OPTIMIZATION OF EDM PROCESS PARAMETERS OF STAINLESS STEEL 430 USING GREY RELATIONAL ANALYSIS WITH TAGUCHI METHOD

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Abstract:

The optimal process parameter of Electric Discharge Machining by the Taguchi method with Grey relational analysis is studied. The Grey relational grade is used to find optimal EDM parameters with multiple response performance characteristics. The EDM parameters (current, pulse on time, pulse off time) are optimized with consideration of the multiple response performance characteristics (Material removal rate and surface roughness). It is shown that the multiple response performance characteristics are greatly improved through this study.

Keywords: Grey relational analysis, EDM, Taguchi Method, Stainless Steel430, Surface roughness, MRR.

1. Introduction

1.1 Electrical Discharge Machining (EDM)

Electrical discharge machining (EDM) is a non-traditional machining technique, which has been widely accepted in the modern metalworking industries, especially in the die making industry because of its versatility and its ability to cut fully hardened steels. It is an advanced machining process primarily used for hard and difficult metals which are difficult to machine with the traditional techniques. EDM is a thermal process which makes use of spark discharges to erode the material from work-piece surface. The cavity formed in EDM is a replica of the tool shape used as the erosions occur in the confined area. Since spark discharges occur in EDM, it is also called as "spark machining".

EDM is mainly used to machine difficult-to-machine materials and high strength temperature resistant alloys also to machine difficult geometries in small batches or even on job-shop basis. Work material to be machined by EDM has to be electrically conductive. Some important input parameters which affects output characteristics of machining process. The basic EDM process is really quite simple. An electrical spark is created between an electrode and a work piece. The spark is visible evidence of the flow of electricity. This electric spark produces intense heat with temperatures reaching 8000 to 12000 degrees Celsius, melting almost anything. The spark is very carefully controlled and localized so that it only affects the surface of the material. The EDM process usually does not affect the heat treat below the surface. With wire EDM the spark always takes place in the dielectric of deionized water. The conductivity of the water is carefully controlled making an excellent environment for the EDM process. The water acts as a coolant and flushes away the eroded metal particles. Electrical Discharge Machining, (EDM) is a well-known machining technique since more than fifty years. Nowadays it is the most widely-used non-traditional machining process mainly to produce injection molds and dies, for mass production of very common objects. It can also produce finished parts, such as cutting tools and items with complex shapes. EDM is used in a large number of industrial areas: automotive industry, electronics, domestic appliances, machines, packaging, telecommunications, watches, aeronautic, toys and surgical instruments. The advantages of EDM over traditional methods such as milling or grinding are multiple. Any material that conducts electricity can be machined, whatever its hardness (hardened steel, tungsten carbide, special alloys for aerospace applications. for example Furthermore, complex cutting geometry, sharp angles and internal corners can be produced. Final surface state with low ridges (< 100 nm) and precise machining (1μm) are other important advantages. Moreover there is no mechanical stress on the machined piece, no rotation of work piece or tool is necessary, and the machines have a high autonomy. On the other hand, the disadvantages are the relatively low material removal rate, surface modification of the machined work piece (white layer) and heat affected zone, typical depth (50 μm), and limited size of work piece and tool.

1.2 Important process parameters of EDM

1.2.1 Spark On-Time (T_{ON})

The duration of time (μs) the current is allowed to flow per cycle. Material removal is directly proportional to the amount of energy applied during this on-time. This energy is really controlled by the peak current and the length of the on-time.

1.2.2 Spark Off-Time (Pulse Time /T_{OFF})

The duration of time (μs) between the consecutive sparks is called off-time. This time allows the molten material to solidify and wash out from the arc gap. This parameter is to affect the speed and the stability of the cut. Thus, if the off-time is too short, it will cause sparks to be unstable.

1.2.3 Peak Current (I_p)

The peak current is represented by I_P and it is the maximum amount of current flowing through the circuit during pulse on time. It is measured in amperage. This parameter actually reveals how much power is used in EDM. Higher value of peak current is required for roughing operations and cutting rate also increases with increase in peak current.

1.3 Work-piece material

1.3.1 Stainless steel 430

Stainless steel grade 430 is non-hardenable steel containing straight chromium, and belongs to the ferritic group of steels. This steel is known for its good corrosion resistance and formability, coupled with practical mechanical properties. It can be used in certain chemical applications due to its resistance to nitric acid. Grade 430F stainless steel is usually provided in bar form to be used in automatic screw machines. Grade 434 has similar properties as grade 430, although it is a molybdenum-bearing version. The molybdenum content enhances its corrosion resistance.

Table 1.1: Composition of Stainless Steel 430

Composition	**Percentage**
C	<0.12
Mn	<1
Si	<1
P	<.04
S	<.03
Cr	16-18
Ni	<.75

1.4 Taguchi Method

Taguchi methods are statistical methods developed by Genichi Taguchi to improve the quality of manufactured goods, and more recently also applied to engineering, biotechnology, marketing and advertising. Taguchi employs design experiments using specially constructed table, known as "Orthogonal Arrays (OA)" to treat the design process, such that the quality is built into the product during the product design stage.

Orthogonal Arrays (OA) are a special set of Latin squares, constructed by Taguchi to lay out the product design experiments. By using this table, an orthogonal array of standard procedure can be used for a number of experimental situations. The results obtained from the orthogonal array are then analyzed to achieve the following objectives:

- To estimate the contribution of individual quality influencing factors in the product design stage.

- To gain the best, or optimum, condition for a process, or a product, so that good quality characteristics can be sustained.
- To approximate the response of the product design parameters under the optimum conditions.

1.5 Grey-Based Taguchi Methods for Optimization of Process Parameters

Optimization of process parameters is the key step in the Taguchi method in achieving high quality (without increasing costs) and improved performance characteristics. The optimal process parameters obtained from the Taguchi method are insensitive to the variation of environmental conditions and other noise factors. Basically, classical process parameter design is complex and not easy to use. Many experiments have to be carried out with increasing process parameters. To solve this task, the Taguchi method uses orthogonal arrays to study the entire process parameter space with few experiments. Taguchi recommends the use of the loss function to measure the performance characteristic deviating from the desired value. The value of the loss function is further transformed into a grade value. The grade value for each level of process parameters is computed based on the S/N analysis, and a larger S/N ratio corresponds to a better performance characteristic. Therefore, the optimal level of the process parameters is the level with the highest S/N ratio. This is true for the optimization of a single performance characteristic. However, optimization of multiple performance characteristics cannot be straightforward as in the optimization of a single performance characteristic. The higher S/N ratio for one performance characteristic may correspond to the lower S/N ratio for another performance characteristic. As a result, the correlated evaluation of the S/N ratio is required for optimization of the multiple performance characteristics. To solve this problem, the Grey relational analysis is adopted in this study.

1.6 Experiment Method

The metal for this experiment is a stainless steel 430 rod, and the test piece is of 25mm diameter as shown in Fig. 1.1.

Figure 1.1: Workpiece

An electric discharge machine is employed for making a cut of 2mm depth and 10mm diameter on the workpiece. The electrode used for this work is copper electrode and the Electric discharge machine which is used for this experiment is shown in Fig. 1.2

Figure 1.2: Electric discharge machine

Initially, this experiment adopts three major EDM process parameters: current, pulse on time and pulse off time. Taguchi orthogonal array is employed for the experiment, and different levels are considered among the EDM process parameters. After the experiment is completed, Grey relational analysis is used with Taguchi method to find out the optimum Grey relation grade and process parameters are assessed via ANOVA for selection of optimal parameters and prediction of the optimum performance characteristics. Finally, the confirmation experiment is conducted.

2.1 SELECTION OF EXPERIMENT PARAMETERS AND LEVELS

In this experiment, the diameter of the rod , voltage, flushing pressure and the duty factor of machine are fixed parameters (factors) while current , pulse on time and pulse off time are control factors. Each control factor is taken to be independent. Three levels are set for current, pulse on time and pulse off time. The levels and data of each factor are as follows:

a) A current

A1 = 10 Amp. , A2 = 20 Amp. , A3 = 30 Amp.

A1 stands for the first level of Factor A

A2 is the second level of Factor A

A3 is the second level of Factor A

The same principle applies below

b) B Spark on time

B1=40µs, B2=60 µs, B3=80 µs

B1 stands for the first level of Factor B

B2 is the second level of Factor B

B3 stands for the first level of Factor B

c) C Spark OFF time

C1=3 µs, C2=6 µs, C3=9 µs

C1 stands for the first level of Factor C

C2 is the second level of Factor C

C3 stands for the first level of Factor C

The EDM factors and levels are shown in Table2.1.

Table 2.1 : Levels of process parameters

Factors	**Variables**	**Levels**		
		1	**2**	**3**
A	Current (A)	10	20	30
B	Pulse On Time	40	60	80
C	Pulse Off Time	3	6	9

2.2 L_9 ORTHOGONAL ARRAY (3 PARAMETERS AND 3 LEVELS):

In this, three input machining parameters were used as control factors and each parameter was designed for three levels. The orthogonal array is presented in below table 2.2:

Table 2.2 : Orthogonal array for Taguchi design

S.NO.	A	B	C
1	1	1	1
2	1	2	2
3	1	3	3
4	2	1	2
5	2	2	3
6	2	3	1
7	3	1	3
8	3	2	1
9	3	3	2

2.3 EXPERIMENTAL RESULT FOR EDM PARAMETERS

MRR = (initial wt.-final wt.)/density*machining time (mm^3/s)

Table 2.3 : Experimental Results

S.No.	CURRENT	T_{ON}	T_{OFF}	MRR	SR	Machining time(sec)
1	10	40	3	0.49099	9.78	352.5
2	10	60	6	0.55705	13.08	313.0
3	10	80	9	0.50732	9.49	336.1
4	20	40	6	0.86779	13.22	202.4
5	20	60	9	0.8904	10.34	199.7
6	20	80	3	0.83124	17.68	211.3
7	30	40	9	0.94732	10.41	183.7
8	30	60	3	0.95706	12.28	187.2
9	30	80	6	0.99123	19.47	175.9

2.4 COMPUTATION OF GREY RELATIONAL COEFFICIENT FOR MRR

For MRR

MRR = (initial wt.-final wt.)/density*machining time (mm^3/s)

To maximize MRR by Grey relational analysis

$$\alpha_i = \frac{current\ value\ of\ MRR - Min.\ value\ of\ MRR}{Max.\ Value\ of\ MRR - Min.\ value\ of\ MRR}$$

Where , α_i = Normalized element

1-α_i = Differential element

Grey relational coefficient(x) = $\frac{0.5}{(1-\alpha_i)+0.5}$

Table 2. 4 : Computation of Grey Relational Coefficient For MRR

S.No	MRR	α	(1 - α)	X
1	0.49099	0	1	0.333333
2	0.55705	0.13205	0.86795	0.36551
3	0.50732	0.03264	0.96736	0.340748
4	0.86779	0.75323	0.24677	0.66955
5	0.8904	0.79843	0.20157	0.712687
6	0.83124	0.68017	0.31983	0.609883
7	0.94732	0.91222	0.08778	0.850658
8	0.95706	0.93169	0.06831	0.879802
9	0.99123	1	0	1

For Surface Roughness

- Surftest SJ 400 is used to measure surface Roughness.

$$\beta_i = \frac{\text{Max. value of surface roughnes} - \text{current value of surface roughness}}{\text{Max. value of surface roughness} - \text{Min. value of surface roughness}}$$

Where, β_i = Normalized element

$(1-\beta_i)$ = differential element

Grey relational coefficient(Y) = $\frac{0.5}{(1-\beta_i)+0.5}$

Table 2.5 : Computation of Grey Relational Coefficient For SR

S.No	SR	β	(1-β)	Y
1	9.78	0.970942	0.029058	0.945076
2	13.08	0.640281	0.359719	0.581585
3	9.49	1	0	1
4	13.22	0.626253	0.373747	0.572248
5	10.34	0.91483	0.08517	0.854452
6	17.68	0.179359	0.820641	0.378604
7	10.41	0.907816	0.092184	0.844332
8	12.28	0.720441	0.279559	0.641388
9	19.47	0	1	0.333333

2.5 Calculation of Grey Relation Grade:

Grade value (ϒ) = $\frac{X+Y}{2}$

Where ϒ represents the Grey relational grade value

Table 2.6 shows the Grey relational grade for each experiment using the L9 orthogonal array. The experiment having higher Grey relational grade indicates that we are closer to optimum value of performance characteristics. It has been shown that experiment 7 has the best multiple performance characteristics among the 9 experiments for it is the highest Grey relational grade as shown in Table 2.6. In other words, optimization of the complicated multiple performance characteristics can be converted into the optimization of a single Grey relational grade.The effect of each EDM process parameter on the Grey relational grade at different levels can be independent because the experimental design is orthogonal. The mean of the Grey relational grade for each level of the EDM process parameters is summarized. In addition, the total mean of the Grey relational grade for the 9 experiments is calculated and listed in Table 2.6. Basically, the larger the Grey relational grade, the better the multiple performance characteristics. However, the relative importance among the EDM process parameters for the multiple performance characteristics still needs to be known, so that the optimal combinations of the EDM process parameter levels can be determined more accurately.

Table 2.6 : Grey relational grade table

S.No.	Grade value	Order
1	0.639205	6
2	0.473548	9
3	0.670374	5
4	0.620899	7
5	0.78357	2
6	0.494243	8
7	0.847495	1
8	0.760595	3
9	0.666667	4

$$\Upsilon_{av} = 0.661844$$

2.6 TAGUCHI ANALYSIS:

Grade versus Current, T_{ON}, T_{OFF}

Table 2.7 : Response Table for Means for Grey relational grade

Level	CURRENT	T(ON)	T(OFF)
1	0.5944	0.7025	0.6313
2	0.6329	0.6726	0.5870
3	0.7583	0.6104	0.7671
Delta	0.1639	0.0921	0.1801
Rank	2	3	1

From table 2.7 three highest values of each factor grey relational grade are chosen according to their rank. The corresponding values of each factor on which grey relational grade is larger represents the optimal value of the factors with which the performance characteristics are optimized.

The values of three highest grey relational grades are according to each factor are as follows:

The value of $\gamma_1 = 0.7671$, γ_2 = 0.7583, , γ_3 =0 .7025 which are taken from response table 2.7.

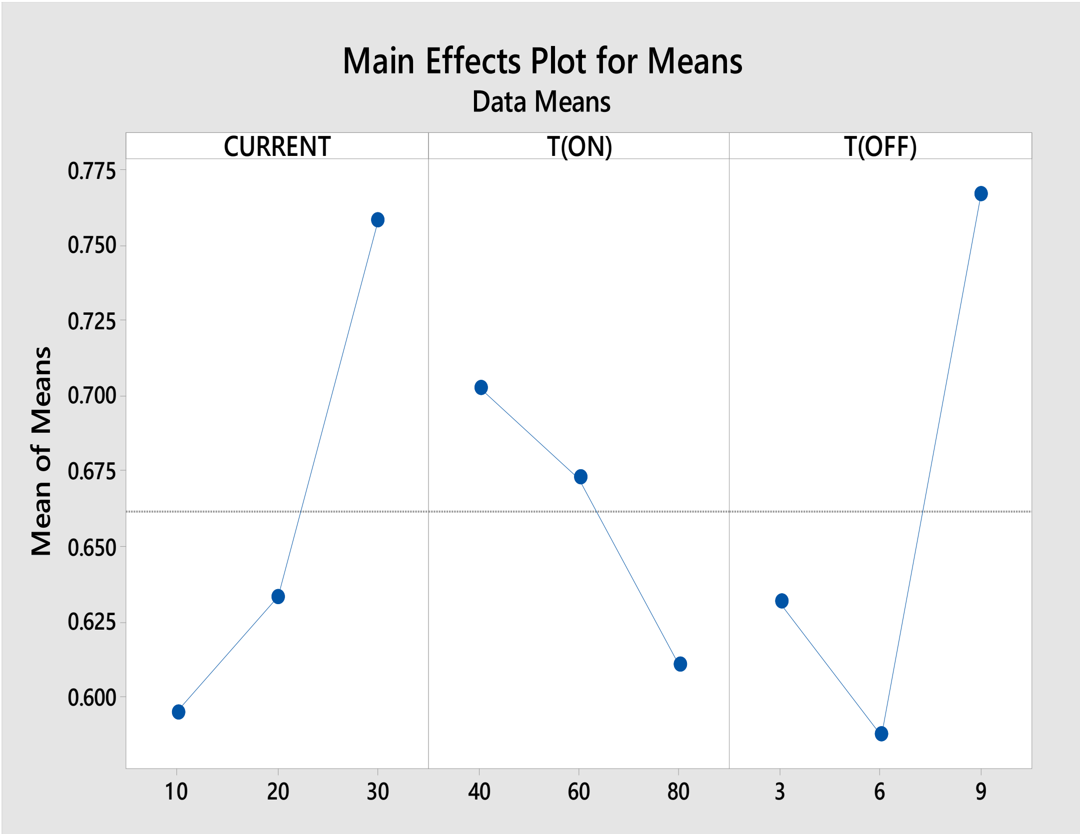

Figure 1.3: Main Effects plot for Means

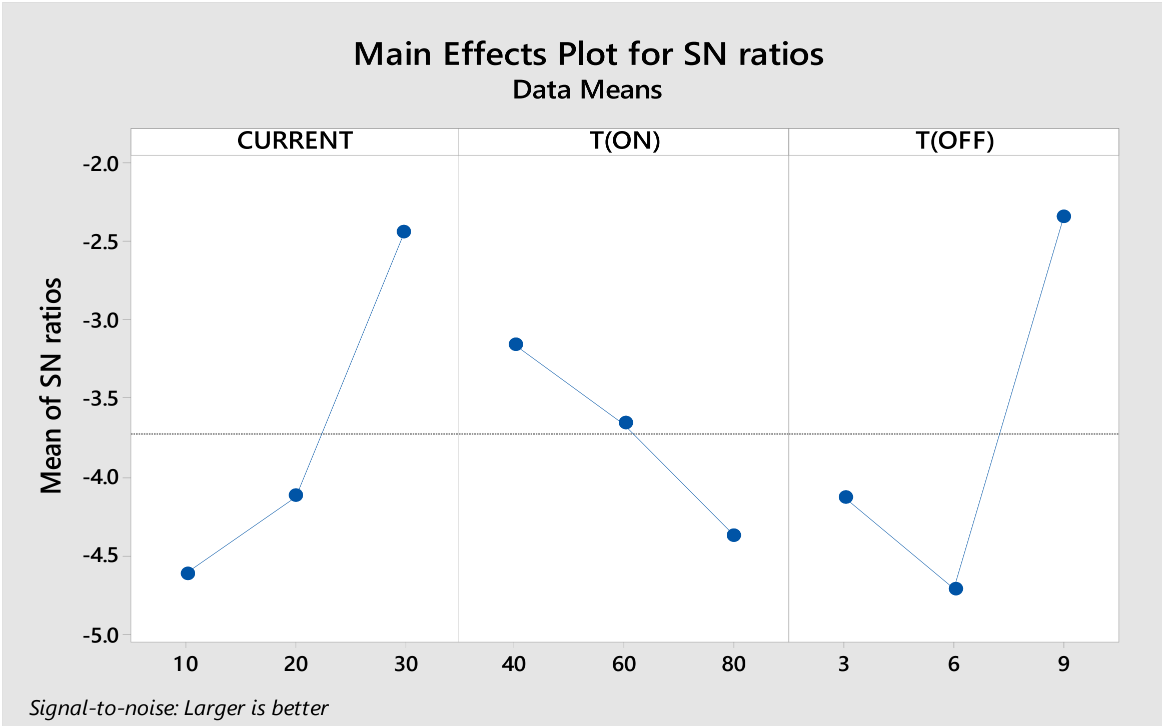

Figure 1.4: Main Effects plot for SN ratios

Experiments through the Taguchi orthogonal array reveal that the optimal EDM process parameter combination is A3B1C3, which is then employed to predict the Grey relation that represents the optimum performance characteristics.

Computation of the Grey relational prediction value of the optimal EDM process parameter. Only the effects of more significant factors (A, B, and C) are taken into account. Prediction of the Grey relational coefficient of the optimal EDM process parameters can be expressed as

$$\Upsilon_{predicted} = \Upsilon_{av} + \sum_{i=1}^{i=3} (\Upsilon i - \Upsilon_{av})$$

=0.661844 + (0.7671- 0.661844) +(0.7583- 0.661844)+(0.7025- 0.661844)

=0.904212

Therefore Υpredicted =0.904212

in which:

$\Upsilon_{predicted}$: Grey relational grade for predicting the optimal EDM process parameters;

Υi : Grey relational grade of the optimal level of a certain significant factor; A, B, and C

Υ_{av} : average Grey relational grade;

Only the effect of A3B1C3 is included.Finally, the confirmation experiment is conducted via the optimal EDM process parameter combination of A3B1C3.

2.7 ANOVA

The purpose of ANOVA is to investigate which EDM process parameters significantly affect the performance characteristic. This is accomplished by separating the total variability of the Grey relational grades, which is measured by the sum of the squared deviations from the total mean of the Grey relational grade, into contributions by each EDM process parameters. The percentage contribution by each of the process parameters in the total sum of the squared deviations can be used to evaluate the importance of the process parameter change on the performance characteristic. In addition, the 'Ftest named after Fisher' can be used to determine which EDM process parameters have a significant effect on the performance characteristic. Usually, the change of the EDM process parameter has a significant effect on the performance characteristic when the F value is large. Results of ANOVA (Table 2.8) indicate that current, spark on time, spark off time are the significant EDM process parameters affecting the multiple performance characteristics. Furthermore, spark off time is the most significant process parameter due to its highest percentage contribution among the process parameters.

Table 2.8: Results of ANOVA

Source	DF	Adj SS	Adj MS	F-Value	Contribution
A	2	0.04405	0.022026	2.99	35.27
B	2	0.01324	0.006621	0.90	10.60
C	2	0.05284	0.026422	3.59	42.31
Error	2	0.01473	0.007364		
Total	8	0.12487			

Results of ANOVA (Table2.8) indicate that current, Spark on time, and spark off time are the significant EDM process parameters affecting the multiple performance characteristics. Furthermore spark off time is the most significant process parameter due to its highest percentage contribution among the process parameters.

3. RESULTS AND DISCUSSION

Table 3.1: The comparison between the initial and optimal process

Maximum grade value of all experiment		Optimal EDM parameters	
		prediction	experiment
level	A3B1C3	A3B1C3	A3B1C3
Material removal rate	0.94732		0.94732
Surface roughness	10.41		10.41
Grey relational Grade	0.847495	0.904212	0.847495

The maximum Grey relational grade value of all 9 experiments has come out to be 0.847495 and optimum Grey relational grade value of the confirmation experiment has come out to be same as maximum grade value of all 9 experiments because the optimum process parameters of Taguchi analysis of grade values A3B1C3 is same of the experiment number 7. The predicted value of Grey relational grade comes out to be 0.904212 which is close to the maximum grade value and confirmation experiment Grey relational Grade value. This confirms that the process parameter A3B1C3 are optimum on which MRR and surface roughness are optimized.From ANOVA we also find out the contribution of each factor.

Spark off time has maximum contribution and spark on time has least contribution which reveals that spark off time has the highest effect on the performance characteristics followed current then spark on time.

CONCLUSIONS:

Stainless steel 430 was machined by electric discharge machine to study the effect of EDM process parameters on material removal rate and surface roughness. Based on the conducted experiments and optimization technique the following conclusion can be made:

1. The higher value of current provides better material removal rate and surface roughness.
2. The lower value of spark on time provides better material removal rate and surface roughness.
3. The higher of spark off time provides better material removal rate and surface roughness.

4. Spark off time has maximum contribution and spark on time has least contribution which reveals that spark off time has the highest effect on the performance characteristics followed current then spark on time.

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