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# Optimization of Electrical Discharge Machining Process Parameters Using Taguchi Method

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***Abstract***— ***The objective of this research study is to investigate the optimal process parameters of Electric Discharge Machining on Inconel 625 Nickel super alloy material with aluminum as a tool electrode. The effect of various process parameters on machining performance is investigated in this study. The input parameters considered are current; pulse on time and pulse off time are used for experimental work and their effect on Material Removal Rate, Tool Wear Rate and Surface Roughness. The Taguchi method is used to formulate the experimental layout, ANOVA method is used to analysis the effect of input process parameters on the machining characteristics and find the optimal process parameters of Electric Discharge Machining. The results of the present work reveal that proper selection of input parameters will play a significant role in Electric Discharge Machining.***

***Keywords***— ***Electrical Discharge Machining, orthogonal array, Metal removal rate, Tool wear rate, ANOVA***

## I. INTRODUCTION

Electric Discharge machining (EDM) is a thermo-electric, non-traditional machining process used to machine precise and intricate shapes on difficult to cut materials and super tough metals such as ceramics, maraging steels, cast-alloys, titanium which are widely used in defense and aerospace industries. Electrical energy is used to generate electrical sparks and material removal mainly occurs due to localized melting and Vaporization of material which is carried away by the dielectric fluid flow between the electrodes. The performance of this process is mainly influenced by many electrical parameters like, current, voltage, polarity, and pulse on time, pulse of time, electrode gap and also on non-electrical parameters like work and tool material, dielectric fluid pressure. All these electrical and non electrical parameters have a significant effect on the EDM output parameters like, Metal Removal Rate (MRR), Tool Wear Rate (TWR) and Surface Roughness (SR). Vikas et al (2013) carried out the optimization of the MRR for EN41 material based on the 4 input parameters like the pulse on time, pulse off time, discharge current and gap voltage. He found out that the current along with the pulse-off time had a larger impact over the MRR followed by some of the interaction plot, while the affect of the other parameters were negligible. Kamal Hassan et al (2012) carried out the same optimization technique using Taguchi to optimize the MRR for medium brass alloy in CNC turning machine. He used the various input parameters like cutting speed, depth of cut, feed, etc to optimize the MRR. He found that the cutting speed and the feed rate had significant effect over the MRR followed by their interaction. He found that the cutting speed and the feed rate had direct effect over the MRR, as they increased directly with them.

## I. EXPERIMENTAL SETUP

EDM Details

The experiments were conducted on V3525 precision die sink electric discharge machine as shown in Fig.1 which consist a work table, a servo control system and a dielectric supply system. The machine has current settings from 3A to 24A, 9 settings of pulse on time, 9 settings of pulse off time and spark gap of 50-75 microns.

Work Piece Properties

The experiments are conducted on Inconel 625 Nickel Super alloy and the work piece dimensions are 70 mm x 35 mm x 5 mm. The experiments are conducted on Inconel 625 Nickel Super alloy and the work piece dimensions are 70 mm x 35 mm x 5 mm.

TABLE 2: PROPERTIES OF INCONEL 625 NICKEL SUPER ALLOY

| **S.No.** | **Properties** | |
|---|---|---|
| 1 | Density | 8.44 g/cm$^3$ |
| 2 | Ultimate tensile strength | 940MPa |
| 3 | Elongation % | 51.5 |
| 4 | Thermal conductivity | 10 W/m$^0$ K |

The tool material used is aluminum- density 2.70gm/cm$^3$ and thermal conductivity 237 w/m0k and the machining is done with straight polarity. EDM oil Grade 30 is used as the dielectric fluid and the experiments were performed for a particular set of input parameters. The number of experiments and, input levels are decided based on the design of experiments and the input parameter sand their levels are presented in Table 1. The MRR and TWR are calculated using digital balance of accuracy 1mg and the machining time is using digital watch of accuracy 1 microsecond and the surface roughness is measured using Taylor Hobson Talysurf machine for a sampling length of 5mm.

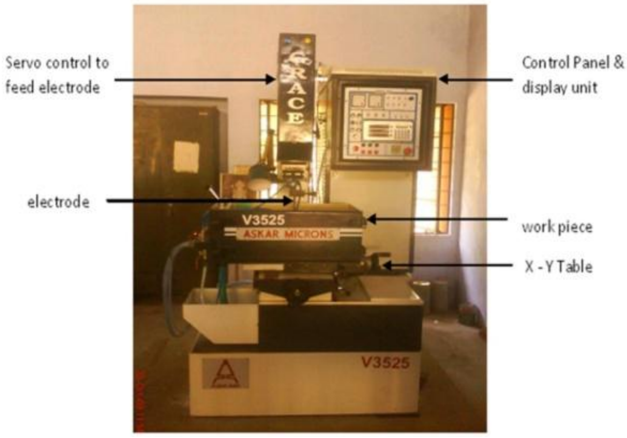


*FIG. 1: THE EXPERIMENTAL EQUIPMENT*

The MRR and TWR are calculated using the following expressions.

MRR= 1000×( Wb- Wa) /t mg/min

TWR= 1000×( Tb–Ta ) /t mg/min

Wb : Weight of the work-piece before machining

Wa : Weight of the work-piece after machining

Tb : Weight of the tool before machining

Ta : Weight of the tool after machining

t: Machining time (minutes)

TABLE 1: INPUT PARAMETERS LEVELS

| **INPUT PARAMETERS** | **CURRENT (AMP)** | **PULSE ON TIME (MS)** | **PULSE OFF TIME (MS)** |
|---|---|---|---|
| SYMBOL | A | B | C |
| LEVEL1 | 8 | 10 | 10 |
| LEVEL2 | 15 | 20 | 25 |
| LEVEL3 | 24 | 30 | 50 |

## II. Over View of Taguchi Method

Taguchi method involves reducing the variation in a process through robust design of experiments. The overall objective of the method is to produce high quality product at low cost to the manufacturer. Taguchi developed a method for designing experiments to investigate how different parameters affect the mean and variance of a process performance characteristic that defines how well the process is functioning. The experimental design proposed by Taguchi involves using orthogonal arrays to organize the parameters affecting the process and the levels at which they should be varied; it allows for the collection of the necessary data to determine which factors most affect product quality with a minimum amount of experimentation, thus saving time and resources. Taguchi design method is to identify the parameter settings which render the quality of the product or process robust to unavoidable variations in external noise. The relative "quality" of a particular parameter design is evaluated using a generic signal to-noise (S/N) ratio. Depending on the particular design problem, different S/N ratios are applicable, including "lower is better" (LB), "nominal is best" (NB), or "higher is better" (HB).

As the objective is to obtain the high material removal rate, low tool wear rate, and best surface finish, it is concerned with obtaining larger value for MRR, smaller value of tool wear rate and smaller value of surface roughness .Hence, the required quality characteristic for high MRR is larger the better, which states that the output must be as large as possible, and for tool wear rate and surface roughness is smaller the better, which states that the output must be as low as possible. Taguchi optimization technique has done in MINI TAB 18.1 software.

## *III. Analysis of Varience (Anova)*

The analysis of variance (ANOVA) is a common statistical technique to determine the percent contribution of each factor for results of the experiment. It calculates parameters known as sum of squares SS, degree of freedom (DOF), variance and percentage of each factor. Since the procedure of ANOVA is a very complicated and employs a considerable of statistical formula. The Sum of Squares SS (tr) is a measure of the deviation of the experimental data from the mean value of the data. The Fisher's ratio is also called F value. The principle of the F testis that the larger value for a particular parameter, the greater the effect on the performance characteristics due to the change in that parameter. F value is defined as the ratio of Mean square for the term to Mean square for the error term. all these statistical calculations are done in MINI TAB 6.0 software.

## *IV . Design Of Experiments and Data Analysis*

Based on L9 orthogonal array experiments are conducted on Inconel 625 nickel super alloy with aluminium tool and EDM grade 30 oil as dielectric medium for different experiment levels which are show in Table.2.

TABLE 3: L9 ORTHOGONAL ARRAY

| **Exp.No.** | **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 |

TABLE.4: OUT PUT PARAMETERS FOR L9 ORTHOGONAL ARRAY

| **Expt. No.** | **MRR** | **TWR** | **SR** |
|---|---|---|---|
| 1 | 18.8 | 4.83 | 3.60 |
| 2 | 8.5 | 5.20 | 5.25 |
| 3 | 9.5 | 3.40 | 3.90 |
| 4 | 128.3 | 26.30 | 4.18 |
| 5 | 87.5 | 14.70 | 5.15 |
| 6 | 52.8 | 9.70 | 6.46 |
| 7 | 253.6 | 48.30 | 5.90 |
| 8 | 165.0 | 35.25 | 5.94 |
| 9 | 212.3 | 33.80 | 6.20 |

*Taguchi Analysis: MRR versus A, B, C*

TABLE.5: MRR VERSUS A, B, C RESPONSE TABLE FOR SIGNAL TO NOISE RATIOS

*Larger is better*

| **Level** | **A** | **B** | **C** |
|---|---|---|---|
| 1 | 21.21 | 38.58 | 34.76 |
| 2 | 38.49 | 33.93 | 35.76 |
| 3 | 46.32 | 33.52 | 35.49 |
| Delta | 25.12 | 5.06 | 1.00 |
| Rank | 1 | 2 | 3 |

TABLE.6: MRR VERSUS A, B, C RESPONSE TABLE FOR MEAN

| **Level** | **A** | **B** | **C** |
|---|---|---|---|
| 1 | 12.27 | 133.57 | 78.87 |
| 2 | 89.53 | 87.00 | 116.37 |
| 3 | 210.30 | 91.53 | 116.87 |
| Delta | 198.03 | 46.57 | 38.00 |
| Rank | 1 | 2 | 3 |

*Taguchi Analysis: TWR versus A, B, C*

TABLE.7: TWR VERSUS A, B, C RESPONSE TABLE FOR SIGNAL TO NOISE RATIOS

*Smaller is better*

| **Level** | **A** | **B** | **C** |
|---|---|---|---|
| 1 | -12.88 | -25.25 | -21.45 |
| 2 | -23.83 | -22.87 | -24.43 |
| 3 | -31.73 | -20.31 | -22.55 |
| Delta | 18.86 | 4.94 | 2.98 |
| Rank | 1 | 2 | 3 |

TABLE.8: TWR VERSUS A, B, C RESPONSE TABLE FOR MEAN

| **Level** | **A** | **B** | **C** |
|---|---|---|---|
| 1 | 4.477 | 26.477 | 16.593 |
| 2 | 16.900 | 18.383 | 21.767 |
| 3 | 39.117 | 15.633 | 22.133 |
| Delta | 34.640 | 10.843 | 5.540 |
| Rank | 1 | 2 | 3 |

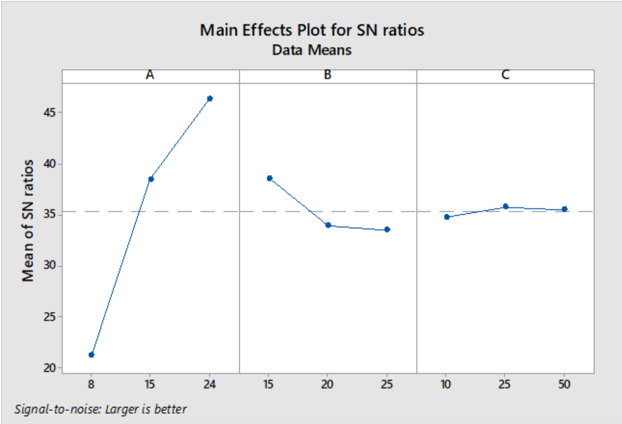


FIG.2.MAIN EFFECTS PLOT FOR S/N RATIOS MRR VERSUS A, B, C


FIG.3.MAIN EFFECTS PLOT FOR MEANS RATIOS MRR VERSUS A, B, C

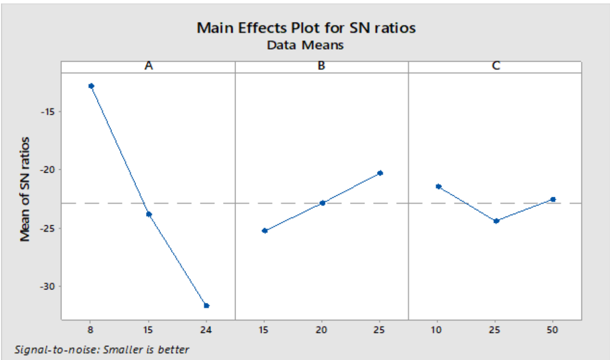


FIG.4.MAIN EFFECTS PLOT FOR S/N RATIOS TWR VERSUS A, B, C


FIG.5.MAIN EFFECTS PLOT FOR MEANS RATIOS MRR VERSUS A, B, AND C

Taguchi Analysis: SR versus A, B, C

TABLE.9: SR VERSUS A, B, C RESPONSE TABLE FOR SIGNAL TO NOISE RATIOS
SMALLER IS BETTER

| Level | A | B | C |
|---|---|---|---|
| 1 | -12.45 | -12.99 | -14.27 |
| 2 | -14.29 | -14.71 | -14.22 |
| 3 | -15.58 | -14.62 | -13.82 |
| Delta | 3.13 | 1.72 | 0.44 |
| Rank | 1 | 2 | 3 |

TABLE.10: SR VERSUS A, B, C RESPONSE TABLE FOR MEAN RATIOS

| Level | A | B | C |
|---|---|---|---|
| 1 | 4.250 | 4.560 | 5.333 |
| 2 | 5.263 | 5.447 | 5.210 |
| 3 | 6.013 | 5.520 | 4.983 |
| Delta | 1.763 | 0.960 | 0.350 |
| Rank | 1 | 2 | 3 |

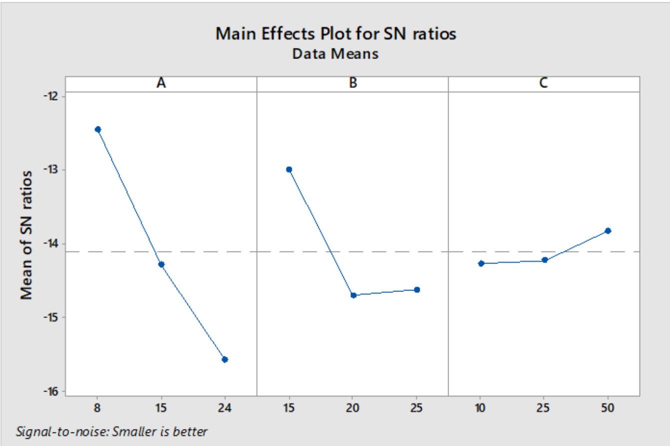


*FIG.6.MAIN EFFECTS PLOT FOR S/N RATIOS SR VERSUS A, B, AND C*

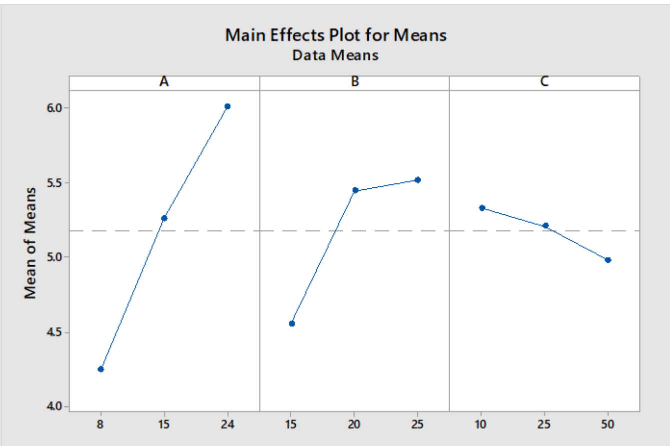


*FIG.7.MAIN EFFECTS PLOT FOR MEANS RATIOS SR VERSUS A, B, AND C*

TABLE.11: ANOVA RESULTS FOR MRR

| Source | DOF | Seq. SS | Adj. MS | F |
|---|---|---|---|---|
| Current | 2 | 59569.3 | 29784.7 | 1004.49 |
| Pulse on time | 2 | 4249.1 | 2124.5 | 71.65 |
| Pulse on time | 2 | 2532.9 | 1266.5 | 42.71 |
| Residual Error | 2 | 59.3 | 29.7 | |
| Total | 8 | 66410.6 | | |
| DF- Degree of freedom, SS- Sum of squares, MS- Mean squares(variance),F- Ratio of variance of a source to variance of error | | | | |

TABLE.12: ANOVA RESULTS FOR TWR

| Source | DOF | Seq. SS | Adj. MS | F |
|---|---|---|---|---|
| Current | 2 | 1744.02 | 872.01 | 82.06 |
| Pulse on time | 2 | 229.18 | 114.59 | 10.78 |
| Pulse on time | 2 | 90.09 | 45.04 | 4.24 |
| Residual Error | 2 | 21.25 | 10.63 | |
| Total | 8 | 2084.53 | | |
| DF- Degree of freedom, SS- Sum of squares, MS- Mean squares(variance),F- Ratio of variance of a source to variance of error | | | | |

TABLE.13: ANOVA RESULTS FOR SR

| Source | DOF | Seq. SS | Adj. MS | F |
|---|---|---|---|---|
| Current | 2 | 4.6651 | 2.33254 | 1.97 |
| Pulse on time | 2 | 1.5551 | 0.77754 | 0.66 |
| Pulse on time | 2 | 0.1643 | 0.08214 | 0.07 |
| Residual Error | 2 | 2.3688 | 1.18441 | |
| Total | 8 | 8.7533 | | |

DF- Degree of freedom, SS- Sum of squares, MS- Mean squares(variance),F- Ratio of variance of a source to variance of error

## *V. EXPERIMENTAL RESULTS AND ANALYSIS*

After the collection of experimental data the calculated S/N ratio value for MRR, TWR and SR is shown in the Table no.5, 7,9. The ANOVA results for MRR, TWR and SR is shown in Table no.11, 12,13 respectively and Response Table for Means of MRR,TWR and SR is shown in table no.6,8, and 10 respectively. Rank 1input parameter as highest contribution factor for the MRR, TWR and SR and Rank 3 input parameter as lowest contribution factor for MRR, TWR and SR. Current Rank is 1 means highest contribution factor on MRR, TWR and SR .Pulse off time is the least contribution parameter on MRR, TWR and SR. From the figure.2, it is observes that MRR goes on increasing with higher values of current. MRR has highest value at current 24A. From the figure 4. TWR has lowest value at current 8A, pulse-on time 25µs and pulse off time value at 10µs. For current 6A, pulse-on time 15µs and pulse off time value at 50µs the surface finish is better than other values which shown in the figure.6.

In the experimental analysis, main effect plot of S/N ratio for MRR, TWR and SR is used for estimating the S/N ratio of MRR with optimal design condition. MRR has highest value at level 3 for current, level 1 for pulse on time and level 3 for pulse off time. As shown in the figure no.2, TWR has lowest value at level 1 for current, level 3 for pulse on time and level 1 for pulse off time.SR has lowest value at level 1 for current, level 1 for pulse on time and level 3 for pulse off time which shown in the figure no.6.

## VI. CONCLUSION

The result shows that current, pulse on time and pulse off time have significant effect on MRR, TWR and SR. The results of the present work reveal that proper selection of input parameters will play a significant role in Electric Discharge Machining.

The MRR is increasing with increase in current.

TWR is increasing linearly with increase in the current.

The SR is increasing with increase in current and pulse on time but decreasing with increase in pulse off time.

For optimum MRR, A3B1C3 levels must be selected and for optimum TWR, A1B3C1 levels and for optimum SR, A1 B1 C3 must be selected.

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