OPTIMIZATION OF PROCESS PARAMETERS IN WIRE-EDM USING RESPONSE SURFACE METHODOLOGY

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Abstract—Wire electrical discharge machining has become an important non-traditional machining process, as it provides an effective solution for producing components made of difficult-to-machine materials like tungsten carbide, titanium, zirconium etc., and intricate shapes, which are not possible by conventional machining methods. This research paper deals with Response Surface Methodology approach for maximizing the material removal rate in wire electrical discharge machining. The investigated machining parameters were wire tension, pulse on time and peak current. Machining was carried on AISI D2 cold work steel, which is widely used in die and mold making industries. The experiments were designed based on response surface design method; in which central composite design method was applied for fitting the second order model. After the experimentation, the effect of the parameters on MRR was determined by analysis of variance (ANOVA). Also the interaction of their parameters was considered for their significance. Regression analysis was done and a second order mathematical model was fitted for MRR considering the parameters and their significant interactions. And at last optimization was carried using desirability approach and confirmation experiments were performed.

Keywords—Response surface methodology (RSM), Wire electrical discharge machining, Wire tension, Pulse on time, AISI D2 cold work steel.

I. INTRODUCTION

The electrical discharge machining (EDM) technology has developed rapidly in the recent years and has become important in precision manufacturing applications like die and mold making, micro machining, etc. Wire electrical discharge machining (WEDM) is a modified electrical discharge technique used for manufacturing components with intricate shapes and profiles, with the help of a numerically controlled travelling wire electrode as shown in figure 1. Material is eroded from the work piece by a series of discrete sparks between the work piece and the wire electrode (tool) separated by a thin film of dielectric fluid. Whereas the wire does not touch the work piece, so there is no physical pressure imparted on the work piece and amount of clamping pressure required to hold the work piece is minimal. Many sparks can be observed at one time. This is because actual discharges can occur more than one hundred thousand times per second. The heat of each Electrical spark is around 15,000° to 21,000°Fahrenheit. This process has been widely used in aerospace, nuclear and automotive industries, to Machine precise, complex and irregular shapes in various difficult-to-machine electrically conductive materials.

There are many input parameters affecting the performance of wire electrical discharge machining. The figure 2 given below visualizes the process parameters and the performance measures of Wire-EDM. From the above mentioned performance measures, wire wear ratio plays dominant role in machining performance of Wire-EDM. In Wire-EDM operations, high wire wear ratio leads to frequent wire breakages.

Proper selection of process parameters is essential to obtain optimum wire wear ratio. Along with wire wear ratio material removal rate and surface roughness also play crucial role in machining performance of Wire-EDM. In Wire-EDM operations, material removal rate determine the economics of machining and rate of production, surface roughness is the measure of quality. Proper selection of process parameters is essential to obtain good Surface Finish (SF) and higher MRR. Wire tension is the most significant factor that affects the wire wear ratio. Wire tension can control the tension of wire in Wire-EDM. If the wire tension is high enough the wire stays straight otherwise wire drags behind as shown in the figure 3.
Fig. 2. Process Parameters and Performance Measures of Wire-EDM.

Fig. 3. Effect of wire tension.

II. EXPERIMENTATION

A. Experimental setup and material

The experiments were carried out on a Wire EDM machine (Fine Sodick Mark EXEDW). The WEDM machine tool has the following specifications:

- X Axis Table Travel - 300 mm
- Y Axis Table Travel - 200 mm
- Z Axis Travel - 175 mm
- Auxiliary Table Travel (UV Axis) - 50 mm x 50 mm
- Max Work piece Dimensions - W: 400 mm x D: 300 mm x H: 175 mm
- Maximum Work piece Height at Submerged Cutting - 150 mm
- Max Work piece Weight – 160 Kg
- Wire Diameter - 0.1 - 0.3 mm
- Wire Capacity - Stand 3 kg (Max 6kg)
- Wire Feed Speed (Max) - 250 mm/sec
- Max Cutting Speed - 380 mm/hr.
- Equipped with Fine Sodick Mark EX EDM Control and Dielectric Supply Tank

AISI D2 cold work steel is used as work piece material for the present experiments. AISI D2 is a high-carbon, high-chromium tool steel alloyed with molybdenum and vanadium characterized by:

- High wear resistance
- High compressive strength
- Good through-hardening properties
- High stability in hardening
- Good resistance to tempering-back.

AISI D2 is recommended for tools requiring very high wear resistance, combined with moderate toughness (shock-resistance). AISI D2 can be supplied in various finishes, including the hot-rolled, pre-machined and fine machined condition. Typical applications if AISI D2 cold work steel are Deep drawing and forming dies, cold drawing punches, hobbing, blanking, lamination and stamping dies, shear blades, burnishing rolls, master tools and gauges, slitting cutters, thread rolling & wire dies, extrusion dies etc.

Chemical composition of AISI D2 cold work steel is represented in the table 1 given below.

The wire wear ratio was measured by using the following formula:

\[
\text{wire wear ratio} = \frac{W1 - W2}{\rho \times t}
\]

Where

\[W1 = \text{Initial weight of the work piece in grams.}\]
\[W2 = \text{Final weight of the work piece in grams.}\]
\[\rho = \text{Density of the work piece in grams/mm}^3\]
\[t = \text{Machining time in minutes.}\]

Table 1. Composition of the material

<table>
<thead>
<tr>
<th>Element</th>
<th>C</th>
<th>Si</th>
<th>Mn</th>
<th>Cr</th>
<th>Mo</th>
<th>V</th>
</tr>
</thead>
<tbody>
<tr>
<td>% Comp</td>
<td>1.55</td>
<td>0.3</td>
<td>0.4</td>
<td>11.8</td>
<td>0.8</td>
<td>0.8</td>
</tr>
</tbody>
</table>

B. Selection of parameters and their levels

The screening experiments were performed on FINE SODICK MARK EXEDW A280L WEDM machine. Various input parameters varied during the experimentation are Pulse on time (Ton), Pulse off time (Toff), peak current (IP) and wire tension (WT). The effects of these input parameters are studied on wire wear ratio using one factor at a time approach.

Apart from the parameters mentioned above following parameters were kept constant at a fixed value during the experiments:

- 1. Work Material : AISI D2 cold work steel
- 2. Cutting Tool : Brass wire of diameter 0.25 mm
- 3. Wire Feed : 2.35 m/min
- 4. Peak Voltage : 2 units (110 volt DC)

Scatter plots were generated from the results of the screening experiments. From the scatter plots it was clear that Pulse Off time was the least significant.
parameter amongst the parameters selected for the screening experiments. Thus, pulse on time, peak current and wire tension were selected for investigation work. By observing the scatter plots for various responses the levels for each input parameter were decided. Table 2 shows the parameters selected and their respective levels.

<table>
<thead>
<tr>
<th>Machining Parameters</th>
<th>Level 1</th>
<th>Level 2</th>
<th>Level 3</th>
</tr>
</thead>
<tbody>
<tr>
<td>Ton (μs)</td>
<td>110</td>
<td>115</td>
<td>120</td>
</tr>
<tr>
<td>IP (Amp)</td>
<td>170</td>
<td>190</td>
<td>210</td>
</tr>
<tr>
<td>WT (units)</td>
<td>5</td>
<td>6</td>
<td>7</td>
</tr>
</tbody>
</table>

C. Response surface methodology
Response surface methodology (RSM) is a collection of mathematical and statistical techniques useful for analyzing problems in which several independent variables influence a dependent variable or response, and the goal is to optimize this response. In many experimental conditions, it is possible to represent independent factors in quantitative form as given in Equation 1. Then these factors can be thought of as having a functional relationship with response as follows:

\[ Y = \Phi(x_1, x_2, x_3, \ldots, x_k) + \epsilon \]  

(1)

This represents the relation between response Y and \( x_1, x_2, \ldots, x_k \) of \( k \) quantitative factors. The function \( \Phi \) is called response surface or response function. The residual \( \epsilon \) measures the experimental errors. For a given set of independent variables, a characteristic surface is responded. When the mathematical form of \( \Phi \) is not known, it can be approximated satisfactorily within the experimental region by a polynomial. Higher the degree of polynomial better is the correlation but at the same time costs of experimentation become higher.

For the present work, RSM has been applied for developing the mathematical models in the form of multiple regression equations for the quality characteristic of machined parts produced by WEDM process. In applying the response surface methodology, the dependent variable is viewed as a surface to which a mathematical model is fitted. For the development of regression equations related to various quality characteristics of WEDM process, the second order response surface has been assumed as:

\[ Y = b_0 + \sum b_i x_i + \sum b_{ii} x_i^2 + \sum b_{ij} x_i x_j + \epsilon \]  

(2)

This assumed surface Y contains linear, squared and cross product terms of variables \( x_i \)'s. In order to estimate the regression coefficients, a number of experimental design techniques are available.

D. Response surface design
The present article gives the application of the response surface methodology. The scheme of carrying out experiments was selected and the experiments were conducted to investigate the effect of process parameters on the wire wear ratio. The experimental results will be discussed subsequently in the following sections. The selected process variables were varied up to three levels and face-centered central composite design was adopted to design the experiments as shown in figure 4. Response Surface Methodology was used to develop second order regression equation relating response characteristics and process variables.

![Fig. 4. Face centered central composite design for k=3](image-url)
### Table 5. Experimental results

<table>
<thead>
<tr>
<th>Sr. No</th>
<th>X1 (TON)</th>
<th>X2 (IP)</th>
<th>X3 (WT)</th>
<th>MRR</th>
</tr>
</thead>
<tbody>
<tr>
<td>1</td>
<td>115</td>
<td>190</td>
<td>7</td>
<td>7.53</td>
</tr>
<tr>
<td>2</td>
<td>115</td>
<td>210</td>
<td>6</td>
<td>8.05</td>
</tr>
<tr>
<td>3</td>
<td>115</td>
<td>170</td>
<td>5</td>
<td>7.32</td>
</tr>
<tr>
<td>4</td>
<td>115</td>
<td>190</td>
<td>6</td>
<td>7.78</td>
</tr>
<tr>
<td>5</td>
<td>120</td>
<td>170</td>
<td>7</td>
<td>8.10</td>
</tr>
<tr>
<td>6</td>
<td>110</td>
<td>210</td>
<td>5</td>
<td>8.56</td>
</tr>
<tr>
<td>7</td>
<td>115</td>
<td>190</td>
<td>6</td>
<td>7.59</td>
</tr>
<tr>
<td>8</td>
<td>110</td>
<td>210</td>
<td>5</td>
<td>8.43</td>
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<tr>
<td>9</td>
<td>110</td>
<td>190</td>
<td>6</td>
<td>7.56</td>
</tr>
<tr>
<td>10</td>
<td>115</td>
<td>190</td>
<td>6</td>
<td>7.33</td>
</tr>
<tr>
<td>11</td>
<td>120</td>
<td>210</td>
<td>5</td>
<td>8.88</td>
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<tr>
<td>12</td>
<td>115</td>
<td>190</td>
<td>6</td>
<td>7.49</td>
</tr>
<tr>
<td>13</td>
<td>115</td>
<td>190</td>
<td>6</td>
<td>7.48</td>
</tr>
<tr>
<td>14</td>
<td>120</td>
<td>210</td>
<td>7</td>
<td>8.78</td>
</tr>
<tr>
<td>15</td>
<td>115</td>
<td>190</td>
<td>5</td>
<td>7.52</td>
</tr>
<tr>
<td>16</td>
<td>115</td>
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<td>6</td>
<td>7.57</td>
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<tr>
<td>17</td>
<td>120</td>
<td>190</td>
<td>6</td>
<td>7.16</td>
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<tr>
<td>18</td>
<td>110</td>
<td>170</td>
<td>7</td>
<td>6.43</td>
</tr>
<tr>
<td>19</td>
<td>110</td>
<td>170</td>
<td>5</td>
<td>6.48</td>
</tr>
<tr>
<td>20</td>
<td>110</td>
<td>170</td>
<td>5</td>
<td>6.40</td>
</tr>
</tbody>
</table>

From the above mentioned main effects plot for MRR, it is clear that peak current is the most affecting parameter for MRR. While pulse ON time and wire tension are less significant for MRR.

### F. Surface plots for MRR

Graph 1. Main effects plot for MRR
G. Optimization using desirability approach

The above graph shows optimization plot for MRR. The ultimate objective of our work was to maximize the MRR. Desirability approach was used for finding out the optimum values of the variables in order to get the maximum value of MRR. From the graph it is clear that highest value 8.7364 is obtained for the following combination of the variables:

Ton = 110 (0.6 microseconds)
IP = 210 A
WT = 5 (600 grams)

The above results are obtained with the composite desirability of 1.000.

H. Regression analysis

The experimental results were used to develop a mathematical model, for expressing the relation between process parameters and MRR. The coefficients of mathematical models are computed using method of multiple regressions.

\[
\text{MRR} = 8.097 - 0.49871 \text{Ton} + 0.34799 \text{IP} - 4.09577 \\
+ 0.00389 \text{Ton}^2 + 0.00002 \text{IP}\times \text{IP} + 0.26227 \\
\times \text{WT} -0.00240 \text{Ton}\times \text{IP} + 0.01950 \text{Ton}\times \text{WT} \\
+ 0.0057 \text{IP}\times \text{WT}.
\]

CONCLUSION

(WEDM) is an advanced thermal machining process capable of accurately machining parts with complicated shapes, especially for the parts that are very difficult to be machine by traditional machining processes. It has been commonly applied for the machining and micro-machining of parts with intricate shapes and varying hardness requiring high profile accuracy and tight dimensional tolerances. In this study an attempt was made to maximize the material removal rate in Wire EDM. RSM approach was employed for designing as well as for finding out the optimal solutions. RSM has greatly helped in reaching towards the most optimal values. From the above work it is clear that MRR increases as the peak current increases. Also the wire tension and pulse on time influences the MRR, but to a smaller extent. Desirability approach was employed for finding out the most optimal values of the process parameters. The results of the optimization plot are as follows:

\[
\begin{align*}
\text{MRR} &= 8.7364 \\
\text{Ton} &= 110 \text{ (0.6 microseconds)} \\
\text{IP} &= 210 \text{ A} \\
\text{WT} &= 5 \text{ (600 grams)}
\end{align*}
\]

The above results are obtained with the composite desirability of 1.000.

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REFERENCES


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