Optimization of WEDM Process with Molybdenum Wire Electrode Using GRA

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Abstract— The correct selection of manufacturing conditions and technique is one of the most important aspects to take into consideration in the majority of manufacturing processes and, particularly, in processes related to Wire Electrical Discharge Machining (WEDM). Optimization is one of the techniques used in manufacturing sectors to arrive for the best manufacturing conditions, which is an essential need for industries towards manufacturing of quality products at lower cost. This paper aims to investigate the optimal set of process parameters such as peak current, gap voltage, pulse on time, pulse off time and wire tension in WEDM process to identify the variations in performance characteristics such as cutting rate and surface roughness for machining D2 tool steel using the molybdenum wire electrode. Based on the experiments conducted using response surface methodology, analysis has been carried out using Grey Relational Analysis. The confirmation experiments were carried out to validate the optimal results. Thus, the machining parameters for WEDM were optimized for achieving the combined objectives of higher cutting rate and lower surface roughness. Grey relational Analysis is being effective technique to deal with multi objective optimization problem.

Key words: WEDM, RSM, Molybdenum Wire Electrode, GRA

I. INTRODUCTION

With the industrial and technological growth, development of harder and difficult to machine materials, which find wide application in aerospace, nuclear engineering and other industries owing to their high strength to weight ratio, hardness and heat resistance qualities has been witnessed. New developments in the field of material science have led to new engineering metallic materials, composite materials and high tech ceramics having good mechanical properties and thermal characteristics as well as sufficient electrical conductivity so that they can readily be machined by non-conventional machining process like spark erosion. The Wire Electrical Discharge Machining process is employed widely for making tools, dies and other precision parts. The WEDM has many advantages, such as non-contact with the workpiece during the machining process and ability to machine any conductive material, regardless of its hardness. Hence, it does not create any vibration during machining as compared to other conventional machining. The quality of the product mainly depends upon the material and process parameters. Optimization of process parameter plays a vital role to increase the quality of the product. Hence, many authors have presented their works on the optimization of process parameters for various machining processes. Bijaya Bijeta Nayak et al. (2016) carried out investigation and optimization of various process parameters during taper cutting of deep cryo-treated Inconel 718 in wire electrical discharge machining process. [1]. U. A. Dabade and S. S. Karidkar (2016) made an attempt to analyse the machining conditions for Material Removal Rate (MRR), Surface Roughness (SR), cutting width (kerf) and dimensional deviation during WEDM of Inconel 718 [2]. Neeraj Sharma et al. (2015) studied the effect of process parameters on the overcut while machining the HSLA steel on WEDM. Pulse on time, pulse off time, gap voltage, peak current and wire tension are chosen as input parameters and experiments are carried out for minimum overcut. [5]. Grey relational analysis (GRA) has been used by many researchers for machining processes which include electric discharge machining [7,8].

The objective of this work is to determine the optimal levels of the process parameters for Wire Electric-Discharge Machining process using GRA. This work was done with D2 tool steel as work piece material and molybdenum as wire electrode. Grey relational analysis was applied to obtain the optimum values of the process parameters. The process parameters such as peak current, gap voltage, pulse on time, pulse off time and wire tension were optimized with the considerations of multiple performance characteristics such as cutting rate and surface roughness.

II. EXPERIMENTATION

During this study, series of experiments on the D2 tool steel were conducted by WEDM process (shown in Fig. 1) to examine the effect of input machining parameters, such as current, voltage, pulse on time, pulse off time and wire tension on cutting rate and surface roughness.

Fig. 1: WEDM Machine

In this experimental work the molybdenum wire electrode was used. Cutting rate was recorded from machine display and surface roughness was measured with Taylor

Hobson surtronic 3 series surface roughness tester. On the basis of preliminary experiments conducted by using one variable at a time approach the range of input parameters were selected. The table 1 shows the Machining parameters and their level chosen for this study.

Parameters	Levels				
	-2	-1	0	1	2
Peak current (Ip)	150	170	190	210	230
Gap voltage (V)	10	20	30	40	50
Pulse on time (Ton)	105	110	115	120	125
Pulse off time (Toff)	43	48	53	58	63
Wire tension (WT)	4	6	8	10	12

Table 1: Machining Parameters and Their Levels

Design of experiment is an effective tool to design and conduct the experiments with minimum resources. In this work, response surface methodology is used to set the control parameters to evaluate the process performance. A well designed CCD experiments for five input variables at five levels were conducted. Total 32 experiments were performed, the result of experiments are listed in table 2.

Expt. No.	Process parameters					Response parameters	
	Ip	V	Ton	Toff	WT	Cutting speed (mm/min)	Surface roughness (µm)
1	190	30	115	53	8	0.97	1.9
2	190	30	115	53	8	0.97	1.98
3	190	30	115	53	8	0.96	2.01
4	170	50	110	48	6	0.48	1.68
5	150	30	115	53	8	0.31	1.14
6	230	40	110	48	12	1.09	2.35
7	190	30	115	53	4	0.96	1.97
8	190	30	115	53	8	0.86	1.89
9	170	40	125	48	10	0.33	1.7
10	210	40	120	48	6	0.78	2.2
11	190	50	115	53	8	0.57	2
12	190	10	115	53	8	1.7	2.3
13	190	30	115	53	8	0.94	2.07
14	190	30	115	53	8	0.93	1.89
15	210	20	120	48	10	1.4	2.29
16	170	40	120	58	6	0.38	1.37
17	210	40	120	58	10	0.89	2.1
18	190	30	115	53	12	0.95	1.96
19	210	40	110	58	6	1.22	2.55
20	210	20	120	58	6	1.58	2.35
21	230	30	115	53	8	1.72	2.58
22	170	40	110	58	10	0.5	1.72
23	190	30	125	53	8	0.68	1.77
24	170	20	110	48	10	0.83	1.62
25	210	20	110	58	10	2.1	2.78
26	170	20	120	48	6	0.63	1.48
27	170	20	110	58	6	1	1.97
28	190	30	105	53	8	1.17	2.5
29	170	20	120	58	10	0.7	1.7
30	190	30	115	43	8	0.87	2.03
31	190	30	115	63	8	1	2.11
32	210	20	110	48	6	1.83	2.65

Table 2: Design Matrix with Actual Values and Experimental Results

III. Grey Relational Analysis

The grey relational analysis is a widely used analyzing system even when a model is uncertain or the information is incomplete. It provides an efficient solution to complicated interrelationships among multiple performance characteristics. Steps of grey relational analysis are given as follow:

A. *Normalization*

There are three different types of data normalization according to whether we require the LB (lower-the-better), the HB (higher-the-better) and NB (nominal-the-best). The normalization is taken by the following equations.

(a) HB (higher-the-better)

$$x_i(k) = \frac{y_i - min\, y_i\,(k)}{\max y_i(k) - min\, y_i\,(k)} \quad (1)$$

(b) LB (lower-the-better)

$$x_i(k) = \frac{\max y_i(k) - y_i\,(k)}{\max y_i(k) - min\, y_i\,(k)} \quad (2)$$

(c) NB (nominal-the-best)

$$X_i^*\,(k) = \frac{y_i\,(k) - y_i}{\max y_i(k) - y_i\,(k)} \quad (3)$$

Where x_i (k) is the value after the grey relational generation, min y_i (k) is the smallest value of y_i (k) for the k^{th} response, and max y_i (k) is the largest value of y_i (k) for the k^{th} response. An ideal sequence is x_0 (k) for the responses. The purpose of grey relational grade is to reveal the degrees of relation between the sequences say, [x_0 (k) and x_i (k) , i = 1, 2,3.......,9].

B. Deviation Sequence

The deviation sequence Δ_{0i} is the absolute the reference sequence x0 (k) and the comparability sequence xi (k) after normalization. It is determined using

$$\Delta_{0i} = |x_0(k) - x_i(k)| \quad (4)$$

C. Grey Relational Coefficient

GRC for all the sequences expresses the relationship between the ideal (best) and actual normalized S/N ratio. If the two sequences agree at all points, then their grey relational coefficient is 1.

$$\xi_i(k) = \frac{\Delta_{min} + \theta\, \Delta_{max}}{\Delta_{0i}(k) + \theta\, \Delta_{max}} \quad (5)$$

Where, $\Delta_{0i} = \|x_o(k) - x_i(k)\|$ = difference of the absolute value $x_o(k)$ and $x_i(k)$; θ is the distinguishing coefficient $0 \leq \theta \leq 1$; $\Delta_{min} = \forall j^{min} \in i \forall k^{min} \|x_o(k) - x_j(k)\|$ = the smallest value of Δ_{0i}; and $\Delta_{max} = \forall j^{max} \in i \forall k^{max} \|x_o(k) - x_j(k)\|$ = largest value of Δ_{0i}. Comparability sequence and ζ is the distinguishing coefficient. The value of θ can be adjusted with the systematic actual need and defined in the range between 0 and 1, θ ∈ [0, 1]. It will be 0.5 generally.

D. Grey Relational Grade

The overall evaluation of the multiple performance characteristics is based on the grey relational grade. After averaging the grey relational coefficients, the grey relational grade γ_i can be computed as:

$$\gamma_i = \frac{1}{n} \sum_{k=1}^{n} \xi_i(k) \quad (6)$$

Where, n = number of process responses.

In this experiment, the normalized MRR corresponds to "higher-the-better" and TWR values corresponds to "smaller-the-better" (SB) criterion that can be calculated Using equation 1 and 2 respectively. The overall performance characteristic of the multiple response process depends on the calculated grey relational grade.

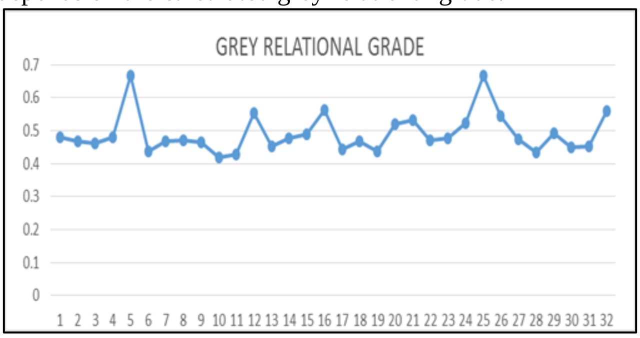

Fig. 2: Scatter Plot of GRG vs Order of Experiment

The larger the grey relational grade, the better is the multiple performance characteristics. However, the relative importance among the machining parameters for the multiple performance characteristics still needs to be known, so that the optimal combinations of the machining parameter levels can be determined more accurately.

IV. RESULT AND DISCUSSION

According to Table 3, the peak current is the most significant controlled parameter for the WEDM operation followed by gap voltage, pulse on time, pulse off time and wire tension for maximization of cutting rate and minimization of surface roughness. The optimal parameter combination is determined as A1-B1-C2-D4-E2. A1 (peak current = 150 A), B1 (Gap voltage = 10 V), C2 (pulse on time = 110 µs) and D4 (pulse off time = 58 µs) and E2 (Wire tension = 6 gram).

Symbols	parameters	Grey Relational Grade					Main effect	Rank
		-2	-1	0	1	2		
Ip	Peak current	0.6666	0.5009	0.4673	0.5046	0.4846	0.1993	1
V	Gap voltage	0.5526	0.5329	0.4829	0.4621	0.4539	0.0987	2
Ton	Pulse on time	0.4332	0.5057	0.488	0.4914	0.476	0.0725	3
Toff	Pulse off time	0.4503	0.4893	0.4884	0.5078	0.4533	0.0575	4
WT	Wire tension	0.4683	0.4988	0.486	0.507	0.4528	0.046	5

Table 3: Response Table for the Grey Relational Grade

Cutting speed = 1.06 + 0.0164 Ip - 0.0263 V - 0.0243 Ton + 0.00975 Toff - 0.0168 WT

Surface roughness = 1.48 + 0.0169 Ip - 0.00767 V - 0.0237 Ton + 0.00707 Toff - 0.0121 WT

The % errors between experimental and predicted values were found within a range of ± 5. Confirmatory experiments were performed using the optimum values and it was found that experimental response values were close enough to predicted values.

V. CONCLUSIONS

Based on the experimental and predicted results, following conclusions are drawn:

1) The Optimal combination of process parameters for obtaining maximum cutting rate and minimum surface roughness are peak current = 150 A, Gap voltage = 10 V, Pulse on time = 110 µsec, Pulse off time = 58 µsec, Wire tension = 6 gram.
2) If the optimum setting is used, it gives MRR of 0.1568 g/min and EWR of 0.02088 g/min.
3) It was found that current is the most dominant parameter for the molybdenum wire electrode that has high influence on both cutting rate and surface roughness.
4) Regression models prepared were used for prediction of responses. The % errors between experimental and predicted values were within a range of ± 5.

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