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# Multi Objective Optimization of Near-Dry EDM using MOORA-PCA based Taguchi Optimization Method

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**ABSTRACT**
In any machining operation, the correct and optimized selection of process parameters is the most important aspect. Particularly in Electric Discharge Machining (EDM) also, its process parameters should be optimized to get the best result. Near-Dry EDM is an advancement in conventional EDM process, which is an eco-friendly process compared to the conventional EDM.

In this paper work has attempted to simultaneously optimize all the parameters of near-dry EDM. Near-dry EDM uses liquid-gas mixture as dielectric. Input parameters considered are discharge current, gap voltage, air pressure, pulse on time electrode material and duty factor. The performance parameters were material removal rate (MRR), tool wear rate (TWR) and surface roughness (Ra). L18 orthogonal array based on Taguchi method is used as design of experiment. For multi objective optimization MOORA combined with PCA analysis is used and then Taguchi method is applied.

***Keywords***: *Electrical Discharge Machining, Near-dry EDM, Taguchi, MOORA, PCA, eco-friendly EDM*

## I. INTRODUCTION

Electrical Discharge Machining (EDM) is one of the non conventional machining processes which is used widely to machine electrically conductive materials. EDM is a thermo-electric type of non conventional machining process in which material is removed using the process of controlled spark generation. Since the work piece has no mechanical contact with tool, thin and fragile components can be machined easily without any risk of damage. It is one of the foremost widespread non-traditional machining processes which are getting used these days within the industry.

Near-dry EDM is a variation of conventional EDM which eliminates the problem of environmental pollution caused by the hydrocarbon oil based dielectric used in conventional EDM. In near-dry EDM, liquid based dielectric is replaced by mixture of liquid and gas which makes this process eco-friendly. As compared to Dry EDM, it shows good surface integrity without the reattachment of debris which occurs in dry EDM [1].

Near-dry EDM was first investigated by Tanimura et al. [2] for wire EDM cutting and EDM drilling under wet, dry and near-dry condition. It was found that near dry EDM was stable under low discharge energy rate but leads to breakage of wire in wire EDM and increases electrode wear in EDM drilling, under high thermal load on electrode. Wet and dry EDM's were proved beneficial for roughing operation and near-dry EDM was proved beneficial for finishing operation [1; 3-4]. Tao et al. [5] used near-dry EDM as finishing process to get a mirror like surface finish and achieved surface finish of 0.32µm. Fujiki et al. [6] developed a Computational fluid dynamics (CFD) model of dielectric fluid flow in near-dry EDM milling to predict the mist flow rate. The optimum lead angle, which maximized material removal rate and minimized tool electrode wear ratio, was also found in the research. The study showed that the MRR is linearly proportional to the mass flow rate of air and kerosene mixture, the TWR is inversely related to the mass flow rate of air and kerosene mixture, and the average surface roughness does not have a good correlation with the flow rate of the mixture. Individual optimization of input parameters of near-dry EDM was done using LPP by Tripathy et al. [7]. Another attempt to optimize MRR, TWR and surface roughness using Taguchi method was done by Mane et al. [8]. Multi objective optimization of two parameters i.e., MRR and Ra of near-dry EDM was done using Response Surface Methodology by Deshmukh et al. [7].

Majumdera et al. [9] combined the Multi Objective Optimization using Ration Analysis (MOORA) with Principal Component Analysis (PCA), and used to find out an optimal combination of input parameters for turning on ASTM A588 mild steel. A comparison between MOORA-PCA and TOPSIS-PCA showed the effectiveness of MOORA over TOPSIS method.

In manufacturing industry, it is important to have a balance between cost and quality. This makes it necessary to design and implement an effective process control in metal cutting operations by optimizing the process parameters. This research paper aims to find out the optimized parameters for the near-dry EDM process using the MOORA-PCA method combined with Taguchi Philosophy.

## II. METHODS AND MATERIAL

The study of metal cutting process mainly focuses on the work materials, properties and features of tools, and machine parameter settings affecting output quality characteristics and process efficiency. A great improvement in process efficiency can be achieved by process parameter optimization that determines and identifies the regions of critical process control factors leading to responses or desired quality characteristics with acceptable variations promising a lower cost of manufacturing. Several optimization methods can be coupled to get the best result.

In this study, computationally easy and simple method MOORA coupled with PCA analysis is used. This method is proved to be robust and simple method for multi objective optimization. With MOORA-PCA another robust and effective method Taguchi Method is coupled. Based on literature survey Mane et al. [8] the following methodology is used.

### A. Experimental Setup

The experiment was conducted on a CNC die sinker EDM from Electronica. Mixture of kerosene and compressed air was used as the dielectric. This mixture was directed to the inter electrode gap (i.e., the gap between electrode and workpiece) through a spray gun to flush away the eroded material through sparking zone. This mixture consist of very small quantity of liquid (kerosene) mixed in compressed air so as to form a mist. AISI SAE D2 tool steel was used as the work piece material. Two different electrodes, copper and copper-tungsten electrodes were used in the experiment. Tool electrodes were kept rotating at a constant speed, rather than stationary. Both electrodes were of diameter 15mm. Polarity of electrode was kept as negative and that of workpiece is kept was positive. Each experiment was performed for 20 minutes.

The responses selected for the experiment were material removal rate (MRR), tool wear rate (TWR) and surface roughness (Ra).

### B. Selection of process parameters and their levels

The process parameters selected based on literature survey were electrode material, air pressure, gap voltage, discharge current, pulse on time and duty factor. The process parameters and their levels are given in Table 1. For the experiment 2 levels electrode material and 3 levels of other remaining parameter were selected [8].

Table 1: Process parameters under study and their levels.

| Factor | Levels | | |
|---|---|---|---|
| | Level 1 | Level 2 | Level 3 |
| A. Electrode material | Copper-Tungsten | Copper | -------- |
| B. Air pressure ($kg/cm^2$) | 4 | 5 | 6 |
| C. Discharge Current (Amps) | 8 | 12 | 16 |
| D. Gap voltage (volts) | 40 | 60 | 80 |
| E. Pulse on time (µs) | 100 | 150 | 200 |
| F. Duty factor (%) | 7 | 9 | 11 |

(Table 1 source: Mane, S.G. and Hargude, N.V., "Parametric Optimization of near Dry Electrical Discharge Machining Process for AISI SAE D-2 Tool steel" [8])

### C. Design of Experiment

For the investigation, Taguchi's Orthogonal Array had been utilized for design of experiment for continuous improvement of quality and productivity. The smallest mixed 2-level and 3-level array, $L_{18}$ orthogonal array, meets the requirements of experiment [8].

Table 2: $L_{18}$ Orthogonal Array

| Exp. No. | Cu/ CuW | $P_a$ | Ip | V | Ton | Ʈ |
|---|---|---|---|---|---|---|
| 1 | CuW | 4 | 8 | 40 | 100 | 7 |
| 2 | CuW | 4 | 12 | 60 | 150 | 9 |
| 3 | CuW | 4 | 16 | 80 | 200 | 11 |
| 4 | CuW | 5 | 8 | 40 | 150 | 9 |
| 5 | CuW | 5 | 12 | 60 | 200 | 11 |
| 6 | CuW | 5 | 16 | 80 | 100 | 7 |
| 7 | CuW | 6 | 8 | 60 | 100 | 11 |
| 8 | CuW | 6 | 12 | 80 | 150 | 7 |
| 9 | CuW | 6 | 16 | 40 | 200 | 9 |
| 10 | Cu | 4 | 8 | 80 | 200 | 9 |
| 11 | Cu | 4 | 12 | 40 | 100 | 11 |
| 12 | Cu | 4 | 16 | 60 | 150 | 7 |
| 13 | Cu | 5 | 8 | 60 | 200 | 7 |
| 14 | Cu | 5 | 12 | 80 | 100 | 9 |
| 15 | Cu | 5 | 16 | 40 | 150 | 11 |
| 16 | Cu | 6 | 8 | 80 | 150 | 11 |
| 17 | Cu | 6 | 12 | 40 | 200 | 7 |
| 18 | Cu | 6 | 16 | 60 | 100 | 9 |

(Table 2 source: Mane, S.G. and Hargude, N.V., "Parametric Optimization of Near Dry Electrical Discharge Machining Process for AISI SAE D-2 Tool steel" [8])

### D. MOORA-PCA based Taguchi method

*Brauers* [11-12] initially proposed MOORA method to elucidate different types of complicated decision making problems related to manufacturing environment. It is a multi-objective optimization technique which can be successfully implemented to simultaneously optimize two or more often conflicting objectives.

Majumder et al. [9] coupled MOORA with PCA for multi objective optimization of turning operation. Since contribution of each performance may not have same impact in real life. So to find the contribution of each parameter PCA is used.

Tansel et al. [10] proposed MOORA based Taguchi method for solving multi response optimization problems. It was found that solution resulting from MOORA-based Taguchi application and from other hybrid models which were used in the literature were not significantly different. But the proposed method reduces the time required in calculation significantly.

Procedure of MOORA-PCA based Taguchi method is as follows:

**Step 1:** Represent all the experimental values for the attributes in the form of a decision matrix.

$$X = \begin{bmatrix} x_{11} & x_{12} & \cdots & x_{1j} & \cdots & x_{1n} \\ x_{21} & x_{22} & \cdots & x_{2j} & \cdots & x_{2n} \\ \vdots & \vdots & \ddots & \vdots & \ddots & \vdots \\ x_{i1} & x_{i2} & \cdots & x_{ij} & \cdots & x_{in} \\ \vdots & \vdots & \ddots & \vdots & \ddots & \vdots \\ x_{m1} & x_{m2} & \cdots & x_{mj} & \cdots & x_{mn} \end{bmatrix}$$

Where, $x_{ij}$ represents the performance measure of $i^{th}$ alternative on $j^{th}$ attributes, *m* represents the number of alternatives and *n* represents the number of attributes.

**Step 2:** In MOORA, each response of particular attribute is compared to a denominator which represents all the alternative of that attribute. Brauers and Zavadskas [12] concluded that for this denominator, the best choice is the square root of the sum of squares of each alternative per attribute. This ratio can be expressed as below [13]:

$$x^{*}_{ij} = \frac{x_{ij}}{\sqrt{\sum_{i=1}^{m} x_{ij}^2}} \quad (i = 1, 2, 3,....., m)$$

Here $x^{*}_{ij}$ is a dimensionless number which belongs to the interval [0, 1] representing the normalized performances of $i^{th}$ alternative on $j^{th}$ attribute.

**Step 3:** For multi-objective optimization, these normalized performances are added in case of maximization (for beneficial attributes) and subtracted in case of minimization (for non beneficial attributes). Then the optimization problem becomes:

$$y_i = \sum_{j=1}^{g} x^{*}_{ij} - \sum_{j=1+1}^{n} x^{*}_{ij}$$

Here, *g* is the number of attributes to be maximized, (n-g) is the number of attributes to be minimized, and $y_i$ is the normalized assessment value of $i^{th}$ alternative with respect to all the attributes. In many cases, it is often found that some attributes have more importance than the others. An attribute could be multiplied with its corresponding weight in order to contribute more importance to that attribute. When these attribute weights are utilized for analysis then, Eq. 3.27 becomes:

$$y_i = \sum_{j=1}^{g} w_j x^{*}_{ij} - \sum_{j=1+1}^{n} w_j x^{*}_{ij}$$

where, $w_j$ known as the weight of $j^{th}$ criterion. Relative weight of each response was evaluated using PCA.

Squares of Eigen vectors of the most influential principal component will be chosen as the weights for analysis of MOORA.

**Step 4:** Depending of the totals of its maxima (beneficial attributes) and minima (non-beneficial attributes) in the decision matrix, the $y_i$ value may be positive or negative. The final preference is obtained by an ordinal ranking of $y_i$. Thus, the best alternative has the highest $y_i$ value, while the worst alternative has the lowest $y_i$ value.

**Step 5:** The Taguchi method is finally to be applied to evaluate this optimal setting (by maximising the MOORA index) [10, 14].

## III. RESULTS AND DISCUSSION

The values of material removal rate, tool wear rate and surface roughness obtained by performing the experiments are given in the Table 3 below.

Table 3: Obtained values of MRR, TWR and Ra

| Exp. No. | MRR ($mm^3/min$) | TWR ($mm^3/min$) | Ra |
|---|---|---|---|
| 1 | 1.1889293 | 0.02702702 | 3.219 |
| 2 | 1.9035862 | 0.03648641 | 3.314 |
| 3 | 8.0509355 | 0.04391891 | 4.447 |
| 4 | 1.2733887 | 0.02837837 | 2.907 |
| 5 | 1.7398648 | 0.04189189 | 2.769 |
| 6 | 12.9677754 | 0.04729729 | 3.933 |
| 7 | 0.8316008 | 0.02027027 | 3.179 |
| 8 | 11.1616424 | 0.05557432 | 3.909 |
| 9 | 10.1611226 | 0.0429054 | 4.317 |
| 10 | 7.4454262 | 0.08928571 | 4.421 |
| 11 | 1.6632017 | 0.08370536 | 3.948 |
| 12 | 10.089657 | 0.12834821 | 4.927 |
| 13 | 10.6678794 | 0.08928571 | 4.419 |
| 14 | 8.7707902 | 0.20089286 | 3.447 |
| 15 | 12.9158004 | 0.15066964 | 3.818 |
| 16 | 7.8742204 | 0.12276785 | 4.526 |
| 17 | 10.5054569 | 0.17299107 | 3.721 |
| 18 | 9.8817567 | 0.06138393 | 4.919 |

(Table 3 source: Mane, S.G. and Hargude, N.V., "Parametric Optimization of Near Dry Electrical Discharge Machining Process for AISI SAE D-2 Tool steel" [8])

PCA analysis is performed on normalized values using MINITAB 15 software and corresponding Eigen Values and Eigen Vectors are given in Table 4.

Table 4: Eigen values and proportions of principal components

| Variable | PC1 | PC2 | PC3 |
|---|---|---|---|
| Eigen Value | 1.9509 | 0.7562 | 0.2929 |
| Proportion (%) | 65 | 25.2 | 9.8 |
| Eigen Vectors | | | |
| MRR | 0.651338 | -0.089326 | 0.753512 |
| TWR | 0.497691 | 0.799889 | -0.335383 |
| Ra | 0.572767 | -0.593464 | -0.565455 |

From the above table, it is clear that first principal component (PC1) is the most influential principal component here. Therefore square of Eigen vectors of first principal component are chosen as the weights for analysis of MOORA.

Table 5: Experimental layout using $L_{18}$, MOORA index and ranking.

| Exp. No. | Cu/ CuW | $P_a$ | Ip | V | Ton | Ʈ | $y_i$ | Rank |
|---|---|---|---|---|---|---|---|---|
| 1 | CuW | 4 | 8 | 40 | 100 | 7 | -0.06528 | 15 |
| 2 | CuW | 4 | 12 | 60 | 150 | 9 | -0.06436 | 13 |
| 3 | CuW | 4 | 16 | 80 | 200 | 11 | -0.01757 | 7 |
| 4 | CuW | 5 | 8 | 40 | 150 | 9 | -0.05899 | 12 |
| 5 | CuW | 5 | 12 | 60 | 200 | 11 | -0.05894 | 11 |
| 6 | CuW | 5 | 16 | 80 | 100 | 7 | 0.049236 | 1 |
| 7 | CuW | 6 | 8 | 60 | 100 | 11 | -0.06466 | 14 |
| 8 | CuW | 6 | 12 | 80 | 150 | 7 | 0.023067 | 2 |
| 9 | CuW | 6 | 16 | 40 | 200 | 9 | 0.01083 | 3 |
| 10 | Cu | 4 | 8 | 80 | 200 | 9 | -0.05193 | 8 |
| 11 | Cu | 4 | 12 | 40 | 100 | 11 | -0.10841 | 18 |
| 12 | Cu | 4 | 16 | 60 | 150 | 7 | -0.05401 | 10 |
| 13 | Cu | 5 | 8 | 60 | 200 | 7 | -0.01336 | 5 |
| 14 | Cu | 5 | 12 | 80 | 100 | 9 | -0.08499 | 17 |
| 15 | Cu | 5 | 16 | 40 | 150 | 11 | -0.0121 | 4 |
| 16 | Cu | 6 | 8 | 80 | 150 | 11 | -0.06925 | 16 |
| 17 | Cu | 6 | 12 | 40 | 200 | 7 | -0.05262 | 9 |
| 18 | Cu | 6 | 16 | 60 | 100 | 9 | -0.01555 | 6 |

### A. Determination of optimal factor levels

The average responses can be determined by using the additive property [14]. For instance, an estimation of the effect 'Ip' at level 2 (60 Volts) from Table 5 (see bold values in Table 5) is:

$$m_{Ip2} = (y_2 + y_5 + y_7 + y_{12} + y_{13} + y_{18})/6$$

$$m_{Ip2} = (-0.06436 - 0.05894 - 0.06466 - 0.05401 - 0.01336 - 0.01555)/6$$

$$m_{Ip2} = -0.05771$$

Similarly the values are calculated for all the levels of each process parameters. The optimal factor effects are illustrated in Table 6. The bold data indicate the preferred levels for each factor. Since the effect value is a larger the better type, hence choosing the level with highest value for each control factors. Table 6 led to the final parameter design of A1B3C3D3E3F1.

Table 6: Factor effects using MOORA index.

| Control Factors | Level 1 | Level 2 | Level 3 | Optimal value of control factors |
|---|---|---|---|---|
| A. Electrode Material | -0.02741 | -0.05136 | ………. | CuW |
| B. Air Pressure | -0.06026 | -0.02985 | -0.02803 | 6 kg/cm$^2$ |
| C. Discharge Current | -0.05391 | -0.05771 | -0.00653 | 16 Amp |
| D. Gap Voltage | -0.04776 | -0.04515 | -0.02524 | 80 Volts |
| E. Pulse on Time | -0.04828 | -0.03927 | -0.0306 | 200 µs |
| F. Duty Factor | -0.01883 | -0.04416 | -0.05515 | 7 |

The optimal setting obtained from additive property of Taguchi method is given in Table 7.

Table 7: Optimal solution obtained by Taguchi method.

| Electrode Material | Air Pressure | Discharge Current | Gap Voltage | Pulse on Time | Duty factor |
|---|---|---|---|---|---|
| Copper - Tungsten | 6 kg/cm$^2$ | 16 amp | 80 V | 200 µ-sec | 7% |

Table 8: Predicted value of performance parameters obtained using optimized process parameters.

| MRR (mm$^3$/min) | TWR (mm$^3$/min) | Ra |
|---|---|---|
| 19.887 | 0.055874 | 4.618 |

## IV. CONCLUSION

In order to achieve best quality characteristics and satisfactory process performance yield; the machining parameters in near-dry EDM of work piece material AISI SAE D2 tool steel need to be optimized. Taguchi's philosophy is primarily concerned with the optimization of single response only. Therefore, in this study a multi-objective hybrid optimization technique MOORA-PCA combined with Taguchi method has been employed successfully for optimizing performance parameters of near-dry EDM reaching to an optimal parameter setting for machining of advanced materials like AISI SAE D2 tool steel.

The predicted values of MRR, TWR and Ra obtained from optimized process parameters shows that obtained MRR is much higher and TWR and surface roughness are relatively low as compared to values obtained from experiment.

## V. FUTURE SCOPE

I. Various combinations of electrode materials and liquid gas mixtures as dielectric mediums can be used to perform near-dry EDM process for different work piece materials.
II. The machined surface and subsurface properties, such as microstructure, micro hardness, residual stress, and material composition, can be investigated to characterize the near-dry EDM process.
III. Different combinations of machining parameters like gap size, frequency etc can be used to perform the experiments.
IV. Different conditions like machine tool vibration, cryogenic effect on tool etc. can be adopted
V. Different multi objective optimization techniques can be applied like grey relational analysis, genetic algorithm, evolutionary algorithms and combined methods like grey-fuzzy method combined with Taguchi method.
VI. Theoretical modelling and process simulation in near dry EDM can be performed. Present literature is insufficient on this regard.

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