Effect of WEDM Process Parameters on Responses through Taguchi's Quality Loss Method

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Abstract

The present work is to examine the effect of wire EDM process parameters on multiple responses and to find the optimal combination which yields the required performances. Medium carbon steel EN8 is machined with Pulse-on-time, Pulse-off-Time, Wire Tension and Wire feed as variables and each at three different levels. Twenty seven experiments were conducted and the results were optimized using a multi-objective optimization method called Taguchi total quality loss method. From the results it is found that the pulse-on-time is the major influencing factor for achieving the multiple responses.

Keywords: Material Removal Rate (MRR), Surface Roughness characteristics (R_a and R_z), Taguchi Total Quality Loss Method and Response Surface Methodology (RSM).

1. Introduction

In present days the researchers were facing the obstacles while setting of suitable cutting parameters for attaining more than one response at a time. Surface roughness is counted as a variation from the mean line. It is a major quality attribute of machined parts as it affecting the appearance, wear resistance, ductility, tensile and fatigue strengths and etc. There are numerous factors which influence the surface quality like cutting parameters (speed, feed and depth of cut), tool nomenclature, work piece properties etc. It is well known that the real time industrial tasks cannot be solved by simple traditional statistical methods hence in order to overcome this, taguchi has evolved a design called orthogonal array. OA helps in investigating the entire parametric space with a very less number of experiments thereby minimizes the experimentation cost and time. Many authors have contributed their works in this area using many multi objective optimization methods. In the present work, Taguchi's total quality loss method has been employed for optimizing multiple performances.

2. Experimental Details

In the present work a plate of EN8 steel has been taken as work material. The experiments were done on CNC WEDM (ULRACUT with pulse generator ELPULS 50f). Brass wire of diameter 0.25 mm and water are used as electrode and dielectric fluid respectively. The chemical composition and mechanical properties of EN8 are given in the tables 1 and 2. For conducting the experiments; Pulse on time (T_{on}), Pulse off time (T_{off}), Wire Tension (WT) and Wire feed rate (WF) are considered as process parameters at three different levels as given in table 3. Taguchi's standard L27 Orthogonal array given in table 4 has been followed for the experiments.

Table 1. Chemical Properties of EN8 Steel

C	Mn	Si	S	P	Cr	Ni	Mo
0.36-0.44	0.6-1.0	0.1-0.4	0.05 max	0.05 max	-	-	-

Table 2. Mechanical Properties of En8 Steel

Maximum Stress (N/mm^2)	Yield stress (N/mm^2)	Elongation (%)	Impact (J)	Hardness (BHN)
700-850	465	16	28	201-255

Table 3. Machining Parameters and Their Levels

Parameter	Level-1	Level-2	Level-3
Pulse on Time (T_{on}), µs	115	123	131
Pulse off Time (T_{off}), µs	53	58	63
Wire Tension (WT), Kg-f	2	3	4
Wire Feed rate (WF), m/min	4	5	6

Table 4. L27 OA with Actual Experiments

S.No.	T_{on}	T_{off}	WT	WF
1	115	53	2	4
2	115	53	3	5
3	115	53	4	6
4	115	58	2	5
5	115	58	3	6
6	115	58	4	4
7	115	63	2	6
8	115	63	3	4
9	115	63	4	5
10	123	53	2	5
11	123	53	3	6
12	123	53	4	4
13	123	58	2	6
14	123	58	3	4
15	123	58	4	5
16	123	63	2	4
17	123	63	3	5
18	123	63	4	6
19	131	53	2	6
20	131	53	3	4
21	131	53	4	5
22	131	58	2	4
23	131	58	3	5
24	131	58	4	6
25	131	63	2	5
26	131	63	3	6
27	131	63	4	4

3. Methodology

In recent days the manufacturers are interested in achieving the several performance characteristics at a time rather to achieve one. Though many multi objective optimization methods are avail, Taguchi quality loss (L_{ij}) method has been employed for the present work as it involves in very less computational procedure and the results were highly accurate as compared with other. The procedural steps are as follows:

Step1: Taguchi quality loss (L_{ij}) for the responses.

$L_{ij} = Y_{ij}^2$ for lower the better (LB)…………….Eq.(1)

$L_{ij} = 1/Y_{ij}^2$ for higher the better (HB)…………...Eq.(2)

Step2: Normalization of the responses.

$N_{ij} = L_{ij}/L^*$..Eq.(3)

Where, $L^* = \max L_{ij}$

Step 3: Calculation of total loss function.

$T_{ij} = (1/n) \sum_{i=1}^{n} W_i\, N_{ij}$…………………………..Eq.(4)

Where,

W is weights of the responses such that $\sum W_i = 1$

Step 4: Finding the optimum parametric levels and their significances using Taguchi and ANOVA.

4. Results And Discussions

The measured values of the material removal rate and surface roughness parameters are mentioned in the table 5. For each trail the corresponding quality loss values are calculated using the equations 1 and 2 for material removal rate and roughness characteristic respectively and they are tabulated in table 6.

Table 5. Experimental Results

S.No.	MRR	R_a (µm)	R_z (µm)
1	12.52	2.5	9.9
2	13.36	5.1	21.5
3	14.15	7.2	26.3
4	13.05	4.3	18.0
5	13.75	6.1	23.9
6	12.94	3.0	13.1
7	13.59	7.1	27.8
8	12.81	4.2	15.9
9	13.55	5.2	22.1
10	14.92	3.7	15.1
11	15.89	7.5	28.9
12	14.75	3.2	13.0
13	15.84	4.3	16.4
14	14.40	3.2	11.9
15	15.56	5.7	21.1
16	14.24	2.8	10.7
17	15.27	4.2	17.1
18	14.24	6.9	28.3
19	18.44	5.5	19.3
20	16.71	3.5	13.7
21	18.31	4.9	19.2
22	16.46	2.3	9.4

23	17.61	3.8	15.8
24	19.60	6.3	23.4
25	17.43	4.2	16.5
26	18.49	5.1	21.7
27	17.34	3.7	13.6

Table 6. Quality Loss (L_{ij}) Values of the Responses

S.No.	MRR	R_a	R_z
1	0.0063	6.25	98.01
2	0.0056	26.01	462.25
3	0.0049	51.84	691.69
4	0.0058	18.49	324
5	0.0052	37.21	571.21
6	0.0059	9.00	171.61
7	0.0054	50.41	772.84
8	0.0060	17.64	252.81
9	0.0054	27.04	488.41
10	0.0044	13.69	228.01
11	0.0039	56.25	835.21
12	0.0045	10.24	169
13	0.0039	18.49	268.96
14	0.0048	10.24	141.61
15	0.0041	32.49	445.21
16	0.0049	7.84	114.49
17	0.0042	17.64	292.41
18	0.0049	47..61	800.89
19	0.0029	30.25	372.49
20	0.0035	12.25	187.69
21	0.0029	24.01	368.64
22	0.0036	5.29	88.36
23	0.0032	14.44	249.64
24	0.0026	39.69	547.56
25	0.0032	17.64	272.25
26	0.0029	26.01	470.89
27	0.0033	13.69	184.96

Now, the quality loss values were normalized using the equation 3 to reduce the variability and obtained values are given in the table 7. From the normalized values the total quality loss values were obtained using equation 4 and given in the table 8. The weights for the individual responses were calculated using analytical hierarchy process (AHP) and they are obtained as W_{MRR} = 0.6370, W_{Ra} = 0.2580 and W_{Rz} = 0.105.

Table 7. Normalized Values of Responses

S.No.	MRR	R_a	R_z
1	1	0.1111	0.1173
2	0.8888	0.4624	0.5535
3	0.7777	0.9216	0.8282
4	0.9206	0.3287	0.3879
5	0.8253	0.6615	0.6839

6	0.9365	0.1600	0.2055
7	0.8571	0.8961	0.9253
8	0.9523	0.3136	0.3027
9	0.8571	0.4807	0.5848
10	0.6984	0.2433	0.2730
11	0.6190	1	1
12	0.7142	0.1820	0.2023
13	0.6190	0.3287	0.3220
14	0.7619	0.1820	0.1696
15	0.6507	0.5776	0.5331
16	0.7777	0.1393	0.1371
17	0.6666	0.3136	0.3501
18	0.7777	0.8464	0.9589
19	0.4603	0.5377	0.4460
20	0.5555	0.2177	0.2247
21	0.4603	0.4268	0.4414
22	0.5714	0.0940	0.1058
23	0.5079	0.2567	0.2989
24	0.4126	0.7056	0.6556
25	0.5079	0.3136	0.3260
26	0.4603	0.4624	0.5638
27	0.5238	0.2434	0.2215

Table 8. Total Quality Loss function and S/N of T_{ij}

S.No.	T_{ij}	S/N of T_{ij}
1	0.2260	12.9178
2	0.2479	12.1145
3	0.2734	11.2640
4	0.2373	12.4940
5	0.2561	11.8318
6	0.2198	13.1594
7	0.2914	10.7102
8	0.2398	12.4030
9	0.2438	12.2593
10	0.1788	14.9526
11	0.2524	11.9582
12	0.1744	15.1691
13	0.1710	15.3401
14	0.1834	14.7320
15	0.2065	13.7016
16	0.1819	14.8033
17	0.1808	14.8560
18	0.2715	11.3246
19	0.1596	15.9393
20	0.1445	16.8026
21	0.1499	16.4840
22	0.1331	17.5164
23	0.1404	17.0527

24	0.1712	15.3299
25	0.1462	16.7011
26	0.1572	16.0709
27	0.1399	17.0836

Table 8 shows, the total quality loss values and their corresponding signal to noise ratios (S/N). Taguchi analysis was employed to find the effect of the machining parameters on the multi response i.e. total quality loss. Table 9 showing the taguchi results and from the results, it is observed that the multi response value is mainly affected by the change in levels of pulse on time (T_{on}) and followed by wire feed rate (WF), wire tension (WT) and pulse off time (T_{off}) respectively.

Table 9. Response Table for Signal to Noise Ratios

Level	T_{on}	T_{off}	WT	WF
1	12.13	14.18	14.60	14.95
2	14.09	14.57	14.20	14.51
3	16.55	14.02	13.98	13.31
Delta	4.43	0.55	0.62	1.65
Rank	1	4	3	2

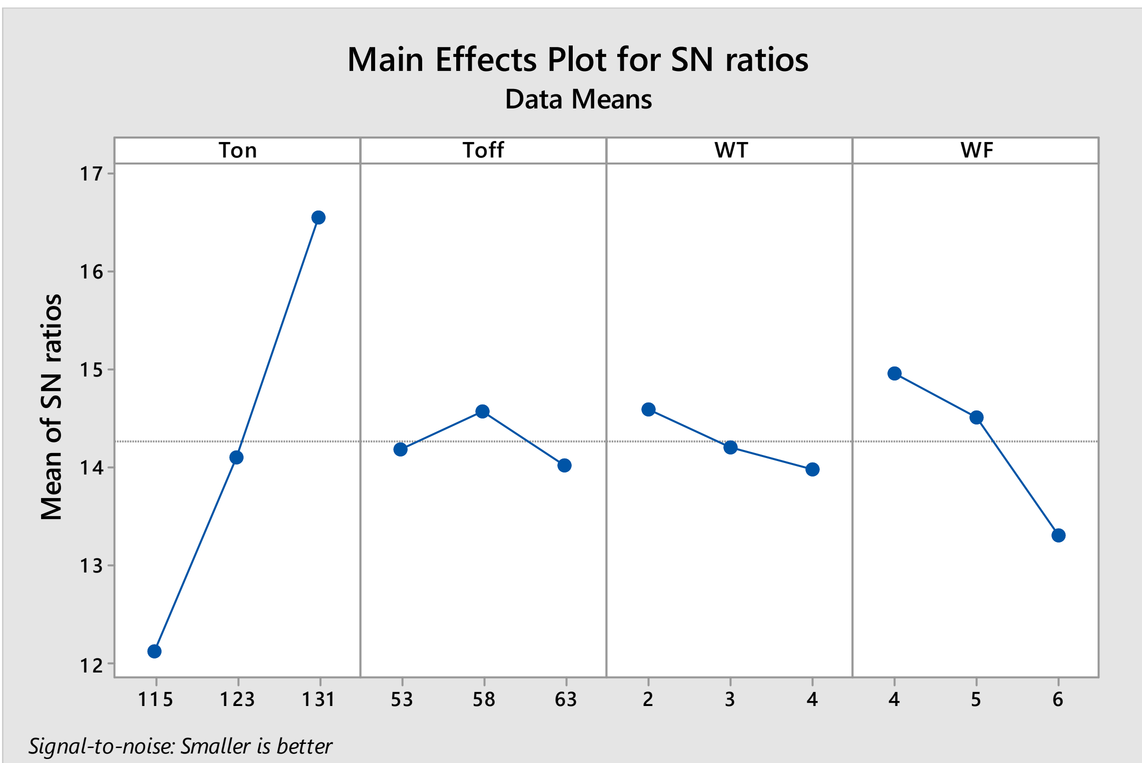

Figure 1. Main Effect Plot for S/N ratios of T_{ij}

Figure 1 shows the main effect plot for mean S/N ratios of the multi response T_{ij}. From the figure, it is clear that the Pulse on time (Ton) is the most affecting parameter on the total quality loss (T_{ij}). The optimum levels of machining parameters are found at 131 µs of T_{on}, 58 µs of T_{off}, 2 Kg-f of WT and 4 m/min of WF mm/rev respectively.

Response Surface Methodology (RSM)

The multiple regression analysis has been conducted to predict the multi response value at the optimum levels of the cutting parameters. The relation between the cutting parameters and the multi response value (T_{ij}) is as given below.

The regression equation is

T_{ij} = 1.32 + 0.0096 T_{on} - 0.0410 T_{off} - 0.100 WT - 0.030 WF - 0.000021 T_{on}*T_{on} + 0.000493 T_{off}*T_{off} - 0.00163 WT*WT + 0.01019 WF*WF - 0.000141 T_{on}*T_{off} + 0.000392 T_{on}*WT - 0.000727 T_{on}*WF + 0.00033 T_{off}*WT + 0.00014 T_{off}*WF + 0.00983 WT*WF

Table 10 shows the ANOVA results of total quality loss (T_{ij}). From the results of RSM it is clear that the model is best fit with the machining parameters as the p value is within the confidence levels i.e. less than 0.05. Figure 2 shows the residual plots of T_{ij}, from the plots it is concluded that the residuals are following the normal distribution and from the versus fits and order plots it is clear that the model is not following any regular pattern hence the model is more accurate and adequate.

Table 10. ANOVA Results

Source	DF	Adj SS	Adj MS	F	P
Model	14	0.055866	0.003990	10.65	0.000
Linear	4	0.052577	0.013144	35.08	0.000
Ton	1	0.044352	0.044352	118.36	0.000
Toff	1	0.000116	0.000116	0.31	0.589
WT	1	0.000869	0.000869	2.32	0.154
WF	1	0.007240	0.007240	19.32	0.001
Square	4	0.001560	0.000390	1.04	0.426
Ton*Ton	1	0.000011	0.000011	0.03	0.869
Toff*Toff	1	0.000911	0.000911	2.43	0.145
WT*WT	1	0.000016	0.000016	0.04	0.840
WF*WF	1	0.000623	0.000623	1.66	0.222
2-way interaction	6	0.001729	0.000288	0.77	0.609
Ton*Toff	1	0.000360	0.000360	0.96	0.346
Ton*WT	1	0.000111	0.000111	0.30	0.597
Ton*WF	1	0.000380	0.000380	1.01	0.334
Toff*WT	1	0.000031	0.000031	0.08	0.779
Toff*WF	1	0.000006	0.000006	0.02	0.903
WT*WF	1	0.001087	0.001087	2.90	0.114
Error	12	0.004497	0.000375		
Total	26	0.060363			

S = 0.0193579; R^2 = 92.55 % R^2 (Adj) = 83.86 %

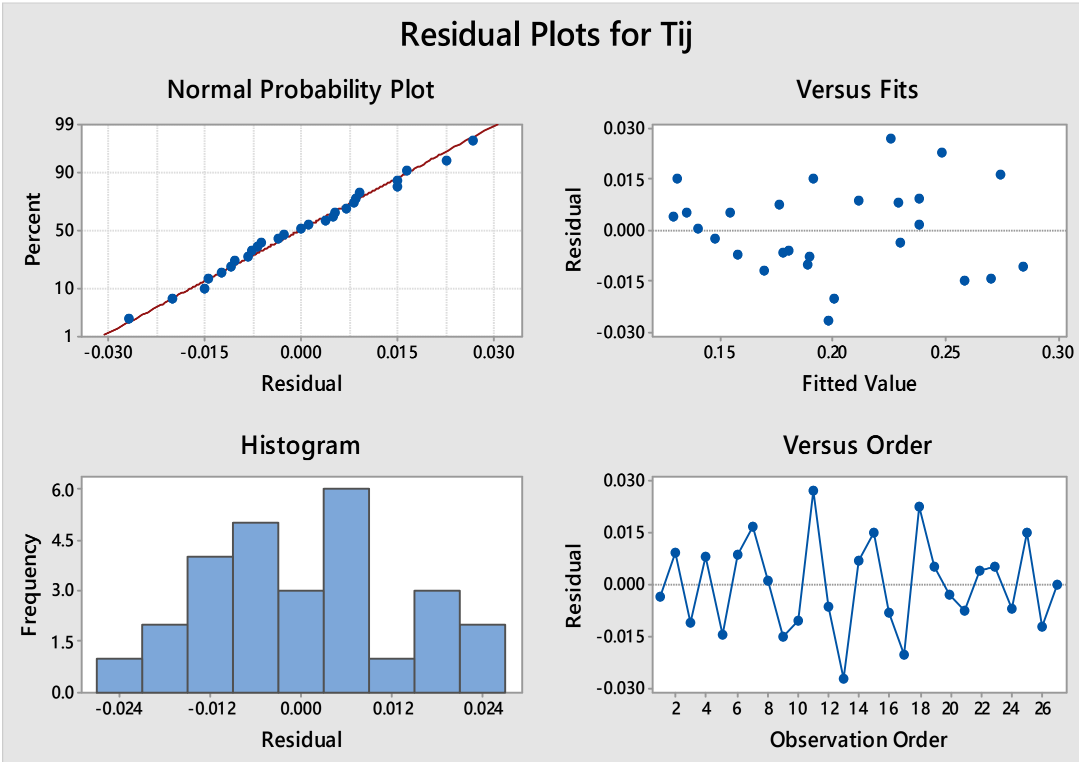

Figure 2. Residual Plots for T_{ij}

5. Conclusions

From the experimental results the following conclusions has been made

The optimal combination for achieving the maximum material removal rate and minimum surface roughness characteristics is obtained at 131 µs of T_{on}, 58 µs of T_{off}, 2 Kg-f of WT and 4 m/min of WF mm/rev respectively.

- The results of ANOVA concluded that pulse on time (T_{on}) is the most influencing parameter in affecting the multi response value.
- The regression model prepared for the multi response values is best fit and is more accurate in prediction of the response as the R^2 value is 92.55%.
- The proposed method of Taguchi quality loss method can be effectively used for all industrial multi objective problems and involves in less computations compared to other multi objective optimization methods.

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