

Application of MARCOS Method for Determining Best Process Factor for EDM using Graphite Electrodes

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Abstract

This paper reports on a study that used graphite electrodes and the multi-criteria decision making (MCDM) approach to determine the optimal process variables for Electrical Discharge Machining (EDM) cylindrical shaped parts of 90CrSi tool steel. The Measurement of Alternatives and Ranking according to COmpromise Solution (MARCOS) methodology was used in the study to answer the MCDM problem, and the Entropy method was used to estimate the weights of the criteria. Additionally, the material removal rate (MRR) and surface roughness (RS) were selected as the investigation's two criteria. In addition, the servo voltage SV, servo current IP, pulse on time T_{on} , pulse off time T_{off} , and type of graphite TOG were the five process parameters that were investigated. Additionally, Minitab R19 software's Taguchi method was used to design the experiment and evaluate the results. Moreover, the design L18 ($6^1 + 3^4$) was applied for this experiment. The optimal process parameters were suggested, and the MCDM problem has been fixed.

Keywords: EDM, MCDM, MARCOS method, Entropy method, Surface Roughness, Material removal rate, 90CrSi.

1. Introduction

In reality, in order to meet a variety of contradictory requirements, it is frequently required to ascertain the input parameters of the mechanical processing process. For instance, the milling process's MRR must be raised while its SR must be lowered. In order to meet the MRR criteria, feed rate and depth of cut will both rise, which will raise SR. MCDM techniques have been widely employed for milling [1, 2], grinding [3-5], turning [6, 7], EDM [8-11], and other operations to address the aforementioned issues.

Nowadays, EDM is the most widely used advanced machining technique. When dealing with cavity-shaped objects, such as plastic molds and forging molds, etc., it works particularly well. As a result, numerous studies on MCDM and EDM in general have been conducted up to this point.

Numerous studies have been conducted on MCDM for the EDM process up to this point. The results of an MCDM study for powder-mixed electrical discharge machining (PMEDM) of 90CrSi (DIN 17350-80) tool steel are presented by the authors in [9].

The study's input process parameters included host voltage, pulse duration, pulse off time, pulse current, and powder concentration. Additionally, the problem was solved using three MCDM methods: MAIRCA (Multi-Attributive Ideal-Real Comparative Analysis), TOPSIS (Technique for Order of Preference by Similarity to Ideal Solution), and MARCOS (Measurement of Alternatives and Ranking according to Compromise Solution). The MEREC (Method based on the Removal Effects of Criteria) method was used to determine the weight calculation for the criteria. The optimal solution for the multi-criteria problem involving EDM cylindrically shaped pieces was suggested based on the findings. The results of an MCDM investigation to determine the ideal input parameters in wire-cut EDM 90CrSi tool steel have been provided to the authors in [12]. The TOPSIS approach was applied in this paper. Additionally, six input parameters were examined: the workpiece cutting radius, the wire feed, the feed speed, the servo voltage, the cutting voltage, and the pulse on and off times. With

PMEDM 90CrSi tool steel, the MABAC (Multi-Attributive Border Approximation Area Comparison) approach has been utilized to determine the optimal input process variables [13]. The goal of this research is to simultaneously get the lowest possible surface roughness (RS), the highest possible material removal rate (MRR), and the lowest possible electrode wear rate (EWR). The Measurement of Alternatives and Ranking according to Compromise Solution (MARCOS) method [14], TOPSIS method [15], Multi-Objective Optimization process on the basis of Ratio Analysis (MOORA method) and TOPSIS [16] are some of the other works on MCDM that have been done to determine the best input parameters for wire-cut EDM. In addition, the white layer thickness prediction on machining treated silicon steel has been implemented using the Adaptive Network based Fuzzy Inference System approach in [17].

The aforementioned research shows that a significant number of studies have used MCDM techniques to identify the ideal input parameters for EDM to date. Nevertheless, there has not been an approach to choose the optimal input settings for EDM with electrodes composed of several kinds of graphite up to now utilizing the MARCOS method. This work presents the results of an MCDM analysis for selecting the optimal mode in EDM 90CrSi tool steel employing electrodes made of several types of graphite. The MARCOS method was employed in the study's MCDM methodology, and the Entropy method was used to calculate the criteria's weights. Following the solution of the MCDM problem with two criteria (SR and MRR), the ideal input factors have been proposed.

2. Methodology

2.1 Method for MCDM

The MARCOS technique was used in this study to solve the MCDM challenge. To adopt this technique, the following steps need to be [18]:

Step 1: Creating the initial decision-making matrix:

$$X = \begin{bmatrix} x_{11} & \cdots & x_{1n} \\ x_{21} & \cdots & x_{2n} \\ \vdots & \cdots & \vdots \\ x_{m1} & \cdots & x_{mn} \end{bmatrix} \quad (1)$$

In which, n and m are the number of criterion and alternatives.

Step 2: By adding an ideal (AI) and anti-ideal solution (AAI) to the initial decision-making matrix, an extended initial matrix can be generated:

$$X = \begin{bmatrix} AAI & x_{aa1} & \cdots & x_{aan} \\ A_1 & x_{11} & \cdots & x_{1n} \\ A_2 & x_{21} & \cdots & x_{2n} \\ \vdots & \vdots & \vdots & \vdots \\ A_m & x_{m1} & \cdots & x_{mn} \\ AI & x_{ai1} & \cdots & x_{ain} \end{bmatrix} \quad (2)$$

Where, $AAI = \min(x_{ij})$ and $AI = \max(x_{ij})$ if criterion j is as large as possible; $AAI = \max(x_{ij})$ and $AI = \min(x_{ij})$ if criterion j is as small as possible; $i = 1, 2, \dots, m$; $j = 1, 2, \dots, n$.

Step 3: Finding the normalized matrix $N = [n_{ij}]_{m \times n}$:

$$u_{ij} = x_{AI} / x_{ij} \quad (3)$$

$$u_{ij} = x_{ij} / x_{AI} \quad (4)$$

Equation (3) is used when the criterion j is as small as possible, and (4) is applied when j is as large as possible.

Step 4: Calculating the weighted normalized matrix $C = [c_{ij}]_{m \times n}$ by:

$$c_{ij} = u_{ij} \cdot w_j \quad (5)$$

In which, w_j is the weight coefficient of criterion j.

Step 5: Determining the utility of alternatives K_i^- and K_i^+ by:

$$K_i^- = S_i / S_{AAI} \quad (6)$$

$$K_i^+ = S_i / S_{AI} \quad (7)$$

In (6) and (7), S_i can be determined by:

$$S_i = \sum_{j=1}^m c_{ij} \quad (8)$$

Step 6: Calculating the utility function $f(K_i)$ of alternatives by:

$$f(K_i) = \frac{K_i^+ + K_i^-}{1 + \frac{1-f(K_i^+)}{f(K_i^+)} + \frac{1-f(K_i^-)}{f(K_i^-)}} \quad (9)$$

Where $f(K_i^-)$ is the utility function linked with the anti-ideal solution and $f(K_i^+)$ is the utility function linked with the ideal solution. These functions are determined by:

$$f(K_i^-) = K_i^+ / (K_i^+ + K_i^-) \quad (10)$$

$$f(K_i^+) = K_i^- / (K_i^+ + K_i^-) \quad (11)$$

Step 7: Arrange the options based on the final utility function values to discover which option has the highest value.

2.2 Method to find the weight of criteria

The entropy technique was used in this work to establish the weights of the criteria. The following actions can be used to put this strategy into practice [19].

Step 1: Calculating indicator normalized values:

$$p_{ij} = \frac{x_{ij}}{m + \sum_{i=1}^m x_{ij}^2} \quad (12)$$

Step 2: Determining the Entropy for each indicator:
 $me_j = - \sum_{i=1}^m [p_{ij} \times \ln(p_{ij})] - (1 - \sum_{i=1}^m p_{ij}) \times \ln(1 - \sum_{i=1}^m p_{ij})$ (13)

Step 3: Finding the weight of each indicator:

$$w_j = \frac{1 - me_j}{\sum_{j=1}^m (1 - me_j)} \quad (14)$$

3. Experimental setup

An investigation was carried out to determine the best input factors when EDM 90CrSi tool steel cylindrical pieces were being produced. Table 1 displays the input parameters along with their respective levels. Furthermore, Minitab R19 software was used to perform the experiment and analyze the data using the Taguchi method. Moreover, the design L18 (6¹ + 3⁴) was applied for this experiment. The experimental setup, shown in Figure 1, included a Sodick A30 EDM (Figure 1.a), graphite electrodes (Figure 1.b), 90CrSi tool steel samples (Figure 1.c), and Dielectric MS 7000 dielectric solution. The experiment was done in this way: Every part's processing time will be tracked during the experiment. In addition, the parts' weights will be measured both before and after machining. Measure SR (R_a) after the experiment is finished, then use formula (15) to determine MRR.

$$MRR = \sum_{i=1}^n \frac{m_{pbi}}{m_{pai}} \quad (15)$$

In which, m_{pbi} and m_{pai} are the mass of part i before and after machining (mg); i is the number of parts.

Table 2 shows the experimental plan and the output results (SR and MRR). The average of three SR measurements and MRR computations is what's shown in this table.



(a) (b)



(c)

Fig. 1. Experimental setup

Table 1. Input dressing parameters

No.	Input factors	Code	Unit	Level					
				1	2	3	4	5	6
1	Servo current	IP	A	3.5	5.5	7.5	9.5	11.5	13.5
2	Servo voltage	SV	V	4	5	6	-	-	-
3	Pulse on time	T _{on}	μs	8	12	16	-	-	-
4	Pulse off time	T _{off}	μs	8	12	16	-	-	-
5	Electrode type	TOG	-	HK0	HK15	HK20	-	-	-

4. Determining the best dressing mode

4.1 Determining the weights for the criteria

Using the entropy approach (see Section 2.2), the weights of the criterion have been determined as follows: First, use equation (12) to obtain the

normalized values of Equation (13), for each indication, yields the entropy value. Finally, use Equation (14). to find the weight of the criteria w_j. The weights of R_a and CS were determined to be 0.6601 and 0.3399, respectively.

Table 2. Experimental plan and output results

No.	IP (A)	SV (V)	T _{on} (μm)	T _{off} (μm)	TOG	R _a (μm)	MRR (mg/min)
1	3.5	4	8	8	HK0	3.917	21.354
2	3.5	5	12	12	HK15	4.093	25.569
3	3.5	6	16	16	HK20	4.704	26.413
4	5.5	4	8	12	HK15	4.217	55.745
5	5.5	5	12	16	HK20	3.948	64.712
6	5.5	6	16	8	HK0	4.443	115.398
7	7.5	4	12	8	HK20	3.814	99.835
8	7.5	5	16	12	HK0	2.744	137.401
9	7.5	6	8	16	HK15	3.142	99.131
10	9.5	4	16	16	HK15	3.772	31.361
11	9.5	5	8	8	HK20	2.618	32.611
12	9.5	6	12	12	HK0	2.050	46.825
13	11.5	4	12	16	HK0	3.524	84.004
14	11.5	5	16	8	HK15	3.908	64.374
15	11.5	6	8	12	HK20	4.087	60.897
16	13.5	4	16	12	HK20	6.354	95.996
17	13.5	5	8	16	HK0	3.688	114.831
18	13.5	6	12	8	HK15	5.453	93.703

4.2 Determining the best dressing mode using MARCOS method

Section 2.1 delineates the multi-objective decision-making phases of the MARCOS technique. In particular, as follows: determine the ideal solution (AI) and the anti-ideal solution (AAI) using formula (2). The outcomes demonstrated that, although Ra and MRR with AAI were 6.35 (μm) and 21.35 (mm/min), Ra and MRR with AI were 2.05 (μm) and 137.40 (mm/min), respectively. The next step is to calculate the normalized values u_{ij} using formulas (3) and (4). Formula (5) was then used to calculate the normalized values while accounting for the weight c_{ij}. Moreover, the coefficients are obtained from Equations (6) and (7). Equations (10) and (11) were used to find the values of f(K_i⁻) and f(K_i⁺). The values of f(K_i⁺)= 0.8342 and f(K_i⁻)= 0.1658 were discovered. Finally, formula (9) is used to compute the values of Table 3 displays the options' rankings as well as the results of a few different parameters.

Among the options in Table 3, Option 8 is the best option. This is because of its largest utility function value (f(K_i)=0.00578). Therefore, the optimal solution consists of the following values: IP = 7.5 (A), SV = 5 (V); T_{on} = 16 (μs); T_{off} = 12 (μs); electrode HK0.

5. Conclusions

In this study, the MARCOS and entropy methods were applied to determine the optimal process parameters for EDM using electrodes made of several types of graphite. Option 8 should be utilized in order to simultaneously attain the highest MRR and lowest SR, according to the study's findings. With a maximum utility function value of f(K_i) = 0.0058, Solution No. 8 demonstrated the best performance characteristic among the 18 test runs. According to the MARCOS technology, the ideal mode for for EDM cylindrical shaped parts of 90CrSi tool steel is IP = 7.5 (A), SV = 5 (V), T_{on} = 16 (μs), T_{off} = 12 (μs), and electrode HK0.

Table 3. Several calculated results and ranking of alternatives

Trial.	K-	K+	f(K-)	f(K+)	f(K _i)	Rank
1	0.014375	0.002856	0.165758	0.834242	0.0028	16

2	0.014216	0.002825	0.165758	0.834242	0.0027	17
3	0.01274	0.002531	0.165758	0.834242	0.0025	18
4	0.016559	0.00329	0.165758	0.834242	0.0032	13
5	0.018149	0.003606	0.165758	0.834242	0.0035	10
6	0.021296	0.004231	0.165758	0.834242	0.0041	8
7	0.021717	0.004315	0.165758	0.834242	0.0042	5
8	0.030063	0.005973	0.165758	0.834242	0.0058	1
	0.024396	0.004847	0.165758	0.834242	0.0047	3
...						
17	0.023493	0.004668	0.165758	0.834242	0.0045	4
18	0.017323	0.003442	0.165758	0.834242	0.0033	12

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