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Multi-objective Optimization of Process Parameters in EDM with Low-Frequency Vibration by VIKOR Method

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Abstract In the present study an efficient Multi-Criteria Decision Making (MCDM) approach has been proposed for optimization of electro-discharge machining (EDM) with low frequency vibration. EDM using low-frequency vibration of workpiece assigned for SKD61 is a MultiCriteria Decision Making (MCDM) problem influenced by multiple performance criteria/attributes. The present study highlights application of VIKOR method adapted from MCDM techniques for obtaining the accurate result. Detail methodology of VIKOR method has been illustrated in this report through a case study. The material removal rate (MRR) and surface roughness (SR) were selected as performance measures in the EDM process. Ananalytical hierarchical process (AHP) was used to determine the weight value of the quality indicators. The results indicate that low-frequency vibrations significantly improve machining efficiency. The optimum parameters required to achieve the multi-objective were Ton = 25µs, I = 8A, Tof = 5.5µs, F = 512Hz, at the resultant quality criteria of MRR = 9.564 mm3/min and SR = 3.24 µm with a maximum error of 8.24%.

Keywords Material removal rate; Surface roughness; Low frequency vibrational-EDM; VIKOR

1. Introduction

Electro-discharge machining (EDM) is one of the most extensively used nonconventional material removal processes. EDM process is based on thermoelectric energy. Thermo electric energy generated between the work piece and an electrode. A pulse discharge occurs between the work piece and the electrode in a small gap and removes the unwanted material from the parent metal through melting and vaporising. In order to generate the spark the electrode and the work piece must have electrical conductivity [1]. There are various types of products which can be produced using EDM such as dies and moulds. Parts of aerospace, automotive industry and surgical components can be finished by EDM [2-4]. Several statistical techniques have also been applied to solve these challenges using a simpler approach, especially the multi-objective optimization problem [5]. This has contributed to the improvement of the overall efficiency of EDM for practical production.

The integration of vibrations into the EDM process has resulted in a significant improvement in machining efficiency. Vibration-assisted EDM is affected by both electrical and non-electrical parameters [6-7]. Therefore, the analysis and optimization of this parameter is essential and has been shown to contribute to the improvement of machining quality. These investigations are mainly at the preliminary stage and there are few studies on process parameter optimization in vibration-assisted EDM, including the optimization problem [8-10]. These methods require both intra- and inter-attribute comparisons, and involve explicit tradeoffs that are appropriate for the problem considered. Each decision matrix in MADM methods has four main parts, namely: (a) alternatives, (b) attributes, (c) weight or relative importance of each attribute (*i.e.*, weight), and (d) measures of performance of alternatives with respect to the attributes. Of the many MADM methods, six methods are commonly used: the weighted sum method (WSM), weighted product method (WPM), analytic hierarchy process (AHP), Revised AHP, and technique for order preference by similarity to ideal solution (TOPSIS) and compromise ranking method (VIKOR) [11]. VIKOR method is a compromise ranking method used for multicriteria decision making (MCDM), which is used to optimize the multiple response process. The proposed method considers both the mean and the standard variation of quality losses associated with several multiple responses, and assure a small variation in quality losses among the responses, along with a small overall average loss. Therefore, VIKOR may be suitable and effective for multi-objective optimization in vibration-assisted EDM. This is a potential area for continued investigations in the future [12].

This report aims to examine multi-objective optimization of the process parameters in EDM via low-frequency vibrations assigned to anSKD61 workpiece. Process parameters including current (I), pulse on time (Ton), pulse off time (Tof), and frequency vibration (F) were selected for examination. MRR and SR were selected as the quality indicators for evaluation. VIKOR was utilized to optimize multiple objectives in this study.

2. Experimental setup

SKD61 steel is commonly used to manufacture small and medium-sized hot dies and cast dies. The prepared workpiece samples had dimensions of 50mm length, 10mm width, and 5mm thickness. Copper (Cu) electrodes with a cylindrical shape with a length of 35mm and a diameter of 25mmwere used in the EDM process. The sets of process parameters are summarized in table 1. The parameters were determined based on the latest literature review and recommendations for industrial practice. The experimental investigations were conducted on a CHEMER EDM machine type (CM 323C). The workpiece was attached to the vibration protection fixture of the vibration unit to facilitate stable and accurate transmission of vibrations to the workpiece. The vibration unit (Modal: Exciter 4824, Brüel & Kjær, Denmark) was used to investigate the vibrations. The amplitude of the vibrations for a chosen frequency value is a = 0.75µm.

Table 1: The input of the process parameters

Levels	**I (A)**	**Ton (µs)**	**Tof (µs)**	**F (Hz)**
1	3	12	5.5	128
2	6	25	12.5	256
3	8	50	25	512

3. Experimental Method

The MCDM method is very popular technique widely applied for determining the best solution among several alternatives having multiple attributes or alternatives. A MCDM problem can be presented by a decision matrix as follows:

$$D=\begin{array}{c} \\ A_1 \\ A_2 \\ \vdots \\ A_m \end{array}\begin{bmatrix} Cx_1 & Cx_2 & \cdots & Cx_n \\ x_{11} & x_{12} & \cdots & x_{1n} \\ x_{21} & x_{22} & \cdots & x_{2n} \\ \vdots & \vdots & \ddots & \vdots \\ x_{m1} & x_{m2} & \cdots & x_{mn} \end{bmatrix}$$

Here, i A represents ith alternative, i =1, 2,.........,m; j Cx represents the jth criterion, j =1, 2,.........,n ; and xij is the individual performance of an alternative. The procedures for evaluating the best solution to an MADM problem include computing the utilities of alternatives and ranking these alternatives. The alternative solution with the highest utility is considered to be the optimal solution. The following steps are involved in VIKOR method [9]:

Step 1: Representation of normalized decision matrix

The normalized decision matrix can be expressed as follows:

$$F=[f_{ij}]_{m\times n} \tag{1}$$

$$f_{ij} = \frac{x_{ij}}{\sqrt{\sum_{i=1}^{m} x_{ij}^2}},\ i=1,2,\cdots,m;$$

Here, and x_{ij} is the performance of alternative A_i with respect to the j_{th} criterion.

Step 2: Determination of ideal and negative-ideal solutions

The ideal solution A^* and the negative ideal solution A^- are determined as follows:

$$A^* = \{(max f_{ij} | j \in J) or \ (min f_{ij} | j \in J'), i = 1,2,\cdots\cdots,m\} = \{f_1^*, f_2^*, \cdots f_j^*, \cdots f_n^*\} \qquad (2)$$

$$A^- = \{(min f_{ij} | j \in J) or \ (max f_{ij} | j \in J'), i = 1,2,\cdots\cdots,m\} = \{f_1^-, f_2^-, \cdots f_j^-, \cdots f_n^-\} \qquad (3)$$

where, $J = \{j = 1,2,\cdots,n | \ f_{ij}, if \ desire \ response \ is \ large\}$

$$J' = \{j = 1,2,\cdots,n | \ f_{ij}, if \ desire \ response \ is \ small\}$$

Step 3: Calculation of utility measure and regret measure

The utility measure and the regret measure for each alternative are given as

$$S_i = \sum_{j=1}^{n} w_j \frac{(f_j^* - f_{ij})}{(f_j^* - f_j^-)} \qquad (4)$$

$$R_i = \underset{j}{Max} \left[w_j \frac{(f_j^* - f_{ij})}{(f_j^* - f_j^-)} \right] \qquad (5)$$

where, Si and Ri , represent the utility measure and the regret measure, respectively, and wj is the weight of the jth criterion

Step 4: Computation of VIKOR index

The VIKOR index can be expressed as follows:

$$Q_i = \upsilon \left[\frac{S_i - S^*}{S^- - S^*} \right] + (1 - \upsilon) \left[\frac{R_i - R^*}{R^- - R^*} \right] \qquad (6)$$

where, Qi , represents the ith alternative VIKOR value, i =1, 2,........,m;

$$S^* = \underset{i}{Min}(S_i), \ S^- = \underset{i}{Max}(S_i), R^* = \underset{i}{Min}(R_i), R^- = \underset{i}{Max}(R_i)$$

and υ is the weight of the maximum group utility (usually it is to be set to 0.5 [38-40]). The alternative having smallest VIKOR value is determined to be the best solution.

4. Results and Discussion

4.1 Calculated by combined MOORA and AHP

Step 1: The MOORA method was used to simultaneously optimize the three quality criterion: MRR, TWR, and SR.

Step 2: The selected criteria are sorted in a matrix form:

$$X = \begin{bmatrix} MRR_1 & SR_1 & TWR_1 \\ . & . & . \\ . & . & . \\ . & . & . \\ MRR_9 & SR_9 & TWR_9 \end{bmatrix}$$

Step 3: Standardize the matrix: The decision matrix is normalized using equation (5) and shown in table 3.

Table 3: Transformation matrix of quality criteria

Exp. No	**I (A)**	**Ton (µs)**	**Tof (µs)**	**F (Hz)**	**fij**	
					MRR (mm^3/min)	**SR (µm)**
1	3	12	5.5	128	0.1510	0.2034
2	3	25	12.5	256	0.1830	0.2722
3	3	50	25	512	0.2307	0.2007
4	6	12	12.5	512	0.2887	0.2089
5	6	25	25	128	0.2041	0.3409
6	6	50	5.5	256	0.3540	0.3033
7	8	12	25	256	0.3789	0.3821
8	8	25	5.5	512	0.6190	0.4802
9	8	50	12.5	128	0.3369	0.4646

Step 4: To assign the weight value to each quality indicator, a priority criterion "W_j" was selected. W_j is determined using the AHP method based on the values given in **Table 4**.

Table 4: Value of the weight

Performance criteria	Weighted
Material removal rate	$W_{MRR} = 0.673$
Surface roughness	$W_{SR} = 0.327$

Step 5: Assignment of the weights to the selected criterion for the normalized matrix.

Table 5: Normalization matrix of criteria with weights

Exp. No	A	B	C	D	Si	Ri	Qj	Rank
1	3	12	5.5	128	0.676	0.673	0.097	1
2	3	25	12.5	256	0.711	0.627	0.124	3
3	3	50	25	512	0.558	0.558	0.399	4
4	6	12	12.5	512	0.485	0.475	0.604	6
5	6	25	25	128	0.761	0.597	**0.110**	2
6	6	50	5.5	256	0.501	0.381	0.721	8
7	8	12	25	256	0.557	0.345	0.708	7
8	8	25	5.5	512	0.327	0.327	1.000	9
9	8	50	12.5	128	0.714	0.406	0.439	5

Step 6: Ranked index by the VIKOR method: Table 5 indicates that the1th experiment has the highestQivalue among all the quality criterion(figure1). Therefore, the 1th experiment provides theoptimal process parameters: Ton = 12µs, I = 3A, Tof= 5.5µs, and F = 128Hz. The corresponding optimal process parameters and the quality criteria such as MRR = 2.33 mm^3/min, and SR = 2.22 µm.

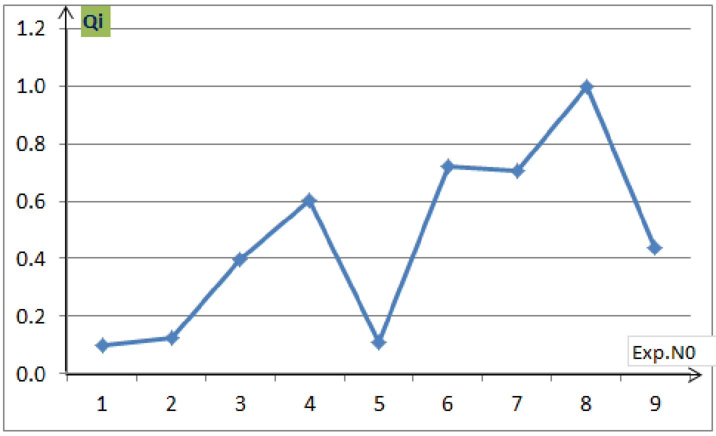

Figure 1: Ranking of Qi

5. Conclusions

The application of low-frequency vibration in EDM can be used to significantly increased machining efficiency. The results of an investigation on the optimization of multi-objective in EDM using low-frequency vibration on the workpiece SKD61 using VIKOR method have shown that a low vibration frequency significantly improves the removal productivity of the material. The optimal process parameters are Ton = 12 µs, I = 3 A, Tof = 5.5 µs, and F = 128 Hzand the associated quality indicators are MRR = 2.33 mm^3/min, and SR = 2.22 µm.

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