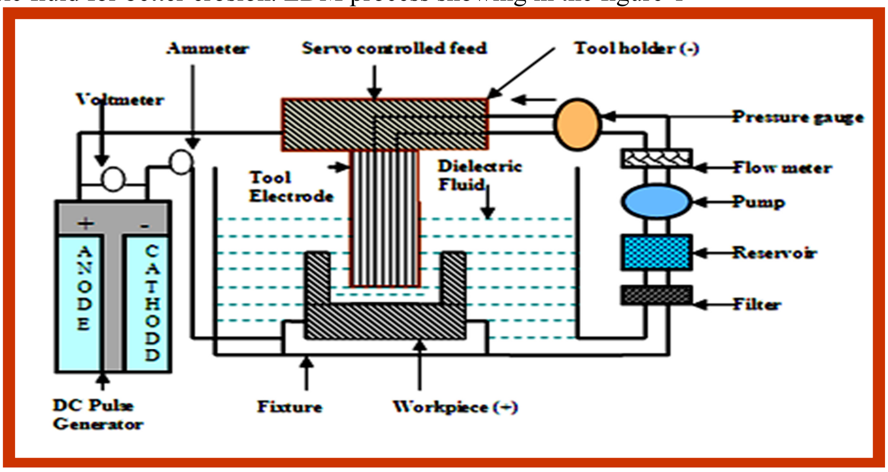

Fig. 1 Line diagram of EDM process [S.K Choudhary & R.S Jadoun (2014)]

1.1 Major part of EDM

- Power generator and control unit: - The power supply control the amount of energy consumed.
- The tool holder: – The tool holder holds the tool with the process of machining.
- The servo system to feed the tool: - The servo control unit is provided to maintain the pre determined gap between the electrode and workpiece.
- Working tank with work holding device:-All the EDM oil kept in the working tank is used to the supply the fluid during the process of machining.
- Dielectric reservoirs pump and circulation system: - Dielectric reservoirs & pump are used to circulate

the EDM oil for every run of the experiment & also used the filter the EDM oil.

1.2 Process Parameters of EDM

- Pulse On-time: The pulse on time represents the duration of discharge and is the time during which the electrode material is heated by the high temperature plasma channel.
- Pulse off time: The pulse off time represents the duration when no discharge exists and the dielectric is allowed to demonize and recover its insulating properties.
- Duty Factor: Duty factor is a percentage of the pulse duration relative to the total cycle time.
- Discharge Current: It is a measure of the amount of electrical charges flowing between the tool and workpiece electrode. As the flow of electrical charges is the heating mechanism in electro-thermal erosion.
- Average Current: Peak current is the maximum current available for each pulse from the power supply/generator. Average current is the average of the amperage in the spark gap measured over a complete cycle. It is calculated by multiplying peak current by duty factor.
- Gap Voltage: This can be measured as two different values during one complete cycle. The voltage which can be read across the electrode / workpiece gap before the spark current begins to flow is called the open gap voltage. The voltage which can be read across the gap during the spark current discharge is the working gap voltage.

2. Literature Review

Guu Y.H. et al, [2003] proposed the electrical discharge machining (EDM) of AISI D2 tool steel was investigated. The surface characteristics and machining damage caused by EDM were studied in terms of machining parameters. Based on the experimental data, an empirical model of the tool steel was also proposed. Surface roughness was determined with a surface profilometer. Guu Y.H. [2005] proposed the surface morphology, surface roughness and micro-crack of AISI D2 tool steel machined by the electrical discharge machining (EDM) process were analyzed by means of the atomic force microscopy (AFM) technique. Pecas, P, et al. [2008] presents on EDM technology with powder mixed dielectric and to compare its performance to the conventional EDM when dealing with the generation of high-quality surfaces. Kansal, H.K, et al., [2005] study has been made to optimize the process parameters of powder mixed electrical discharge machining (PMEDM). S.Prabhu, et al [2008] analysed the surface characteristics of tool steel material using multiwall carbon nano tube to improve the surface finish of material to nanolevel. Ko-Ta Chiang, et al [2007] methodology for modeling and analysis of the rapidly resolidified layer of spheroidal graphite (SG) cast iron in the EDM process using the response surface methodology. The results of analysis of variance (ANOVA) indicate that the proposed mathematical model obtained can adequately describes the performance within the limits of the factors being studied. Seung-Han Yang, et al [2009] proposes an optimization methodology for the selection of best process parameters in electro discharge machining. Regular cutting experiments are carried out on die-sinking machine under different conditions of process parameters

3. Experimental Methodology

In this paper we will discuss about the experimental work formulated prior to execution of work. It consists of an L9 orthogonal array using Taguchi design, selection of workpiece, experimental set-up, tool design and calculation of Material Removal Rate (MRR).

3.1 Experimental Setup

The experiments were conducted using the Electric Discharge Machine model C- 3822 WITH PSR-20. The polarity of the electrode was set as positive while that of workpiece was negative. The dielectric fluid used was EDM oil kerosene oil (specific gravity 0.820). The EDM consists of the following parts:

- Dielectric reservoir, pump and circulation system.
- Power generator and control unit.
- Working tank with work holding device.
- X-Y working table
- The tool holder
- The servo system for feeding the tool.

3.2 Selection of the Workpiece

AISI D2 Die Steel is one of the most widely used materials in all industrial applications and accounts for approximately half of the world's D2 Die Steel production and consumption. AISI D2 Die Steel block of 50 mm x 50mm x 5mm size has been used as a work piece material for the present experiments.

Fig.2: A View of Work piece Machined by EDM

The chemical composition and mechanical properties of the work-piece materials are shown in Table-1 & Table -2.

Table-1 Chemical composition of AISI D2 Die Steel

Element	Chemical Compositions (wt %)
C	1.50
Si	0.30
Cr	12.00
Mo	0.80
V	0.90
Fe	84.5

Table-2 Mechanical Properties of AISI D2 Die Steel

AISI D2 Die Steel	
Density (gm./cc)	7.7
Thermal Conductivity (W/m °C)	20.0
Modulus of elasticity (MPa)	210×10^3
Specific heat (J/kg °C)	460

3.3 Tool Design

The tool material used in Electro Discharge Machining can be of a variety of metals like copper, brass, aluminium alloys, silver alloys etc. The material used in this experiment is copper. The tool electrode is in the shape of a cylinder having a diameter of 8 mm.

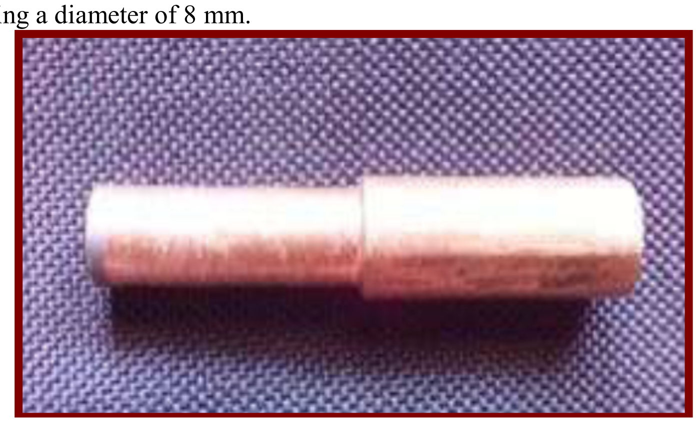

Fig.3 Copper Electrode

3.4 Mechanism and evaluation of MRR

MRR is the rate at which the material is removed the work-piece. Electric sparks are produced between the tool and the work-piece during the machining process. Each spark produces a tiny crater and thus erosion of material is caused. The MRR is defined as the ratio of the difference in weight of the work-piece before and after machining to the density of the material and the machining time.

$$\text{MRR} = \frac{W_b - W_a}{t * \rho}$$

Where W_b = weight of work-piece before machining (gm.)
W_a = weight of work-piece after machining (gm.)
t = machining time (min)
ρ is the density of AISI D2 Die steel = $7.7\text{x}10^3$ kg/m^3

4. Results

The effects of the machining parameters in electrical discharge machining on the machining characteristics of D2 Die Steel work piece has been investigated in this study. Material removal rate (MRR) is considered as responses while machining variables are pulse on time, pulse off time, current and voltage. Taguchi method is used to develop empirical models correlating process variables and their interactions with the said response functions. The significant parameters that critically influence the machining characteristics are examined and the variations of responses with the process parameters are studied.

4.1 Data Analysis for Metal Removal Rate (MRR)

In this section, the data of MRR obtained from experiments are analysed. As mentioned earlier, experiments are carried out varying the process parameters (pulse on time, pulse off time, current and voltage) in EDM of D2 Die Steel. The experiments are conducted by Minitab15 software based on L9 Orthogonal array (OA) consisting 9 no. of experiments. The raw data for MRR is presented in Table 3.

Table-3 Experimental results for MRR

Exp. No	Ton (µs)	Toff (µs)	Ip (amp)	Vg (volt)	Work piece Weight (gm)	
					W_b	W_a
1	20	7	6	40	117.2050	117.0128
2	20	8	8	50	110.6675	110.4391
3	20	9	10	60	116.7384	116.5223
4	30	7	8	60	116.5786	116.0769
5	30	8	10	40	116.5223	115.6140
6	30	9	6	50	117.0128	116.5784
7	40	7	10	50	115.6140	114.6519
8	40	8	6	60	110.4391	110.2174
9	40	9	8	40	111.21010	110.6675

After taking the raw data from table-3, we conclude the metal removal rate by applying the formula which is discussed in materials and methods. The S/N ratio and mean ratio are to be given by the Minitab15 software.

Table -4 Average Table for MRR

Exp. No	Ton µs	Toff µs	Ip amp	Vg volt	MRR mm^3/min	S/N Ratio	Mean ratio
1	20	7	6	40	2.4961	7.9452	2.4961
2	20	8	8	50	2.9662	9.4440	2.9662
3	20	9	10	60	2.8065	8.9633	2.8065
4	30	7	8	60	6.5260	16.2929	6.5260
5	30	8	10	40	11.7961	21.4348	11.7961
6	30	9	6	50	5.6415	15.0279	5.6415
7	40	7	10	50	12.4948	21.9346	12.4948
8	40	8	6	60	2.8792	9.1854	2.8792
9	40	9	8	40	7.0468	16.9598	7.0468

Taguchi method is applied to analyze the effect of individual parameters. On the basis of response table-5it is finding that the pulse on time is more contribution to metal removal rate. The main effect plot for S/N ratio and main effect plot for means shows that the indivisiual effects of the different parameters which is used in this experiments.

Table-5 Response for S/N Ratio Larger is better (MRR)

Level	Pulse on time (A)	Pulse-off Time (B)	Current (C)	Voltage (D)
1	8.784	15.391	10.720	15.447
2	17.585	13.355	14.232	15.469
3	16.027	13.650	17.444	11.481
Delta	8.801	2.036	6.725	3.988
Rank	1	4	2	3

Table -6 Responses for Means Larger is better (MRR)

Level	Pulse on time (A)	Pulse-off Time (B)	Current (C)	Voltage (D)
1	2.756	7.172	3.672	7.113
2	7.988	5.880	5.513	7.034
3	7.474	5.165	9.032	4.071
Delta	5.232	2.007	5.360	3.042
Rank	2	4	1	3

From the main effect plot for S/N ratios shows in fig .4 that the material removal rate is linearly vary with the process parameters. MRR with respect to Ton, it is increases rapidly initially and after that it is decrease.MRR also increases with respect to the current. Whereas Toff factor is less contribution to metal removal rate shows in fig.4 the metal removal rate decreases with increases the level of pulse off time. Gap voltage is also less contribution to metal remove, at initial level of the voltage the MRR remains constants and after that it is falls down rapidly.

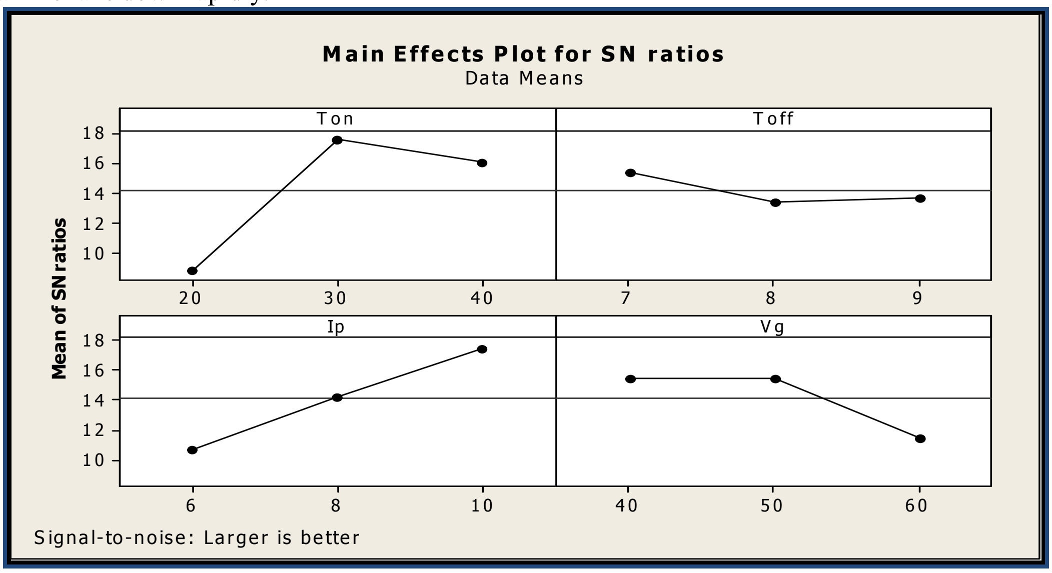

Fig.4. Main Effect Plot for S/N Ratio of MRR

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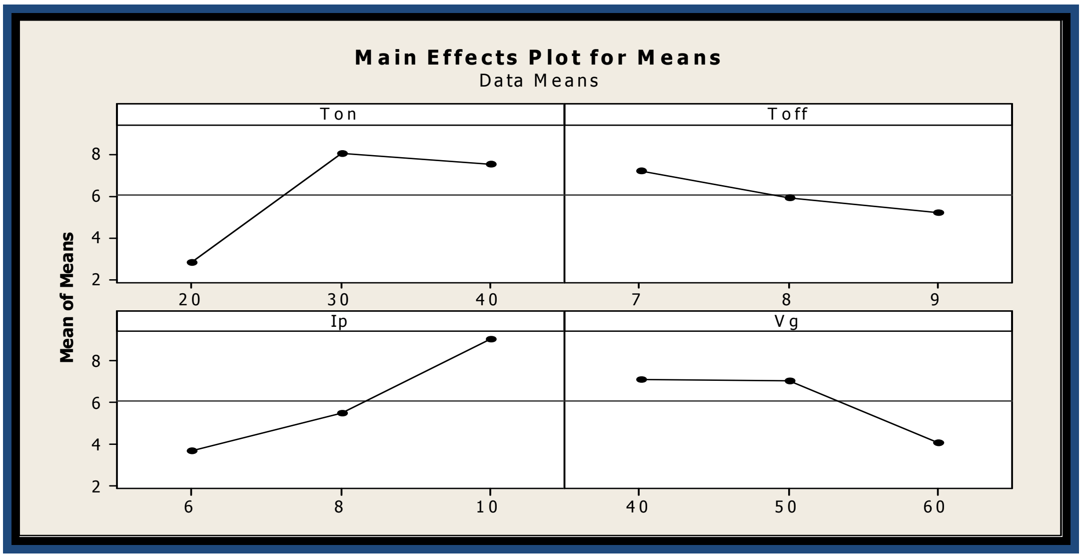

Fig. 5 Main Effect Plot for Means of MRR

4.2 Selection of Optimal Settings for MRR

Metal removal rate (MRR) is larger-the-better type quality characteristic. Therefore higher values of MRR are considered to be optimal. It is clear from Fig. 4. and Fig. 5 that metal removal rate is highest at second level of pulse on time, first level of pulse off time, third level of current and first level of voltage. Process parameters and their selected optimal levels are given below:

Pulse on time (Ton)	A (2)	30µs
Pulse off time (Toff)	B (1)	7 µ
Current (Ip)	C (3)	10 amp
Voltage (Vg)	D (1)	40Volt

4.3 Analysis of Variance (ANOVA) For Metal Removal Rate (MRR)

Using the experimental results for MRR (Table 4.), Taguchi method is developed and analysis of variance (ANOVA) for the adequacy of the model is then performed in the subsequent step. The F ratio is calculated for 95% level of confidence. The value which are less than 0.05 are considered significant and the values greater than 0.05 are not significant and the model is adequate to represent the relationship between machining response and the machining parameters.

The results were analysed using ANOVA for identifying the significant factors affecting the performance measures. The Analysis of Variance (ANOVA) for the mean MRR at 95% confidence interval is given in Tables. The variation data for each factor and their interactions were F-tested to find significance of each calculated by the formula. The principle of the F-test is that the larger the F value for a particular parameter, the greater the effect on the performance characteristic due to the change in that process parameter. ANOVA table shows that current, pulse on time, pulses off time, voltage are the factors that significantly affect the MRR. Pulse on time has highest contribution to MRR. Main effect plot for the mean MRR is shown in the graph which shows the variation of MRR with the input parameters.

Table-7: ANOVA for S/N Ratio (MRR)

Source	DOF	Seq SS	Adj SS	Adj MS	F	P(%)
Ton	2	132.340	132.340	66.170	23.544	54.07
Toff	2	7.263	7.263	3.632	1.292	2.96
I_p	2	67.878	67.878	33.939	12.076	27.73
V_g	2	31.636	31.636	15.818	5.628	12.92
Residual error	0	5.621	5.621			2.32
Total	8	244.738				100

Table-8: ANOVA for Means (MRR)

Source	DOF	Seq SS	Adj SS	Adj MS	F	P (%)
Ton	2	49.887	49.887	24.943	10.013	40.35
Toff	2	6.210	6.2103	3.1052	1.246	5.02
I_p	2	44.507	44.506	22.253	8.934	35.99
V_g	2	18.046	18.045	9.0228	3.622	14.59
Residual error	0	4.982				4.05
Total	8	123.63				100

Seq, SS, sum of squares;
DOF, Degree of freedom;
Adj MS, Adjusted Mean square
P, Percentage contribution;
Significance at 95% confidence level

The ANOVA for AISI D2 die steel indicates that F-ratio for the four factors is greater than the limiting value of the F-ratio . For D2 die steel the most significant factor found to be pulse on time then current followed by Voltage. Pulse on time has the highest contribution to the MRR of the D2 die steel at 95% confidence level.

4.4 Optimal design for MRR

In the experimental analysis, main effect plot of S/N ratio is used for estimating the S/N ratio of MRR with optimal design condition. As shown in the graphs, there are highest values which affect the material removal rate which are the pulse on (A2), pulse-off (B1), current (C3) and voltage (D1) respectively. After evaluating the optimal parameter settings, the next step of the Taguchi approach is to predict and verify the enhancement of quality characteristics using the optimal parametric combination. The estimated S/N ratio using the optimal level of the design parameters can be calculated.

$$n_{opt} = n_m + \sum_i^a (n_i - n_m)$$

Where n_m = the total mean of S/N ratio
$\overline{n_i}$ = mean S/N ratio at optimum level
a = number of design parameters that effect quality characteristics

Based on the above equation the estimated multi response signal to noise ratio can be obtained.

n_{opt} = 14.13199 + (17.585 – 14.13199) + (15.391 - 14.13199) + (17.444 – 14.1399) + (15.447 – 14.1319)
= 23.471

$$\boxed{\text{Corresponding value of MRR} = y^2{}_{opt} = \frac{1}{10^{\frac{-nopt}{10}}}}$$

$$\boxed{y^2{}_{opt} = \frac{1}{10^{\frac{-23.471}{10}}}}$$

y_{opt} = **14.91 mm^3/ min**

As per the optimal level again the experiment is performed as A2, B1, C3 and D1.And the optimal vale of MRR is 14.9 mm^3/min.

Effects of Process Parameters on Metal Removal Rate (MRR)

From above main effect plot of MRR we can conclude the optimum condition for MRR is A2, B1, C3, D1 i.e. Pulse-on (30µs) and Pulse-off (7 µs), Current (10 amp), Voltage (40V).

Pulse on time factor have more contribution for removing the material after that current have been giving there contribution for that. The increasing order of influence parameters are showed in below.

Ton (30µs)> Ip (10 amp)> Vg (40V) >Toff (7 µs)

5. Conclusion

In this study the experiment was conducted by considering four variable parameters namely current, pulse on time, pulse off time and voltage. The objective was to find the Material Removal Rate (MRR) is to study the effects of the variable parameters on these characteristics. The tool material was taken as copper and the workpiece was chosen as AISI D2 Die Steel. Using the Taguchi method an L_9orthogonal array was created and the experiments were performed accordingly. The following conclusions were drawn:

For MRR the most significant factor was found to be pulse on time followed by current and the least significant was pulse off time. The optimum condition for MRR is A2, B1, C3, D1 i.e. Pulse-on time (30µs), Pulse-off time (7 µs), Current (10 amp), Voltage (40V). As per the optimal level again the experiment is performed as A2, B1, C3 and D1, and the optimal value of MRR is 14.91 mm^3/min.

6. Future Scope of Work

The present study is extremely useful for maximizing MRR and minimizing TWR. Future study on this method may evaluate the following aspects.

- Instead of copper electrode other electrode material like brass or graphite may be used, in EDM process.
- Different grades of tool steels may be used for the optimization of machining parameters for the interest of industries.
- In this study, only four machining parameters are chosen. A detailed study may be done, considering other parameters also.
- Responses other than MRR and TWR like fractal dimension & surface roughness which may be optimized for the different machining parameters.
- There are several optimization tools, viz. RSM, ANN, ANFIS, GA and WPCA may be employed for the optimization procedure.

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