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Multiple Objective Optimizations of Parameters in Rotary Edm of P20 Steel

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Abstract: *Electrical discharge machining (EDM) is one of the advanced methods of machining. Most publications on the EDM process are directed towards non-rotational tools. But rotation of the tool provides a good flushing effect in the machining zone. Optimization of process parameters in rotary EDM to arrive at the best manufacturing conditions, is an essential need for industries towards manufacturing of quality products at lower cost. This paper aims to investigate the optimal set of process parameters such as work piece polarity, current, pulse ON and OFF time and tool rotational speed in rotary EDM process to identify the variations in three performance characteristics such as material removal rate, tool wear rate and surface roughness value during machining of P20 die steel using copper electrode. Based on the experiments conducted using L18 orthogonal array, analysis has been carried out with Grey relational analysis. Response tables and graphs were used to find the optimal levels of parameters in rotary EDM process. Confirmation experiments were carried out to validate the optimal results. Thus the machining parameters for rotary EDM were optimized for achieving the combined objectives of performance characteristics on the work piece material. The obtained results show that the Grey relational Analysis is being effective technique to optimize the machining parameters for EDM process.*

Keywords: *Electrical Discharge Machining (EDM), Material Removal Rate (MRR), Rotary EDM, Surface*

I. Introduction

Being systematic application of the design and analysis of experiments, Taguchi method can be used for the purpose of designing and improving the product quality. During the research and development in recent years, the Taguchi method has become a powerful tool for improving productivity so that high quality products can be produced quickly with affordable cost. But, the Taguchi method has been designed for the optimization of a single performance characteristic. For the EDM process higher-the-better performance characteristic is material removal rate (MRR). However, surface roughness (SR) and tool wear rate (TWR) etc. are lower-the-better performance characteristics. As a result, improvement in one performance characteristic will degrade another performance characteristic. Hence optimization of the multiple performance characteristics is much more important, but complicated than that of a single performance characteristic optimization. In this work, the orthogonal array with grey relational analysis is used to investigate the multiple performancecharacteristics in Rotary EDM of P20 die steel. Many studies have proved that rotation of the electrode had great impact on the EDM process. Rotation of the tool electrode (Rotary EDM) is an important gap flushing technique that can improve the performance of the machining process [1][2][3][4]. Lot of optimization researches has been carried out in die sinking EDM process. But the distinct advantages of the Rotary EDM process is the reason for choosing this technique in die sinking process for this paper [5][6].

P20 steel is very widely used for manufacturing of dies and moulds. The characteristics of the P20 steel such as distinctive hardness, resistance to abrasion, and resistance to deformation at elevated temperatures made this material an important one in the manufacturing of many core sub-inserts in the plastic injection moulding. In this paper, the optimization of parameters considering multiple performance characteristics of the EDM process to P20 die steel using Grey relational analysis is reported. Performance characteristics selected for the evaluation of the machining effects were MRR, TWR and SR. Those process parameters that are closely correlated with the selected performance characteristics in this study are work piece polarity, discharge current, pulse on time, pulse off time and rotational speed of the tool electrode. Based on the appropriate orthogonal array, experiments are conducted first. The normalised experimental results of the performance characteristics are then used to calculate the coefficient and grades according to grey relational analysis. Optimized process parameters that simultaneously lead to higher MRR and lower TWR, SR are then verified through a confirmation experiment.

II. Experimental Procedure.

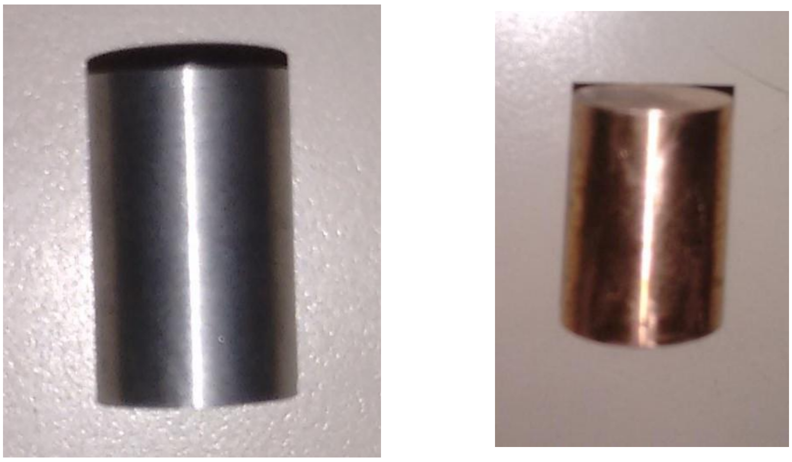
2.1 Design Of Experiments

The application of design-of-experiments (DoE) requires careful planning, prudent layout of the experiment, and expert analysis of the results. Taguchi has standardized methods for each of these DoE application steps. This approach in finding factors that affect a product in a DoE can dramatically reduce the number of trials required to gather necessary data. Thus, DoE using Taguchi approach has become a much more attractive tool to practising engineers and scientists [7][8].

2.2 Machining parameters selection.

A series of experiments were performed on an Electrical Discharge Machine AGI CHARMILLES FO 350 SP shown in figure 1. CSTL EDM FLUID SE 180 was used as the dielectric fluid. A jet flushing system was used to assure adequate flushing of the debris from the gap zone. Figure 2 shows the electrolytic cylindrical copper rod of 10 mm diameter (Ø10X15mm) and work piece of P20 die steel (Ø10X15mm) used in this work.

Fig.1 Agi Charmilles Fo 350 Sp



P20 Copper

Fig. 2 Work Piece (P20) And Tool Electrode (Copper)

The machining parameters considered in this project were work piece polarity, discharge current, pulse on time, pulse off time and rotation of the tool electrode. Table.1 shows there are discharge current with levels of 5, 7, 9 amp; pulse on and off time with levels of 100, 50, 25 µs and tool rotation speed with levels of 0, 45, and 90 RPM. Moreover, many past researchers have shown that polarity of the electrode had important effect on material removal rate, tool wear rate and surface roughness. Therefore work piece polarity with positive and negative levels were also selected as one of the machining parameters.

Response parameters	Material Removal Rate (gm. /min.) Tool Wear Rate (gm. /min.) Surface Roughness (µm)		
Control parameters	**Levels**		
	1	**2**	**3**
Work piece polarity	Positive	Negative	
Discharge current (A)	5	7	9
Pulse on time (µs)	100	50	25
Pulse off time (µs)	100	50	25
Tool rotation (RPM)	0	45	90

Table1. Response parameters and control parameters with their level

3.3 Machining performance evaluations.

Response variables namely MRR, TWR and SR were used for the evaluation of the machining performance. The MRR and TWR were calculated based on the weight difference of the work piece and the tool, before and after undergoing the EDM process. A high precision electronic weighing balance shown in figure 3(a), INFRA having capacity Max: 200 gms, readability: 0.1mg was used for this purpose.

Figure 3(a) weighing machine Figure 3(b) MITUTOYO SJ 410

The MRR and TWR were calculated using the following formula.

MRR=work piece volume loss/machining time (gm. /min.) (1) TWR=electrode volume loss/machining time (gm. /min.) (2)

The surface roughness measurement was carried out using MITUTOYO SJ 410 surface roughness testing machine shown in figure 3(b). A test length of 4.8 mm was used during the measurement. Surface roughness is calculated by averaging the centre line surface roughness values. To evaluate the EDM process efficiently the MRR and TWR, SR are regarded as "larger-the-better" and "smaller-the-better" characteristics, respectively, in this study.

3.4 Selection of the orthogonal array.

Total degrees of freedom needs to be computed for the selection of an appropriate orthogonal array needed for the experiment. The degrees of freedom are defined as the number of comparisons between machining parameters that need to be made to determine which level is better and specifically how much better it is. For example, a four level machining parameter counts for three degrees of freedom [9][10]. In this study, there are 9 degrees of freedom owing to one two-level machining parameter and four three level machining parameter in the EDM process.

The next step after calculating the degrees of freedom is the selection of the appropriate orthogonal array for the specific task. For the orthogonal array, the degrees of freedom should be greater than or at least equal to those for the machining parameters. In this paper, an L18 orthogonal array is used because it has 17 degrees of freedom, which is greater than 9 degrees of freedom in the selected machining parameters. This array consists of eight columns and eighteen rows and it can handle one two level machining parameter and seven three level machining parameters at most. Each machining parameter is assigned to a column and 18 parameter combinations are required. Therefore, only 18 experiments are needed to study the entire machining parameter space using the L18 orthogonal array. The experimental layout for the machining parameters using the L18 orthogonal array is shown in table 2.

III. Grey Relational Analysis Of The Experimental Data.

Optimization of the process parameters is the key step in the Taguchi method to achieve high quality without increasing cost. A special design of the orthogonal arrays is used in the Taguchi method to study the entire process parameter space with small number of experiments. In this method, the deviation between experimental value and the desired value is calculated by defining a loss function. Then the value of the loss function is further transformed in to signal-to-noise ratio (S/N ratio). Usually, there are three categories of the performance characteristics in the analysis of the S/N ratio, lower-the-better, higher-the-better and nominal-the-better. Then the level with highest S/N ratio is the optimal level of the process parameters. But this is suitable for the optimization of single performance characteristic. However, the optimization of the multiple performance characteristics cannot be straight forward and simple like optimization of a single performance characteristic. The higher S/N ratio for one performance characteristics may correspond to the lower S/N ratio for another characteristic. As a result, overall evaluation of the S/N ratio is needed for the optimization of the multiple performance characteristics. To solve this problem, the grey relational analysis is adopted in this work. Experimental results using an L18 orthogonal array and performance results were shown in table 3.

4.1 Data pre-processing

In grey relational analysis, data pre-processing is used since the range and unit in one data sequence may differ from the others. Data pre-processing is also required when the sequence scatter range is too large, or when the directions of the target in the sequence are different. The process of transferring the original sequence in to a comparable sequence is called data pre-processing [9][10]. Here the experimental results are normalized in the range between zero and one. The different steps involved in the grey relational analysis are shown in the figure 1

Exp. No.	**Parameters**				
	A	**B**	**C**	**D**	**E**
1	1	1	1	1	1
2	1	1	2	2	2
3	1	1	3	3	3
4	1	2	1	1	2
5	1	2	2	2	3
6	1	2	3	3	1
7	1	3	1	2	1
8	1	3	2	3	2
9	1	3	3	1	3
10	2	1	1	3	3
11	2	1	2	1	1
12	2	1	3	2	2
13	2	2	1	2	3
14	2	2	2	3	1
15	2	2	3	1	2
16	2	3	1	3	2
17	2	3	2	1	3
18	2	3	3	2	1

Table2. Design Matrix of L18 Orthogonal Array

Exp. No	**Work piece polarity**	**Current (A)**	**Pulse on time (μs)**	**Pulse off time (μs)**	**Tool rotation (RPM)**	**MRR (gm./min.)**	**TWR (gm./min.)**	**Surface roughness (μm)**
1	positive	5	100	100	0	0.00895	0.0003	3.15
2	positive	5	50	50	45	0.01205	0.0005	3.0995
3	positive	5	25	25	90	0.01515	0.0005	2.527

4	positive	7	100	100	45	0.0265	0.00015	4.617
5	positive	7	50	50	90	0.03595	0.0006	3.224
6	positive	7	25	25	0	0.0322	0.00095	3.6765
7	positive	9	100	50	0	0.0543	0.0006	6.475
8	positive	9	50	25	45	0.0618	0.00125	5.142
9	positive	9	25	100	90	0.02745	0.00175	3.091
10	negative	5	100	25	90	0.00175	0.0005	1.176
11	negative	5	50	100	0	0.0012	0.0003	0.9555
12	negative	5	25	50	45	0.00085	0.00025	0.9755
13	negative	7	100	50	90	0.001	0.0003	1.4125
14	negative	7	50	25	0	0.00045	0.0003	2.058
15	negative	7	25	100	45	0.00155	0.00055	1.254
16	negative	9	100	25	45	0.00135	0.00035	1.6365
17	negative	9	50	100	90	0.00275	0.00075	1.5545
18	negative	9	25	50	0	0.00245	0.00075	1.7835

Table3. Experimental results

The normalized experimental results for MRR, higher-the-better characteristic can be expressed as

min / (max min) (3)

For TWR and SR, smaller-the-better characteristics, the normalization can be done by using the equation

(4) Where is the ith experimental result for the jth experiment.

Table 4 shows the normalized results for MRR, SR and TWR. The larger normalized results correspond to the better performance and the best result should be equal to one [9].

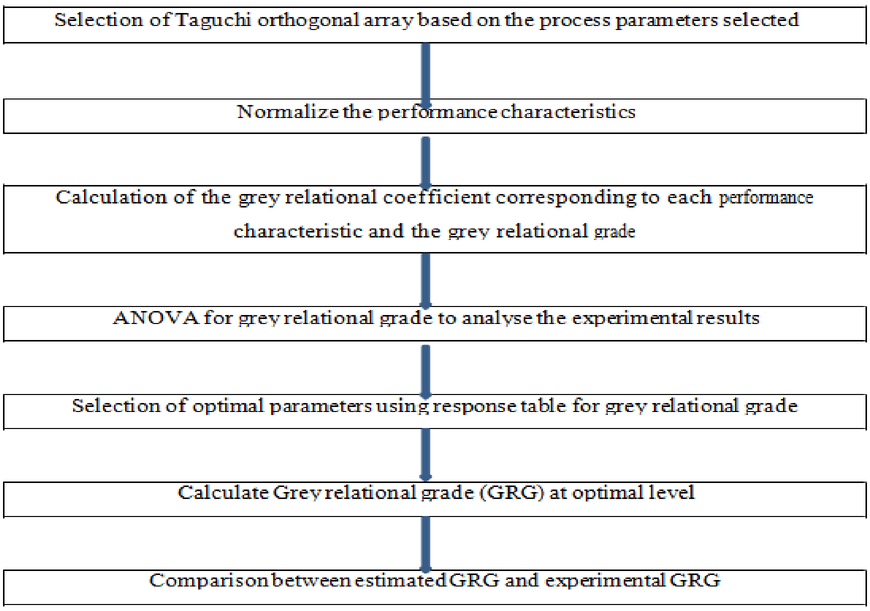


Fig.1. steps of grey relational analysis to optimize the process with multiple performance characteristics.

Then the deviation sequence of each performance characteristics could be calculated by subtracting processed values from one. The table 5 gives the deviation sequence.

4.2 Computing the Grey relational coefficient and the grey relational grade.

The pre-processed sequence could be used for the calculation of grey relational coefficient after the data pre- processing. It expresses the relationship between the ideal and actual normalized experimental results. The grey relational coefficient can be expressed by the following equation [9][10].(5)

Where, is the minimum value among the deviation sequence and is the maximum value. is the distinguishing or identification coefficient and is the pre-processed response value. If all the parameters are given equal preferences then, is taken as 0.5. The grey relational coefficient calculated by using equation 5 is given in the table 6. After finding the grey relational coefficient, the grey relational grade is computed by averaging the grey relational coefficient corresponding to each performance characteristics. The overall evaluation of the multiple performance characteristics is based on the grey relational grade, given by the equation [8][9].

$\sum$ (6)

Where, is the grey relational grade for the jth experiment and k is the number of performance characteristics. The grey relational grade for each experiment using L18 orthogonal array is shown in the table 6.

Exp No.	**Response values**			**Sequences of each performance characteristic after data processing**		
	MRR (gm./min)	**TWR (gm./min)**	**SR (μm)**	**MRR (gm./min)**	**TWR (gm./min)**	**SR (μm)**
1	0.00895	0.0003	3.15	0.138549	0.90625	0.60241
2	0.01205	0.0005	3.0995	0.189079	0.78125	0.611559
3	0.01515	0.0005	2.527	0.239609	0.78125	0.715282
4	0.0265	0.00015	4.617	0.424613	1.0000	0.336625
5	0.03595	0.0006	3.224	0.578649	0.71875	0.589003
6	0.0322	0.00095	3.6765	0.517522	0.5000	0.507021
7	0.0543	0.0006	6.475	0.877751	0.71875	0.0000
8	0.0618	0.00125	5.142	1.00000	0.3125	0.241507
9	0.02745	0.00175	3.091	0.440098	0.0000	0.613099
10	0.00175	0.0005	1.176	0.02119	0.78125	0.960051
11	0.0012	0.0003	0.9555	0.012225	0.90625	1.0000
12	0.00085	0.00025	0.9755	0.00652	0.9375	0.996376
13	0.001	0.0003	1.4125	0.008965	0.90625	0.917203
14	0.00045	0.0003	2.058	0.0000	0.90625	0.800254
15	0.00155	0.00055	1.254	0.01793	0.7500	0.945919
16	0.00135	0.00035	1.6365	0.01467	0.8750	0.876619
17	0.00275	0.00075	1.5545	0.03749	0.6250	0.891476
18	0.00245	0.00075	1.7835	0.0326	0.6250	0.849986

Table4. Data pre-processing of the experimental result for each performance characteristics

Exp. No	Work piece polarity	Current (A)	Pulse on time (µs)	Pulse off time (µs)	Tool rotation (RPM)	The deviation sequences		
						MRR (gm./min.)	TWR (gm./min.)	Surface roughness (µm)
1	positive	5	100	100	0	0.861451	0.09375	0.39759
2	positive	5	50	50	45	0.810921	0.21875	0.388441
3	positive	5	25	25	90	0.760391	0.21875	0.284718
4	positive	7	100	100	45	0.575387	0.0000	0.663375
5	positive	7	50	50	90	0.421353	0.28125	0.410997
6	positive	7	25	25	0	0.482478	0.5000	0.492979
7	positive	9	100	50	0	0.122249	0.28125	1.0000
8	positive	9	50	25	45	0.0000	0.6875	0.758493
9	positive	9	25	100	90	0.559902	1.0000	0.386901
10	negative	5	100	25	90	0.97881	0.21875	0.039949
11	negative	5	50	100	0	0.987775	0.09375	0.0000
12	negative	5	25	50	45	0.99348	0.0625	0.003624
13	negative	7	100	50	90	0.991035	0.09375	0.082797
14	negative	7	50	25	0	1.0000	0.09375	0.199746
15	negative	7	25	100	45	0.98207	0.25	0.054081
16	negative	9	100	25	45	0.98533	0.125	0.123381
17	negative	9	50	100	90	0.96251	0.375	0.108524
18	negative	9	25	50	0	0.9674	0.375	0.150014

Table5. The deviation sequences

The higher grey relational grade from the table indicates that the corresponding experimental result is closer to the ideally normalized value. From the table it is clear that among 18 experiments, experiment 12 has the highest grey relational grade. Therefore experiment 12 has the best multiple-performance characteristics. In this project optimization of the complicated multiple performance characteristics of rotary EDM of P20 die steel has been converted in to optimization of a grey relational grade.

Since the experimental design is orthogonal, it is possible to separate out the effect of each machining parameter on the grey relational grade at different levels. For example, the mean of grey relational grade for the work piece polarity at levels 1, 2 and 3 could be found out by averaging the grey relational grade for the experiments 1 to 9 and 10 to 18 respectively (table 7). The mean of grey relational grade for each level of other machining parameters, namely, current, pulse on time, pulse off time and rotational speed of the electrode can be computed in the same manner. The mean of the grey relational grade for each level of machining parameters is summarized and shown in the multi response performance index table 7.

The total mean of the grey relational grade for the 18 experiments is calculated and listed in the table 7. Figure

2 shows the grey relational grade graph and the centre line indicated horizontally in figure 2 is the mean value of the grey relational grade. We know that when the grey relational grade increases, the multiple performance characteristics also become better [8][9][10][11]. The optimal combinations of the machining parameter can be determined more accurately only if the relative importance against the machining parameters is known.

EXP. NO:	GREY RELATIONAL COEFFICIENT			GREY RELATIONL	RANK
	MRR (gm./min.)	TWR (gm./min.)	SR (µm)		
1	0.367255	0.842105	0.557047	0.588802	11
2	0.381411	0.695652	0.562784	0.546616	16
3	0.396702	0.695652	0.637172	0.576509	14
4	0.464949	1	0.429784	0.631578	7
5	0.54268		0.548849	0.577176	13
6	0.508917	0.5	0.503535	0.504151	17
7	0.803536	0.64	0.333333	0.59229	10
8		0.421053	0.397301	0.606118	9
9	0.471742	0.333333	0.563761	0.456279	18
10	0.33811	0.695652	0.926013	0.653258	4
11	0.33811	0.842105	1	0.726059	2
12	0.334789	0.888889	0.992805	0.738828	1
13	0.335338	0.842105	0.857931	0.678458	3
14	0.333333	0.842105	0.714545	0.629994	8
15	0.337366	0.666667	0.902395	0.635476	6
16		0.8	0.802078	0.646235	5
17	0.341878	0.571429	0.82166	0.578322	12
18	0.340739	0.571429	0.769215	0.560461	15

Table 6. Grey relational grade

Parameters	Level 1	Level 2	Level 3	Max-Min	Rank
Work piece polarity	0.564391	**0.649677**		0.085286	1
current	**0.638345**	0.609472	0.573284	0.065061	2
Pulse on time	**0.63177**	0.610714	0.578617	0.053153	3
Pulse off time	0.602753	**0.615638**	0.602711	0.012927	5
Tool rotation	0.600293	**0.634141**	0.586667	0.047474	4

Total mean value of the grey relational grade=.607034, optimal setting-A2B1C1D2E2.

Table7. The main effects of the factors on the grey relational grade.

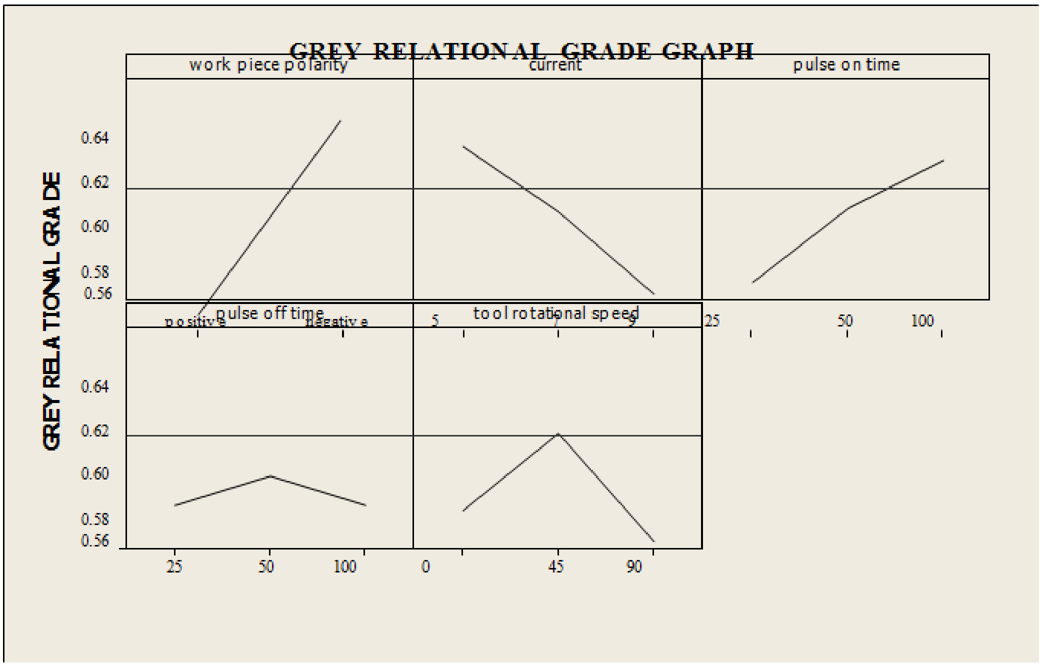


Fig 2. Grey relational grade graph. (Optimal setting from graph-A2B1C1D2E2)

IV. Confirmation Experiment

The improvement in the performance characteristics during the rotary EDM of P20 die steel can be verified using the confirmation test. The estimated grey relational grade using the optimal level of machining parameters can be calculated using the following equation.

$\sum$ (7)

Where, is the total mean of the grey relational grade, is the mean of the grey relational grade at the optimal level and q is the number of machining parameters that significantly affects the multiple performance characteristics. Based on the equation 7, the estimated grey relational grade using the optimal machining parameters can then be obtained. Table 9 shows the result of confirmation experiment using the optimal machining parameters.

Initial Machining parameters		Optimal machining parameters	
		prediction	experiment
Setting level	A2B1C3D2E1	A2B1C1D2E2	A2B1C1D2E2
MRR (gm. /min)	0.00245		0.01425
TWR (gm./min)	0.00075		0.0002
SR (μs)	1.7835		1.17
Grey relational grade	0.560461	0.741436	0.753732
Improvement of grey relational grade=0.193271			

Table 9. Results of machining performance using the initial and optimal machining.

V. Results and Discussions

As shown in the table 9, MRR is accelerated from 0.00245 to 0.01425 gm. /min, surface roughness is improved from 1.7835 to 1.17µs, and TWR is reduced from 0.00075 to 0.0002 gm. /min. It is clearly shown that multiple performance characteristics in the rotary EDM process are greatly improved through this study.

VI. Conclusions

The use of orthogonal array with grey relational analysis to optimize the rotary EDM process with multiple performance characteristics has been reported in this project. A grey relational analysis of the experimental results of the MRR, TWR and SR can convert optimization of multiple performance characteristics in to optimization of single performance characteristics called the Grey relational grade. Optimization of the complicated multiple performance characteristics can be greatly simplified through this approach. It is shown that the performance characteristics of the EDM process such as MRR, TWR and SR are improved together by method proposed in this study.

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