Research Paper

PARAMETER OPTIMIZATION OF ELECTRO DISCHARGE MACHINING OF AISI D3 STEEL MATERIAL BY USING TAGUCHI METHOD

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ABSTRACT

In this paper, the cutting of D3 Steel material using electro discharge machining (EDM) with a copper electrode by using Taguchi methodology has been reported. The Taguchi method is used to formulate the experimental layout, to analyse the effect of each parameter on the machining characteristics, and to predict the optimal choice for each EDM parameter such as peak current, gap voltage, duty cycle and pulse on time. It is found that these parameters have a significant influence on machining characteristic such as material removal rate (MRR), electrode wear rate (EWR), radial overcut (ROC). The analysis using Taguchi method reveals that, in general the peak current significantly affects the MRR, EWR and ROC.

KEYWORDS: EDM, Taguchi method, D3 Steel, material removal rate, electrode wear rate, radial overcut.

INTRODUCTION:

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 technique has 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. 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 be machined with EDM include hardened tool-steel, titanium and carbide, Inconel etc. One critical limitation, however, is that EDM only works with materials that are electrically conductive.

EDM is a thermoelectric process in which heat energy of spark is used to remove material from the workpiece. The workpiece and the tool should be made of electrically conductive material. A spark is produced between the two electrodes (tool and workpiece) and its location is determined by the narrowest gap between the two.

Experimental Process:

AISI D3 steel material was the target material used in this investigation because no machining data of AISI D3 steel material is available. AISI D3 steel material is used for Blanking, Stamping & cold forming dies and punches for long runs. Bending, forming and seaming rolls. Burnishing dies or rolls. Drawing dies for bars and wires. Slitting cutters etc. Table 1 shows the material related properties. Experiments were performed using a electric discharge machine.

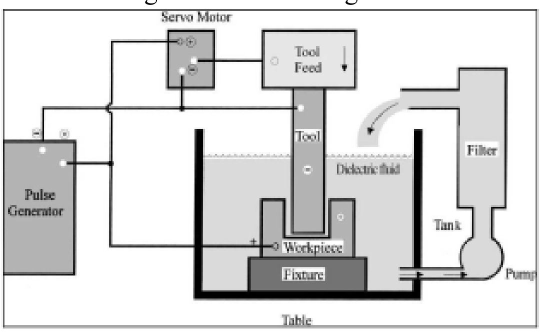

Fig: 1 Experimental set up

Figure 1 depicts schematically the experimental set up. A copper electrode with a diameter of 9.5mm was used as an electrode to erode a workpiece of D3 Steel.

Table 1: Material properties of D3 Steel material

Sr.No.	Parameter	Value
01	Poisson's ratio	0.27 – 0.30
02	Brinell Hardness	212-248
03	Elastic modulus	190 – 210 GPa
04	Density kg/cu m	7700

EDM oil was used as a dielectric fluid in this experiment. Diameter of electrode and thickness of workpiece is measured by digimatic micrometer. (Make: Mitutoyo, Least count: 0.001 mm). Weight of workpiece is measured by Precisa-make weighing machine (Accuracy: 0.1mg).

Principle of EDM:- Electric discharge machining is a controlled metal removing technique whereby an electric spark is used to cut the workpiece, which takes a shape opposite to that of the cutting tool or electrode. The electrode is made from electrically conductive material. The electrode, made to the shape of the cavity required, and the workpiece are both submerged in a dielectric fluid. Dielectric fluid should be nonconductor of electricity. A servo mechanism maintains a gap of about 0.01 to 0.02mm between the electrode & the workpiece, preventing them from coming into contact with each other. A direct current of low voltage & high amperage is delivered to the electrode at the rate of approximately 50 KHz. These electrical energy impulses vaporize the oil at this point. This permits the spark to jump the gap between the electrode and the workpiece through the dielectric fluid. Intense heat is created in the localized area of the spark impact, the metal melts and a small particle of molten metal is expelled from the surface of the workpiece. The dielectric fluid which is constantly being circulated carries away the eroded particles of metal during the off cycle of the pulse and also assists in dissipating the heat caused by the spark.

Design of Experiments:-

Taguchi Method:

Taguchi methods are the most recent additions to the toolkit of design, process and manufacturing engineers, and quality assurance experts. In contrast to statistical process control, which attempts to control the factors that adversely affect the quality of production, Taguchi methods focus on design – the development of superior performance designs (of products and manufacturing processes) to deliver quality.

An experimental design scheme of statistical experiments that uses orthogonal arrays however entails the following considerations and consequences: -

- The orthogonal array leads only to a main effect design. Use of an orthogonal array forces the investigator to assume that the response one observe can be approximated by an additive function, separable into the effects of the individual (main) control factors under study. One assumes no other effects, in particular no interactions, to be present. A verification experiment can later verify whether this approximation is satisfactory and a valid one.
- The columns of the orthogonal arrays are pair wise orthogonal. In every pair of columns, all combinations of the levels of each (independent) factor under study occur and they do so equal number of times.
- It follows from no. 2 that the main effect estimates of all factors and their associated sum of squares are independent under the assumption of normality and equality of observation variance. Hence the significance test (ANOVA) for these factors are independent.
- When orthogonal array guides the experiments, one computes the main factor effect. These computed effect may be then used to predict the response for any combination of factor treatments, because one assumes that these effects are separable and additive.
- The variance of the prediction error (caused by factors not controlled in the experiments and the exclusion of interactions) is the same for all such treatment combinations.
- Factors which are studied may be discrete or continuous. For continuous factors it is possible to break down main effects of three level factors into linear and quadratic terms. A non-linear effect may sometimes be useful in fine tuning and improving the initial design.
- In the initial stages of optimization, one may limit the investigation to the study of main effect. Later on, it is possible to run larger orthogonally designed experiments to study interaction effects also, if necessary.

Signal to Noise Ratio:

Classical experimental design methods are too complex and not easy to use. Furthermore, a large number of experiments have to be carried out as the number of the process parameters increases. To solve this important task, the Taguchi method uses a special design of orthogonal array to study the entire parameter space with only a small number of experiments. The experimental results are then transformed into a signal-to-noise (S/N) ratio. The S/N ratio can be used to measure the deviation of the performance characteristics from the desired values. The categories of performance characteristics in the analysis of the S/N ratio depend upon output parameters to be controlled. We have selected two categories which are as follows.

- The lower-the-better for EWR & ROC
- The higher-the-better for MRR

Regardless of the category of the performance characteristic, a larger S/N ratio corresponds to better performance characteristic. Therefore, the optimal level of the process parameters is the level with the highest S/N ratio.

Design of Experiment for EDM of AISI D3 Steel Material:

The design of experiment (D.O.E.) chosen for the electric discharge machining of AISI D3 steel was a Taguchi L9 orthogonal array, by carrying out a total number of 9 experiments along with 4 verification experiments (optional).

L9 Orthogonal Array:

In L9 (3^4) array 9 rows represent the 9 experiment to be conducted with 4 columns at, 3 levels of the corresponding factor. The matrix form of these arrays is shown in Table 3.1, where 1, 2, 3 in the table represents the level of each parameters.

Input Factors:-

1) Pulse – On Time (T_{on}),
2) Peak Current (I_p),
3) Duty Cycle (t),
4) Gap Voltage (V_g).

Responses measured:-

1) Material Removal Rate (MRR),
2) Electrode Wear Rate (EWR),
3) Overcut,(ROC)

Table2: Taguchi L9 Orthogonal array Design Matrix

Exp. No.	Factor 1	Factor 2	Factor 3	Factor 4
E1	1	1	1	1
E2	1	2	2	2
E3	1	3	3	3
E4	2	1	2	3
E5	2	2	3	1
E6	2	3	1	2
E7	3	1	3	2
E8	3	2	1	3
E9	3	3	2	1

Table3: Level values of input factor

Sr.No	Factors	Levels		
		1	2	3
1	T_{on}(µs)	75	100	150
2	I_p (Amp)	8	12	16
3	t	8	10	12
4	Vg (volt)	50	55	60

Table 4: L9 Design Matrix

Exp. No.	T_{on}(µs)	I_p (Amp)	t	Vg (volt)
E1	75	8	8	50
E2	75	12	10	55
E3	75	16	12	60
E4	100	8	10	60
E5	100	12	12	50
E6	100	16	8	55
E7	150	8	12	55
E8	150	12	8	60
E9	150	16	10	55

Table5: Experimental Results & Calculation of Various Response Factors based on Taguchi L9 Orthogonal Array

Exp. No.	MRR (gm/min)	EWR (gm/min)	ROC (mm)
E1	0.0661	0.000931	0.140
E2	0.0803	0.004217	0.145
E3	0.1024	0.005944	0.165
E4	0.0812	0.001171	0.145
E5	0.1094	0.003333	0.150
E6	0.1000	0.006528	0.200
E7	0.0649	0.000376	0.135
E8	0.0948	0.002233	0.185
E9	0.1014	0.003175	0.195

Where,

ROC= (Top dia. of hole- Electrode dia.) / 2 And,

Table 6 : Calculation of Signal to Noise ratio for Various Response Factors

Exp. No	S/N Ratio for MRR	S/N Ratio for EWR	S/N Ratio for ROC
E1	-23.5959	60.6210	17.0774
E2	-21.9057	47.4999	16.7726
E3	-19.7940	44.5184	15.6503
E4	-21.8089	58.6289	16.7729
E5	-19.2196	49.5433	16.4782
E6	-20.000	43.7044	13.9794
E7	-23.7551	68.5194	17.3933
E8	-20.4638	53.0222	14.6566
E9	-19.8792	49.9651	14.1993

Analysis of Experimental Data:

Effect of input factors on MRR:

The response table for signal to noise ratio for MRR is shown in Table 7 and the corresponding ANOVA table is shown in Table 8.For MRR, the calculation of S/N ratio follows "Larger the Better "model

Table 7: Response Table for Signal to Noise Ratios for MRR

Level	T_{on}	I_p	t	Vg
1	-21.7652	-23.0533	-21.3532	-20.8982
2	-20.3428	-20.5297	-21.1979	-21.8869
3	-21.3660	-19.8911	-20.9229	-20.6889
Delta	1.4224	3.1622	0.4303	1.196
Rank	2	1	4	3

Table 8: ANOVA for MRR

Sources	D.O.F.	Sum of squares	Mean square	% contribution
T_{on}	2	3.2295	1.61475	14.20
I_p	2	16.7759	8.38795	73.75
t	2	0.2849	0.14245	1.25
Vg	2	2.4565	1.22825	10.80
Total	8	22.7468		

Therefore, peak current (I_p) have the maximum effect on material removal rate.

Effect of input factors on EWR:

The response table for signal to noise ratio for EWR is shown in Table 9.and the corresponding ANOVA table is shown in Table 10. For EWR, the calculation of S/N ratio follows "Smaller the Better" model

Table 9: Response Table for Signal to Noise Ratios for EWR

Level	T_{on}	I_p	t	Vg
1	50.8798	62.5898	52.4492	53.3765
2	50.6255	50.0218	52.0313	53.2412
3	57.1689	46.0626	54.1937	53.0565
Delta	6.5434	16.5272	2.1624	1.32
Rank	2	1	3	4

Table 10: ANOVA for EWR

Sources	D.O.F.	Sum of squares	Mean square	% contribution
T_{on}	2	82.4335	41.21675	15.26
I_p	2	446.7782	223.3891	82.70
t	2	7.8939	3.94695	1.46
Vg	2	3.1642	1.5821	0.58
Total	8	540.2698		

Therefore, peak current (I_p) have the maximum effect on electrode wear rate.

Effect of input factors on ROC:

The response table for signal to noise ratio for ROC is shown in Table 11.and the corresponding ANOVA table is shown in Table 12. For ROC, the calculation of S/N ratio follows "Smaller the Better" model.

Table 11: Response Table for Signal to Noise Ratios for ROC

Level	T_{on}	I_p	t	Vg
1	16.5001	17.0811	15.2378	15.9183
2	15.7434	15.9691	15.9148	16.0484
3	15.4164	14.6097	16.5073	15.6932
Delta	1.0837	2.4714	1.2695	0.3552
Rank	3	1	2	4

Table 12: ANOVA for ROC

Sources	D.O.F.	Sum of squares	Mean square	% contribution
T_{on}	2	1.8539	0.9269	13.57
I_p	2	9.1923	4.5961	67.29
t	2	2.4210	1.2105	17.72
Vg	2	0.1938	0.0969	1.42
Total	8	13.661		

Therefore, peak current (I_p) have the maximum effect on ROC.

Experimental Verification:-

After performing the statistical analysis on the experimental data, it has been observed that there is one particular level for each factor for which the responses are either maximum (in case of MRR) or minimum (in case of EWR and ROC). The signal to noise ratio (S/N ratio) of each responses corresponding to each factor level also has a maximum and a minimum value. So for finding the optimum parameter setting for each response factors, the additive model of Taguchi method is used. S/N ratio is calculated based on the formula containing negative of logarithmic value, which is a monotonic decreasing function. So S/N ratio should be always kept at maximum value. Therefore in finding the optimum parameter setting, the levels of input factors are chosen in such a way that the S/N ratios for those levels have maximum values (for each input factor).

There are four optimum parameter settings corresponding to the four response factors. The combination of input factor levels, for which optimum settings will be obtained, is given in Table 13.

Table13: Optimal Parameter Settings of Input Factors

Physical Requirement	Optimal Combination			
	T_{on}	I_p	t	Vg
Maximum MRR	100	16	12	60
Minimum EWR	150	8	12	50
Minimum ROC	75	8	12	55

Using these four optimum parameter settings, three verification experiments has been carried out and the experimental results are shown in Table 14.

Table 14: Verification Experimental Results & Calculation of Various Response Factors.

Verification Exp. For	MRR	EWR	ROC
Max.MRR	0.1161	0.00361	0.12
Min. EWR	0.0546	0.00264	0.11
Min.ROC	0.0476	0.00806	0.09

Results & Discussion:

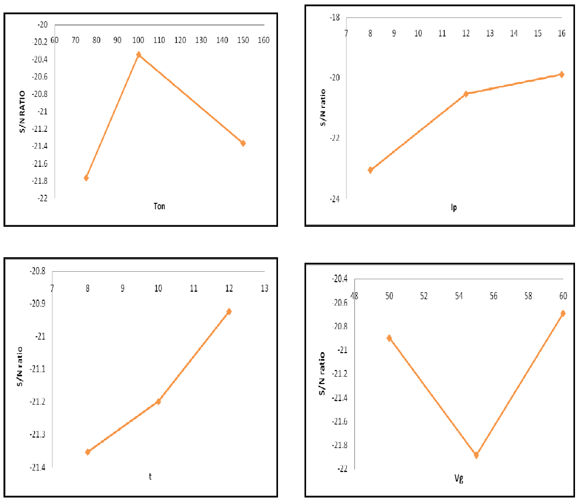

Fig. 2:- S/N Ratio Curve for MRR

From fig.2: By increasing the peak current (Ip) high MRR can be achieved

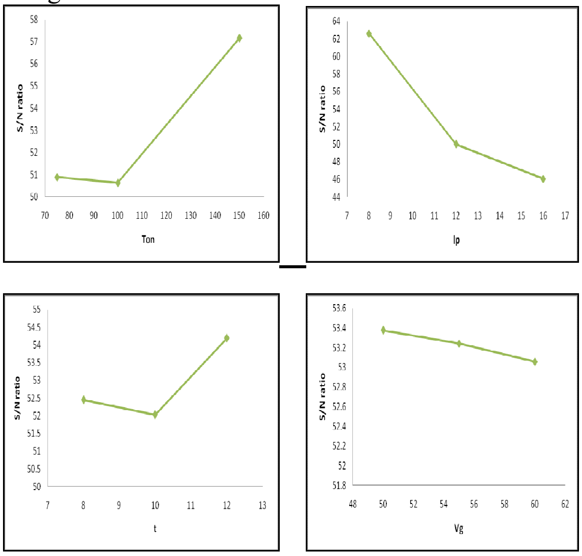

Fig. 3:- S/N Ratio Curve for EWR

From fig.3: EWR increases when the peak current (Ip) is increases.

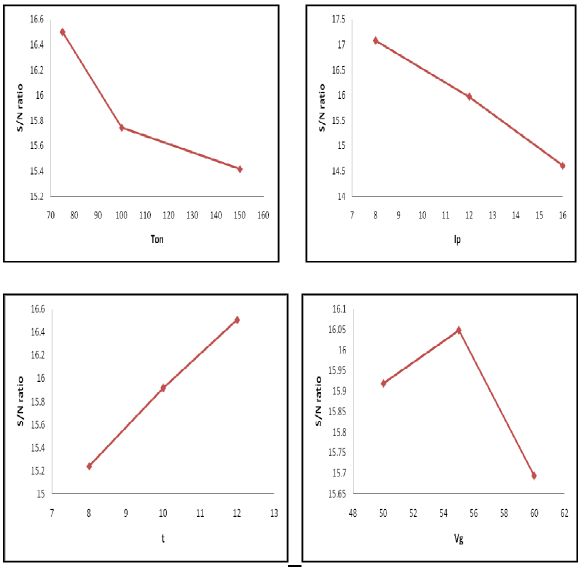

Fig. 4:- S/N Ratio Curve for ROC

From fig.4: ROC increases when the Peak current (Ip) is increases.

- From Table No.14 experiment of minimum ROC is the optimum set of input factors because the value of minimum ROC is within the required range because the ROC is the required qualitative output parameters.

CONCLUSION:-

- The material removal rate (MRR) mainly affected by peak current (Ip). Duty cycle (t) has least effect on it.
- The electrode wear rate (EWR) is mainly influenced by peak current (Ip). The effect of gap voltage (V_g) is less on EWR and has least effect on it.
- Peak current (Ip) have the maximum effect on the radial overcut (ROC). The gap voltage (Vg) has least effect on it.
- Optimum parameters of input factors are as follows;

  Ton: 75 µs Ip:8 Amp t:12 Vg:55volt
- In Taguchi L9 orthogonal matrix experiment, no interactions between the input factors are considered. But some interaction effect may be present during the experiment. This may result in some observations which do not go with the theoretical belief.
- Some portion of the material is conductive and some portion is non-conductive. But EDM requires conductive workpiece. So the composite properties of the workpiece may also lead to some observations which contradict the theoretical belief.

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