# Optimization of Electric Discharge Machining Process Parameters based on Gray relational Analysis for nickel super alloy material

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**ABSTRACT**

Electrical discharge machining (EDM) is an unconventional machining process. The desired geometries are obtained by using electrical sparks. This process involves controlled erosion of electrically conducting materials by the initiation of repetitive and rapid spark discharge between tool and work piece. The electrodes are separated by a small gap. As advancement in material science the emerging of new hard materials such as alloys, composite, ceramics posses difficulties in smooth machining in traditional machining processes. In order to control the input parameters and to increase the spark efficiency, numerous experiments have been conducted on different hard materials over the past decade. Parametric optimization of machining operations is involved with Taguchi design of experimental method and Grey relational analysis is to obtain high-quality machining. In this paper L18 orthogonal array used to determine the optimal levels of parameters. Taguchi method and grey relational analysis are used to achieve high Metal Removal Rate (MRR), low tool wear rate and low Surface finish.

***Keywords:*** *Electric discharge machining, L18 orthogonal array, Grey relational analysis, Metal removal rate, Tool wear rate, Surface roughness.*

## 1. Introduction

Electrical discharge machining (EDM) is one of the most extensively used non-conventional machining process. It uses thermal energy to machine electrically conductive parts regardless of hardness of the material the distinctive advantage of EDM is in the manufacture of mould, die, automotive, aerospace and surgical components. EDM does not make direct contact between the electrode and the workpiece eliminating mechanical stresses, chatter and vibration during machining. The traditional machining techniques are often incapable to machine the nickel super alloys due to its high toughness and hardness and these can be machined economically by EDM.

P. Balasubramanian and T. Senthilvelan studied on the two different materials EN-8 and D-3 steel have been used as a work pieces. The important process parameters that have been selected are peak current, pulse on time, die electric pressure and tool diameter. The outputs responses are MRR, TWR and SR. The cast copper and sintered powder metallurgy copper has been used as tool electrode. They use response surface methodology to analyze the parameters and ANNOVA has been applied to identify the significant process parameters. [1].

Mohan K Pradhan investigated on AISI D2 tool steel using a hybrid optimization method. A new combination of response surface methodology (RSM) and grey relational analysis coupled with principal component analysis (PCA) has been proposed to evaluate and estimate the effect of machining parameters on the responses. The results indicate that the grey relational grade was significantly affected by the machining parameters considered and some of their interactions [2].

Mohammad reza Shabgard carried out experimental studies to conduct a comprehensive investigation on the influence of EDM. The machining parameters are material removal rate, tool wear ratio, and arithmetical mean roughness, as well surface integrity characteristics comprised of the thickness of white layer and the depth of heat affected zone of AISI H13 tool steel as work piece. The experiments performed under the designed full factorial procedure, and the considered EDM input parameters included pulse on- time and pulse current[3]

J Laxman and K. Gururaj investigated on EDM process parameters and used the Taguchi technique for optimization of process parameters. Experiments are conducted on the Titanium super alloy with copper as Tool by taking three levels of each factor. The experiments were designed based on Taguchi Design of Experiments, L27 orthogonal array. Analysis of variance (ANOVA) has been carried out to study the effect of each factor on the measured performance characteristics. It is found from the ANOVA that all the selected factors have significant effect on the MRR, TWR and SR[4].

Chandramouli and Dr. K. Eswaraiah studied the optimal setting of the process parameters of EDM was determined. The important process parameters that have been selected are peak current, pulse on time, pulse off time and tool lift time with output response as Material Removal Rate and Surface Roughness. L27 Taguchi experimental design was used to conduct the experiments on 17-4 Precipitation Hardening Stainless Steel (PH Steel) with copper tungsten electrode and ANOVA method was used for the analysis of process parameters[5].

## 2. Design of Experiments and Selection of Work Piece and Tool Material

Design of Experiments (DOE), is a tool to develop an experimentation strategy that maximizes learning using a minimum of resources. The selection of OA to use predominantly depends on the number of factors and interactions of interest, the number of levels for the factors of interest, The desired experimental resolution or cost limitations. In the present work L18 orthogonal array is used for conduction of experiments. The number in the array designation indicates the number of trials and MINITAB was used for the analysis of process parameters.

ISBN : 978-93-87793-90-3

Nickel based super alloy is one of the most difficult-to-machine material which attributed to its ability to maintain hardness at elevated temperature and consequently it's very useful for hot working environment. Formation of complex shapes by this material along with reasonable speed and surface finish is not possible in traditional machining. This alloy is characteristically difficult to machine due to its poor thermal properties, high toughness, high hardness, and high work hardening rate. Usually, a nonconventional machining method like EDM is used for cutting of these materials.

As the material is new, to find the suitable tool materials we selected two electrodes namely cooper and brass. Experiments are conducted with these two electrodes on nickel super alloy to find the best electrode for machining of nickel super alloy and find optimal process parameters for machining of selected material.

## 3. Experimental work

Experiments are conducted on EDM machine with the selected process parameters. L18 orthogonal array has been used for conducting the experiments. The work piece size considered as 60 mm X 60 mm X 6 mm and electrode with diameter12mm and 50 mm length has considered during experimental work. Three input parameters current, pulse on time and pulse off time and three output parameters MRR, TWR and SR are selected to conduct the experiments. The MRR and TWR is calculated using the following relations. The Surface Roughness of machined profiles was measured by using the Surface Roughness Tester (Mututiyo SJ210). The figure 1 shows the machined surface on work piece.

$$MRR = \frac{(W_i - W_f)\times 1000}{D_W \times t} \quad ......(1)$$

$$TWR = \frac{(T_i - T_f)\times 1000}{D_e - t} \quad ......(2)$$

The table 1 represents the Selection of input parameters and Experimental outputs of MRR, TWR and SR are tabulated in the Table 2.

Figure 1 Work Piece after Machining

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Table. 1. Selection of input parameters

| Factors \ Levels | **1** | **2** | **3** |
|---|---|---|---|
| Current(amp) | 9 | 12 | 15 |
| Pulse on time(µsec) | 50 | 100 | 150 |
| Pulse off time(µsec) | 40 | 60 | 80 |
| Tool | Cu | Brass | - |

Table 2. Experimental results of MRR, TWR and SR

| S. No | Levels of parameter | | | | MRR Mg/min | TWR Mg/min | SR (microns) |
|---|---|---|---|---|---|---|---|
| | Tool Level | Current | Pulse on time | Pulse off time | | | |
| 1. | 1 | 1 | 1 | 1 | 134.9 | 0.82 | 3.495 |
| 2. | 1 | 1 | 2 | 2 | 156.8 | 1.04 | 2.987 |
| 3. | 1 | 1 | 3 | 3 | 195.4 | 2.24 | 3.053 |
| 4. | 1 | 2 | 1 | 2 | 172.6 | 7.14 | 3.631 |
| 5. | 1 | 2 | 2 | 3 | 206.0 | 2.86 | 4.725 |
| 6. | 1 | 2 | 3 | 1 | 212.8 | 1.92 | 3.502 |
| 7. | 1 | 3 | 1 | 1 | 228.4 | 15.92 | 4.372 |
| 8. | 1 | 3 | 2 | 2 | 281.5 | 6.64 | 3.374 |
| 9. | 1 | 3 | 3 | 3 | 293.7 | 1.86 | 2.296 |
| 10. | 2 | 1 | 1 | 3 | 39.32 | 114.3 | 1.584 |
| 11. | 2 | 1 | 2 | 1 | 36.5 | 100.3 | 1.376 |
| 12. | 2 | 1 | 3 | 2 | 34.1 | 94.84 | 1.542 |
| 13. | 2 | 2 | 1 | 3 | 44.6 | 132.9 | 1.693 |
| 14. | 2 | 2 | 2 | 1 | 39.24 | 121.2 | 1.401 |
| 15. | 2 | 2 | 3 | 2 | 37.16 | 97.24 | 1.639 |
| 16. | 2 | 3 | 1 | 2 | 69.84 | 217.2 | 2.782 |
| 17. | 2 | 3 | 2 | 3 | 64.1 | 208.6 | 1.498 |
| 18. | 2 | 3 | 3 | 1 | 57.1 | 167 | 1.665 |

**4. Grey Relational Analysis**

Multi-objective optimization problem can be converted to single objective optimization by using grey relational analysis principle Grey relational analysis will obtain single parametric combination that optimizes the overall process and it can be used to identify the most influencing factors affecting the response variables. The following steps are used in Grey relational analysis to obtained better values ( Deng 1982):

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**Normalization of MRR and TWR**

The Larger-the-better quality characteristic of metal removal rate can be normalized using the following equation 3. Using this formula for lower the better and higher the better the experimental values are normalized and presented in table 3.

$$x_{ijk}=\frac{\eta_{ijk}-\min\eta_{ijk}}{\max\eta_{ijk}-\min\eta_{ijk}}\text{……………(3)}$$

The Smaller-the-better quality characteristics of TWR and SR are normalized using the equation 4.

$$x_{ijk}=\frac{\max\eta_{ijk}-\eta_{ijk}}{\max\eta_{ijk}-\eta_{ijk}}\text{………………..(4)}$$

Where

i= 1, 2,.........., 18 ; j= 1, 2; k=1. $x_{ijk}$ is normalized value, $\eta_{ijk}$ is the experimental value of $i^{th}$ experiment in $j^{th}$response of $k^{th}$ replica, Min$\eta_{ijk}$ is the smallest value of $\eta_{ijk}$

Max$\eta_{ijk}$ is the largest value of $\eta_{ijk}$ and $x_{ijk}$ is normalized.

**Grey Relation coefficient**

The grey relational coefficient is calculated to express the relationship between the ideal and actual normalized experimental results. The grey relational coefficient of $i^{th}$ experiment for $j^{th}$ response in the *k* replication is expressed as $\xi_{ijk}$ given in equation 5. $\beta_{ijk}$ is the deviation sequence. The Deviation sequence for each parameter is obtained by calculating the amount of each response which deviates from the reference sequence.

$$\xi_{ijk} = \frac{\beta_{min} + \phi\beta_{max}}{\beta_{ijk} + \phi\beta_{max}}\text{……………...(5)}$$

Where $\beta_{ijk}$ is the absolute value of the difference between ideal sequences $x_{ojk}$ and $x_{ijk}$ ,Øis the distinguishing coefficient in the range of 0 to 1.

**Grey Relation Grade**

The grey relational grade $\gamma_i$ represent the level of correlation between the reference sequence and the comparability sequence. Performance of the multi response is evaluated by grey relational grade. It is the weighted summation of all the grey relational coefficients and is calculated by the following equation 6:

$$\gamma_i = \frac{1}{n}\sum_{i=1}^{n}\xi_{ijk}\text{……………(6)}$$

Where i the grey relational grade for the ith experiment and n is is the number of performance characteristics

Table 3. Normalization of MRR,TWR and SR

ISBN : 978-93-87793-90-3

| EXP NO | MRR | TWR | Ra |
|---|---|---|---|
| 1 | 0.388337 | 1 | 0.367274 |
| 2 | 0.472768 | 0.998983 | 0.518961 |
| 3 | 0.62137 | 0.993437 | 0.499254 |
| 4 | 0.533472 | 0.970792 | 0.326665 |
| 5 | 0.661967 | 0.990572 | 0 |
| 6 | 0.688314 | 0.994916 | 0.365184 |
| 7 | 0.748324 | 0.930215 | 0.105405 |
| 8 | 0.952931 | 0.973103 | 0.403404 |
| 9 | 1 | 0.995194 | 0.725291 |
| 1 | 0.020106 | 0.475552 | 0.937892 |
| 11 | 0.009244 | 0.540161 | 1 |
| 12 | 0 | 0.565487 | 0.950433 |
| 13 | 0.040444 | 0.389592 | 0.905345 |
| 14 | 0.019798 | 0.443571 | 0.992535 |
| 15 | 0.011786 | 0.554395 | 0.921469 |
| 16 | 0.137663 | 0 | 0.580173 |
| 17 | 0.115554 | 0.039745 | 0.963571 |
| 18 | 0.088591 | 0.231999 | 0.913706 |

Table 4. Grey Relation coefficient and GRG

| S. NO. | MRR GRC | TWR GRC | SR GRC | GRG |
|---|---|---|---|---|
| 1 | 0.4497 | 1.0000 | 0.4414 | 0.6303 |
| 2 | 0.4867 | 0.9979 | 0.5096 | 0.6647 |
| 3 | 0.5690 | 0.9870 | 0.4996 | 0.6852 |
| 4 | 0.5173 | 0.9448 | 0.4261 | 0.6294 |
| 5 | 0.5966 | 0.9814 | 0.3333 | 0.6371 |
| 6 | 0.6160 | 0.9899 | 0.4406 | 0.6821 |
| 7 | 0.6651 | 0.8775 | 0.3585 | 0.6337 |
| 8 | 0.9139 | 0.9489 | 0.4559 | 0.7729 |
| 9 | 1.0000 | 0.9904 | 0.6454 | 0.8786 |
| 10 | 0.3378 | 0.4880 | 0.8895 | 0.5718 |
| 11 | 0.3354 | 0.5209 | 1.0000 | 0.6187 |
| 12 | 0.3333 | 0.5350 | 0.9098 | 0.5927 |
| 13 | 0.3425 | 0.4502 | 0.8408 | 0.5445 |

| | | | | |
|---|---|---|---|---|
| 14 | 0.3377 | 0.4732 | 0.9852 | 0.5987 |
| 15 | 0.3359 | 0.5287 | 0.8642 | 0.5763 |
| 16 | 0.3670 | 0.3333 | 0.5435 | 0.4146 |
| 17 | 0.3611 | 0.3424 | 0.9320 | 0.5452 |
| 18 | 0.3542 | 0.3943 | 0.8528 | 0.5337 |

From this grey relational grade for each experiment using L18. The higher grey relational grade represents that the corresponding experimental result is closer to the ideally normalized value. Experiment 9 has the best multiple performance characteristics among18 experiments because it has the highest grey relational grade.

**5. Results and Discussions**

Figure2 shows the grey relational grade obtained for different process parameters. Basically, the larger the grey relational grade, the closer will be the product quality to the ideal value. Thus, larger grey relational grade is desired for optimum performance. Therefore, the optimal parameters setting for better MRR and lesser TWR and SR are (A1B3C3D3) as presented in Table 5. Optimal level of the process parameters is the level with the highest grey relational grade. Grey Relational Analysis is applied in this work to improve the characteristics such as MRR , TWR and SR. In this greater influence the copper tool and pulse on time (Ton).

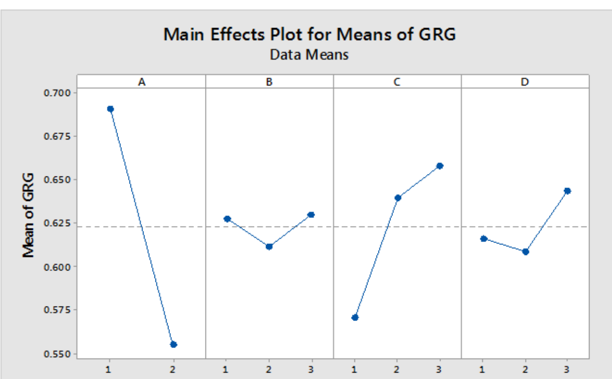


Figure 2. Main Effects Plot for Means of GRG

Table 5 Response Table for Means

| Level | Tool A | Current B | Pulse on time C | Pulse off time D |
|---|---|---|---|---|
| 1 | 0.6905 | 0.6273 | 0.5708 | 0.6163 |
| 2 | 0.5552 | 0.6114 | 0.6396 | 0.6085 |
| 3 | - | 0.6298 | 0.6582 | 0.6438 |
| Delta | 0.1353 | 0.0184 | 0.0874 | 0.0353 |
| Rank | 1 | 4 | 2 | 3 |

Mean GRG for each level of the input parameters and their total mean are calculated from table5, the optimal level of input parameters is found to be 15 Amp for peak current, 150 µs for pulse-on time and150 µs pulse-of time. The ranking of the process parameter reveals that pulse on time is the most dominant parameter on the output response and a similar behavior is observed in the case of optimization of EDM parameters using GRA for nickel super alloy.

**Confirmation test**

Table 6. Results of Confirmation test

| Tool | Current | Pulse on time | Pulse off time | S/N Ratio | GRG | MRR Mg/min | TWR Mg/min | SR µm |
|---|---|---|---|---|---|---|---|---|
| Copper | 15 | 150 | 80 | -2.61081 | 0.753725 | 293.7 | 1.86 | 2.296 |

The final result has been obtained after applying grey relation analysis technique using L18 orthogonal array and then by obtaining the optimized parameter, a confirmation test has been performed and the final values of MRR and TWR are as shown in the table 6 and our objective of the project is to find the optimized parameters for large MRR and smaller TWR which has been achieved and so it is positive case of machining efficiency.

## Conclusion

In this work the application of GRA coupled with Taguchi design of experiments using L18 orthogonal array. The experiments were conducted under various parameters setting of Discharge Current, Pulse On time, Pulse off time and cylindrical shaped copper and brass tool. In the present study the obtained optimal input parameters Ip=15A, Ton =150, Toff= 80 with copper tool, while machining on nickel based super alloy. The parametric optimization of EDM process will save the time required for machining, improve surface roughness, and avoid excess tool wear in EDM process.

**REFERENCESS**


**1.** P. Balasubramaniana , T. Senthilvelanb "Optimization of Machining Parameters in EDM Process Using Cast and Sintered Copper Electrodes" *Procedia Materials Science* 6 ( 2014 ) 1292 – 1302

**2.** Mohan K Pradhan, "Estimating the effect of Process parameters on surface integrity of EDM AISI D2 tool steel by response Surface methodology coupled with gray relational analysis" ,*International Journal of Machining and Machinability of Materials*, August 2013, volume 67, Issue 9-12.

**3.** Mohammadreza Shabgard. Carried out experimental studies to conduct a comprehensive investigation on the influence of Electrical Discharge Machining (EDM) input parameters on the characteristics of the EDM process, *Journal of Mechanical Science and Technology*, August 2016, Volume 30, Issue 8, pp 3799–3804,

**4.** J Laxman and K. Gururaj, "Single Objective Optimization of EDM Process Parameters Based on Design of Experiments" *International Journal of Applied Engineering Research*, ISSN 0973-4562 Vol. 10, pp.31759-31764 (2015)

ISBN : 978-93-87793-90-3

**5.** S. Chandramouli, Dr. Eswaraiah, "Experimental investigation of EDM process parameters in machining of 17-4 PH Steel using taguchi method", *Materials Today: Proceedings*, march 2017,Volume 5, Issue 2, Pages 5058-5067