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# OPTIMIZATION OF EDM PROCESS PARAMETERS USING TAGUCHI METHOD FOR MACHINING OF HSS

**Senthil J*, Rajasekaran D**
Mechanical Engineering, AarupadaiVeedu Institute of Technology, Vinayaka Missions University
***Corresponding author: Email: jsenthil@avit.ac.in**

## ABSTRACT

The objective of this study is to optimize the various process parameters such as duty cycle, current and flushing in electrical discharge machining on High Speed Steel. The effect of these parameters on material removal rate is analysed using ANOVA. Taguchi method is used in experimental design. ANOM is used to find the optimal level of process parameters. Based on ANOVA it was observed that the duty cycle is the most significant process parameter which increases MRR, while machining on HSS, in EDM. Optimized process parameters leading to higher material removal rate are then verified through a confirmation experiment.
**Keywords**: Electric Discharge Machining, ANOM, ANOVA, Orthogonal array and MRR.

## INTRODUCTION

Electric discharge machining (EDM) is a non-conventional thermo-electric process used for machining hard to cut materials such as Titanium, ceramics, HSS etc. Electric spark is generated in the gap between electrode and work piece for melting and vapourising the material which is removed by dielectric fluid flow in the gap.This process depends on various process parameters like duty cycle, current, voltage, electrode gap, tool material, work material etc. Output parameters such as MRR, TWR and SR depend on these input parameters. By optimizing these process parameters better output characteristics can be obtained on various materials.

S.Raguraman,K.Thiuppathi andSanthosh.S studied EDM process optimization with copper electrode for machining M.S using Taguchi method and Grey rational analysis. They observed that the MRR increases with increase in pulse on time. N.Natarajan and R.M. Arunachalam studied EDM process optimization with brass electrode for machining stainless steel 304, using Taguchi method and Grey rational analysis. They found that the increase in pulse on time increases MRR and OC. In this study the input parameters duty cycle, current and flushing were optimized using ANOM and ANOVA for better Material Removal Rate (MRR) on HSS.

## MATERIALS AND METHODOLOGY

**A.Machine and material:** A series of experiments were conducted on Electronica make EDM machine. A copper rod of 6mm diameter is used as electrode to machine a work piece made of HSS of size 60x20x20. Kerosene derivative is used as dielectric medium. The properties of electrode and work piece material are shown in Table I.

**Table.1.Properties of Electrode and Work materials**

| Properties | Copper (Electrode) | HSS ( Work piece) |
|---|---|---|
| **Melting Point** | 1084.62˚C | 1550˚C |
| **Elastic Modulus** | 128 GPa | 207 GPa |
| **Poisson's ratio** | 0.34 | 0.28 |
| **Density** | 8.96 gm/cm$^3$ | 8.138 gm/cm$^3$ |
| **Thermal Conductivity** | 401 W/mK | W/mK |

**B. Selection of process and response parameters:** Duty cycle, pulse current and flushing are taken as control parameters. Material removal rate (MRR) is the response parameter. Three levels are chosen for each input parameter. Chosen parameters and their levels are given in Table II.

**Table.2.Process parameters and their levels**

| Levels | Control parameters | | |
|---|---|---|---|
| | A | B | C |
| | Duty cycle | Current | Flushing |
| 1 | 21–9(70%) | 15 amps | 3.5 lpm |
| 2 | 24–6(80%) | 20 amps | 5.0lpm |
| 3 | 27-3 (90%) | 25 amps | 6.5Lpm |

**B1.Material Removal rate (MRR):** The material removal rate is the volume of material removed per minute. It is calculated using the formula given below.

$$MRR = \frac{(W_i - W_f)*1000}{(D_w * t)} \quad (1)$$

MRR – Material removal rate (mm$^3$/min)
$W_i$ - Initial mass of work piece (gm)
$W_f$– Final mass of work piece (gm)

$D_w$ - Density of work piece ($gm/mm^3$)

t – Machining time (min)

**C. Experimental Method:** Taguchi method is used to design the experiments for investigating how different parameters affect the various performance characteristics. The main objective of this method is to produce high quality in machining at low cost. Taguchi method is used to identify parameter settings which give quality in the process. The steps involved in Taguchi parameter design are selecting proper orthogonal array, conducting experiments based on orthogonal array, analysing data, identifying optimum conditions and conducting confirmation experiment with optimum conditions. In this study we select $L_9$ orthogonal array to design the set of process parameters to evaluate the process performance.The experimental combination of machining parameters using $L_9$ orthogonal array are shown in Table III.

**Table.3.L9 Orthogonal array**

| Exp. No | Control parameters | | |
|---|---|---|---|
| | A | B | C |
| 1 | 1 | 1 | 1 |
| 2 | 1 | 2 | 2 |
| 3 | 1 | 3 | 3 |
| 4 | 2 | 1 | 2 |
| 5 | 2 | 2 | 3 |
| 6 | 2 | 3 | 1 |
| 7 | 3 | 1 | 3 |
| 8 | 3 | 2 | 1 |
| 9 | 3 | 3 | 2 |

## RESULTS AND DISCUSSIONS

**Experimental Results:** As per $L_9$ orthogonal array, nine experiments were conducted, considering three machining parameters. Different values of the levels to the parameters are assigned for conducting experiments. The working time for each experiment was 10 minutes. Each experiment was repeated for three times. The average values were taken for the calculation. Material removal rate is calculated using the equation 1. The final results are given in Table IV.

**Table.4.Experimental Conditions and their results**

| Exp.No. | Duty cycle (%) | Current (Amps) | Flushing (lpm) | MRR ($mm^3/min$) |
|---|---|---|---|---|
| 1 | 70 | 15 | 3.5 | 15.09833333 |
| 2 | 70 | 20 | 5 | 16.12 |
| 3 | 70 | 25 | 6.5 | 14.12533333 |
| 4 | 80 | 15 | 5 | 16.114 |
| 5 | 80 | 20 | 6.5 | 12.52466667 |
| 6 | 80 | 25 | 3.5 | 10.37733333 |
| 7 | 90 | 15 | 6.5 | 19.50166667 |
| 8 | 90 | 20 | 3.5 | 18.72066667 |
| 9 | 90 | 25 | 5 | 16.2733333 |

**Optimization using ANOM and ANOVA**

**Step 1: Calculation of effects of parameters:** The effect of parameter level is defined as the deviation it causes from the overall mean the overall mean value is calculated from the experimental results available in the Table 4 using the relation,

$$= \frac{1}{9}\sum_{i=1}^{9} Mi = (M_1+M_2+......+M_9)$$

$$= 15.42837037 mm^3/min \quad (2)$$

The effect of parameter A (Duty cycle) at different levels can be calculated from the relations,

$$M_{A1\,-} = (M_1+M_2+M_3) - \quad (3)$$

$$M_{A2\,-} = (M_4+M_5+M_6) - \quad (4)$$

$$M_{A3\,-} = (M_7+M_8+M_9) - \quad (5)$$

Using the data available in Table IV the average value of each level of the three parameters is calculated and listed in Table.5..

**Table.5.Average MRR for different parameter levels**

| Parameter | Levels | | |
|---|---|---|---|
| | 1 | 2 | 3 |
| A. Duty Cycle | 15.11456 | 13.00533 | 18.16522 |
| Current | 16.90467 | 15.78844 | 13.592 |
| Flushing | 14.73211 | 16.16911 | 15.38389 |

The average values of MRR are shown in Fig 1. They are separate effect of each parameter and are commonly called main effects.The graph shows MRR on HSS with respect to three parameters at three levels.

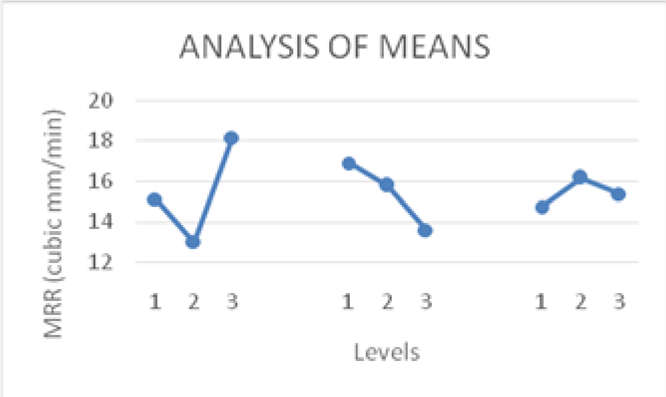


**Figure.1.Analysis of Mean Graph**

**Step 2:** Selection of optimum parameter level. Our goal in this study is to increase the MRR. The optimum level for a parameter is the level that gives highest value of MRR in the experimental region. Analysis of mean (ANOM) is a graphical analogy to ANOVA that tests the equality of popular means. The graph displays each factor level mean. From the Figure 1 and Table V, it can be observed that theoptimum set of parameter levels are $A_3$, $B_1$ and $C_2$.

**Step 3:** Analysis of variance (ANOVA): The analysis of variance is a statistical technique used to interpret experimental results and to determine the percent contribution of each parameter for the results.Different parameters affect the material removal rate to a different degree. The relative magnitude of parameter effects are listed in Table.5. In ANOVA the relative effect of the different parameters is obtained by the decomposition of variance.This is obtained by calculating sum of squares.

ANOVA is used to calculate the total sum of squares $SS_T$, degree of freedom (DOF) and percentage contribution of each factor. The total sum of squares can be calculated using the relation,

$SS_T = \sum_{i=}^{N} M_i-)^2 = 64.84466$

Where,

N – Number of experiments

$M_i$ – Experimental result for $i^{th}$ experiment

The total sum of squares is decomposed into two sources, the sum of squared deviation of each parameter $SS_i$and the sum of squared error $SS_e$. The sum of squared deviation of each parameter is calculated as follows,

$SS_i = \sum_{j=}^{N} M_{ij}-)^2$

$SS_A = 3\ (M_{A1} –)^2 + 3\ (M_{A2} – \bar{T})^2 + 3\ (M_{A3} – \bar{T})^2 = 40.379842$

$SS_B = 3\ (M_{B1} –)^2 + 3\ (M_{B2} – \bar{T})^2 + 3\ (M_{B3} – \bar{T})^2 = 17.0441$

$SS_C = 3\ (M_{C1} –)^2 + 3\ (M_{C2} – \bar{T})^2 + 3\ (M_{C3} – \bar{T})^2 = 3.106357$

Sum of squared error,

$SS_e = SS_T – ( SS_A + SS_B + SS_C ) = 4.314383$

The Table VI shows the result of analysis ofvariance for MRR of HSS. The total degrees of freedom is $D_T = N-1$ and the degrees of freedom of each tested parameter is $D_P = t-1$. The variance of parameter tested (Mean square) is $V_P = SS_P / D_P$. The F value for each design parameter is the ratio of mean squares to the mean of squared error $F_P = V_P / V_e$. The percentage contribution can be calculated as,

$$\rho = SS_P / SS_T$$

**Table.6.Results of Analysis of variance for MRR of HSS**

| Parameter | DOF | Sum of squares | Mean square | F | ρ |
|---|---|---|---|---|---|
| **A** | 2 | 40.37984 | 20.18992 | 9.359354 | 62.27% |
| **B** | 2 | 17.04408 | 8.52204 | 3.950925 | 26.28% |
| **C** | 2 | 3.106357 | 1.553178 | 0.71999 | 4.79% |
| **Error** | 2 | 4.314383 | 2.157191 | | 6.66% |
| **Total** | 8 | 64.84466 | | | |

**Step 4:** Interpretation of ANOVA table: From the ANOVA Table 4.2, it is understood that, the parameter A (Duty cycle) makes largest contribution to the total sum of squares (62.27%). The parameter B (Current) makes next largest contribution to the total sum of squares(26.28%), whereas the parameter C (Flushing) makes only 4.79% contribution. The duty cycle is the most influencing process parameter, which followed by pulse current in material removal rate on HSS. The influence of parameter C (Flushing) has only less effect on MRR.

**Step 5:** Prediction of Maximum theoretical value of material removal rate (MRR). In this study, the optimum level of process parameter is identified as $A_3B_1C_2$ (Step 2). From these optimum set of parameter levels, the value of MRR can be predicted using the relation,

$MRR_{opt} = \quad + ( \quad - M_{A3}) + ( \quad - M_{B1}) + ( \quad - M_{C2}) = 20.3823\ mm^3/\ min.$

**C. Confirming results:** A confirmation experiment is conducted with optimal parameter levels to evaluate MRR for EDM of HSS. The Fig 1 shows the optimum set of parameter levels as $A_3B_1C_2$. The Table VII shows the comparison of experimental result for the optimal parameter levels ($A_3B_1C_2$) with predicted result.

**Table.7.Results of confirmation test**

| Levels | Value of Material Removal Rate | |
|---|---|---|
| | Predicted | Experiment |
| $A_3B_1C_2$ | 20.3823$mm^3$/ min | 19.60333333 $mm^3$/ min |

## CONCLUSIONS

Taguchi method is applied in this study to determine the influence of process parameters on EDM. The results in this study reveal that the proper selection of process parameters will give significant effect in Electric discharge machining.

- The optimal parameter levels are determined as $A_3B_1C_2$, ie Duty cycle 90%,Current 15A and Flushing 5 lpm.
- The predicted results were checked with experimental results.
- It was observed that the duty cycle is the most influenced process parameter in machining HSS on EDM, followed by current and flushing.

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