Parametric optimization of WEDM machining using TOPSIS

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ABSTRACT

KEYWORDS

WEDM,
Orthogonal Array,
Multi-objective Optimization,
TOPSIS,
ANOVA.

Wire Electrical Discharge Machining (WEDM) is an advanced non-conventional machining process specifically used for difficult to machine conducting materials such as, ceramics, nemonic alloys, heat treated tool steels, composites, carbides, super alloys, heat resistant steels etc. with high precision. The present study investigates the effect of the four process parameters viz. pulse on time, pulse off time, peak current and servo voltage on three response variables such as Surface Roughness (SR), Material Removal Rate (MRR), and Kerf Width (KW) while machining titanium alloys. Each parameter was set at three levels. Taguchi's L_9 *orthogonal array has been used for conducting the experiments. A technique for order preference by similarity to ideal solution (TOPSIS) approach has been used to determine the optimal level of machining parameters. Analysis of variance (ANOVA) has been conducted for investigating the effect of process parameters on overall machining performance. The effectiveness of proposed optimal condition is validated through the confirmation test.*

1. Introduction

WEDM is considered as a unique adoption of the conventional EDM process, which uses an electrode to initialize the sparking process. However, WEDM utilizes a continuously travelling wire electrode made of thin copper, brass or tungsten of diameter 0.05-0.30 mm, which is capable of achieving very small corner radii. The wire is kept in tension using a mechanical tensioning device reducing the tendency of producing inaccurate parts. During the WEDM process, the material is eroded ahead of the wire and there is no direct contact between the work piece and the wire, eliminating the mechanical stresses during machining. Manufacturers continue to produce thinner and thinner wires to allow for smaller kerfs and even finer precision. Various parameters influencing on the WEDM are pulse on time, pulse off time, peak current, wire feed, gap voltage, dielectric flow rate and wire feed etc. The response considered are cutting speed, material removal rate, kerf width, surface roughness and wire wear ratio etc.

Sarat Kumar Sahoo et al., [1] investigated the effect of various process parameters on response variables such as cutting speed, material removal rate, kerf width and surface roughness on machining of high carbon high chromium steel using Taguchi's L_9 orthogonal array. TOPSIS and Analysis of variance (ANOVA) used for investigating the effect of process parameters on overall machining performance [1]. The effect of powder concentration (C_p), peak current (I_p), pulse on time (T_{on}), duty cycle (DC) and gap voltage (V_g) on MRR, tool wear rate (TWR), electrode wear ratio (EWR), and surface roughness (SR) simultaneously for H-11 die steel using SiC powder studied by S. Tripathy & D.K. Tripathy [2]. Multi-objective optimization has been performed using grey relational analysis (GRA) and TOPSIS to maximize the MRR, minimize the TWR, EWR, and SR, and determine the optimal set of process parameters. Manivannan & Pradeep Kumar presents the multi-attribute decision-making of cryogenically cooled micro-EDM (CμEDM) drilling process. TOPSIS approach is used for the identification of optimal parameters on AISI 304 stainless steel [3]. An attempt was made to model the four response variables, i.e., machining rate, surface roughness, dimensional deviation and wire wear ratio in WEDM process of pure titanium using response surface methodology [4]. Optimal subsystem selection was evaluated with the help of TOPSIS method in composite product

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development [5]. The machinability has been evaluated in turning operation of titanium using combined TOPSIS and AHP method [6].

The optimal input parameters were determined by using combined TOPSIS and AHP method [7]. Tosun, N. et. al, [8] investigated the effects of pulse duration, open circuit voltage, wire speed and dielectric flushing pressure on the kerf (cutting width) and material removal rate (MRR) in wire electrical discharge machining (WEDM) operations. The Taguchi experimental design method used to perform the experiments. The optimum machining parameter combination was obtained by using the analysis of variance with respect to signal-to-noise (S/N) ratio. Modeling for kerfwidth and MRR has been performed using regression method hence established the optimum values for machining parameters. Multi objective optimization of gear cutting process of Inconel 718 using WEDM has been performed by Mohapatra and Sahoo [9]. The each parameter pulse on time, pulse off time and wire tension are considered at four levels to maximize the material removal rate and minimize the kerf in a gear cutting process. The optimum settings of parameters were identified using TOPSIS technique. Bharathi et. al, [10] studied the machining parameters Ton, Toff, WF & voltage while machining SS304 material for high MRR, lower SR and kerf width using multi objective optimization. Srinivasarao et al. [11] carried out experiments on Titanium Grade-5 material with CCF design with input parameters as Ton, Toff, Peak current (IP), Servo Voltage (SV) and WF. Mathematical models were developed for MRR and SR and multi-objective optimization using desirability approach has been performed to determine the optimum levels.

2. Experimental Details

The work material used for experimentation is TITANIUM GRADE5. Annealed brass wire was used as a cutting tool with a diameter 0.25 mm & 1000 Mpa tensile strength to produce very fine, precise and clean cuts. Titanium is a metal with excellent corrosion resistance, fatigue resistance, a high strength-to weight ratio that is maintained at elevated temperature. Titanium is a very strong and light metal. This property causes that titanium has the highest strength-to-weight ratio in comparison the other metal that are studied to medical use. Machining titanium and its alloys by conventional machining methods has some difficulties such as high cutting temperature and high tool wear ratio. Thus, titanium and its alloys are classified as difficult-to-machine materials. Therefore, unconventional machining processes are introduced for machining titanium and its alloys. An alpha-beta type titanium alloy (Ti-6Al-4V) has been selected as work material for this present study. Ti-6Al-4V has a resistivity on the order of five times larger than steel which is used in various applications such aircraft gas turbine disks and blades, airframe structural components, prosthetic devices, engine components, offshore, power generation industries etc.

2.1 Plan of experiments

Four parameters namely pulse on time, pulse off time, peak current and servo voltage are considered as input factors to study their effect on three response variables such as surface roughness, material removal rate and kerf width. It has been decided to use three levels for each input parameter and is shown in Table 1.

$L_9(3^4)$ orthogonal array (OA), the smallest array to accommodate four 3-level factors, has been used to perform experiments is shown in Table 2. A 30 mm length of cut is considered in each experiment and observed the responses. The surface roughness (µm) value is measured using talysurf with 8mm cut off length. Material

Table 1
Factors and their levels.

Factor	Level		
	1	2	3
Pulse on time (A) µs	100	105	110
Pulse off time (B) µs	50	55	60
Peak current (C) Amp	10	11	12
Servo voltage (D) V	10	15	20

Table 2
Experimental layout.

Exp.no	A	B	C	D
1	100	50	10	10
2	100	55	11	15
3	100	60	12	20
4	105	50	11	20
5	105	55	12	10
6	105	60	10	15
7	110	50	12	15
8	110	55	10	20
9	110	60	11	10

Table 3
Experimental results.

Exp.No	SR	MRR	KW
1	1.30	0.3212	0.1535
2	1.45	1.0600	0.2725
3	1.32	0.5746	0.3125
4	2.07	2.0597	0.2525
5	1.98	1.4373	0.2350
6	1.58	1.0800	0.3075
7	2.58	3.6050	0.2650
8	2.27	3.5483	0.3300
9	2.12	3.4323	0.2650

Table 4
Level means for SR.

Level	A	B	C	D
1	1.356	1.985	1.717	1.802
2	1.878	1.902	1.880	1.872
3	2.325	1.673	1.963	1.886
Difference	0.969	0.312	0.246	0.084
Rank	1	2	3	4

Table 5
Level means for MRR.

LEVEL	A	B	C	D
1	0.6519	1.9953	1.6498	1.7302
2	1.5256	2.0151	2.1839	1.9150
3	3.5285	1.6956	1.8722	2.0608
Diff	2.8766	0.2997	0.2224	0.3306
Rank	1	3	4	2

removal rate (MRR) should be calculated for each experiment by using the formula as:

MRR (mm^3/min) = width of workpiece × kerf width x cutting speed

Kerf width (mm) is measured with tool makers microscope. The experimental results are shown in Table 3.

3. Analysis of Results

The influence of each control factor on the response considered i.e. surface roughness, material removal rate and kerf width has been performed with level mean analysis. A level mean of a factor is the average of the response value of experiments in which the factor is at the particular level. For example, the mean value of the response for the surface roughness with respect to pulse on time at level 1, 2 and 3 can be calculated by averaging the response for experiments 1-3, 4-6 and 7-9 respectively. The mean of the response for each level of the other parameters can be computed in a similar manner. The control factor with the strongest influence is determined by the difference between mean values of the factor at high and low levels. The response tables and corresponding response graphs for each response are shown below in tables 4, 5 and 6 & figures 1, 2 and 3 respectively.

Table 6
Level means for KW.

LEVEL	A	B	C	D
1	0.2462	0.2237	0.2634	0.2178
2	0.2650	0.2792	0.2633	02817
3	0.2867	0.2950	0.2708	0.2983
Diff	0.0405	0.0713	0.0074	0.0805
Rank	3	2	4	1

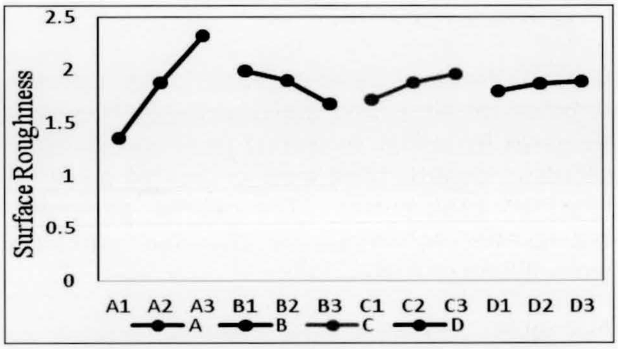

Fig. 1. Response graph for surface roughness.

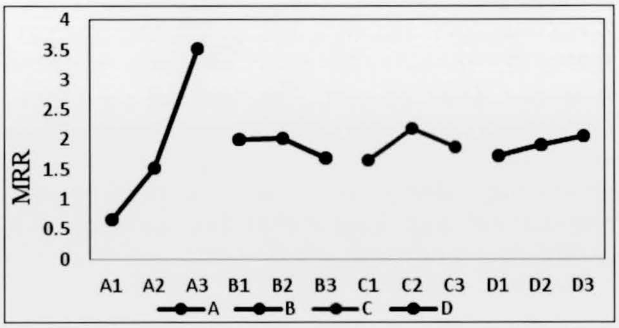

Fig. 2. Response graph for material removal rate.

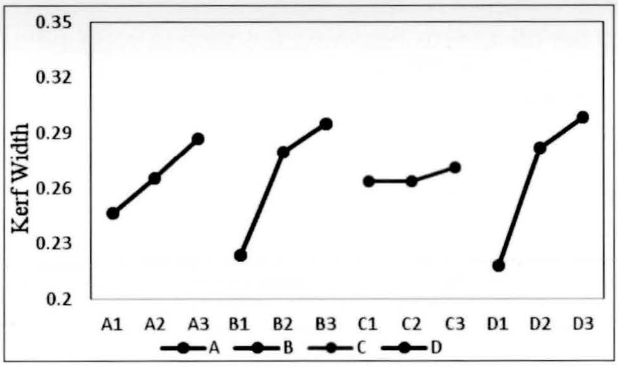

Fig. 3. Response graph for kerf width.

From the response tables and response graphs, it can be observed that surface roughness increases with increase in pulse on time, peak current and servo voltage and decreases with increase in pulse off time. Pulse on time is having more significant affect on surface roughness followed by pulse off time, peak current and servo voltage. The affect of servo voltage is negligible and it can be kept at any level. The optimal parameter settings for achieving the mimimum surface roughness is A1B3C1D1.

Material removal rate increases with increase in pulse on time and servo voltage. The MRR increases from first to second level and starts to decrease towards third level in case of pulse off time and peak current. The optimal parameter settings for achieving the maximum material removal rate is A3B2C2D3.

Kerf width increases with increase in pulse on time, pulse off time, peak current and servo voltage and showing the consistent behaviour. Servo voltage is having more significant affect on kerf width followed by pulse off time, pulse on time and peak current. The optimal parameter settings for achieving the mimimum kerf width is A1B1C1D1. The first and second level kerf width values for peak current are almost same. Due to this any level either first or second is considered as optimal.

By observing the above optimal parameter settings, the optimal level for each response is not unique, i.e. third, second and first level of pulse off time is optimum for surface roughness, material removal rate and kerf width respectively. In order to arrive unique set of optimal parameters for the given responses, multi-objective optimization is desirable. Hence application of technique for order preference by similarity to ideal solution (TOPSIS) has been considered for this purpose.

3.1 TOPSIS

Hawang and Yoon developed TOPSIS to assess the alternatives before multiple-attribute decision-making. It originates from the concept of displaced ideal that the alternative acquired should have the shortest distance from the ideal solution and the farthest from the negative-ideal solution. TOPSIS considers simultaneously the distances to both ideal solution and negative-ideal solution regarding each alternative, and also selects the best alternative based on relative closeness to the ideal solution. That is, the best alternative is the nearest one to the ideal solution and the farthest one from the negative-ideal solution.

3.2 TOPSIS procedure

The procedure involved in TOPSIS is summarized into following steps.

1. Establishing an alternative performance matrix. The structure of the alternative performance matrix is expressed as follows:

$$D=\begin{array}{c|cccccc|} & X_1 & X_2 & \cdot & X_j & \cdot & X_n \\ A_1 & x_{11} & x_{12} & \cdot & x_{1j} & \cdot & x_{1n} \\ A_2 & x_{21} & x_{22} & \cdot & x_{2j} & \cdot & x_{2n} \\ \cdot & \cdot & \cdot & \cdot & \cdot & \cdot & \cdot \\ A_i & x_{i1} & x_{i2} & \cdot & x_{ij} & \cdot & x_{in} \\ \cdot & \cdot & \cdot & \cdot & \cdot & \cdot & \cdot \\ A_m & x_{m1} & x_{m2} & \cdot & x_{mj} & \cdot & x_{mn} \end{array}$$

   Where A_i denotes the possible alternatives, i=1,2..m; X_j represents attributes relating to alternative performance, j = 1,2..n; and x_{ij} is the performance of A_i with respect to attribute X_j.

2. Normalizing the performance matrix. The normalized performance matrix is expressed as follows:

$$R=\lfloor r_{ij} \rfloor$$

   Where r_{ij} represents the normalized performance of A_i with respect to attribute X_j, and is obtained using the following transformation:

$$r_{ij}=\frac{x_{ij}}{\sqrt{\sum_{i=1}^{m} x_{ij}^2}}$$

3. Multiplying the performance matrix by its associated weights. Each column of the matrix R is multiplied by weights associated with each attribute. The weighted performance matrix V is obtained as follows:

$$V=\begin{bmatrix} w_1 r_{11} & w_2 r_{12} & \cdot & w_j r_{1j} & \cdot & w_n r_{1n} \\ w_1 r_{21} & w_2 r_{22} & \cdot & w_j r_{2j} & \cdot & w_n r_{2n} \\ \cdot & \cdot & \cdot & \cdot & \cdot & \cdot \\ w_1 r_{i1} & w_2 r_{i2} & \cdot & w_j r_{ij} & \cdot & w_n r_{in} \\ \cdot & \cdot & \cdot & \cdot & \cdot & \cdot \\ w_1 r_{m1} & w_2 r_{m2} & \cdot & w_j r_{mj} & \cdot & w_n r_{mn} \end{bmatrix}$$

$$= \begin{bmatrix} v_{11} & v_{12} & . & v_{1j} & . & v_{1n} \\ v_{21} & v_{22} & . & v_{2j} & . & v_{2n} \\ . & . & . & . & . & . \\ v_{i1} & v_{i2} & . & v_{ij} & . & v_{in} \\ . & . & . & . & . & . \\ v_{m1} & v_{m2} & . & v_{mj} & . & v_{mn} \end{bmatrix}$$

Where w_j represents the weight of attribute X_j and v_{ij} represents the weighted normalized performance of A_i with respect to X_j for i =1, 2, ..., m and j = 1, 2, ..., n.

4. Determine the ideal and negative-ideal solutions. The ideal value set V^+ and the negative-ideal value set V^- are determined as follows:

When a larger response is desired

$V^+ = \{\max v_{ij} | j \text{ for } i = 1, 2, ..., m\}$

$= \{v_1^+, v_2^+, ... v_n^+\}$

$V^- = \{\min v_{ij} | j \text{ for } i = 1, 2, ..., m\}$

$= \{v_1^-, v_2^-, ... v_n^-\}$

When a smaller response is desired

$V^+ = \{\min v_{ij} | j \text{ for } i = 1, 2, ..., m\}$

$= \{v_1^+, v_2^+, ... v_n^+\}$

$V^- = \{\max v_{ij} | j \text{ for } i = 1, 2, ..., m\}$

$= \{v_1^-, v_2^-, ... v_n^-\}$

5. Calculating the separation measures. The separation of each alternative from the ideal solution (S_i^+) and negative-ideal solution (S_i^-) are given as follows:

$$S_i^+ = \sqrt{\sum_{j=1}^{n} (v_{ij} - v_j^+)^2} \quad \text{for } i = 1, 2, ..., m$$

$$S_i^- = \sqrt{\sum_{j=1}^{n} (v_{ij} - v_j^-)^2} \quad \text{for } i = 1, 2, ..., m$$

6. Calculating the relative closeness to the ideal solution and ranking the preference order. The relative closeness, C_i, to the ideal solution can be expressed as follows:

$$C_i = \frac{S_i^-}{S_i^+ + S_i^-}$$

for i = 1, 2, ..., m

The value of C_i lies between 0 and 1. The C_i is closer to 1, the higher the priority of the i^th alternative.

3.3. Conduct TOPSIS to obtain the C_i for multi responses.

The experimental runs are treated as alternatives and the normalized values are treated as attributes and a quality performance matrix is formed. The C_i values (for i = 1,2,....,m) for each experiment run are determined. Table 7 lists the C_i values, which are measures of relative closeness to the ideal solution resulting from TOPSIS. The mean TOPSIS values of C_i were determined and are shown in table 8. Accordingly, a response diagram on C_i values is established as shown in fig. 4.

The larger the C_i value, the better is the performance characteristic. From the above, the optimal factor/level combination is determined as A3 B3 C2 D3(pulse on time at level 3, pulse off time at level 3, peak current at level 2, and servo voltage at level 3).

TOPSIS technique was applied to the L_9 experimental data to determine the optimum levels of each factor and values are given as follows:

Pulse on time - 110 µsec (level, '3')
Pulse off time - 60 µsec (level, '3')
Peak current - 11 amp (level, '2')
Servo voltage - 10 Volts (level, '1')

3.4 ANOVA

Analysis of variance (ANOVA) is used to investigate which process parameters significantly affect the process response. This is accomplished by separating the total variability of C_i, which is measured by the sum of the squared deviations from the total mean of the C_i value, into contributions by each of the process parameter and by the error. The total sum of the squared deviations is decomposed into two sources: the sum of squared deviations due to each process parameter and the sum of squared error. The percentage contribution by each of the process parameter, in the total sum of the squared deviations, can be used to evaluate the importance of the process parameter change on the process response. In addition, the F-test is used to determine which process

Table 7
TOPSIS calculations.

Exp. NO	Normalized values			S_i^+	S_i^-	C_i
	SR	MRR	KW			
1	.296	.015	.0290	1.8928	.8770	.3166
2	.368	.165	.0915	1.7456	.8134	.3179
3	.305	.048	.1204	1.8617	.8622	.3165
4	.751	.622	.0786	1.3641	.7384	.3512
5	.687	.303	.0681	1.6520	.5635	.2543
6	.437	.171	.1165	1.7446	.7460	.2995
7	1.166	1.908	.0865	.8725	1.8934	.6846
8	.903	1.848	.1342	.6189	1.8521	.7495
9	.787	1.729	.0865	.5261	1.7564	.7695

Table 8
Level means for C_i values.

LEVEL	A	B	C	D
1	0.3170	0.4508	0.4552	0.447
2	0.3016	0.4405	0.4795	0.434
3	0.7345	0.4618	0.4185	0.472
Difference	0.352	0.023	0.043	0.022
Rank	1	3	2	4

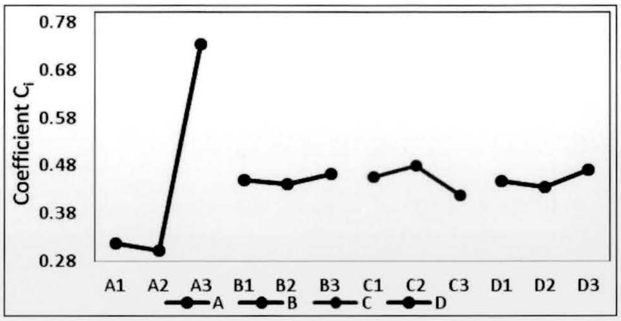

Fig. 4. Response graph for C_i values.

Table 9
ANOVA-Analysis of variance.

S.V	df		SS	MS	F	%
A	2		0.3619	0.18095	603.2	97.55
B	2	Error	0.0006	0.0003	1.0	0.16
C	2		0.0056	0.0028	9.33	1.51
D	2		0.0029	0.00145	4.83	0.50
total	8		0.371			

parameters have a significant effect on the process response. Usually, the change of the process parameter has a significant effect on the process response when the F value is large. The results of ANOVA (Table 9) indicate that pulse on time is the most significant parameter affecting the multiple responses.

3.5 Confirmation test

Predicted value at optimal combination of parameters is determined from the following relation:

$\gamma = \mu + (A3-\mu) + (B3-\mu) + (C2-\mu) + (D3-\mu)$

μ = Mean of topsis values (Ci)

γ=0.7949 and it matches with A3B3C2D1-0.7695. Confirmation tests were also conducted at the optimal setting level and identified the improvement in responses.

4. Conclusions

In this work, optimization of process parameters in WEDM has been performed using TOPSIS. From the experiment, we get the optimum level A3B3C2D3 and that value is 0.7949 and it matches with A3B2C2D1=0.7695. The sequence is pulse on time is 110 µs, pulse off time is 60 µs, peak current is 11 amp and servo voltage is 20V. The C_i value is increased at the optimum level. So this method is optimized the process parameters significantly. Here the ANOVA table shows that pulse on time is more significant than other parameters.

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