

# Experimental Investigation & Taguchi Optimization using micro-EDM

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**Abstract**— There is a huge demand in the production of microstructures by a non-traditional method which is known as Micro-Electrical discharge machining (Micro-EDM). Micro-EDM process is based on the thermoelectric energy between the workpiece and an electrode. Micro-EDM is a newly developed method to produce micro-parts which in the range of 50  $\mu\text{m}$  -100  $\mu\text{m}$ . Micro-EDM is an efficient machining process for the fabrication of a micro-metal hole with various advantages resulting from its characteristics of non-contact and thermal process. A pulse discharges occur in a small gap time removes the unwanted material from the parent metal through the process of melting and vaporization. The characteristics parameters of material removal rate, tool wear ratio and the tool wear rate that are essential in the Micro-EDM process. This procedure deals with optimization of micro- Electrical Discharge Machining (micro-EDM) drilling process using Taguchi method. Micro-EDM is a thermal process that utilizes spark discharges to erode a conductive material. The objective is to study the effect of independent variable to accuracy of micro EDM drilling process and to optimize it by using Taguchi method. Taguchi Method is used to find the optimal drilling parameters for hole diameter in drilling operation. The orthogonal array, the signal-to-noise ratio, and analysis of variance are employed to study the performance characteristics in drilling operations. Three operational parameters namely, pulse off time, peak current, and servo standard voltage, are optimized with considerations of hole diameter. It is found that Taguchi's robust orthogonal array design method is suitable to analyze the hole diameter problem. Also parameter design of Taguchi method provides a simple, systematic and efficient methodology for the optimization of drilling process. The result concluded that use of greater pulse off time, greater peak current and medium servo standard voltage give the better hole diameter for the specific test range. The results also significantly reduce the cost and time market and improve product reliability and customer confidence. There are several suggestions that could be implanted as to improve results and obtained more accurate finding. In addition, further study could consider more factor such as pulse on time, material removal rate (MRR), coolants and etc in the research to see how the factors would affect hole diameter.

**Key words:** Grey Taguchi Method, Micro-EDM, Metal Removal Rate Analysis of Variance, MINITAB Surface Roughness

## I. INTRODUCTION

Micro-Electrical discharge machining (Micro-EDM) is a thermo-electric process which erodes material from the work-piece by a series of discrete sparks between the work-piece and the tool electrode, both submerged in a dielectric fluid. The sparks, occurring at high frequency, continuously and effectively remove the work-piece material by melting

and evaporation. The dielectric acts as a deionising medium between two electrodes, and its flow evacuates the resolidified material debris from the gap, assuring optimal conditions for spark generation. The thermal nature of Micro-EDM allows machining any electrical conductive material irrespective of its hardness and strength. Generally, Micro-EDM allows the shaping of complex structures with high machining accuracy in the order of several micrometers and achievable surface roughness  $R_z = 0.4 \mu\text{m}$ . During last few decades, this process has found wide applications in many industrial domains, such as mould and die manufacturing and small and burr-free hole drilling. Furthermore, it proves to be a competitive method for ceramic processing because of the abilities to provide accurate, cost-effective and flexible products. As a consequence, the use of Micro-EDM for micro-scale manufacturing is inevitable and has been attracting more and more attention in recent years. Promising applications are not only limited to the machining of hard materials for micro-moulds or cutting tools but also the production of difficult-to-make structures such as fuel injection nozzles, spinneret holes for synthetic fibers, electronic and optical devices, micro-mechatronic actuator parts and micro-tools for producing these devices. Moreover, machinable materials are no longer restricted to high-hardness alloys or cemented carbides. More extended applications are the machining of semi-conduct materials such as silicon and even insulating ceramics like  $\text{Si}_3\text{N}_4$  using conductive assisting electrodes. By introducing a conductive secondary phase such as TiN, WC and  $\text{TiB}_2$  etc. based advanced engineering ceramics, which have excellent mechanical and physical properties, can also be machined by Micro EDM. In addition, the implementation of high frequency electrical components in pulse generators, development of accurate motion drive devices and the availability of advanced CNC systems allows high precision manufacturing and complex 3D micro-structuring. However, the knowledge of micro-EDM of these ceramic composites is still limited, especially on process capability, machining performances and material properties. By characterizing discharge pulses of the micro-EDM process, machining behaviour of a ceramic composite, thus, is investigated concerning machining speed and surface quality.

## II. METHODOLOGY

Taguchi method: Taguchi's method is an efficient tool for the design of high quality manufacturing system. Dr. Genichi Taguchi, a Japanese engineer has developed a method based on orthogonal arrays (OA). In this method quality is measured by the deviation of a characteristic from its target value. A loss function is developed from this deviation. Uncontrollable factors which are also known as noise cause such deviation and result into loss. Taguchi method seeks to minimize the noise because the elimination

of noise factor is impractical. This method provides much reduced variance for the experiment with optimum setting of process control parameters. So Taguchi philosophy is based on integration of design of experiments (DOE) with parametric optimization of processes to get the desired results. A three stage design operation is done in Taguchi's method to determine the target value and tolerances for relevant parameters in the product. The three stage designs are-

- 1) System design
- 2) Parameter design
- 3) Tolerance design

#### A. Grey Based Taguchi Method

Genichi Taguchi, a Japanese scientist, developed a technique based on OA of experiments. This technique has been widely used in different fields of engineering to optimize the process parameters. The integration of DOE with parametric optimization of process can be achieved in the Taguchi method. An OA provides a set of well-balanced experiments, and Taguchi's signal-to-noise. (S/N) ratios, which are logarithmic functions of the desired output, serve as objective functions for optimization. It helps to learn the whole parameter space with a small number (minimum experimental runs) of experiments.

#### B. Grey Relational Analysis

In grey relational analysis following steps are used:

##### 1) Grey Relation Generation

In grey relational analysis experimental data's are first normalized in the range of 0 to 1. This process is known as grey relational generation. According to the normalization three types of data normalization are done:

- 1) Lower the better (LB)
- 2) Higher the better (HB)
- 3) Nominal is the best (NB)

Generally normalization is used for the above two lower the better and higher the better.

For lower the better (LB) criteria:

$$X_i^*(k) = [\max X_i(k) - X_i(k) / \max X_i(k) - \min X_i(k)] \quad (1)$$

For higher the better (HB) criteria:

$$X_i^*(k) = [X_i(k) - \min X_i(k) / \max X_i(k) - \min X_i(k)] \quad (2)$$

where  $x_i^*(k)$  is the value after the Grey relational generation,  $\min X_i(k)$  is the smallest value of  $X_i(k)$  for the kth response, and  $\max X_i(k)$  is the largest value of  $X_i(k)$  for the k<sup>th</sup> response.

##### 2) Deviation

After calculating the grey relation generation or normalization process the deviation is calculation by following formula:

$$\Delta_{0i}(k) = |X_0(k) - X_i(k)| \quad (3)$$

$\Delta_{0i}(k)$  is deviation sequence of reference sequence  $X_0(k)$  and comparability sequence  $X_i(k)$ .

##### 3) Grey Relational Coefficient (GRC)

Grey relational co-efficient are calculated to represent the correlation between ideal and the actual normalized data. After calculating the deviation the grey relational coefficient is calculated by following formula:

$$\xi_i(k) = (\Delta_{\min} + \zeta \Delta_{\max}) / (\Delta_{0i}(k) + \zeta \Delta_{\max}) \quad (4)$$

$\zeta$  is distinguishing or identification coefficient, and the value of  $\zeta$  is taken 0.5.

#### 4) Grey Relational Grade (GRG)

The grey relational grade is calculated after calculating the grey relational coefficient by the given formula:

$$\gamma_i = \frac{1}{n} \sum_{k=1}^n \xi_i(k) \quad (5)$$

Where n = number of process responses. When there are two process responses When n=2, then the GRG:

$$\gamma_i = \frac{1}{2} [\xi_i(1) + \xi_i(2)] \quad (6)$$

The mean grey relation grade is also calculated.

#### 5) For calculating the S/N ratio

$$\eta_{ij} = -10 \log \left( \frac{1}{n} \sum_{k=1}^n \frac{1}{V_{ijk}^2} \right) \quad (7)$$

$$\eta_{ij} = -10 \log \left( \frac{1}{n} \sum_{k=1}^n V_{ijk}^2 \right) \quad (8)$$

Equation (7) is used for higher the better and equation (8) is used for lower the better.

### III. EXPERIMENTAL DETAIL AND SET UP

- 1) According to the Taguchi design method L9 Orthogonal array was chosen for the optimization of the process.
- 2) Three control factors are chosen at three levels-
  - 1) Voltage (A)
  - 2) Capacitance (B)
  - 3) Feed rate (C)
- 3) Two response parameters will be measured at different levels of control parameters are given below:
  - 1) MRR (Material removal rate)
  - 2) TWR (Tool wear rate)

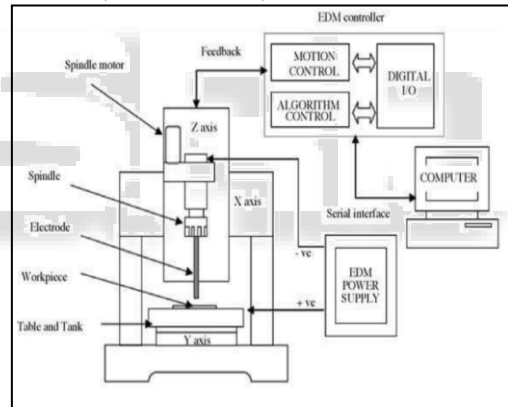


Fig. 1: Micro-EDM experimental Setup.

#### A. Specification of Micro-EDM

Model	UPL 4040	
Travel	X-Axis	200mm
	Y-Axis	100mm
	Z-Axis	100mm
Table	Table working surface	350×200mm
	T-slot configuration	6mm×7(Qty)×25mm
Spindle Head	Spindle	Power(Speed Range)
	Spindle AC Servo High Speed Spindle Air Braking Spindle	100W(1to500rpm) 10000 to 60000 rpm 20000 to 200000 rpm
Power requirement	Electrical Power Supply	230V, 50/60 Hz
	Pneumatic supply	6 to 7 kg/sq.cm

Machine Size	Height Machine Space	1900mm (2700mm with open door) 1.5×1.1mm
Machine Accuracy	Resolution Accuracy repeatability	100nm +/-1mic./100mm 1 micron for all axes
Standard accessories	Tanks for different machining processes	
Optional Accessories	Micro EDM attachments	

Table 2:

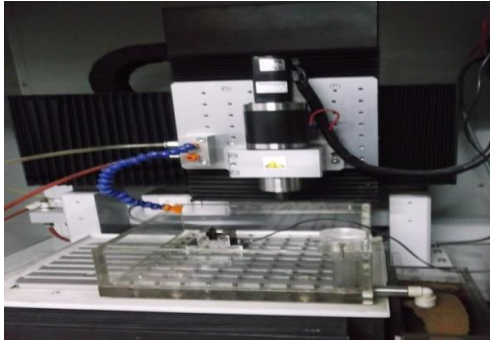


Fig. 2: Experimental Setup of Micro-EDM.



Fig. 3: Manual Axis Movement Controller.

### B. Workpiece and Tool Details

Tool : Tungsten (500 micro meters)  
 Workpiece : Copper alloy  
 Speed : 2000 rpm  
 Polarity : Workpiece (+ve)  
 Dielectric Fluid : EDM oil  
 Machining depth : 200 micro meter

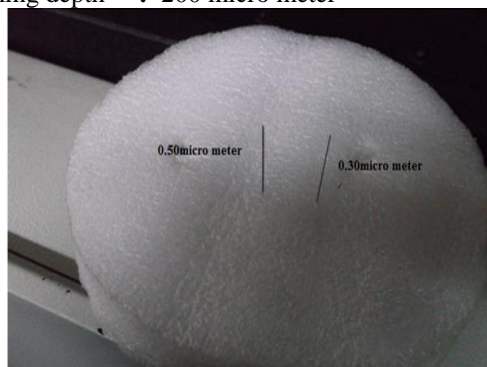


Fig. 4: Tools of micro-EDM.

### C. Input Parameters

Symbol	Parameters	Unit	Level 1	Level 2	Level 3
A	Capacitance	n farad	0.10	1.00	10.0
B	Voltage	Volt	80.0	100	120

C	Feed rate	$\mu$ meter/sec.	2.00	4.00	6.00
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Table 2:

## IV. RESULTS AND DISCUSSION

S. No	Feed rate (micro meter/sec)	Capacitance (n Farad)	Voltage (Volt)	TWR (Tool Wear Ratio)	MRR (mg/min.)
1	2	0.10	80	0.12	0.02
2	2	1.00	100	0.19	0.06
3	2	10.0	120	0.26	0.16
4	4	0.10	100	0.05	0.09
5	4	1.00	120	0.09	0.36
6	4	10.0	80	0.09	0.10
7	6	0.10	120	0.17	0.10
8	6	1.00	80	0.17	0.09
9	6	10.0	100	0.22	0.13

Table 3: Experimental results

Run order	MRR	TWR
Ideal sequence	1	1
1	0.000	0.667
2	0.118	0.333
3	0.412	0.000
4	0.206	1.000
5	1.000	0.809
6	0.235	0.809
7	0.235	0.429
8	0.206	0.429
9	0.324	0.190

Table 4: Calculation of grey relation generation for material removal rate (MRR).

Run Order	MRR	TWR
Ideal sequence	1	1
1	1	0.333
2	0.882	0.667
3	0.588	1.000
4	0.794	0
5	0	0.191
6	0.765	0.191
7	0.765	0.571
8	0.794	0.571
9	0.676	0.810

Table 5: Calculation of deviation.

Run order	MRR	TWR
Ideal sequence	1	1
1	0.333	0.600
2	0.362	0.428
3	0.460	0.333
4	0.386	1.000
5	1.000	0.724
6	0.395	0.724
7	0.395	0.467
8	0.386	0.467
9	0.425	0.382

Table 6: Calculation of grey relation coefficient

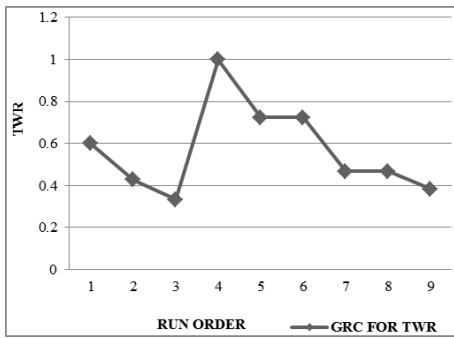


Fig. 5: Schematic representation of Tool Wear Rate.

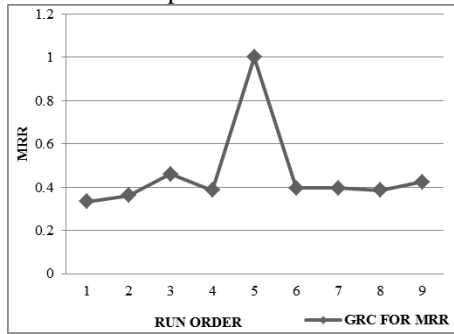


Fig. 6: Schematic representation of Material Removal Rate.

Figure 5 and Figure 6 are plotted with the help of Table 4 in which two values are given material removal rate and tool wear rate. The values of material removal rate and tool wear rate can be calculated with the help of Equation-4.

Run order	Grey Relational Grade
1	0.467
2	0.395
3	0.397
4	0.693
5	0.862
6	0.560
7	0.431
8	0.427
9	0.404

Table 7: Calculation of grey relational grade.

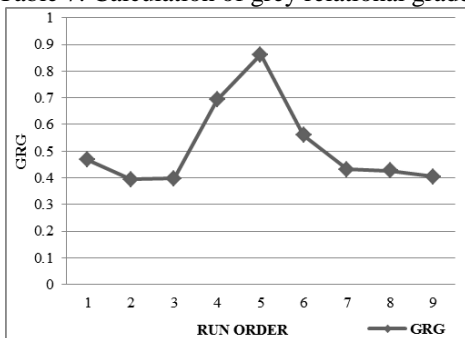


Fig. 7: variation of Grey Relational Grade.

Factor	Level 1	Level 2	Level 3
Feed Rate	0.420	0.705	0.421
Capacitance	0.530	0.561	0.454
Voltage	0.485	0.497	0.563

Table 8: Mean grey relation grade.

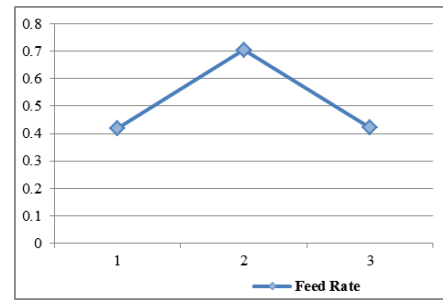


Fig. 8: Feed Rate Analysis by Grey Based Taguchi Method.

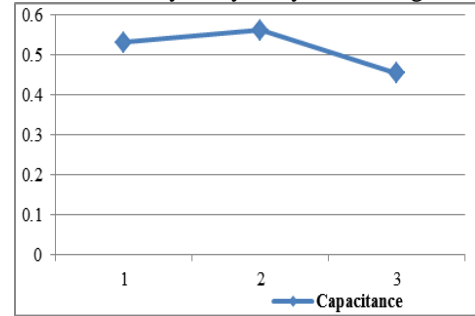


Fig. 9: Capacitance Analysis by Grey Based Taguchi Method.

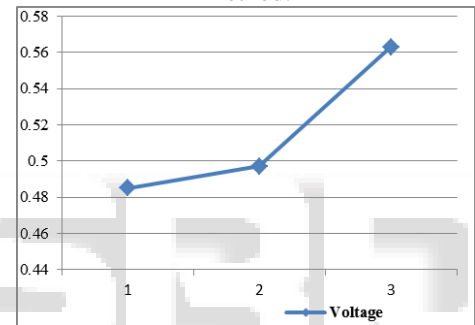


Fig. 10: Voltage Analysis by Grey Based Taguchi Method.

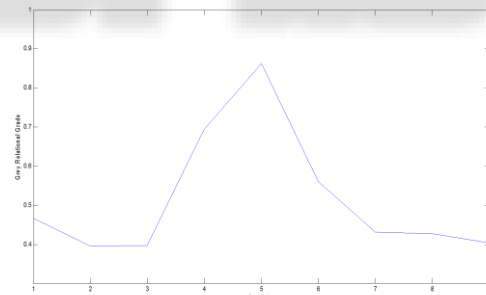


Fig. 11: Analysis by MATLAB for Grey Relational Grade.

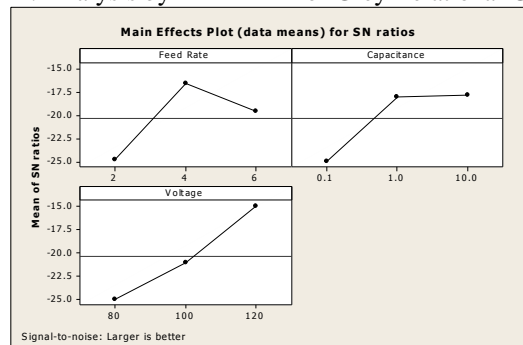


Fig. 12: Analysis by MINITAB for MRR.

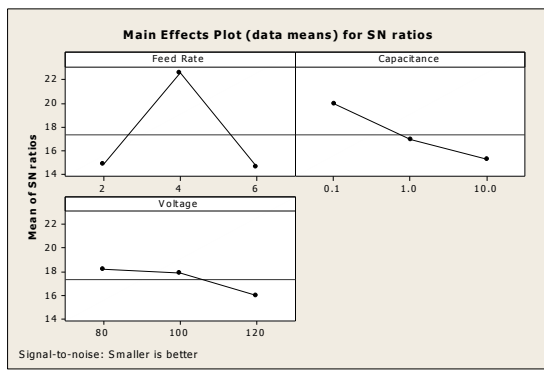


Fig. 13: Analysis by MINITAB for TWR.

Wire EDM is a complex process having many numbers of factors affecting the process, but for current study the main factors considered are: Voltage, capacitance, wire feed. The effects of these factors on TWR and MRR have been studied. For optimizing the process variables Grey-based Taguchi method has been applied.

- By Grey relational analysis Based Taguchi method Feed Rate at level 2(4 micro meter/sec), Capacitance at level 2 (1.00 nano farad) and Voltage at level 3 (120 volt) provide.
- By Minitab software for single-objective optimization, Maximum value of MRR obtained at Feed Rate level 2 (4 micro meter/sec), Capacitance at level 3 (nano farad/sec) and Voltage at level 3(120 volt).
- By Minitab software for single-objective optimization, Minimum value of TWR obtained at Feed Rate level 2(4 micro meter/sec), Capacitance at level 1(0.10 nano farad) and Voltage at Level 1(80 volt).
- By MATLAB software same result is obtained as mathematical calculation for Multi Response.

## V. CONCLUSIONS

It is interesting to note that optimal settings of parameters for MRR, TWR are quite different & poses difficulty to achieve the goals of all objectives. An attempt will be made to determine important machining parameters for performance measures like MRR, TWR separately in the Micro WEDM process. Factors like discharge current, pulse on time & their interactions may play a significant role in rough cutting operations. Lastly it can be concluded that in order to optimize for all the three objectives i.e. MRR, TWR simultaneously, mathematical models using the non linear regression model will have to be developed.

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