Optimization of EDM Machining Parameters Process (Through ANOVA & Taguchi Methods)

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Abstract:

This paper has been reported the complexity of electrical discharge machining process which is very difficult to determine optimal cutting parameters for improving cutting performance. An optimization of the operating parameters is an important step in machining, particularly for operating unconventional machining procedure like EDM and a suitable selection of machining parameters for the electrical discharge machining process relies heavily on the operators' technologies and experience because of their numerous and diverse range. The Machining parameters tables provided by the machine tool builder cannot meet the operators' requirements, since for an arbitrary desired machining time for a particular job; they do not provide the optimal machining conditions. The researchers in this paper proposed an approach to determine the parameters setting for an optimization. With the help of Taguchi parameter design method and the Analysis Of Variance (ANOVA), the significant factors affecting the machining performance such as total machining time, oversize and taper for a hole machined by EDM process, are determined.

Key Words: Taguchi method, ANOVA, EDM, Optimization.

Introduction:-

Electrical Discharge Machining (EDM) was first introduced in the 1940's as a crude device used to cut broken machining tools from expensive in-process parts. Since that time EDM has become a sophisticated and indispensable technology, revolutionizing the tool, die, and mould making industries, and making significant inroads into the production of highly accurate, intricate and difficult to machine production parts. The Electro Discharge Machining (EDM) is an electro-thermal non-traditional machining process, where electrical energy is used to generate electrical spark and material removal mainly occurs due to thermal energy of the spark. The EDM is mainly used to machine difficult-to-machine materials and high strength temperature resistant alloys. EDM can be used to machine difficult geometries in small batches or even on job-shop basis. Work material to be machined by EDM has to be electrically conductive.

Electric Discharge Machining

The Electric discharge machining (EDM) is a manufacturing process whereby a desired shape is obtained using electrical discharges (sparks). Material is removed from the work piece by a series of rapidly recurring current discharges between two electrodes, separated by a dielectric liquid and subject to an electric voltage. One of the electrodes is called the tool-electrode, or simply the 'tool' or 'electrode', while the other is called the work piece-electrode, or 'work piece'.When the distance between these two electrodes is reduced, then the intensity of the electric field in the volume between the electrodes becomes greater than the strength of the dielectric (at some point(s)), this breaks, allowing current to flow between the two electrodes. The same phenomenon is the same as the breakdown of a capacitor (condenser) (see also breakdown voltage).

Hence as a result, the material is removed from both the electrodes. When the current flow stops, a new liquid dielectric is usually conveyed into the inter-electrode volume enabling the solid particles (debris) to be carried away and the insulating proprieties of the dielectric to be restored. This adding new liquid dielectric in the inter-electrode volume is commonly referred to as flushing. And also, after a current flow, a difference of potential between the two electrodes is restored to what it was before the breakdown, so that a new liquid dielectric breakdown can occur. The researchers in this work tried to investigate the erosion behaviour of Stainless Steel & Aluminium in an EDM. It is important to select process parameters and study the effect of these parameters on responses. Normally, the desired fused deposition modelling process parameters are determined based on experience or referring to machine manual/handbook. But, this does not ensure always that the selected process parameters result in optimal or near optimal response for that particular FDM machine and environment. Hence, an alternative approach based on the Taguchi method is used in this study as an efficient method to determine the optimal process parameters. As a result, this method provides a simple and systematic approach to optimizing designs for performance, quality and cost.

Objectives of study:

- To investigate erosion characteristics of Stainless Steel and Al empirically.
- To compare the MRR (i.e. material removal rate) of the work piece.
- To validate the Taguchi's additive method.

Material used:

The work material, electrode and the other machining conditions were as follows:-

(1) The Work piece (anode), Stainless Steel 340C and Aluminium;

(2) The Electrode (cathode), Tungsten Ø 1.6mm;

(3) The Dielectric fluid, Kerosene, EDM oil;

(4) The Work piece height 50 mm, length also 50mm and same for both materials;

A total of two machining parameters (current and feed) were chosen for the controlling factors.

Experimentaldetails:

The Electric discharge machining is a non-conventional machining process in which material is removed from the workpiece by a repetitive spark discharge between two electrodes separated by a small gap known as spark gap. EDM tool and the workpiece are immersed in a dielectric fluid. A schematic representation of basic working principle of EDM process is shown in Figure 1 and EDM set up is shown in Figures 2 and 3.

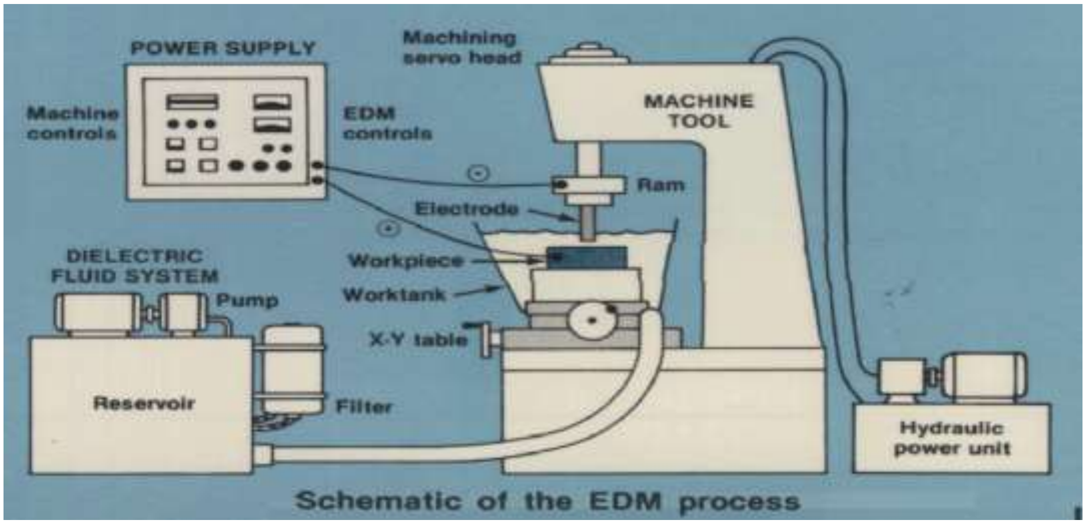


Figure 1: Schematic diagram of EDM process

2: EDM apparatus Figure 3: Flushing position in EDM machine

Under an EDM, a potential difference is applied between the tool and workpiece. Here both the tool and the work material are to be conductors of electricity and the setup is immersed in a dielectric medium i.e. the EDM oil for the setup.A gap is maintained between the tool and the work piece and it is maintained as per the applied potential difference for which an electric field is established for the process.

In the setupnegative terminal of the generator is connected to the tool and the work piece is connected to positive terminal of the generator. Once the gap is maintained the potential difference is established between the tool and the work piece by creating electrostatic forces from the free electrons. In the setup electron is emitted from the tool to the work piece, if the electron emission is less it is termed as cold emission and these electrons are accelerated through the dielectric medium towards the work piece.
The accelerated electron gain energy, velocity and moves towards the work piece before that collisions between the electron and dielectric molecules result in ionisation of the dielectric molecule and electron.
These accelerated electron get more positive ions and electrons generated due to collision.
These continuous processes would increase the concentrate of electron and ion in the dielectric medium between the work piece and tool at the spark gap.
This concentrated of electron is so high that a large number of electron flow from tool to work piece and ion from work piece to tool and the flow is called Avalanche motion of electron which can be visible as a spark thus electrical energy is called as a dissipated thermal energy of the spark.
The high speed electron impinge on the work piece and ions on the tool converting thermal energy or heat flux. These localised heat flux can be increased to a temperatureupto $10{,}000^0$C to intense the heat flux by this rise in temperature leads to material removal.
The material removals occur by generating pressure or shock waves and evacuate molten material forming a carter of removed material around the site of spark from the work piece.
The previous research suggests that major part of quality output of EDM processed part primarily depends on few control factors. On the basis of these exhaustive literature review, three important control factors such as input current (I_p), spark on time (T_{on}) and duty factor (Tau) are considered to study their influence on erosion behaviour of EDM processed component.

The selected control parameters and their values at different levels are listed in Table 1.

Table 1: Parameters and their levels

Parameters	Symbol	level-1	level-2	level-3	Unit
I_p	A	4	7	10	Ampere
T_{on}	B	100	200	300	Seconds
T_{au}	C	7	8	9	-

The study of three factors each at three level requires more number of experiments if classical design of experiment is used but same statistically valid results can be obtained if Taguchi method is adopted with lesser number of experiments. For design of experiment approach, Taguchi's orthogonal array is important for obtaining valid conclusions. In this present study, the appropriate orthogonal array is L_9. The EDM process parameters showing their values at three levels using L_9 orthogonal array are presented in Table 2.

Table 2: Experimental plan using L_9 orthogonal array

Experiment Number	EDM parameters		
	A	B	C
1	4	100	7
2	4	200	8
3	4	300	9
4	7	100	7
5	7	200	8
6	7	300	9
7	10	100	7
8	10	200	8
9	10	300	9

Methodology:

The Taguchi Method is a new engineering design optimization methodology that improves the quality of existing products and processes and simultaneously reduces their costs very rapidly, with minimum engineering resources and development man-hours. It achieves this by making the product or process performance "insensitive" to variations in factors such as materials, manufacturing equipment, workmanship and operating conditions.

(i) Taguchi's design of experiment

The Taguchi methods are the most recent additions to the toolkit of design, process and manufacturing engineers, and quality assurance experts. Contrast to the 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.

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

1) Anorthogonal 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. It assumed no other effects, in particular no interactions, to be present. Than verification experiment can later verify whether this approximation is satisfactory and a valid one.

2) 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.

3) 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 tests (ANOVA) for these factors are independent.

4) While orthogonal array guides the experiments, one computes the main factor effect. The 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.

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.

5) The factors which are studied may be discrete or continuous and for continuous factors it is possible to break down main effects of three level factors into linear and quadratic terms, where a non-linear effect may sometimes be useful in fine tuning and improving the initial design.

6) During 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.

The Taguchi method design is used for finding the optimal setting of the controllable process parameter.

An orthogonal array is selected and used for design of experiment plan and the experiments are carried out to design plan. An MRR analysis has been made and Analysis of Variance(ANOVA)test and conformation test have been carried out to judge the adequacy of the additive model for optimal prediction with Taguchi method based on main effect plot diagram and ANOVA ,the optimal combination between I_P , T_{on} , T_{au} for achieving maximum MRR has been determined.

To observe the influence of control factors such as current (A), on time (B) and tau(C) in EDM and three level of each factor are considered for the material removal rate response. A selected process parameters and the values are taken with total degree of freedom (DOF) for 3 factors at levels and each is calculated with the available standard orthogonal array L_9 for three level factors.L_9 (3) orthogonal array is used to deal with 3 level factors by carrying out experiments for 3 setting and each setting is repeated for 3 times thereby decreasing cost, time and effort compared with full factorial design. Therefore a number of experiments are reduced to the great extent.

(ii) Main effect plot and ANOVA

An Experimental analysis is made using Minitab R14 software. The main effect of process parameter on metal erosion was determined and the analysis was done by averaging the measured value at each level of each parameter and plotted the value in graphical form and the highest values of these plots correspond to the optimum condition. A significant effect of the selected EDM process parameters on the selected performance characteristics have been investigated through analysis of variance (ANOVA). An optimum condition for each of the performance characteristics have been determined by main factor effect plot and the results of the MRR between the two workpiece materials have been analysed using Taguchi method.

(iii) MRR Calculation

EDM material removal occurs mainly due to intense localised heating almost by paint heat source for a rather small time frame , which lead to melting and crater formation .the molten crater assumed to be hemispherical in nature and is generated by a single pulse or spark. During this the energy generated in single spark is get lost in heating dielectric fluid and test is distributed between impinging electronics and ions. Practically, it has been observed that MRR increases with increase in working voltage, current, pulse on time and decrease in pulse off time. Normally, material removal rate is defined as the volume of material removed per unit time and is expressed as:

$$MRR = \frac{\text{Initial weight} - \text{Final weight}}{\text{Density of work piece(D)} \times \text{Time(t)}}$$

Under the present study, erosion behaviour of stainless steel and aluminium with parameters keeping constant for both have been studied.

Results and discussion:

Experimental results showing MRR of stainless steel and Aluminium using Table 2 are presented in Table 3 and 4.

Table 3: MRR of stainless steel

Sl NO.	**Ip**	**Ton**	**Tau**	**Indent No**	**Initial Wt.**	**Final Wt.**	**MRR=(Int-Fin)/(t*D)**
1	4	100	7	*1*	116.9	116.688	5.401
2	4	200	8	*2*	114.185	113.965	5.605
3	4	300	9	*3*	116.688	116.467	5.630
4	7	100	9	*4*	113.965	113.399	14.420
5	7	200	7	*5*	113.59	113.153	11.133
6	7	300	8	*6*	110.881	110.542	8.636
7	10	100	8	*7*	113.153	112.45	17.910
8	10	200	7	*8*	110.542	109.765	19.796
9	10	300	9	*9*	109.765	109.15	15.668

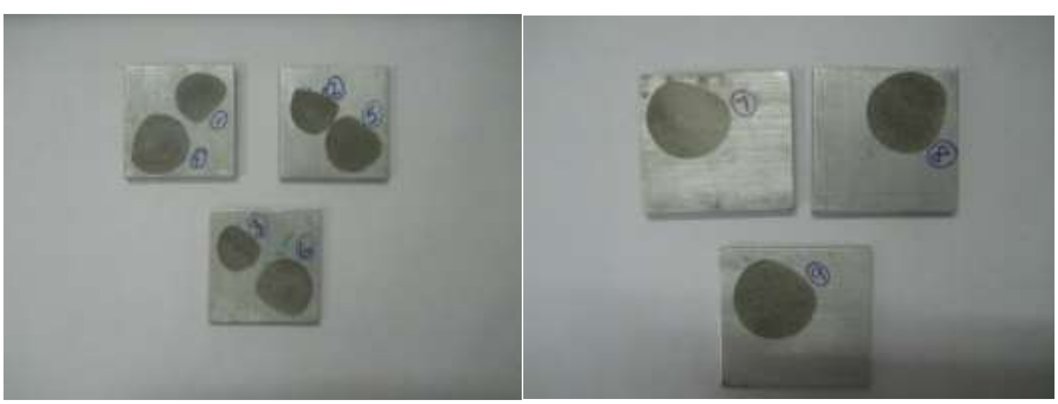
Table 4: MRR of Aluminium

Sl NO.	Ip	Ton	Tau	Indent No	Initial Wt.	Final Wt.	MRR=(Int-Fin)/(t*D)
1	4	100	7	*1*	43.799	43.629	12.592
2	4	200	8	*2*	43.291	43.173	8.740
3	4	300	9	*3*	43.479	43.378	7.481
4	7	100	9	*4*	43.629	43.098	39.333
5	7	200	7	*5*	43.173	42.803	27.407
6	7	300	8	*6*	43.378	43.013	27.037
7	10	100	8	*7*	43.098	42.375	53.555
8	10	200	7	*8*	42.803	42.026	57.555
9	10	300	9	*9*	43.013	42.365	48.000

Surfaces of the stainless steel and Aluminium are machined at a flushing pressure of 0.2 kg/cm^2 as shown in Figures 4 and 5 and the corresponding material removal rates are obtained (Table 3 and 4).

Figure 4: Machined surfaces of stainless steel with indent numbers

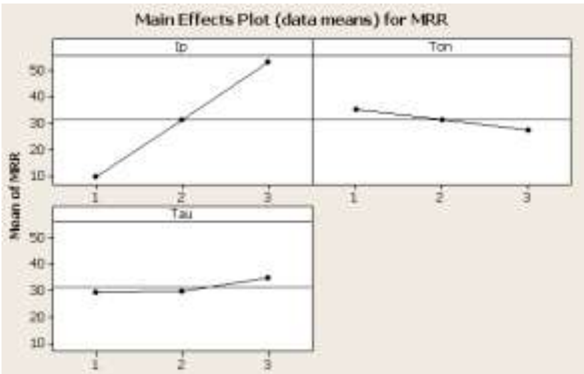
Figure 5: Machined surfaces of Aluminium with indent numbers



The main effect plot for MRR of stainless steel and Aluminium are shown in Figures 6 and 7 and ANOVA for both are presented in Table 5 & 6.

In the Figure 6, the optimum factor level for MRR of stainless steel have found to be I_p -3, T_{on} -1 and Tau -3 and from Figure 7, the optimum factor level for MRR of aluminium have found to be I_p -3, T_{on} -1 and Tau -3.

Figure 6: Main effect plot for MRR of stainless steelFigure 7: Main effect plot for MRR of aluminium



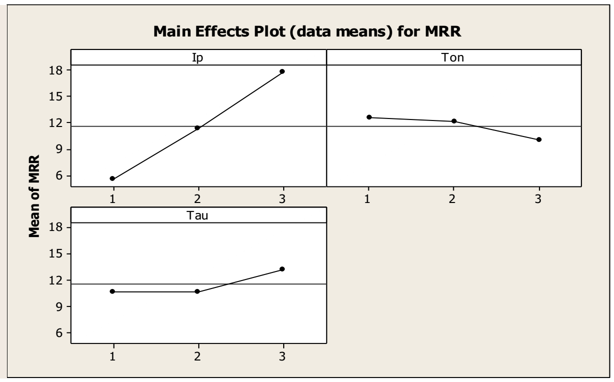


Table 5: ANOVA for MRR of stainless steel

Analysis of Variance for MRR, using Adjusted SS for Tests

Source	DF	Seq SS	Adj SS	Adj MS	F	P
Ip	2	225.107	225.107	112.553	389.24	0.003
Ton	2	11.748	11.748	5.874	20.31	0.047
Tau	2	13.068	13.068	6.534	22.60	0.042
Error	2	0.578	0.578	0.289		
Total	8	250.501				

S = 0.537736 R-Sq = 99.77% R-Sq(adj) = 99.08%

Table 6: ANOVA for MRR of aluminium

Analysis of Variance for MRR, using Adjusted SS for Tests

Source	DF	Seq SS	Adj SS	Adj MS	F	P
Ip	2	2829.56	2829.56	1414.78	187.42	0.005
Ton	2	87.91	87.91	43.96	5.82	0.147
Tau	2	55.09	55.09	27.55	3.65	0.215
Error	2	15.10	15.10	7.55		
Total	8	2987.66				

S = 2.74748 R-Sq = 99.49% R-Sq(adj) = 97.98%

In the Table 5, I_p has most significant effect than T_{on} and Tau on MRR of stainless steel and from Table 6, I_p significantly affect the MRR of aluminium whereas T_{on} and Tau are insignificant.

Confirmation Test:

	I_p	T_{on}	T_{au}	Initial	Final	MRR
10-stainless steel	10	100	9	112.434	111.656	19.949
10- Aluminium	10	100	9	42.356	41.548	60

As per the results of confirmation test, it has been observed that material removal rate of aluminium is high as compared to stainless steel in EDM. Also, small error in the tune of 2-3% indicates that Taguchi's design of experiment is smooth and the proposed additive method is valid.

Conclusions:

With carrying out experimental investigations on the selected optimal combination of process parameters on EDM characteristics, specifically MRR, the following conclusions can be drawn:

(1) The optimal process parameters for MRR of stainless steel:
I_p – 10 ampere, T_{on} – 100 sec and Tau – 9.
The optimal process parameters for MRR of aluminium:
I_p – 10 ampere, T_{on} – 100 sec and Tau – 9.

(2) Input current is the main significant factor for affecting the MRR.

(3) The proposed Taguchi’s additive is effective and valid.

Future Scope of the research

The scope of this novel and efficient methodology will open up further scope of optimisation of EDM performance characteristics considering larger number of process parameters and their interactions with faster rate and accuracy.

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