EXPERIMENTAL INVESTIGATION OF VARIATION IN SURFACE ROUGHNESS DURING WIRE ELECTRIC DISCHARGE MACHINING

Rohan KHANDALE¹, Sujit PARDESHI², Preetam SELMOKAR³, Shyam KAJALE⁴

ABSTRACT
Wire Electric Discharge Machining (WEDM), provides an effective solution in machining of hard and difficult to machine materials, which are conductive. During cutting of a linear profile with a defined set of machining parameters, the surface roughness obtained is expected to be constant at all machining angles i.e., during polygonal machining. After experimentation at some defined parameters it has been found that the surface roughness varied in a definite form. This possibility was not explored before and hence a mathematical model relating the surface roughness with process parameters was developed. The Regression and ANOVA analysis have been used for modeling.

KEYWORDS Wire Electrical Discharge Machine (WEDM)_1, Polygonal Machining_2, Surface Roughness_3, ANOVA_4

1. INTRODUCTION
Wire Electro-Discharge Machining (WEDM), provides an effective solution in machining of hard and difficult to machine materials, which are electrically conductive. Its versatile characteristics such as; absence of cutting force, high accuracy, ability to machine hard materials and composites, and ability to achieve complex profiles with precision has made it popular.
Wire EDM is a special form of electrical discharge machining, wherein the electrode is a continuously moving conductive wire. This process removes the work material, by a series of discrete electrical sparks (at very high frequency) in the gap between wire electrode and the work piece in presence of a dielectric fluid. Eroded particles are then flushed away by the dielectric fluid. The result of this process is that each discharge leaves a small crater on both the workpiece and the electrode. This crater affects final surface quality [1,2].
Wire EDM can be used for cutting various polygons like square, triangle and hexagon. The surface roughness obtained depends on various parameters like current, gap voltage, wire feed, wire composition, workpiece material and machining angle.

Hence experiments are carried out to establish an empirical relationship between the various process parameters and the surface roughness [3]. The machining angle is considered as shown in Fig.1 where X and Y axes are along the worktable.

2. PROBLEM DESCRIPTION
The surface roughness obtained during machining is expected to be constant at various machining angles. Experimentation carried out in this respect proved that there exists variation in surface roughness with the machining angle. A mathematical relationship has been established to correlate surface roughness with machining parameter. During the course of machining it was found that machining parameters like pulse on, pulse
off, gap voltage and machining angle influenced the surface roughness [2, 3]. The experiments are carried out on the Ecocut WEDM (Make- Electronica Machine Tools Ltd, Pune, (India).

3. EXPERIMENTATION AND OBSERVATIONS

Profiles were processed at varying machining angles and with different permutations and combinations of the machining parameters. All the experiments were carried out on low carbon steel (grade C 1020) components. The surface roughness was measured using the Mitutoyo surface roughness tester.

The machining conditions are as followed:
Ton=0.365 µs , Toff=128 µs,
Voltage=45 V, Current=1 A
Machining speed=1.1-1.3 mm/min [4]

<table>
<thead>
<tr>
<th>Sr.No</th>
<th>Machining Angle (θ)</th>
<th>Surface Roughness (Ra)</th>
</tr>
</thead>
<tbody>
<tr>
<td>1</td>
<td>-150</td>
<td>1.52</td>
</tr>
<tr>
<td>2</td>
<td>-108</td>
<td>1.69</td>
</tr>
<tr>
<td>3</td>
<td>-90</td>
<td>1.47</td>
</tr>
<tr>
<td>4</td>
<td>-60</td>
<td>1.73</td>
</tr>
<tr>
<td>5</td>
<td>-36</td>
<td>1.35</td>
</tr>
<tr>
<td>6</td>
<td>-30</td>
<td>1.44</td>
</tr>
<tr>
<td>7</td>
<td>0</td>
<td>1.4</td>
</tr>
<tr>
<td>8</td>
<td>30</td>
<td>1.49</td>
</tr>
<tr>
<td>9</td>
<td>36</td>
<td>1.53</td>
</tr>
<tr>
<td>10</td>
<td>60</td>
<td>1.42</td>
</tr>
<tr>
<td>11</td>
<td>90</td>
<td>1.42</td>
</tr>
<tr>
<td>12</td>
<td>108</td>
<td>1.46</td>
</tr>
<tr>
<td>13</td>
<td>150</td>
<td>1.58</td>
</tr>
<tr>
<td>14</td>
<td>180</td>
<td>1.68</td>
</tr>
</tbody>
</table>

The CURVE EXPERT Release 1.38 software was used for curve fitting purpose.

\[ Y = a + bx + cx^2 \]

The CURVE EXPERT Release 1.38 software was used for curve fitting purpose.

The curve fitting was obtained by using a quadratic fit.

\[ y=a+bx+cx^2 \quad (1) \]

![Fig. 2. Curve of the mathematical model developed](image)

Fig. 3. Values of Coefficients

Values obtained are as illustrated below:
\[ a = 1.4563319, b = -0.00023468278 \]
\[ c = 6.372375e-006 \]

Thus, the equation (1) becomes

\[ Ra = 1.4563319 -0.00023468278*θ + 6.372375 *10^-6*θ^2 \quad (2) \]

The standard error was 0.1088625 whereas the correlation coefficient was 0.5184647.
3.1. Test for confirmation:

Table 2 Confirmatory Results

<table>
<thead>
<tr>
<th>Angle</th>
<th>Ra (Experimental)</th>
<th>Ra (Obtained from Model)</th>
</tr>
</thead>
<tbody>
<tr>
<td>-45</td>
<td>1.42</td>
<td>1.4735</td>
</tr>
<tr>
<td>80</td>
<td>1.44</td>
<td>1.47</td>
</tr>
</tbody>
</table>

Thus it is observed from above table that the values obtained by mathematical model are close to the one obtained experimentally. Hence, the model can be useful for obtaining a trend.

4. ANALYSIS FOR EFFECT OF PROCESS PARAMETERS

From the results obtained (Table 1), it is observed that the machining angle has significant effect on surface roughness when all other parameters are held constant. Hence, we consider the combined effect of the process parameters [2,3] along with machining angle on surface roughness.

4.1. Selection of factors and output response variables

The output response variables and design factors were selected after review of literature.

A. Response variable: Surface Roughness.

B. Design factors : Factors that are actually selected for the experiment .

Range of factors was selected to know about performance over a region and to decide optimum condition. For each factor, 2 levels, were chosen within feasible range[5].

Table 3 Design Levels

<table>
<thead>
<tr>
<th>Sr.No.</th>
<th>Parameters</th>
<th>Levels</th>
<th>Levels</th>
</tr>
</thead>
<tbody>
<tr>
<td>1</td>
<td>Pulse On time</td>
<td>0.365</td>
<td>0.825</td>
</tr>
<tr>
<td>2</td>
<td>Pulse Off time</td>
<td>100.8</td>
<td>128</td>
</tr>
<tr>
<td>3</td>
<td>Voltage</td>
<td>35</td>
<td>45</td>
</tr>
<tr>
<td>4</td>
<td>Machining Angle</td>
<td>0</td>
<td>180</td>
</tr>
</tbody>
</table>

During the experiments, following factors were held constant.

Wire feed rate - 7 m/min, Jog Speed - 10 mm/min, Conductivity of Dielectric - 150 S

4.2. Design of Experiment

A fractional factorial design is used to determine the relationship between four factors (Pulse ON time, Pulse OFF time, Voltage and Machining angle) with output response (Surface Roughness). Each factor is kept at two levels.

Shape of samples = Square

Total number of trials = \(2^4=16\),
Number of samples per trial = 1
Total number of samples = 16. [5,6,7]

Table 4 Experimental Results

<table>
<thead>
<tr>
<th>Sr.No.</th>
<th>(T_{on}) (µs)</th>
<th>(T_{off}) (µs)</th>
<th>V</th>
<th>(\theta)</th>
<th>Ra (µm)</th>
</tr>
</thead>
<tbody>
<tr>
<td>1</td>
<td>0.365</td>
<td>100.8</td>
<td>35</td>
<td>0</td>
<td>2.15</td>
</tr>
<tr>
<td>2</td>
<td>0.365</td>
<td>100.8</td>
<td>35</td>
<td>180</td>
<td>2.34</td>
</tr>
<tr>
<td>3</td>
<td>0.365</td>
<td>100.8</td>
<td>45</td>
<td>0</td>
<td>2.33</td>
</tr>
<tr>
<td>4</td>
<td>0.365</td>
<td>100.8</td>
<td>45</td>
<td>180</td>
<td>2.37</td>
</tr>
<tr>
<td>5</td>
<td>0.365</td>
<td>128</td>
<td>35</td>
<td>0</td>
<td>2.17</td>
</tr>
<tr>
<td>6</td>
<td>0.365</td>
<td>128</td>
<td>35</td>
<td>180</td>
<td>2.28</td>
</tr>
<tr>
<td>7</td>
<td>0.365</td>
<td>128</td>
<td>45</td>
<td>0</td>
<td>2.33</td>
</tr>
<tr>
<td>8</td>
<td>0.365</td>
<td>128</td>
<td>45</td>
<td>180</td>
<td>2.44</td>
</tr>
<tr>
<td>9</td>
<td>0.825</td>
<td>100.8</td>
<td>35</td>
<td>0</td>
<td>2.45</td>
</tr>
<tr>
<td>10</td>
<td>0.825</td>
<td>100.8</td>
<td>35</td>
<td>180</td>
<td>2.53</td>
</tr>
<tr>
<td>11</td>
<td>0.825</td>
<td>100.8</td>
<td>45</td>
<td>0</td>
<td>2.49</td>
</tr>
<tr>
<td>12</td>
<td>0.825</td>
<td>100.8</td>
<td>45</td>
<td>180</td>
<td>2.524</td>
</tr>
<tr>
<td>13</td>
<td>0.825</td>
<td>128</td>
<td>35</td>
<td>0</td>
<td>1.93</td>
</tr>
<tr>
<td>14</td>
<td>0.825</td>
<td>128</td>
<td>35</td>
<td>180</td>
<td>2.01</td>
</tr>
<tr>
<td>15</td>
<td>0.825</td>
<td>128</td>
<td>45</td>
<td>0</td>
<td>2.32</td>
</tr>
<tr>
<td>16</td>
<td>0.825</td>
<td>128</td>
<td>45</td>
<td>180</td>
<td>2.44</td>
</tr>
</tbody>
</table>

The equation obtained after regression is

\[Ra = -569.484k + 2.325861 Ton + 2.309608 Toff + 2.329813 V + 2.36675 \theta\]  

To confirm the result, the ANOVA of the data was done by using the QUALITEK-4 software. The L8 array \((2^4)\) was
The eight combinations of the table are given below.

Table 5 Combinations for the L8 array Used in ANOVA

<table>
<thead>
<tr>
<th>Ton</th>
<th>Toff</th>
<th>Voltage</th>
<th>$\Theta$</th>
<th>$Ra$</th>
</tr>
</thead>
<tbody>
<tr>
<td>0.365</td>
<td>100.8</td>
<td>35</td>
<td>0</td>
<td>2.15</td>
</tr>
<tr>
<td>0.365</td>
<td>100.8</td>
<td>35</td>
<td>180</td>
<td>2.34</td>
</tr>
<tr>
<td>0.365</td>
<td>128</td>
<td>45</td>
<td>0</td>
<td>2.33</td>
</tr>
<tr>
<td>0.365</td>
<td>128</td>
<td>45</td>
<td>180</td>
<td>2.44</td>
</tr>
<tr>
<td>0.825</td>
<td>100.8</td>
<td>45</td>
<td>0</td>
<td>2.49</td>
</tr>
<tr>
<td>0.825</td>
<td>100.8</td>
<td>45</td>
<td>180</td>
<td>2.524</td>
</tr>
<tr>
<td>0.825</td>
<td>128</td>
<td>35</td>
<td>0</td>
<td>1.93</td>
</tr>
<tr>
<td>0.825</td>
<td>128</td>
<td>45</td>
<td>180</td>
<td>2.01</td>
</tr>
</tbody>
</table>

The results obtained after the ANOVA analysis are given below:

![Pie-chart Showing Relative Influence of Factors and Errors](image)

Fig. 5. Significance of Individual Parameters, using QUALITEK-4 software

<table>
<thead>
<tr>
<th>Column#/Factor</th>
<th>Level Description</th>
<th>Level</th>
<th>Contribution</th>
</tr>
</thead>
<tbody>
<tr>
<td>1 Ton</td>
<td>0.825</td>
<td>2</td>
<td>-0.39</td>
</tr>
<tr>
<td>2 Toff</td>
<td>1.28</td>
<td>2</td>
<td>-0.1</td>
</tr>
<tr>
<td>3 Spark voltage</td>
<td>35</td>
<td>1</td>
<td>-0.17</td>
</tr>
<tr>
<td>4 Machining angle</td>
<td>0</td>
<td>1</td>
<td>-0.52</td>
</tr>
</tbody>
</table>

Total Contribution From All Factors... -3.61
Current Grand Average Of Performance... 2.276
Expected Result At Optimum Condition... 1.915

Fig. 6. Optimum values of Individual Parameters, using QUALITEK-4 software
5. CONCLUSION

From the mathematical model (equation 2) obtained it can be concluded that the surface roughness varies with machining angle in a definite form and which has been validated (Table 2). By observing the F values in the above ANOVA table, it is clear that gap voltage is the most significant factor affecting the surface roughness. The interaction table (Fig.7) clearly reflects the significance of Pulse on – off time which also has a significant effect on surface roughness. This observation is also confirmed and reported by earlier researches [3,8].

REFERENCES


AUTHORS

Undergraduate student, Rohan KHANDALE 1, Department of Mechanical Engineering, College of Engineering, Pune, (M.S.), India. rohankhandale@rediffmail.com +91-9881542372
Faculty, Sujit PARDESHI 2, Micro Systems Engineering Laboratory, Department of Mechanical Engineering, College of Engineering, Pune, (M.S.), India. ssp@mech.coep.org.in +91-9850407263
Faculty, Preetam SELMOKAR 3, Micro Systems Engineering Laboratory, Department of Mechanical Engineering, College of Engineering, Pune, (M.S.), India. pjm@mech.coep.org.in +91-9890184940
Dean R & D, Shyam KAJALE 4, Micro Systems Engineering Laboratory, Department of Mechanical Engineering, College of Engineering, Pune, (M.S.), India. deanr_d@coep.org.on +91-9423582535