Parametric Optimization of in μ-Edm Using Anova Technique for Semi Circular Feature Generation

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Abstract. Development of semi circular Feature and optimization of its process parameters is carried out in this paper. In the research work, Energy, RPM and Feed were taken as input parameters. The response parameters were selected as Material removal rate and Taper. From the main effect plot and S/N ratio graphs, it can be seen that energy and tool rotation are most significant parameter that affect taper. Energy is the only significant parameter that affects machining time. These results have been validated by ANOVA. The optimal combination of input parameters comes out be as energy as 2645μ joules, Tool rotation as 600 rpm and feed rate as 1mm/m. This combination gave the value of material removal rate and taper as 0.0690088 mm3/m and 1.63024° respectively.

Key words: Material removal rate, Tool rotation, feed rate, ANOVA, Optimizations

1. Introduction

Electrical Discharge Machining (EDM) is a controlled machining of an electrically conductive material both tool and work piece within a dielectric medium using pulsed direct electronic current. The process is excellent in giving high quality finish and is primarily used for those materials which cannot be machined using the conventional methods. It is widely used in almost every manufacturing industry wherever high quality finish is required. It is necessary for the material to be conductive for machining through this process, but an alternate in the form of electro chemical discharge machining is available for the materials which are not electrically conductive but that would require entirely different setup.

Shabgard and Shotorbani (2011), conducted electric discharge machining on AISI H13 using a commercial copper electrode tool to investigate the effects of various input parameters on the characteristics of the EDM process. Another study was conducted by Datta and Mahapatra (2010) on same process. Ali (2009) used molybdenum as a material and determined the material change effect on same process. This combination of parameters gave the value of material removal rate and taper as 0.0690088 mm3/m and 1.63024° respectively.

2. Materials and Methods
A hollow circular copper electrode of 2 mm outer and 1mm inner diameter was used for generating micro feature on edge of die steel (W/P). To identify the capability, the parametric combination for effective machining with RC-pulsed μ-EDM, experiments are conducted with different values of energy, rotation and feed. The depth of μ feature is set to 800 µm. DIEL 7500 IN was used as a dielectric. The schematic set up MIKROTOOLS-DT110 is shown in 1(a) and Machined work piece taken from stereo zoom microscope are shown in 1(b). The experimental setup is under figure 1(a).

![Figure 1(a) Schematic diagram of micro-EDM set-up for machining of die steel and Mikrotools Dt-110 hybrid micro-electric discharge machine (b) Tool condition after machining](image)

| Table 1 Machining conditions | Sr.no | Parameters ( units ) | Condition |
|------------------------------|------|----------------------|-----------|
| 1                            |      | Capacitance (uf)     | 0.4       |
| 2                            |      | Voltage (v)          | 100 115 130 |
| 3                            |      | Rotation speed n (rpm) | 400 600 800 |
| 4                            |      | Feed Rate (mm/m)     | 0.5 1.0 1.5 |
| 5                            |      | Tool electrode       | Cu φ( 2mm OD & 1mm ID) |
| 6                            |      | Tool electrode Polarity | Tool (+) W/p( -) |
| 7                            |      | Workspace            | Diestee skd7 |
| 8                            |      | Dielectric           | Total make ( 7500 IN) |

3.0 Design of experiments
Various input factors used in this paper are given in Table 2. The response parameters were selected as Material removal rate and Taper. Machining is done at the edge of the work piece for micro circular feature generation. Further stereo zoom microscope is used for taking images of feature. Those images are imported in AutoCAD 2013 for taper measurement. Machining time is calculated during machining and further MRR is calculated on weight basis using A&D GR-202 Weighing balance. The initial levels selected for input parameters can be seen in Table 2. The L-9 array thus, developed is shown in Table 3. The experimental array with output parameters can be seen in Table 4.

Table 2 Levels assigned for input parameters

| Input Factors         | Levels assigned for input parameters |
|----------------------|--------------------------------------|
| Energy in μJ         | 2000, 2645, 3380                     |
| Tool rotation in RPM | 400, 600, 800                        |
| Feed rate in mm/m    | 0.5, 1, 1.5                          |

Table 3 Design of L-9 Array

| Run | Energy | Tool rotation in RPM | Feed rate |
|-----|--------|----------------------|-----------|
| 1   | 1      | 1                    | 1         |
| 2   | 2      | 2                    | 2         |
| 3   | 3      | 3                    | 3         |
| 4   | 1      | 2                    | 2         |
| 5   | 2      | 3                    | 3         |
| 6   | 3      | 1                    | 1         |
| 7   | 2      | 1                    | 3         |
| 8   | 3      | 2                    | 1         |
| 9   | 1      | 3                    | 2         |

Table 4 Experimental L9 array with output parameters

| Run | Energy in μJ | Tool rotation in RPM | Feed rate | MRR in mm3/m | Taper in (°) |
|-----|--------------|----------------------|-----------|--------------|--------------|
| 1   | 2000         | 400                  | 0.5       | 0.0268103    | 2.48         |
| 2   | 2000         | 600                  | 1.0       | 0.045        | 1.638        |
| 3   | 2000         | 800                  | 1.5       | 0.032        | 1.33         |
| 4   | 2645         | 400                  | 1.0       | 0.0536       | 1.923        |
| 5   | 2645         | 600                  | 1.5       | 0.0772       | 2.26488      |
| 6   | 2645         | 800                  | 0.5       | 0.0502       | 1.55         |
| 7   | 3380         | 400                  | 1.5       | 0.0671       | 3.52         |
| 8   | 3380         | 600                  | 0.5       | 0.0637       | 2.8818       |
| 9   | 3380         | 800                  | 1.0       | 0.0558       | 1.59687      |

4.0 Results for Taper

The F-value of 24.49 implies the model is significant. There is only a 3.97% chance that an F-value this large could occur due to noise. From the ANOVA results, it is evident that energy and tool rotation are most significant factors. These results are given in Table 5. The results are verified in the figure 2. Table 6 shows statistically obtained values for experimental data. "Adeq Precision" has value greater than 4 and appropriate one.
Table 5 ANOVA table for surface Taper

| Source                  | Sum of Squares | df | Mean Square | F       | p-value | Prob > F |
|-------------------------|----------------|----|-------------|---------|---------|----------|
| Model                   | 4.1273         | 6  | 0.68789     | 24.493  | 0.039741| significant |
| Energy                  | 1.3001         | 2  | 0.65006     | 23.146  | 0.041414|
| Tool rotation in RPM    | 2.0553         | 2  | 1.0276      | 36.591  | 0.026602|
| Feed rate               | 0.77193        | 2  | 0.38597     | 13.743  | 0.067829|
| Residual                | 0.056170       | 2  | 0.028085    |         |         |
| Cor Total               | 4.1835         | 8  |             |         |         |

Table 6 Statistically obtained values for experimental data

| Std. Dev.   | R-Squared | Adj R-Squared | Pred R-Squared |
|-------------|-----------|---------------|---------------|
| 0.16759     | 0.98657   | 0.94629       | 0.72812       |
| 2.1316      | 7.8619    | 1.374         | 13.525        |

5.0 Results for Material removal rate

The F-value of 21.75 implies the model is significant. From the ANOVA results, it is evident that energy is only most significant factor in this case. These results are given in Table 7. The results are verified in the figure 3. Table 8 shows statistically obtained values for experimental data. "Adeq Precision" has value greater than 4 and appropriate one.
Figure 3 Main effect of mean and S/N ratio for Material removal rate

Table 7 ANOVA table for Machining time

| Source                  | Sum of Squares | df   | Mean Square  | F       | Prob > F  |
|-------------------------|----------------|------|--------------|---------|-----------|
| Model                   | 0.0020707      | 6    | 0.00034511   | 21.746  | 0.044611  |
| Energy                  | 0.0014271      | 2    | 0.00071354   | 44.961  | 0.021758  |
| Tool rotation in RPM    | 0.00042874     | 2    | 0.00021437   | 13.508  | 0.068930  |
| Feed rate               | 0.00021485     | 2    | 0.00010742   | 6.7689  | 0.12872   |
| Residual                | 3.1741E-005    | 2    | 1.5870E-005  |         |           |
| Cor Total               | 0.0021024      | 8    |               |         |           |

Table 8 Statistically obtained values for experimental data

| Std. Dev. | 0.0039838 | R-Squared | 0.98490 |
| Mean      | 0.052379  | Adj R-Squared | 0.93961 |
| C.V. %    | 7.6056   | Pred R-Squared | 0.69428 |
| PRESS     | 0.00064275 | Adeq Precision | 14.342 |

6.0 Optimization of results

As per objective i.e. to increase Material removal rate and decrease taper Table 9 is designed. The material removal rate was set to maximize itself with lower and upper target as 0.0268103 and 0.0772 respectively. The taper value was set to minimize itself with lower and upper target as 1.33 and 3.52 respectively. The optimal combination of input parameters comes out be as energy as 2645μ joules at 115 volt and 0.4 μF, Tool rotation as 600 rpm and Feed rate as 1mm/m.

Table 9 Setting of initial parameters

| Response           | Goal      | Lower Target | Upper Target | Weight |
|--------------------|-----------|--------------|--------------|--------|
| Material removal   | Maximum   | 0.0268103    | 0.0772       | 1      |
| Taper              | Minimum   | 1.33         | 3.52         | 1      |
Table 10 Multiple response prediction for response variables

| Solution | Energy       | Tool rotation in RPM | Feed rate | MRR | Taper | Desirability |
|----------|--------------|-----------------------|-----------|-----|-------|--------------|
| 1        | 2645 μJ at 115 v 600 | 1                     | 0.0690    | 1.630 | 24    | 0.850078     |
|          | C0.4μF       |                       |           | 088  |       |              |

7.0Conclusions

In this research work, various process parameters i.e. energy, tool rotation and feed rate are varied in a specific range to get optimal results. From these plots it can be seen that energy and tool rotation are most significant parameter that affect taper.

![Figure 4 Graphical illustration of crater size to energy values](image)

Energy is the only significant parameter that affects machining time. Further, It is evident from the SEM images higher is the energy, higher will be the MRR which results in more is the taper Similarly lower the energy lower will be MRR lower is the taper. These observed phenomena can be seen in Fig.4 This was basically done to get optimal combination of input variables with their desired output results. The material removal rate was set to maximize itself with lower and upper target as 0.0268103 mm3/m and 0.0772 mm3/m respectively. The taper value was set to minimize itself with lower and upper target as 1.33° and 3.52° respectively The optimal combination of input parameters comes out be as energy as 2645μ joules, Tool rotation as 600 rpm and feed rate as 1.

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