

Influence of Wire EDM Parameters on the Multiple Performance Characteristics using TOPSIS

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Abstract

The present work is to explore the influence of wire electro discharge machining (EDM) process parameters on the multiple performance characteristics of material removal rate (MRR) and surface roughness characteristics (Ra and Rz). A number of controlled experiments were done on a medium carbon steel EN8 using CNC wire EDM machine. Taguchi's standard L18 orthogonal array (OA) has been followed for conducting the experiments. The optimal setting of process parameters was analysed by employing entropy method coupled with technique of order preference similarity to ideal solution (TOPSIS) and analysis of variance (ANOVA). From the analysis, the optimal combination of process parameters in order to achieve multi-responses is obtained at flushing pressure of 8Kg/cm², pulse-on-time of 125µsec, pulse-off-time of 55 µsec, wire tension of 6 mm/min, wire feed of 2 Kg-f, servo voltage of 25 volts respectively.

Keywords: *- Material removal rate, surface roughness characteristics (Ra and Rz), Taguchi method, technique of order preference similarity to ideal solution (TOPSIS)*

INTRODUCTION

Among all the non-traditional machining processes, wire electro discharges machining (WEDM) is highly accurate in

machining of composites and inter-metallic materials. The machining efficiency and surface quality of WEDM machined parts depends on spark intensity

and discharge time. While machining, appropriate selection of process parameters is required as it implies problems like short-circuiting of wire, wire breakage and work surface damage there by reduces the productivity. As Material Removal Rate (MRR), Surface Roughness (Ra) are most important responses in WEDM; various investigations have been carried out by several researchers for improving the MRR, Surface Finish simultaneously using many multi objective optimization methods.

S V Subrahmanyam et al. [1] demonstrated the optimization of Wire Electrical Discharge Machining process parameters for the machining of H13 HOT DIE STEEL, with multiple responses Material Removal Rate (MRR), surface roughness (Ra) based on the Grey–Taguchi Method. For the selected process parameters of TON, TOFF, IP, SV, WF, WT, SF, WP, each at three different levels Taguchi's standard L27 OA has been employed for the experiments.

Patel et al., [2] applied AHP/TOPSIS technique for the selection of optimal process parameters in the WEDM process in which pulse on time, pulse off time, flushing pressure, wire tension, servo

voltage, wire feed are taken as input process parameters. Material removal rate, kerf width and surface roughness are considered as output responses.

Joshi et al., [3] examined the control process parameters of WEDM to elaborate process limitations for tool and die steel. This research work has been done to examine the cutting and metal removal rate of tool steel EN 31. ELECTRONICA DL-25P unit 4-axis CNC WEDM with Brass wire of diameter 0.18 mm was used for experiment work. Pulse ON time, pulse OFF time, bed speed and current was input process parameters. Obtained results were examined using S/N ratios, response graph and response table in Minitab software. In this practical work results were analysed and regression equation was developed to calculate the MRR. It was concluded that with increase in pulse ON time and bed speed, MRR increases, and low pulse OFF time results in low MRR.

H Singh et al. [4] provided the effect of various input parameters of WEDM on MRR. The Hot die steel (H11) was used as work piece material, and brass wire was used as electrode wire. The experiments were done on Electronica sprint cut WEDM machine. Six input parameters

such as Pulse ON time, Pulse OFF time, servo voltage, peak current, wire feed & wire tension were investigated individually, keeping other parameter fixed at specified value. It was concluded that the MRR increases with increase in Pulse ON time and Peak current and wherever wire feed and Wire tension produce no substantial effect on MRR.

V. M. Kumar et al. [5] demonstrated optimization of parameters of WEDM process with Incoloy800 super alloy regarding multiple performance characteristics such as Material Removal Rate (MRR), surface roughness and Kerf width with reference to Grey-Taguchi Method based analysis. Gap Voltage, Pulse On-time, Pulse Off-time and Wire Feed were considered as process parameters. Taguchi's L9 Orthogonal Array is used for conducting experiments. Optimized values of process parameters were determined using Grey Relational

Analysis and the other prominent parameters were determined by Analysis of Variance ANOVA. Mathematical model was constructed by using non-linear regression analysis with variation of output responses with process parameters method and thus checked for significance. It was concluded that mathematical

models can predict the output responses with substantial accuracy.

V. S. Gadakh et. al. [6] investigated the applications of TOPSIS (Technique of order preference similarity to ideal solution) in solving multi-criteria optimization problems for wire electrical discharge machining. Results obtained by this technique were corresponding to the result obtained through past researchers work. Gap voltage, pulse on time, pulse-off time and wire feed were selected as input parameters. TOPSIS was used for optimization of multi performance characteristics like MRR and kerf width. The suggested methodology can be employed for any type of selection problem involving any number of selection criterions.

M. Durairaj et al. [7] used the grey relational theory and Taguchi optimization technique, for optimization of the cutting parameters in Wire EDM for SS304. The aim of optimization was to attain the minimum kerf width and the best surface integrity individually. Stainless steel 304 was employed as work piece; brass wire of 0.25mm diameter was selected as tool along with distilled water which was used as dielectric fluid. Taguchi's L16, orthogonal array technique was used for

experiments. The input parameters such as gap voltage, wire feed, pulse on time, and pulse off time were selected for optimization. Dielectric fluid pressure, wire speed, wire tension, resistance and cutting length were categorized as fixed parameters. In experiments surface roughness was determined by using contact type surf coder and kerf width was determined through video measuring system. The multiple results were optimized using grey relational analysis and finally optimized values are obtained by Taguchi method.

P. S. Rao et al. [8] investigated effects of input parameters WEDM on MRR by employing aluminum BIS-24345 alloy for work piece material. Taguchi design L18 orthogonal array was used for study of different levels of input parameters. Pulse on time, pulse off time, peak current, flushing pressure of dielectric, wire feed rate, wire tension, spark voltage and servo feed were selected as input parameters. First orthogonal array was used for preparation of table then analysis was done through ANOVA and finally MRR is calculated with S/N ratio. Through experiments, it was determined that Peak current was most substantial parameter, while Pulse on time, Pulse off time, Spark

voltage and Flushing pressure of dielectric were other prominent parameters.

D. V. Kashid et al. [9] in this research investigation on effect of input process parameters on MRR in WEDM machining process of steel grade EN 9 were done. Experimental work was performed on SPRINTCUT ELPULS 40 A DLX CNC WEDM using a negatively charged brass wire of diameter of 0.25 mm. Three input process parameters were chosen, pulse ON time (Ton), pulse OFF time (Toff) and wire feed. Taguchi's L9 orthogonal array was used to perform experiments and signal to noise ratio was estimated for MRR. Analysis work was performed using ANOVA and response graphs. At last it was found that MRR mostly influenced by Ton and Toff. Maximum MRR was obtained by using high value of Ton and low values of Toff and wire feed. Wire feed have minimum effect on MRR.

J. R. Mevada et al. [10] investigated the wire wear rate with relation to separate machining parameters such as peak current, pulse ON/OFF time through factorial design of experiment. EN-8 material was used as work piece and molybdenum wire of 0.18 mm was selected as tool material for the experiments. The effect of peak current,

pulse ON/OFF time on wire wear was analysed through ANOVA. It was concluded that wire wear increases with increase peak current and pulse ON time. Also, it was found that wire wear was not much affected with pulse OFF time proposed the outlines of the development of a model and the application of this model in optimization of WEDM machining parameters. Experiments were conducted to test the developed model and to analyse the results so produced. Pulse ON time, pulse OFF time, discharge current, wire feed, wire tension and dielectric flow rate were employed as process parameters. D2 tool steel was selected for carrying out the experiments.

V. M. Kumar et al. [11] demonstrated optimization of parameters of WEDM process with Incoloy800 super alloy regarding multiple performance characteristics such as material removal rate (MRR), surface roughness and Kerf width with reference to grey-Taguchi method based analysis. Gap voltage, pulse on-time, pulse off-time and wire feed were considered as process parameters. Taguchi's L9 Orthogonal Array is used for conducting experiments. Optimized values of process parameters were determined using Grey Relational Analysis and the other prominent parameters were

determined by Analysis of Variance ANOVA. Mathematical model was constructed by using non-linear regression analysis with variation of output responses with process parameters method and thus checked for significance. It was concluded that mathematical models can predict the output responses with substantial accuracy.

V. Parashar et al. [12] investigated kerf width for WEDM with Stainless Steel grade 304L as work piece material and CNC Ezee cut WEDM machine was used for execution of experiments. Tool electrode is selected of Brass wire of 0.25 mm diameter. The variables affecting the kerf width were determined through Analysis of variance (ANOVA) technique. It was concluded that pulse ON time and dielectric flushing pressure has prominent effect on kerf width while Pulse OFF time, wire feed, gap voltage were less.

Sivaraman et al. [13] evaluated the effect of various control parameters on WEDM using Titanium as work piece. The input process parameters included dielectric pressure, pulse ON/OFF time, wire tension, wire feed rate, gap voltage, and average gap current which effect the output response parameters such as surface roughness, electrode wear,

material removal rate were studied through orthogonal arrays and L9 techniques of Taguchi method, and concluded in favour of Taguchi method regarding parametric optimization of WEDM on using multiple performance characteristics such as MRR and surface roughness. In the present work, MCDM method of TOPSIS was employed in order to convert the multiple responses to a single response.

Taguchi approach is used to analyse the effect of wire EDM parameters such as flushing pressure, pulse-on-time, pulse-off-time, wire feed, wire tension and servo voltage. Statistical analysis of variance (ANOVA) is performed to judge the significance of factor for multiple responses.

Experimental Details

In the present work, a medium carbon and medium tensile steel called EN8 or AISI 1040 was taken as the work piece. EN8 steel is suitable for the engineering applications where higher tensile strengths are required. It is used in shafts, gears, spindles, axles, bolts & studs, automobile parts and etc. The chemical composition and mechanical properties of EN8 steel are given in Tables 1 and 2 respectively. For machining CNC WEDM (ELECTRONICA Hitech, JOB MASTER D-ZIRE) was used. Brass wire of 0.25mm and distilled water are used as electrode and dielectric fluid. The wire EDM process parameters used with their levels and the orthogonal design selected for the experiments were given in the Table 3 and 4. The machined work pieces are shown in Fig. 1.

Table 1: Chemical composition of EN8 Steel

Element	C	Si	Mn	S	P
Reference Range %	0.36-0.44	0.10-0.40	0.60-1.00	0.05	0.05

Table 2: Mechanical properties of EN8 steel

Ultimate Tensile Strength	Yield Strength	Elongation	Rockwell Hardness
550 MPa	280 MPa	16 %	201–255

Table 3: Process parameters with their levels

Parameter	Units	Level-1	Level-2	Level-3
Flushing Pressure (FP)	Kg/cm ²	4	8	–
Pulse-On-Time (T _{on})	µsec	115	120	125

Pulse-Off-Time (T_{off})	μ sec	55	58	61
Wire Feed (WF)	mm/min	2	3	4
Wire Tension (WT)	Kg-f	2	4	6
Servo Voltage (SV)	Volts	20	25	30

Table 4: L18 Orthogonal array (OA)

Sr. No.	F P	T_{on}	T_{off}	WT	WF	S V
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



Figure 1: Machined work pieces.

METHODOLOGY

TOPSIS decision making method is a technique introduced by Yoon and Hwang. It is a worldwide accepted approach to finding the best alternative that is closest to the ideal solution. TOPSIS follows a principle the chosen alternative should have the least distance from the positive ideal solution (PIS) and the highest distance from the negative ideal solution (NIS). In TOPSIS method of decision making problems, first step is to determine the weights using an entropy approach.

Step 1: Determination of Weights using Entropy Approach

The entropy approach includes in four steps they are,

1. Formation of a decision matrix (D)
2. Formation of Normalized decision matrix (Y_{ij})
3. Calculation of output entropy (ϵ_j)
4. Calculation of the weight (W_j)

Formation of a decision matrix (D)

In a decision matrix, the rows are assigned to available alternatives and the columns are assigned to characteristics. The general decision matrix can be shown as:

$$D = \begin{matrix} & A_1 & A_2 & \dots & A_m \end{matrix} \begin{bmatrix} Y_{11} & Y_{12} & \dots & Y_{1j} & Y_{1n} \\ Y_{i1} & Y_{i2} & \dots & Y_{ij} & \dots \\ Y_{m1} & Y_{m2} & \dots & Y_{mj} & Y_{mn} \end{bmatrix}$$

Where, A_i ($i = 1, 2, 3, \dots, m$) signifies the potential alternatives, Y_j ($j = 1, 2, 3, \dots, n$) signifies the attributes and Y_{ij} is the performance of A_i with respect to characteristic Y_j .

Formation of Normalized decision matrix ($\bar{Y}_{ij}$)

$$\bar{Y}_{ij} = \frac{Y_{ij}}{\sum_{i=1}^m Y_{ij}} \quad (1 \leq i \leq m, 1 \leq j \leq n)$$

Calculation of output entropy (ϵ_j)

$$\epsilon_j = \frac{-1}{\ln(m)} \sum_{i=1}^m \bar{Y}_{ij} \ln \bar{Y}_{ij}$$

Calculation of the weight (W_j)

$$W_j = \frac{1 - \epsilon_j}{\sum_{j=1}^n (1 - \epsilon_j)}$$

Where, $\sum_{j=1}^n W_j = 1$ and $(1 - \epsilon_j)$ is called uncertainty.

Step 2: Determination of the Normalized decision making matrix (r_{ij})

Normalize the decision matrix of r_{ij} can be determined by using

$$r_{ij} = \frac{Y_{ij}}{\sqrt{\sum_{i=1}^n Y_{ij}^2}}$$

Where, r_{ij} represents the normalized performance of A_i with respect to characteristic Y_j .

Step 3: Construction of a weighted normalized decision matrix (V_{ij})

$$V_{ij} = W_j r_{ij}$$

Where, W_j represents the relative weight of the J^{th} criteria.

Step 4: Determination of Positive ideal solution (PIS) and Negative ideal solutions (NIS)

Positive ideal solution

$$A^+ = \{(\max_i V_{ij} | j \in J), (\min_i V_{ij} | j \in J) \mid i = 1, 2, \dots, m\}$$

$$= \{v_1^+, v_2^+, \dots, v_j^+, \dots, v_n^+\}$$

Negative ideal solution

$$A^- = \{(\min_i V_{ij} | j \in J), (\max_i V_{ij} | j \in J) \mid i = 1, 2, \dots, m\}$$

$$= \{v_1^-, v_2^-, \dots, v_j^-, \dots, v_n^-\}$$

$J = 1, 2, 3, \dots, n$, associated with the beneficial attributes.

$J = 1, 2, 3, \dots, n$, associated with non-beneficial adverse attributes.

Step 5: Determination of the separation values from the PIS and NIS

The separation of each alternative from PIS is given by

$$S_i^+ = \sqrt{\sum_{j=1}^n (v_i^+ - v_{ij})^2}; \text{ Where, } i = 1, 2, \dots, m.$$

The separation of each alternative from NIS is given by

$$S_i^- = \sqrt{\sum_{j=1}^n (v_i^- - v_{ij})^2}; \text{ Where, } i = 1, 2, \dots, m.$$

Step 6: Determination of the relative closeness to the ideal solutions and corresponding Signal to noise (S/N) ratios

Relative closeness coefficient, $C_i^+ =$

$$\frac{S_i^-}{S_i^+ + S_i^-};$$

Where $i = 1, 2, \dots, m$

The larger the C_i^+ value the better the performance of the alternatives. The corresponding S/N ratios of C_i^+ were calculated from Taguchi's Larger-the-Better characteristic.

Step 7: Rank the alternatives in descending order of S_i^+ .

RESULTS AND DISCUSSIONS

After machining of EN8 work pieces the performance characteristics of material removal rate (MRR) and surface roughness characteristics (R_a and R_z) are measured for the analysis. The experimental results are shown in the Table 5. The weights obtained from the entropy method are given in the Table 6.

Table 5: Experimental results of responses

Sr. No	MRR	R _a	R _z
1	9.7	2.43	13.564
2	7.32	2.755	15.992
3	7.34	2.355	14.415
4	8.33	2.351	14.391
5	7.33	2.524	15.727
6	7.7	2.491	15.846
7	8.01	2.526	15.196
8	8.55	2.726	15.999
9	7	2.59	15.322
10	8.45	2.492	15.589
11	7.06	2.251	13.758
12	7.07	2.645	15.1
13	10.05	2.964	17.048
14	8.24	2.752	17.366
15	6.69	2.433	14.459
16	9.72	2.679	16.008
17	8.48	2.768	16.822
18	7.01	2.704	16.533

Table 6: Output entropy and the weights of the responses.

	MRR	R _a	R _z
e _j	0.8967	0.9543	0.9337
w _j	0.4799	0.2121	0.3080

In TOPSIS, the first step is to normalize the experimental results as described in methodology and the obtained results are shown in the Table 7. The Normalized values (r_{ij}) of the responses were now turned into weighted normalized (A_{ij}) values by multiplying the normalized values with the corresponding weights of the responses the obtained results are shown in the Table 8.

Table 7: Normalized values of responses (r_{ij})

Sr. No.	MRR	R _a	R _z
1	0.2835	0.2511	0.2057
2	0.2139	0.2147	0.2425
3	0.2145	0.2143	0.2186
4	0.2435	0.2301	0.2182
5	0.2142	0.2271	0.2385
6	0.2251	0.2302	0.2403
7	0.2341	0.2485	0.2304
8	0.2499	0.2361	0.2426
9	0.2046	0.2271	0.2323

10	0.2470	0.2052	0.2364
11	0.2063	0.2411	0.2086
12	0.2066	0.2702	0.2290
13	0.2937	0.2508	0.2585
14	0.2408	0.2218	0.2633
15	0.1955	0.2442	0.2193
16	0.2841	0.2523	0.2427
17	0.2478	0.2465	0.2551
18	0.2049	0.0000	0.2507

Table 8: Weighted normalized values of the responses (A_{ij})

Sr. No.	MRR	R_a	R_z
1	0.1361	0.0533	0.0634
2	0.1027	0.0455	0.0747
3	0.1030	0.0455	0.0673
4	0.1168	0.0488	0.0672
5	0.1028	0.0482	0.0735
6	0.1080	0.0488	0.0740
7	0.1123	0.0527	0.0710
8	0.1199	0.0501	0.0747
9	0.0982	0.0482	0.0716
10	0.1185	0.0435	0.0728
11	0.0990	0.0511	0.0643
12	0.0992	0.0573	0.0705
13	0.1410	0.0532	0.0796
14	0.1156	0.0470	0.0811
15	0.0938	0.0518	0.0675
16	0.1363	0.0535	0.0748
17	0.1189	0.0523	0.0786
18	0.0983	0.0000	0.0772

Now, the ideal and negative ideal solutions are chosen from the weighted normalized values of responses, values are given in the Table 9.

Table 9: PIS & NIS values

		MRR	R_a	R_z
PIS	A+	0.141	0	0.0634
NIS	A-	0.0938	0.0573	0.0811

The separation values of each alternative from the positive ideal solution (PIS) and negative ideal solutions (NIS) of the responses are determined; the corresponding values are shown in the Table 10. Finally, the relative closeness (S_{i+}) values are obtained and the signal-to-noise ratios (S/N) are calculated based on the Higher-the-Better characteristic and values are shown in Table 11.

Table 10: Separation distances of the responses from PIS & NIS

Sr.N.	Si+	Si-
1	0.0535	0.0460
2	0.0606	0.0161
3	0.0594	0.0203
4	0.0546	0.0282
5	0.0623	0.0149
6	0.0599	0.0180
7	0.0605	0.0216
8	0.0555	0.0278
9	0.0650	0.0139
10	0.0499	0.0295
11	0.0662	0.0187
12	0.0713	0.0119
13	0.0556	0.0474
14	0.0563	0.0241
15	0.0702	0.0146
16	0.0549	0.0432
17	0.0258	0.0587
18	0.0576	0.0449

Table 11: Relative closeness values (si+) and s/n ratios

Sr. No.	Si+	S/N Ratios
1	0.4624	-6.6996
2	0.2097	-13.5680
3	0.2551	-11.8658
4	0.3407	-9.3526
5	0.1935	-14.2664
6	0.2310	-12.7278

7	0.2635	-11.5844
8	0.3341	-9.5225
9	0.1763	-15.0750
10	0.3716	-8.5985
11	0.2202	-13.1437
12	0.1426	-16.9176
13	0.4599	-6.7467
14	0.2994	-10.4750
15	0.1727	-15.2542
16	0.4402	-7.1270
17	0.3049	-10.3169
18	0.5622	-5.0022

For finding the optimal conditions of process parameters Taguchi's higher the better characteristic is used. From the mean values of signal-to-noise ratios of process parameters the main effect plot was drawn and shown in the Fig. 2. Residual plot for the combined response are drawn and shown in Fig. 3.

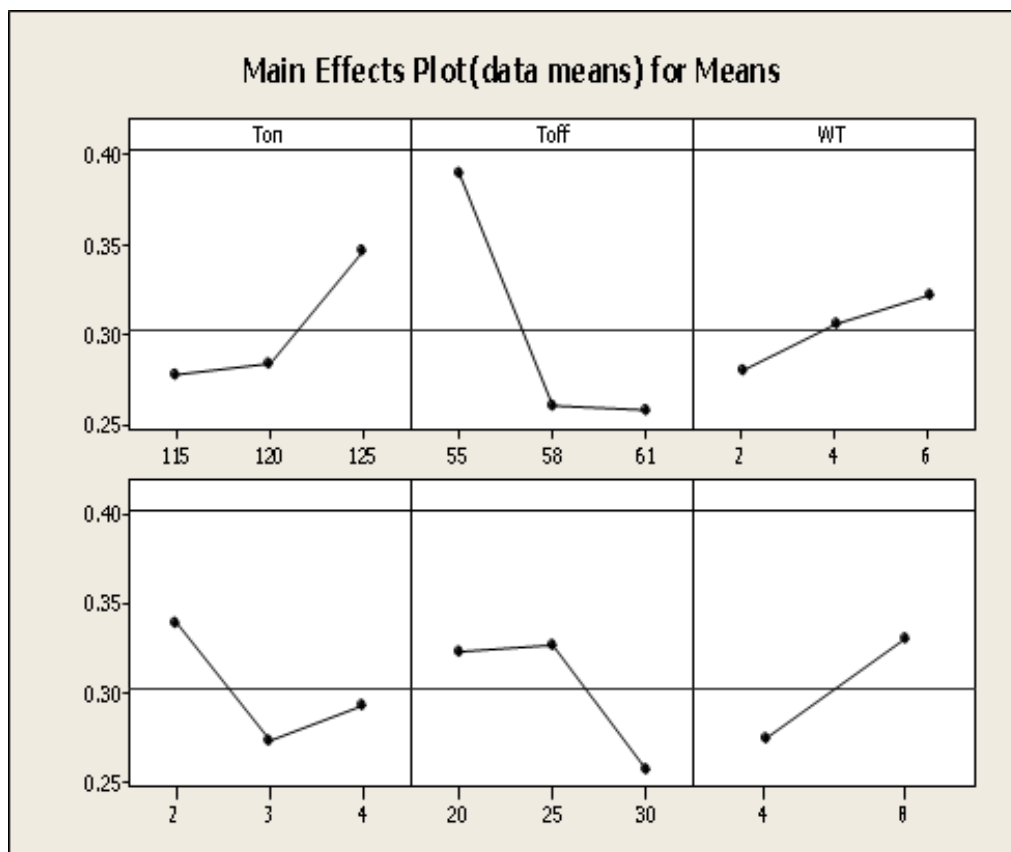


Figure 2: Main effect plot for S/N ratios of $Ci+$.

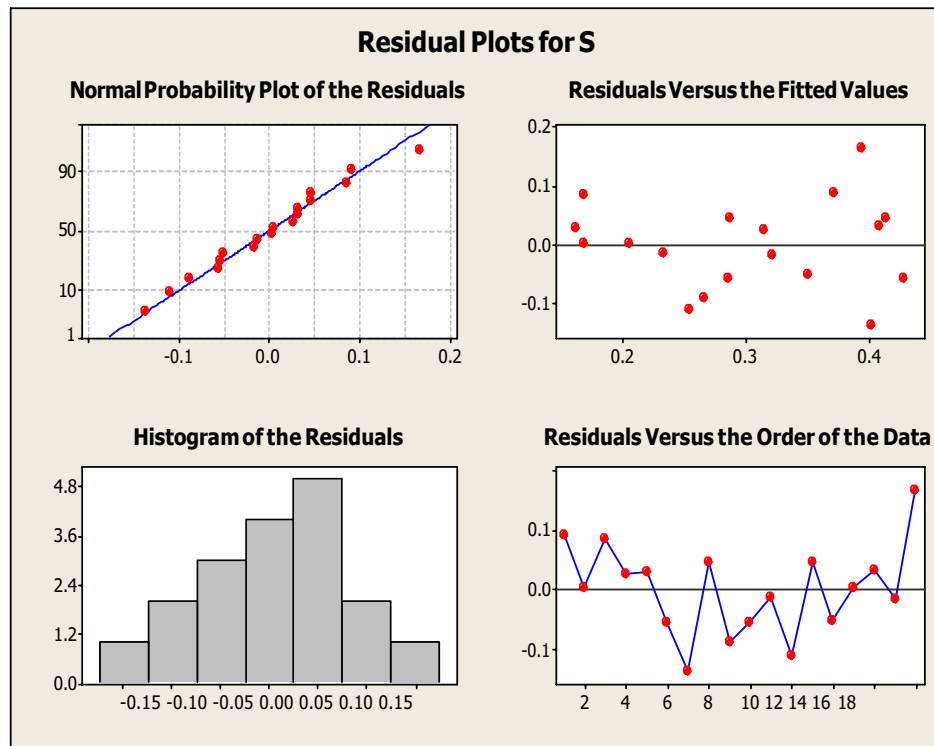


Figure 3: Residual plots for S_i^+ .

CONCLUSIONS

From the experimental results the following conclusions can be drawn:

- The optimal combination of the process parameters to achieve higher relative closeness (C_i^+) value is found at flushing pressure: 8 Kg/cm² Pulse-on-time: 125 μ sec Pulse-off-time: 55 μ sec Wire tension: 6 mm/min Wire feed: 2 Kg-f Servo voltage: 25 volts.
- The residuals are following the normality and constant variance as they lie nearer to the straight line and do not representing any regular pattern.
- The proposed method of entropy combined with TOPSIS can be applied to all industrial sectors for solving the

multi objective optimization problems effectively.

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