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Experimental Investigation of MRR and EWR onAISI-01 Die Steel on Electrical Discharge Machine

RautTrupti Gopal[1],

[1]*MechanicalDepartment, Dnyanshree Institute of Engineering & Technology, Satara*

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Abstract –Nowadays, Non conventional machining process is widely used in industries than conventional machining process where intricate shapes are required such as in automotive, defense, aerospace and micro systems industries. Electrical Discharge Machining method is mostly used in industries for removing of material from hard and difficult to cut materials such as super alloys, ceramics and composites etc.In this work, the input parameters like Peak Current (Ip), Pulse-On Time (Ton), Gap Voltage (Vg) and Sensitivity were used for experimental work. Mean effect plot and S/N ratio graphs have been used tooptimize the machining parameters of EDM on AISI-01 Die steel using the Taguchi method and ANOVA methods.

Key Words:EDM, MRR, Copper Electrode, OHNS, ANOVA

1.INTRODUCTION

EDM is non-conventional machining processin which heat energy of spark is used to remove material from the work piece. Electrical Discharge Machining or EDM is a machining method primarily used for hard metals or those that would be impossible to machine with traditional techniques. The non-contact machining techniquehas been continuously evolving from a mere tool and dies making process to a micro-scale application machining alternative attracting a significant amount of research interests. One critical limitation, however, is that EDM only works with materials that are electrically conductive. EDM is especially well-suited for cutting intricate contours or delicate cavities that would be difficult to produce with a grinder, an end mill or other cutting tools. Metals that can bemachined with EDM include hardened tool-steel, titanium and carbide etc.

2.METHODOLOGY

The Taguchi method was developed by Dr. Genichi Taguchi of Japan. It is an experimental design technique, which is useful in reducing the number of experiments by using orthogonal arrays, instead of having to test all the possible combinations like the full factorial design. Orthogonal array is useful to systematically arrange the affecting process parameters and their levels. It also reduces variations in the process by robust design of experiments and minimizes effects of the uncontrolled factors. It assures quality in the design phase. The advantages of the Taguchi method are to find out significant factors in a shorter time period, to decrease the experimental time, and to reduce the cost.

A. The basic steps for the methodology are:

- Identify the quality characteristics and select process parameters to be evaluated.
- Select the appropriate orthogonal array and assign these parameters to the orthogonal array.
- Conduct the experiments based on the arrangement of the orthogonal array.
- Analyze the experimental results using the signal to noise(S/N) ratio and analysis of variance (ANOVA).

B. Experimental design

1) Step1- Selection of process parameters: Process parameters and their ranges were determined by the trial tests.The parameters are identified for the test such as Peak current (Ip), Pulse-on Time (Ton), Gap Voltage (Vg) and Sensitivity.
2)Step2- Selection of orthogonal array: To select an appropriate orthogonal array for the experiments, on thebasis of parameter selection and its levels. Here we have four parameters and three levels are selected.
3) Step 3- Recording of responses: Nine experimental runs were conducted as per the Taguchi's L9 orthogonalarray.
4) Step 4- Calculation of signal-to-noise ratio: In the Taguchi's method, the signal-to-noise ratio is used tomeasure the quality characteristics and also to evaluate the influence of each selected factor on the responses.The signals indicate the effect of selected factors on the average responses. The noises are measured by thedeviations from the average responses, which would reveal the sensitiveness of the experiment output to thenoise factors. Therefore, the S/N ratio is the ratio of the mean to the square of the deviation.
5) Step 5- ANOVA analysis: The analysis of variance (ANOVA) is used to discuss the relative importance of allcontrol factors on the machined material quality and also to determine which control factor has the mostsignificant effect. Analysis of variance (ANOVA) is employed to find the optimal process parameter levels andto analyze the effect of these parameters on metal removal rate values and electrode wear rate.

3. EXPERIMENTATION

A.Experimental Set up

Experimental set-up for machining of AISI-01 Die Steel is designed as shown in fig.The machine is used for the experiments of electric discharge machining of AISI-01 material was a "Electra R-50 ZNC" Die sinking EDM machine. The machine has following specifications:-

Fig 1.EDM Experimental Setup

Sr. No.	Parameters	Specifications
1	Input Voltage	3 ϕ, 415 V, ± 5R, 50Hz
2	Power Consumption	7.2 KVA
3	Mean working voltage	50 - 100 V
4	Mean working current	35A
5	Range of T_{ON}	2µs - 1000 µs
6	Range of Pulse Duty Factor	0.85 – 0.1
7	Dimensions of inductor box	460 X 460X 960mm
8	Dimensions of power supply unit	550 X 790 X 1870
9	Weight (Kg) Approx.	500

Table 1. Specifications of ELECTRA R-50 ZNC Die-Sinking EDM machine

B. Selection of work-piece and electrode

Oil Hardening and Non Shrinking Die Steel (AISI-01) is used in blanking and stamping dies, punches, rotary shear blades, thread cutting tools, milling cutters, reamers, measuring tools, gauging tools, wood working tools, broaches, chasers etc.It has a high specific strength so it cannot be easily machinable by conventional machining techniques.So, this material is chosen for machining.
The AISI-01 plate is having size 100 X 50 X 4 mm.The electrode material selected as Copper which is having diameter ϕ10mm.

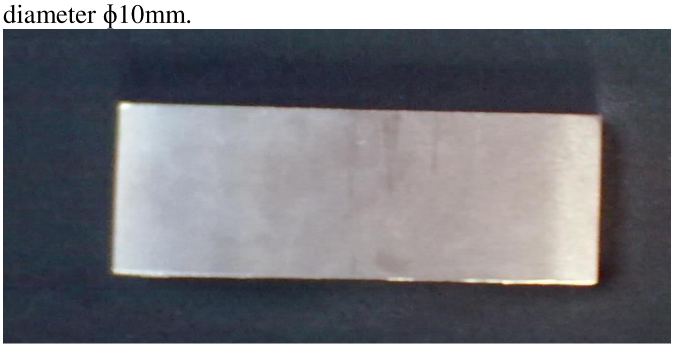

Fig 2.Work Material

4. TAGUCHI'S DESIGN OF EXPERIMENT
Experiments will be conducted by Taguchi's L9 array and ANOVA method. The process parameters i.e. Peak Current (Ip), Pulse ON Time (Ton),Gap Voltage (Vg) and Sensitivity were selected for conducting experiment with three levels each. Selected parameters and their levels are shown in Table The level values of input factors are shown in table:-

Sr. No.	Symbol	Factors	Levels		
			1	2	3
1	A	Ip (Amp)	5	7	9
2	B	Ton(µs)	50	100	150
3	C	Vg (Volt)	38	45	50
4	D	Sensitivity	7	8	9

Table 2. Level values of input Factors

Based on Taguchi L9 Orthogonal array the values of input factors are placed in design matrix and it is shown in table:-

Exp.No.	A(Amp)	B (µs)	C (Volt)	D
E1	5	50	38	7
E2	5	100	45	8
E3	5	150	50	9
E4	7	50	45	9
E5	7	100	50	7
E6	7	150	38	8
E7	9	50	50	8
E8	9	100	38	9
E9	9	150	45	7

Table 3.L9 Design Matrix

5. OBSERVATIONS
During each operation based on Taguchi L9 orthogonal array, the machining time was noted down. The weights of work pieces and the tools were measured by Digital weighing machine before and after each operation.

(A)Material Removal Rate (MRR):- It is the rate at which the material is removed from the workpiece. The MRR is defined as the ratio of the difference in weight of the workpiece before and after machining to the machining time.

$$MRR = \frac{Wi - Wf}{t}$$

Where , W_i- Initial weight of work-piece in gram
W_f - Final weight of work-piece in gram
t - time required for machining in min

(B) Electrode Wear Rate (EWR):-EWR is the rate at which the material is removed from the electrode. The EWR is defined as the ratio of the difference in weight of the electrode before and after machining to the machining time.

$$EWR = \frac{EWi - EWf}{t}$$

Where ,EW_i - Initial weight of electrode in gram
EW_f- Final weight of electrode in gram
t - time required for machining in min

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The experimental observations and calculations are shown in following table:-

Ex. No.	Weight loss by Job (Wi) in gm	Weight loss by electrode (We)in gm	Machining Time (t)(min)	MRR (mm^3/min)	EWR (mm^3/min)
1	3.09	0.02	102	3.8591	0.0219
2	2.88	0.03	35	10.4822	0.0957
3	3.67	0.02	44	10.6254	0.0507
4	3.15	0.1	34	11.8021	0.3283
5	2.3	0.03	21	13.9521	0.1594
6	3.29	0.1	27	15.5225	0.4134
7	2.57	0.04	27	12.1255	0.1653
8	3.07	0.07	26	15.0416	0.3005
9	3.05	0.04	20	19.4268	0.2232

Table 4. Calculation Table

6. RESULT AND DISCUSSION

(A) Response Table:-Taguchi analysis is mainly associated with Signal to Noise ratio. Taguchi's signal to noise ratio are the logarithmic functions of desired output. It is taken as the objective function for optimization.there are three possible categories of quality characteristics.
They are as follows:

(1) Smaller the better
(2) Nominal the better
(3) Higher the better

The S/N ratio **smaller-the-better** characteristics can be calculated as :

S/N = -10 log $_{10}$ (mean of sum of squares of measured data)

S/N = -10 log $_{10}$ $(\frac{1}{n}\sum_{i=1}^{n} yi\ 2)$

Where, y_i is the value of quality characteristics for the i^{th} test, n is number of measured data samples for one particular experiment.

The S/N ratio **nominal-the-better** characteristics can be calculated as :

S/N = -10 log $_{10}$ (mean of sum of squares of measured data)

S/N = -10 log $_{10}$ $(\frac{1}{n}\sum_{i=1}^{n}(yi - m)^2)$

Where, y_i is the value of quality characteristics for the i^{th} test, m is the target value, n is number of measured data samples for one particular experiment.

The S/N ratio **higher-the-better** characteristics can be calculated as :

S/N = -10 log $_{10}$ (1/mean of sum of squares of measured data)

S/N = -10 log $_{10}$ $(\frac{1}{n}\sum_{i=1}^{n}\frac{1}{y2})$

Where, y_i is the value of quality characteristics for the i^{th} test, n is number of measured data samples for one particular experiment.

Ex No	Material Removal Rate (MRR) (mm3/min)	Electrode Wear Rate (EWR) (mm3/min)	S/N Ratio For MRR	S/N Ratio For EWR
1	3.8591	0.0219	11.7297	33.1911
2	10.4822	0.0957	20.4090	20.3818
3	10.6254	0.0507	20.5269	25.8998
4	11.8021	0.3283	21.4392	9.6746
5	13.9521	0.1594	22.8928	15.9502
6	15.5225	0.4134	23.8192	7.6726
7	12.1255	0.1653	21.6740	15.6345
8	15.0416	0.3005	23.5458	10.4431
9	19.4268	0.2232	25.7680	13.0261

Table 5. Response Table

(B) Influence on MRR:-
The response table for signal to noise ratio for material removal rate (MRR) is shown in table 6 and corresponding analysis of variance (ANOVA) table is shown in table 8.For MRR, the calculation of S/N ratio follows "Larger the better" model.

Calculation S/N ratios of Peak Current input factor for MRR are as follows:-

Level 1 of Peak Current (I_p) = $(S/N)_1 + (S/N)_2 + (S/N)_3$ / 3
= (11.7297 + 20.4090 + 20.5269) / 3
= 17.5552

Level 2 of Peak Current (I_p) = $(S/N)_4 + (S/N)_5 + (S/N)_6$ / 3
= (21.4392 + 22.8928 + 23.8192) / 3
= 22.7171

Level 3 of Peak Current (I_p) = $(S/N)_7 + (S/N)_8 + (S/N)_9$ / 3
= (21.6740 + 23.5458 + 25.7680) / 3
= 23.6626

Similarly, calculating S/N Ratio of three levels of Pulse-on Time (T_{on}), Gap Voltage (V_g) and Sensitivity.

Level	Peak Current (Ip)	Pulse on Time (Ton)	Gap Voltage (V)	Sensitivity
1	17.5552	18.2809	19.6982	20.1302
2	22.7171	22.2825	**22.5387**	**21.9674**
3	**23.6626**	**23.3714**	21.6979	21.8373
Delta	6.1074	5.0905	2.8405	1.8372
Rank	1	2	3	4

Table 6.Response Table for Signal-to-Noise Ratios for MRR

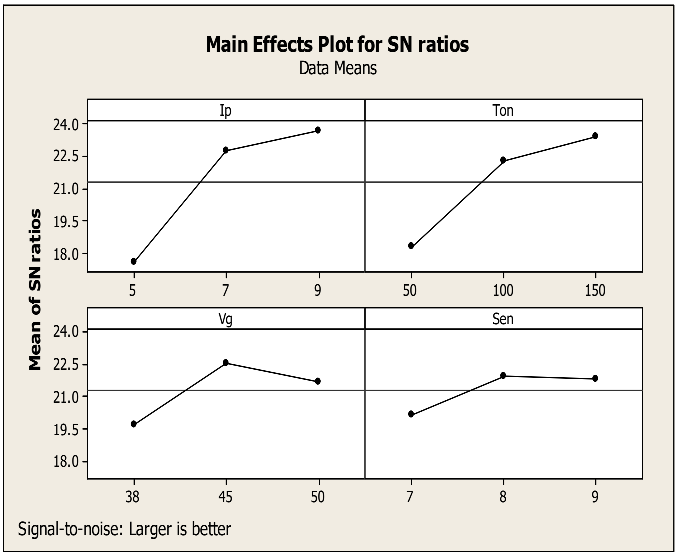

Fig 3.S/N Ratio curve for MRR with Ip, Ton, Vg, Sen

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The optimum parameter setting for MRR is shown in table:-

Physical Requirement	Ip	Ton	Vg	Sensitivity
Max. MRR	9	150	45	8

Table 7.Optimal combination for MRR

Calculation of Delta:
Delta = (Max. of S/N Ratio – Min. of S/N Ratio)
Delta of Peak Current (I_p) = (23.6626 – 17.5552) = 6.1074
Similarly calculating Delta for each input factor i.e. pulse-on time (T_{on}), Gap voltage (V_g) and Sensitivity (Sensitivity).

Sources	D.O.F.	Sum of Squares	Mean Square	% Contribution
Ip	2	64.8395	32.4198	**51.0419**
Ton	2	43.1117	21.5559	33.9377
Vg	2	12.7742	6.3871	10.0559
Sensitivity	2	6.3064	3.1532	4.9844
Total	8	127.0318	6.516	100

Table 8.Analysis Of Variance (ANOVA) for MRR

Sample calculations for table 8:-
Calculations of sum of squares for MRR of Peak Current (I_p) input factor is as follows:
From table 6,
$= (I_{p1} – I_{p2})^2 + (I_{p1} – I_{p3})^2 + (I_{p2} – I_{p3})^3$
$= (17.5552\text{-}22.7171)^2 + (17.5552\text{-}23.6626)^2 + (22.7171\text{-}23.6626)^2$
= 64.8395
Similarly, calculating sum of squares for MRR of Pulse-On Time (T_{on}), Gap Voltage (V_g), Sensitivity.

Calculating % contribution of Peak current (I_p) for MRR:
Total sum of squares = 127.0318
Sum of squares of Peak current = 64.8395
% Contribution of Peak current = (Sum of squares of Peak current / Total sum of squares) X 100
= (64.8395 / 127.0318) X 100
= 51.0419
Similarly, calculating % contribution of pulse-on time, gap voltage and sensitivity.

From Table 8, It is noted that factor Peak current (I_p) has the largest contribution to total sum of squares i.e. **51.0419 %**.So, peak current (I_p) has maximum effect on material removal rate , Pulse-on time (T_{on}) and Gap Voltage (V_g) have considerable effect on material removal rate whereas sensitivity has very less effect on MRR.

(C) Influence on EWR:-
The response table for signal to noise ratio for electrode wear rate (EWR) is shown in table 9and corresponding analysis of variance (ANOVA) table is shown in table 11. For EWR, the calculation of S/N ratio follows "Smaller the better" model.

Level	Peak Current (Ip)	Pulse on Time (Ton)	Gap Voltage (V)	Sensitivity
1	**26.4909**	**19.5001**	17.1023	**20.7225**
2	11.0991	15.5917	14.3608	14.5630
3	13.0346	15.5328	**19.1615**	15.3392
Delta	15.918	3.9673	4.8007	6.1595
Rank	1	4	3	2

Table 9.Response Table for Signal-to-Noise Ratios for EWR

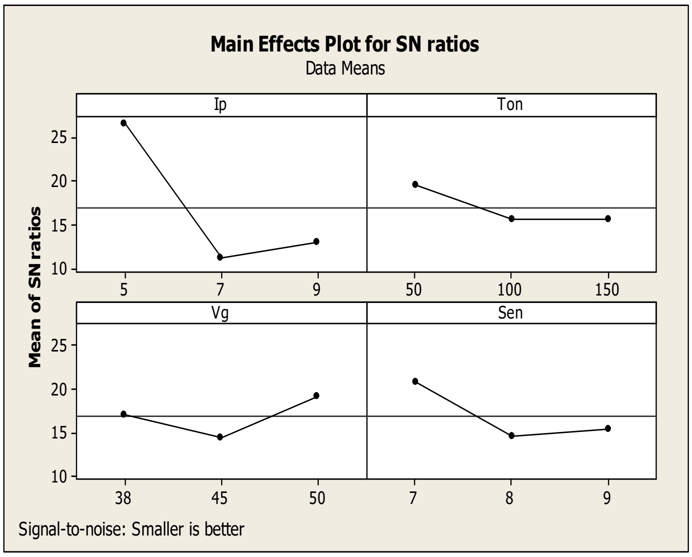

Fig 4. S/N Ratio curve for EWR with Ip, Ton, Vg, Sen

Calculation S/N ratio of Peak Current input factor for EWR is as follows:
Level 1 of Peak Current (I_p) = $(S/N)_1 + (S/N)_2 + (S/N)_3$ / 3
= (33.1911 + 20.3818 + 25.8998) / 3
= 26.4909
Level 2 of Peak Current (I_p) = $(S/N)_4 + (S/N)_5 + (S/N)_6$ / 3
= (9.6746 + 15.9502 + 7.6726) / 3
= 11.0991
Level 3 of Peak Current (I_p) = $(S/N)_7 + (S/N)_8 + (S/N)_9$ / 3
= (15.6345 + 10.4431 + 13.0261) / 3
= 13.0346
Similarly calculating S/N Ratio of three levels of Pulse-on Time (T_{on}), Gap Voltage (V_g) and Sensitivity. The optimum parameter setting for EWR is shown in table 10.

The optimum parameter setting for EWR is shown in table:-

Physical Requirement	Ip	Ton	Vg	Sensitivity
Min. EWR	5	50	50	7

Table 10. Optimal combination for EWR

Calculation of Delta :
Delta = (Max. of S/N Ratio – Min. of S/N Ratio)
Delta of Peak Current (I_p) = (26.4909 – 11.0991) = 15.3918
Similarly calculating Delta for each input factor i.e. pulse-on time (T_{on}), Gap voltage (V_g) and Sensitivity.

Sources	D.O.F.	Sum of Squares	Mean Square	% Contribution
Ip	2	421.7257	210.86	**75.9772**
Ton	2	31.0185	15.5093	5.5882
Vg	2	34.8028	17.4014	6.2194
Sensitivity	2	67.5218	33.7609	12.1646
Total	8	555.0688	277.5316	100

Table 11.Analysis Of Variance (ANOVA) for EWR

Sample calculations for table 11:-

Calculations of sum of squares for EWR of Peak Current (I_p) input factor from response table is as follows:

From table 9,

$= (I_{p1} - I_{p2})^2 + (I_{p1} - I_{p3})^2 + (I_{p2} - I_{p3})^3$

$=(26.4909-11.0991)^2 + (26.4909-13.0346)^2 + (11.0991-13.0346)^2$

$= 421.7257$

Similarly, calculating sum of squares for EWR of Pulse-On Time (T_{on}), Gap Voltage (V_g), Sensitivity.

Calculating % contribution of Peak current (I_p) for EWR:-

Total sum of squares = 555.0688

Sum of squares of Peak current = 421.7257

% Contribution of Peak current = (Sum of squares of Peak current / Total sum of squares) X 100

= (421.7257/ 555.0688) X 100

= 75.9772

Similarly, calculating % contribution of pulse-on time, gap voltage and sensitivity.

From Table 11, It is noted that factor Peak current (I_p) has the largest contribution to total sum of squares i.e. **75.9772%.**So, peak current (I_p) has maximum effect on electrode wear rate, sensitivity and Gap Voltage (V_g) have considerable effect on material removal rate whereas Pulse-on time(T_{on}) has very less effect on EWR.

7. CONCLUSIONS

The conclusion drawn from ANOVAare as follows :-

1. It is noted that factor Peak current (I_p) has the largest contribution to material removal rate. i.e. **51.04 %.** The factors Pulse-on time (T_{on}) and Gap Voltage (V_g) also have considerable contribution in total sum of squares which is 33.93 % and 10.05 % respectively. The factor sensitivity has much less contribution of 4.98 %.
2. It is noted that factor Peak current (I_p) has the largest contribution to electrode wear rate. i.e. **75.97 %.** The factor sensitivity and Gap Voltage (V_g) also have considerable contribution in total sum of squares which is 12.16 % and 6.21% respectively. The factor Pulse-on time(T_{on}) has much less contribution of 5.58 %.

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