Optimization of Wire EDM Process Parameters using a Composite Method of AHP based TOPSIS

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***Abstract*— The present work deals in finding the optimal combination of WEDM process parameters during machining of a medium carbon steel EN8. The experiments were conducted as per the standard taguchi's L18 orthogonal array. The multiple performances of cutting speed, material removal rate and surface roughness are optimized by employing a MCDM technique called TOPSIS. From the optimization results, the optimal combination of process parameters is obtained at Flushing pressure of 8 Kg/cm^2, Pulse-on-time of 120 µs, Pulse-off-time of 55 µs, Wire tension of 6 Kg-f, Wire feed of 3 m/min and Servo voltage of 20 volts respectively. Finally ANOVA is employed and the results showed that the flushing pressure is the most significant process parameter in affecting the multiple responses.**

Keywords—Cutting Speed, Material Removal Rate, Surface Roughness, AHP and TOPSIS.

I. INTRODUCTION

Wire EDM is a versatile machining process employed for manufacturing of complex geometries and shapes. In WEDM process a suitable voltage is applied across the tool and work piece separated by dielectric fluid, the liberated electrons gets accelerated due to presence of electric field and then ionization of dielectric fluid takes place causing the erosion of tool and work piece. [1-3] Many authors reported their contributions by taking the WEDM process parameters for performance characteristics like material removal rate, surface roughness, cutting speed, kerf width, dimensional deviation and etc. [4-6] Tosun and Cogun [7] evaluated the impact of WEDM parameters on the wire wear ratio during machining of AISI 4140 steel using brass wire. Three process parameters such as cutting speed, feed rate and depth of cut were selected to minimize the surface roughness. They found that, with an increase in pulse duration and open circuit voltage the wire wear ratio (WWR) is increased. Surinder Kumar et al., [8] proposed an approach for WEDM of a EN-31 alloy steel using brass wire. Four parameters such as pulse-on-time, pulse-off-time, spark gap voltage, wire feed were selected to maximize the material removal rate. It was concluded that the Pulse-on time (Ton) is the major factor in affecting the MRR. Patil and Naik [9] have performed an experimental investigation to examine the significance of process parameter on performance characteristics in wire EDM of SS410. Nine experimental readings were taken for all process parameters to analyze effect of input parameters on performance measures of MRR and SR. They concluded that, MRR increases with increase in peak current, pulse on time and wire feed. Also, SR increases with increase in peak current, pulse on time and wire feed. Prajapati et al., [10] studied the effect of process parameters like pulse on time, pulse off time, voltage, wire feed and wire tension on performance measures like MRR, SR, Kerf and Gap current of wire EDM for AISI A2 tool steel. The experiments were performed using Taguchi orthogonal array. Response surface methodology was used to analyze the data for optimization and performance. They found that the Pulse off time, pulses on time were the significant factor for surface roughness and spark gap was significant factor for kerf width. Goswami and Kumar [11] investigated the surface integrity, material removal rate and wire wear ratio in machining of Nimonic 80A using WEDM process. Taguchi's design of experiments methodology has been used for planning and designing the experiments. They concluded that Pulse on time and pulse off time have been found to be the most significant factors for MRR at 95% significance level. Goyal [12] has investigated the effect on MRR and SR during WEDM of Inconel 625 super alloy by cryogenically treated tool electrode. The experiments were performed by considering different process parameters of tool electrode, current intensity, pulse on time, pulse off time, wire feed and wire tension. Taguchi L18 orthogonal array of experimental design was used to perform the experiments. Based on ANOVA results, it was found that pulse on time, tool electrode and current intensity were the significant parameters that affect the MRR and SR. Based on the result obtained they found that cryogenic tool electrode provides better machining performance (maximum MRR and better SR) as compared with normal tool electrode. MCDM/MADM techniques have high applications in manufacturing industries and used for making decisions to the problems with multiple conflicting attributes. Technique for order preference by similarity to ideal solution method

ISSN: 2278-0181
AMDMM - 2019 Conference Proceedings

(TOPSIS) is one of the MCDM method developed by Ching-lai Hwang and Yoon in 1981. [13] It is based on the concept that the chosen alternative should have the shortest geometric distance from the positive ideal solution (PIS) and the longest geometric distance from the negative ideal solution (NIS). Senthil, et al., [14] focused on optimization of process parameters in WEDM of Al-CuTiB2 metal matrix composites. This composite was synthesized using in-situ casting and L18 orthogonal arrays were employed to optimize the process parameters. A multi-attribute decision making technique, namely TOPSIS was applied for solving multi-criteria optimization. The optimal EDM process parameters were found and the results obtained using TOPSIS were in good agreement with the practitioners' parameters.

In the present work, the effect of WEDM process parameters on cutting speed, material removal rate and surface roughness were studied during machining of a medium carbon steel EN8. The experiments were conducted as per the taguchi's standard L18 orthogonal array for the selected parameters at specified levels. A MCDM technique called TOPSIS was employed for the optimization of multiple responses. Finally, ANOVA was employed for finding the significance of process parameters on the multiple responses.

II. EXPERIMENTAL DETAILS

In the present experiment, a medium carbon steel EN8 of 20 mm thickness was machined with Wire EDM (Electronica shown in "Fig. 1") using a brass wire of 0.25 mm diameter as electrode. EN8 is generally applied for axles, shafts, gears, bolts and studs, spindles, automotive components and etc. The physical and mechanical properties of EN8 steel are given in Tables 1 and 2. The selected process parameters of Flushing Pressure (FP), Pulse-on-time (T_{ON}), Pulse-off-time (T_{OFF}), Wire Tension (WT), Wire Feed (WF) and Servo Voltage (SV) with their levels are given in Table 3. The L18 orthogonal array employed for the experiments is given in table 4. The cutting faces shown in "Fig. 2" are tested for roughness at three different locations using SJ 301 tester (Mitutoyo) shown in "Fig. 3" and the average is taken as the final value.

TABLE I. CHEMICAL COMPOSITION OF EN8 STEEL

C	Si	Mn	S	P
0.36-0.44	0.10-0.40	0.60-1.00	0.005 max	0.05 max

TABLE II. MECHANICAL PROPERTIES OF EN8 STEEL

Tensile strength (N/mm^2)	Yield strength (N/mm^2)	Elongation (%)	Impact (J)	Hardness
700-850	465	16	25	201-255

Fig. 1. WEDM MACHINE

Fig. 2. CUTTING PIECE WITH FACES

Fig. 3. SJ 301 ROUGHNESS TESTER

TABLE III. PROCESS PARAMETERS AND THEIR LEVELS

Parameter	Units	Level 1	Level 2	Level 3
FP	Kg/Cm^2	4	8	-
TON	µs	115	120	125
TOFF	µs	55	58	61
WT	Kg-f	2	4	6
WF	m/min	2	3	4
SV	Volts	20	25	30

TABLE IV. L18 ORTHOGONAL ARRAY

S.N0	FP	TON	TOFF	WT	WF	SV
1	4	115	55	2	2	20
2	4	115	58	4	3	25
3	4	115	61	6	4	30
4	4	120	55	2	3	25
5	4	120	58	4	4	30
6	4	120	61	6	2	20
7	4	125	55	4	2	30
8	4	125	58	6	3	20
9	4	125	61	2	4	25
10	8	115	55	6	4	25
11	8	115	58	2	2	30
12	8	115	61	4	3	20
13	8	120	55	4	4	20
14	8	120	58	6	2	25
15	8	120	61	2	3	30
16	8	125	55	6	3	30
17	8	125	58	2	4	20
18	8	125	61	4	2	25

III. METHODOLOGY

Technique for Order Preference by Similarity to Ideal Solution (TOPSIS)

The basic concept behind the TOPSIS method is that the chosen alternative should have the shortest distance from the ideal solution and the farthest from the non-ideal solution. Various steps involved in TOPSIS method are as follows:

Step 1: Determine the objective and identify the pertinent evaluation criteria.

Step 2: Construct a decision matrix based on all the information available for the criteria. Each row of the decision matrix is allocated to one alternative and each column to one criterion. Therefore, an element, of the decision matrix shows the performance of i^{th} alternative with respect to j^{th} criterion.

Step 3: Obtain the normalized decision matrix, using the following equation:

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

Step 4: Finding of weights for the each criteria's. This can be done using Analytical Hierarchy Process (AHP) by following below steps:

$$GN_j = \left[\prod_{j=1}^{N} a_{ij}\right]^{1/N}$$

$$W_j = GN_j \Big/ \sum_{j=1}^{N} GN_j \quad (2)$$

Calculate the matrices A_3 and A_4 such that $A_3 = A_1 \times A_2$ and $A_4 = A_3/A_2$

a) Determine the maximum eigen value (λ_{max}) which is average of matrix A_4.

b) Calculate the consistency index as CI = (λ_{max} –N)/(N-1). The smaller the value of CI, the smaller is the deviation from consistency.

c) Calculate the consistency ratio, CR = CI/RI, where RI is the random index value obtained by different orders of the pair wise comparison matrices. Usually, a CR of 0.1 or less is considered as acceptable, indicating the unbiased judgements made by the decision makers.

Step 5: Obtain the weighted normalized matrix, V_{ij}

$$V_{ij} = W_{ij} r_{ij} \quad (3)$$

Step 6: Determine ideal (Best) and non-ideal (worst) solutions using the following equations:

$$V^+ = \left\{\left(\sum_i^{max} V_{ij}/j \in J\right), \left(\sum_i^{min} V_{ij}/j \in \hat{J}\right)/ 1,2..N\right\} \quad (4)$$

$$V^- = \left\{\left(\sum_i^{min} V_{ij}/j \in J\right), \left(\sum_i^{max} V_{ij}/j \in \hat{J}\right)/ 1,2..N\right\} \quad (5)$$

Where, J = (j=1,2,….N)/j is associated with beneficial attributes and J' = (j=1,2,….n)/j is associated with non-beneficial attributes.

Step 7: Obtain the separation measures.

Step 8: The relative closeness of a particular alternative to the ideal solution is computed as follows:

$$C_i^+ = S_i^- \Big/ (S_i^+ + S_i^-) \quad (6)$$

Step 9: A set of alternatives is arranged in the descending order, according to value, indicating the most preferred and the least preferred solutions.

IV. RESULTS & DISCUSSIONS

A total of eighteen experiments were performed to study the influence of the WEDM process parameters on the multiple performance characteristics. Attributes of cutting speed, material removal rate and surface roughness were measured and mentioned in the Table 5. The responses were first normalized as per "(1)" and the obtained values are given in Table 6.

TABLE V. EXPERIMENTAL RESULTS

S.No.	CS	MRR	SR
1	1.94	9.70	2.26
2	1.45	7.25	1.98
3	1.48	7.40	2.75
4	1.66	8.30	1.71
5	1.46	7.30	2.06
6	1.54	7.70	2.34
7	1.55	7.75	2.21
8	1.71	8.55	2.53
9	1.40	7.00	2.19
10	1.69	8.45	1.41
11	1.41	7.05	1.63
12	1.42	7.10	1.48
13	2.01	10.05	1.87
14	1.64	8.20	2.31
15	1.33	6.65	1.67
16	1.94	9.70	2.21
17	1.69	8.45	1.87
18	1.40	7.00	2.73

TABLE VI. NORMALIZED VALUES OF RESPONSES

S.No.	CS	MRR	SR
1	0.2844	0.2844	0.2533
2	0.2125	0.2125	0.2219
3	0.2169	0.2169	0.3082
4	0.2433	0.2433	0.1917
5	0.2140	0.2140	0.2309
6	0.2257	0.2257	0.2623
7	0.2272	0.2272	0.2477
8	0.2507	0.2507	0.2830
9	0.2052	0.2052	0.2455
10	0.2477	0.2477	0.1580
11	0.2067	0.2067	0.1827
12	0.2082	0.2082	0.1659
13	0.2946	0.2946	0.2096
14	0.2404	0.2404	0.2589
15	0.1950	0.1950	0.1872
16	0.2844	0.2844	0.2477
17	0.2477	0.2477	0.2096
18	0.2052	0.2052	0.3060

AHP was employed for finding the weights of the individual criteria's. The pairwise comparison matrix obtained given in Table 7. The weights are calculated using "(2)" and found as W_{CS} = 0.2490, W_{MRR} = 0.1570 and W_{SR} = 0.5940 respectively.

TABLE VII. PAIRWISE COMPARISON MATRIX

	CS	MRR	SR
CS	1	2	1/3
MRR	½	1	1/3
SR	3	3	1

λ_{max} = 3.054, CR = 0.056 < 0.1

After finding the individual weights for the responses, the next step is to find the weighted normalized values of the responses as per "(3)". The results obtained are given in Table 8. From the table, by following "(4)" and "(5)" the positive and negative ideal solutions for the each criteria's are found and tabulated in Table 9.

TABLE VIII. WEIGHTED NORMALIZED VALUES OF RESPONSES

S.No.	CS	MRR	SR
1	0.0708	0.0446	0.1505
2	0.0529	0.0334	0.1318
3	0.0540	0.0341	0.1831
4	0.0606	0.0382	0.1138
5	0.0533	0.0336	0.1371
6	0.0562	0.0354	0.1558
7	0.0566	0.0357	0.1471
8	0.0624	0.0394	0.1684
9	0.0511	0.0322	0.1458
10	0.0617	0.0389	0.0939
11	0.0515	0.0324	0.1085
12	0.0518	0.0327	0.0985
13	0.0734	0.0463	0.1245
14	0.0599	0.0377	0.1538
15	0.0485	0.0306	0.1112
16	0.0708	0.0446	0.1471
17	0.0617	0.0389	0.1245
18	0.0511	0.0322	0.1818

TABLE IX. PIS & NIS VALUES OF RESPONSES

	CS	MRR	SR
PIS	0.0734	0.0463	0.0939
NIS	0.0485	0.0306	0.1831

The next step is finding of the separation measures of responses from the ideal values. The results obtained are given in Table 10. Finally, the relative closeness of criteria to ideal solutions is calculated using "(6)" for each alternative and is given in Table 11. For the obtained closeness values, Higher-the-Better characteristic was employed for finding the optimal process parameters.

TABLE X. SEPARATION MEASURES FROM IDEAL SOLUTIONS

S.No.	S_i^+	S_i^-
1	0.0566	0.0420
2	0.0450	0.0515
3	0.0921	0.0065
4	0.0250	0.0707
5	0.0494	0.0463
6	0.0651	0.0288
7	0.0568	0.0372
8	0.0757	0.0220
9	0.0582	0.0374
10	0.0139	0.0906
11	0.0298	0.0747
12	0.0259	0.0847
13	0.0306	0.0656
14	0.0620	0.0322
15	0.0341	0.0719
16	0.0533	0.0446
17	0.0336	0.0606
18	0.0917	0.0033

TABLE XI. RELATIVE CLOSENESS VALUES (C_I^+) AND S/N RATIOS OF C_I^+

S.No.	C_i^+	S/N of C_i^+
1	0.4255	-7.4216
2	0.5339	-5.4502
3	0.0661	-23.5999
4	0.7384	-2.6339
5	0.4840	-6.3025
6	0.3065	-10.2713
7	0.3957	-8.0531
8	0.2255	-12.9372
9	0.3913	-8.1497
10	0.8673	-1.2368
11	0.7149	-2.9153
12	0.7655	-2.3206
13	0.6818	-3.3269
14	0.3421	-9.3170
15	0.6784	-3.3706
16	0.4554	-6.8313
17	0.6435	-3.8286
18	0.0352	-29.0699

The mean values of each process parameters for the corresponding levels are calculated and given in the Table 12. For the mean values obtained the main effect plot was drawn and shown in "Fig. 4". From the figure, the optimal combination of process parameters is found at Flushing pressure of 8 Kg/cm^2, Pulse-on-time of 120 µs, Pulse-off-time of 55 µs, Wire tension of 6 Kg-f, Wire feed of 3 m/min and Servo voltage of 20 volts respectively.

TABLE XII. RESPONSE TABLE OF MEANS OF C_I^+

Level	FP	T ON	T OFF	WT	WF	SV
1	0.3963	0.5622	0.5940	0.4590	0.3700	0.5081
2	0.5760	0.5385	0.4907	0.5055	0.5662	0.4847
3		0.3578	0.3738	0.4957	0.5223	0.4657
Delta		0.2044	0.2202	0.0465	0.1962	0.0423
Rank	4	2	1	5	3	6

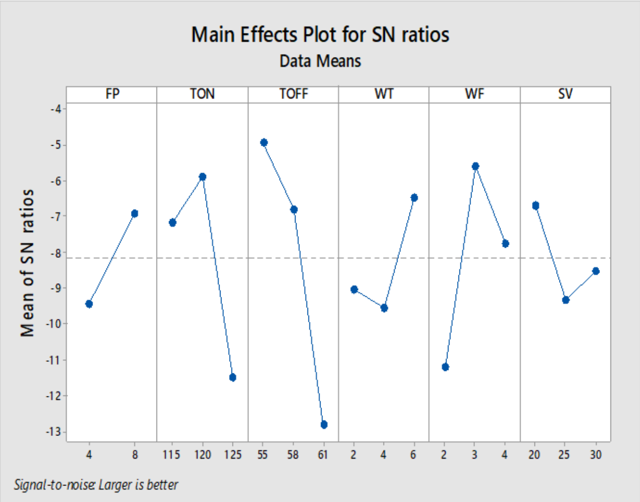

Fig. 4. MAIN EFFECT PLOT FOR S/N RATIOS

Analysis of variance (ANOVA) is employed for finding the significance of individual process parameters on the multiple responses. From the results shown in Table 13, it is found that the flushing pressure is the high significant factor and wire tension is the low significant factor in affecting the multiple responses. The residual plots drawn and shown in “Fig. 5”, indicating that the errors are following the normal distribution as the residuals are lie near to the straight line.

TABLE XIII. ANOVA RESULTS OF C_I^+

Source	DF	Adj SS	Adj MS	F
FP	1	0.143799	0.143799	2.23
TON	2	0.148954	0.074477	1.16
TOFF	2	0.110950	0.055475	0.86
WT	2	0.004354	0.002177	0.03
WF	2	0.124342	0.062171	0.97
SV	2	0.007037	0.003518	0.05
Error	6	0.386150	0.064358	
Total	17	0.964158		

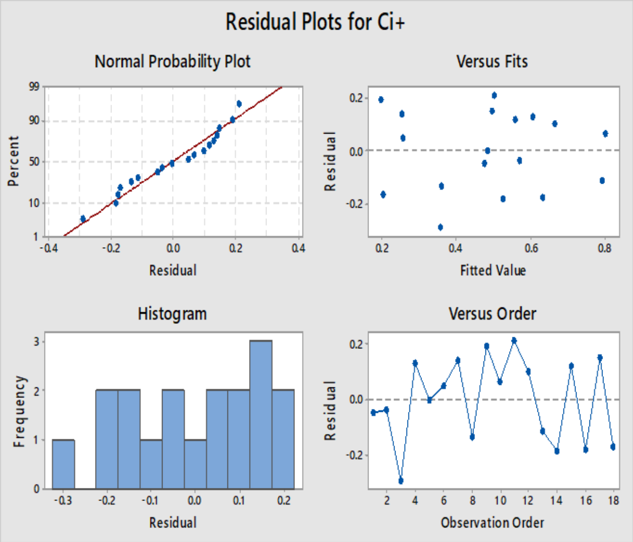

FIG. 5. RESIDUAL PLOTS FOR C_I^+

V. CONCLUSIONS

From the results obtained the following conclusions can be drawn

- The optimal combination of WEDM process parameters which optimizes the multiple performance characteristics was found at Flushing pressure of 8 Kg/cm^2, Pulse-on-time of 120 µs, Pulse-off-time of 55 µs, Wire tension of 6 Kg-f, Wire feed of 3 m/min and Servo voltage of 20 volts respectively.
- From the results of ANOVA it is clear that the flushing pressure is the most significant process parameter.
- From the residual plots, it is concluded that all the residuals are following the normal distribution and constant variance hence followed the assumptions of ANOVA.
- TOPSIS method can be employed for any multi objective optimization problems effectively and the results are significant.

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