ANALYSIS OF MACHINING CHARACTERISTICS DURING ELECTRO DISCHARGE MACHINING OF AISID3 STEEL

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Abstract- Electrical Discharge Machining is nontraditional process which is used for making complex 3D shapes and can be machined using a simple shaped tool electrode. D3 is a high carbon-high chromium steel developed for applications requiring high resistance to wear or to abrasion and for resistance to heavy pressure rather than to sudden shock. Because of these qualities and its non-deforming properties, D3 is unsurpassed for die work on long production runs. In Electro Discharge Machining in order to determine the effect of 4 input parameters those are namely: Pulse on Time (T_{on}), Discharge Current (I_P), Gap Voltage (V_g) and Duty Cycle (t) on performances as Material Removal Rate (MRR), Tool Wear Rate (TWR), and Radial Overcut (RO) on Electro Discharged Machined Surface. In the present study the experiment was conducted in an experiment matrix of 27 runs designed using a L27 Orthogonal Array of Taguchi Design of Experiment and grey relational analysis method is subsequently applied to determine an optimal parameter setting. All this experimental observations and subsequent data analysis study assures that GRA method is a powerful and most versatile tool which can manipulate the input data as per requirement and comes with results that can be used to have best multi performance in respective concerns

Keywords: Electro-Discharge Machining, AISID3 Steel, Graphite electrode, Taguchi approach, Grey Relational Analysis

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1. INTRODUCTION

Electrical Discharge Machining is nontraditional process which is used for making complex 3D shapes and can be machined using a simple shaped tool electrode. It is developed in the late 1940s and has been accepted worldwide as a standard processing manufacture of forming tools to produce plastics moldings, die castings, forging dies and etc.[1] New developments in the field of material science have led to new engineering metallic materials, composite materials, and high tech ceramics, having good mechanical properties and thermal characteristics as well as sufficient electrical conductivity so that they can readily be machined by spark erosion. At the present time, Electrical discharge machine (EDM) is a widespread technique used in industry for high precision machining of all types of conductive materials such as: metals, metallic alloys, graphite, or even some ceramic materials, of whatsoever hardness.[2] Electrical discharge machine (EDM) technology is increasingly being used in tool, die and mould making industries, for machining of heat treated tool steels and advanced materials (super alloys, ceramics, and metal matrix composites) requiring high precision, complex shapes and high surface finish. Steel is one of the world's most essential materials. About 75% of the weight of typical household appliances comes from steel. D3 is a high carbon-high chromium steel developed for applications requiring high resistance to wear or to abrasion and for resistance to heavy pressure rather than to sudden shock. Because of these qualities and its non-deforming properties, D3 is unsurpassed for die work on long production runs. This steel is used for manufacturing press tools, dies, die-casting, and sheering blades, both basic application exhibits some limitation due the abrasion phenomenon [4].

A considerable number of studies have investigated the general effects of process parameters on performance measures some of these studies are discussed below.

T. Muthuramalingam, B. Mohan.[1] discussed about having an overview of the EDM process, modeling of process parameters, and influence of process parameters such as input electrical variables, pulse shape, and discharge energy on performance measures such as material removal rate, surface roughness and electrode wear rate. From the review results, it has been observed that the efficacy of the machining process can be improved by electrical process parameters, and only less attention has been given for enhancing such parameters.

Rajesh Choudhary, Parlad Kumar and Jagdeep Singh [2] performed the experiments by using copper silicon carbide (CuSiCp) composite tool electrode on an EDM with selected input parameters on AISID3 die Steel workpiece. Micro structure analysis reveals the presence of micro-holes and cavities on machined surface .Depth of re-solidified layer increases with increase of gap current.

Singh Jaspreet, Singh Mukhtiar, Singh Harpreet [3] investigated comparison of machining characteristics of D3 Steel, EN8 Steel and EN31 Steel materials, before and after deep cryogenic treatment using taguchi L18 array in EDM. Results of study suggested that best improvement in tool wear and surface roughness was reported by D3 Steel followed by EN8 and then by EN 31.

B.Venkatesh, Naveen.P , Maurya.B , Shanthi Priya.D [4] discussed the effect of increase in pulsed current on MRR,TWR,SR in alloy steels viz.,EN31,EN8,HCHCr.The electrode materials viz. copper ,brass, chromium copper .Results of study suggested that SR increases with increases in pulse current .Chromium Copper electrode has been preferred for highest MRR ,Dimensional accuracy and surface finish.

Vikas, Shashikant, A.K.Roy and Kaushik Kumar [5] investigated comparison ofMRR for EN19 and EN41 in die sinking EDM machine using discharge current and voltage as input processing parameters. Taguchi method with S/N ratio and ANOVA suggested that discharge current in case of the EN41 material and EN19 material had a larger impact as compare to other processing parameters on the MRR.

Sunil. B. Mishra, Prof. J. K. Sawale [6] conducted experiments on AISID3 Steel using EDM by Taguchi method for design of experiment and Optimum values of process parameters are obtained using grey relational analysis method. Experiment showed that process control parameters like discharge current, pulse on time, pulse off time and spark gap affects MRR and SR in such a way that MRR increases with the increase in discharge current and Spark on time.

Harpreet Singh, Amandeep Singh [7] compared MRR using AISID3 Steel as workpiece and tool materials as copper and brass with pulse on /pulse off as parameters. Experiment showed that MRR is increased with increase in pulse off time and MRR decreased with increase in pulse on time in case of brass electrode and decrease in copper electrode.

Anand Prakash Dwivedi, IAENG, Sounak Kumar Choudhary [8] conducted comparative study on of Rotational and Stationary Tool EDM, which deals with providing rotational motion to the copper tool for the machining of AISI D3 Tool Steel and the results have been compared with stationary tool EDM. It has been found that the tool rotation substantially increases the MRR up to 28%. The average surface finish increases around 9-10% by using the rotational tool EDM.

Harpreet Singh, Amandeep Singh [9] studied wear behavior of AISID3 Steel in EDM and compare tool wear rate of cryogenic treated copper and brass electrode eith simple copper and brass electrode using current setting as 4A and 8A.Results obtained as tool wear of cryogenic treated copper electrode is 50% less than copper electrode at 4 ampere current and 30% less at 8 ampere. And that of brass electrode is 8% less than brass electrode at 4 ampere and 5% less at 8 ampere.

Pravin R. Kubade, V. S. Jadhav [10] conducted and analyzed experiments using taguchi method with L9 orthogonal array. It is found that MRR is mainly influenced by peak current .TWR is influenced by peak current and pulse on time ,duty cycle and gap voltage has very less effect on TWR .Peak current has most influence on radial overcut then followed by duty cycle and pulse on time with almost very less influence by gap voltage.

Ajeet Bergaley, Narendra Sharma [11**]** performed parameter optimization for MRR and TWR considering electrical and non electrical factors such as pulse on time, pulse off time, dielectric fluid material, flushing pressure, tool rotation. Design of experiment is done by using taguchi method which showed that peak current had significant effect on MRR.

2. EXPERIMENTAL DETAILS

The experimentations be there performed by operating on Electric Discharge Machine "Electra R-50 ZNC Die-Sinking Machine

2.1 Work piece Material-

The work piece material used is AISI D3 steel and then the job for electric discharge machining was prepared in 40 mm x 50 mm x 15 mm dimension. It is high carbon high chromium steel developed for applications requiring high resistance to wear and abrasion and for resistance to heavy pressure rather than to sudden shock. Due to all above qualities and its non deforming properties D3 is used for die works on long production works It is primarily an oil hardened steel and it hardens to a great depth.

Table 2.1 Composition of AISI D3 steel

Carbon	Vanadium	Chromium	Mn	Phosphorous	Silicon	Tungsten	Iron
2.20	1	12	0.60	0.03	0.60	1	Balance

Before machining the work piece is finished using surface grinding process .Mechanical Properties of AISID3 Steel material are given in table 2.2 as below

Table 2.2 Mechanical Properties of AISID3 Steel

Property	Value
Density	7.70gm/cm^3
Brinell Hardness	212-248
Modulus of Elasticity	190-210 GPa
Poisson's Ratio	0.27-0.30

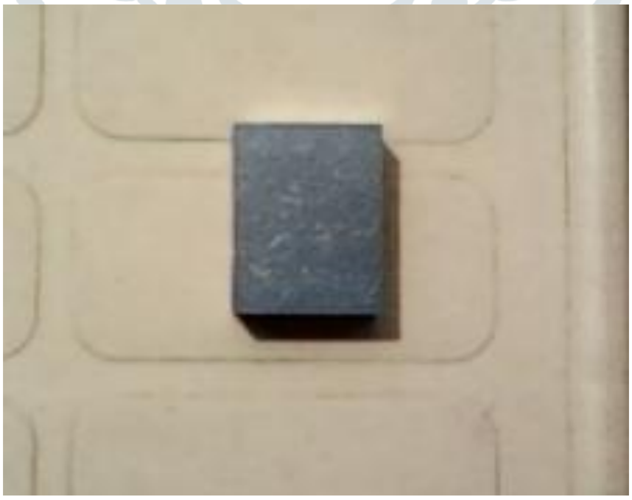

Fig. 2.1 AISID3 Steel work piece

2.2 Tool Material-

Graphite is the preferred electrode material for 90% of all sinker EDM application. Graphite was introduced to the EDM industry approximately 50 years ago. One of the early well known brands of graphite was manufactured by General Electric, and known by the trade name of "Gentrode". Graphite is made from Carbon derived from petroleum. Graphite has significantly lower mechanical strength properties than metallic electrode materials Graphite has an extremely high melting point.It is a round section having electrode diameter 9.8 mm which is used for experimentation. Electrode was prepared by keeping minus 0.2 mm to actual required size. Properties of graphite electrode are tabulated in Table 2.3

Table 2.3 Properties of Graphite electrode

Apparent Density	g/cm^3	1.66 - 1.76
Specific Electrical Resistivity	μΩm	4.9 - 5.7
Flexural Strength	N/mm^2	8-13
Thermal Conductivity	W/(Km)	220 – 270
Coefficient of Thermal Expansion	μm/(Km)	0.3 - 0.7

2.3 Process parameters and range-

Process parameters for this work are selected as discharge current, gap voltage, pulse on time and duty cycle. Many researchers have considered these parameters for analysis and optimization in electro discharge machining method along with other parameters. The levels for the process parameters were selected based on the literature review. 3 levels of each process parameters were selected. Ranges of the process parameters were decided as per the literature review, practical manual, experienced person from industry and set up range available on machine and its capability. All the parameters were varied for the 3 levels each. The levels and ranges of the parameters along with the units are shown in Table 2.4

Table 2.4 Levels of experiment

Machining Parameter	**Symbol**	**Unit**	**Levels**		
			Level 1	**Level 2**	**Level 3**
Pulse on time	Ton	μs	50	100	150
Discharge current	Ip	A	8	12	16
Gap Voltage	V	V	50	55	60
Duty Cycle	T		8	10	12

2.4 Performance Measures-

Material Removal Rate, Tool Wear Rate and Radial Overcut are performance measures in the given experimentation.

2.4.1 Material removal rate-

Material removal rate is a performance measure for the erosion rate of the workpiece and is typically used to quantify the speed at which machining is carried out. It is expressed as the volumetric amount of workpiece material removed per unit time.

$$\mathrm{MRR} = \frac{(\mathrm{W_i} - \mathrm{W_f}) \times 1000}{(\rho \times \mathrm{t})} \mathrm{mm^3/min}$$

Where,

W_i – Initial weight of work piece (gm)
W_f – Final weight of work piece (gm)
t – Period of trial (min)
ρ – Density of work piece material (gm/cm^3)

2.4.2 Tool wear rate –

Tool wear rate is a performance measure for the erosion rate of the tool electrode and is a factor commonly taken into account when considering the geometrical accuracy of the machined feature. It is expressed as the volumetric amount of tool electrode material removed per unit time.

$$\mathrm{TWR} = \frac{(\mathrm{W_i} - \mathrm{W_f}) \times 1000}{(\rho \times \mathrm{t})} \mathrm{mm^3/min}$$

Where,

W_i – Initial weight of tool (gm)
W_f – Final weight of tool (gm)
t – Period of trial (min)
ρ – Density of tool material (gm/cm^3)

2.4.3. Radial Overcut-

The EDM process produces a cavity slightly larger than the electrode. This excess dimension on the work piece cut out by the tool during machining is called Tool Overcut (TOC). It is always desirable to achieve minimum TOC for better performance of the EDM process.

$$\mathrm{ROC} = \frac{(\text{diameter of hole} - \text{diameter of tool})}{2}$$

3. DESIGN OF EXPERIMENT

Design of experiment is a powerful tool for modeling and analysis of process variables over some specific variable, The present experimental investigation deals with the analysis of the experiment by the Taguchi methodology. Taguchi's design of experiment with a standard orthogonal array L27 was used because it gives a satisfied result. Orthogonal array has been used to minimize the number of test runs while keeping the pair-wise balancing property in Taguchi's method for that purpose. The S/N ratio takes both the mean and the variability into account. The S/N ratio is the ratio of the mean (Signal) to the standard deviation (Noise). The ratio depends on the quality characteristics of the process

The S/N ratio η is expressed in logarithmic decibel scales as;

$$S/N = -10log\frac{1}{n}\sum_{i=1}^{n} y_i^2 \quad - \text{for lower the better characteristics}$$

$$S/N = -10log\frac{1}{n}\sum_{i=1}^{n} \frac{1}{y_i^2} \quad - \text{for higher the better characteristics}$$

$$S/N = -10log\frac{1}{ns}\sum_{i=1}^{n} y_i^2 \quad - \text{for normal the better characteristics}$$

Based on the number of control factors and levels of variation for each parameter, L27 orthogonal array is selected to design the experiments after performing each experiment the operation was stopped and the work piece and electrode was removed from the machine. Machining time was noted using a digital stopwatch to evaluate MRR and TWR. At the end of each experiment, the work piece and electrode were removed and weighed using the electronic weighing machine. Radial overcut is measured using digital Vernier.

Table 3.1 Experimentation results after machining

Expt No.	Process Parameters				Performance Measures		
	Pulse on Time (µs)	Discharge Current (A)	Gap Voltage (V)	Duty Cycle	MRR (mm^3/min)	TWR (mm^3/min)	RO (mm)
1	50	8	50	8	8.7792	0.0894	0.125
2	50	8	55	10	7.1428	0.1	0.115
3	50	8	60	12	6.9299	0.3631	0.135
4	50	12	50	10	12.8781	0.4538	0.125
5	50	12	55	12	11.0235	0.3612	0.115
6	50	12	60	8	11.1219	0.2	0.12
7	50	16	50	12	11.2693	0.2855	0.125
8	50	16	55	8	10.7686	0.2311	0.125
9	50	16	60	10	10.2429	0.1383	0.14
10	100	8	50	10	4.7619	0.5269	0.145
11	100	8	55	12	2.0096	0.3726	0.140
12	100	8	60	8	3.9617	0.2269	0.150
13	100	12	50	12	9.3583	0.8817	0.155
14	100	12	55	8	8.5506	0.3087	0.140
15	100	12	60	10	7.7177	0.7175	0.150
16	100	16	50	8	6.5542	0.1929	0.150
17	100	16	55	10	5.0448	0.5506	0.145
18	100	16	60	12	3.1968	0.6807	0.155
19	150	8	50	12	3.2008	0.5463	0.130
20	150	8	55	8	4.9134	0.292	0.120
21	150	8	60	10	3.5693	0.3605	0.150
22	150	12	50	8	9.3535	0.4987	0.145
23	150	12	55	10	7.8922	0.7055	0.140
24	150	12	60	12	5.4422	0.9608	0.145
25	150	16	50	10	6.0181	0.6933	0.150
26	150	16	55	12	6.2337	0.8949	0.135
27	150	16	60	8	5.1313	0.2139	0.140

4. METHODOLOGY

While optimizing the responses in single objective optimization, the effects of process parameters on other performances have not been considered. Grey relational grade is employ to convert multi objective problem into a single objective .However, in actual practice, all the performance criteria should be optimized so as to achieve the optimum machining condition, which will provide the best results for higher productivity as well as higher reliable products in terms of higher accuracy during machining.

The steps for carrying out grey relational analysis are as follows

Step 1- Normalization of experimental result-

In grey relational generation, the normalized data corresponding to ―Smaller-the-Better‖ quality characteristics can be expressed as,

Xij =(Max(Yij) − (Yij))/(Max(Yij) − Min(Yij))

For ―Higher-the-Better quality characteristics, the normalized data can be expressed as ,

Xij=((Yij) − Min(Yij))/(Max(Yij) − Min(Yij))

Yij= Experimental result for which normalization calculated

Min Yij = Smallest value of respective experimental results

Max Yij = Highest value of respective experimental result

Step 2- Grey relational coefficient (GRC)-

Grey relational coefficient is calculated to express the relationship between the ideal best (Xoj) and actual normalized experimental result (Xij). Higher values of grey relational coefficient mean closer Xij to Xoj.

$\gamma = \Delta min + \xi \Delta max / \Delta ij + + \xi \Delta max$

Where,

$\Delta ij = |Xoj - Xij|$

Δ min = Minimum *Xij*

Δ max = Maximum *Xij*

ξ = Distinguish coefficient which can be adjusted with the systematic actual need and defined in range between 0 and 1 .Generally it is consider as a 0.5.

Step 3- Grey relational grade (GRG)-

Grey relational grade is the weighted sum of the grey relational coefficients for a particular experiment. The overall evaluation of multiple performance characteristics is based on grey relational grade and it is expressed as,

$$\Gamma(Xo,Xi)=\frac{1}{m}\sum_{i=1}^{m} \gamma\, ij$$

Where,

Γ *(xo, xi)* = Grey relational grade for j^{th} experiment

m = number of performance characteristic

Table 4.1-Normalised S/N Ratio, Grey Relational Coefficient and GRG

	Normalized S/N Ratio			Grey Relational Coefficient				
Expt. No.	**MRR (mm^3/min)**	**TWR (mm^3/min)**	**RO (mm)**	**MRR (mm^3/min)**	**TWR (mm^3/min)**	**RO (mm)**	**GRG**	**Rank**
1	0.7937	0	0.2956	0.7079	0.3333	0.4149	0.4854	25
2	0.6826	0.0471	0	0.6117	0.3441	0.3461	0.4340	27
3	0.6664	0.5902	0.5410	0.5998	0.5495	0.5216	0.5570	18
4	1	0.6840	0.2956	1	0.6128	0.4149	0.6759	8
5	0.9162	0.5879	0	0.8565	0.5482	0.3333	0.5793	16
6	0.9214	0.3390	0.1641	0.8636	0.4306	0.3743	0.5562	19
7	0.9281	0.4889	0.2956	0.8743	0.4945	0.4149	0.5946	12
8	0.9036	0.3999	0.2956	0.8384	0.4545	0.4079	0.5669	17
9	0.8767	0.1837	0.6582	0.8022	0.3798	0.5938	0.5919	13
10	0.4644	0.7470	0.770	0.4828	0.6640	0.6852	0.6107	11
11	0	0.6010	0.6582	0.3333	0.5562	0.6029	0.4974	24
12	0.3653	0.3922	0.8357	0.4406	0.4513	0.7529	0.5483	20
13	0.8281	0.9637	1	**0.6441**	**0.8324**	**0.8689**	**0.7818**	**1**
14	0.7795	0.5218	0.6582	0.6940	0.5111	0.5630	0.5893	14
15	0.7243	0.8770	0.8357	0.6446	0.8025	0.8296	0.7589	2
16	0.6363	0.3238	0.8357	0.5789	0.4251	0.7529	0.5856	15
17	0.4954	0.7655	0.770	0.4977	0.6807	0.6852	0.6212	10
18	0.2499	0.8548	1	0.3999	0.7749	1	0.7249	4
19	0.2505	0.7622	0.4998	0.4001	0.6777	0.4469	0.5082	23
20	0.4812	0.4984	0.1641	0.4908	0.4992	0.3651	0.4517	26
21	0.3092	0.5872	0.8357	0.4198	0.5477	0.6650	0.5442	21
22	0.8278	0.7238	0.770	0.7438	0.6441	0.6852	0.6911	7
23	0.7364	0.8699	0.6582	0.6547	0.7935	0.6276	0.6920	6
24	0.5363	1	0.770	0.5188	1	0.6854	0.7347	3
25	0.5904	0.8625	0.8357	0.5497	0.7843	0.7529	0.6956	5
26	0.6094	0.9700	0.5410	0.5614	0.9434	0.4996	0.6681	9
27	0.5046	0.3673	0.6582	0.5023	0.4414	0.6018	0.5152	22

5. RESULT AND DISCUSSION

The grey relational grade calculated for each sequence (as shown in Table 4.1) is taken as a response for the further analysis. The larger-the better quality characteristic was used for analyzing the GRG, since a larger value indicates the better performance of the process. The Figure 5.1 shows the main effect plot for grey relational grade.

The level of parameter with the highest S/N ratio gives the optimal level. So the optimal process parameter setting was $T_{on2}I_{p2}V_{g1}t_3$. Thus, the best combination values for increasing material removal rate were pulse on time (Ton) as 100µs,Discharge Current as 12 A ,Gap Voltage as 50 V and Duty Cycle as 12.

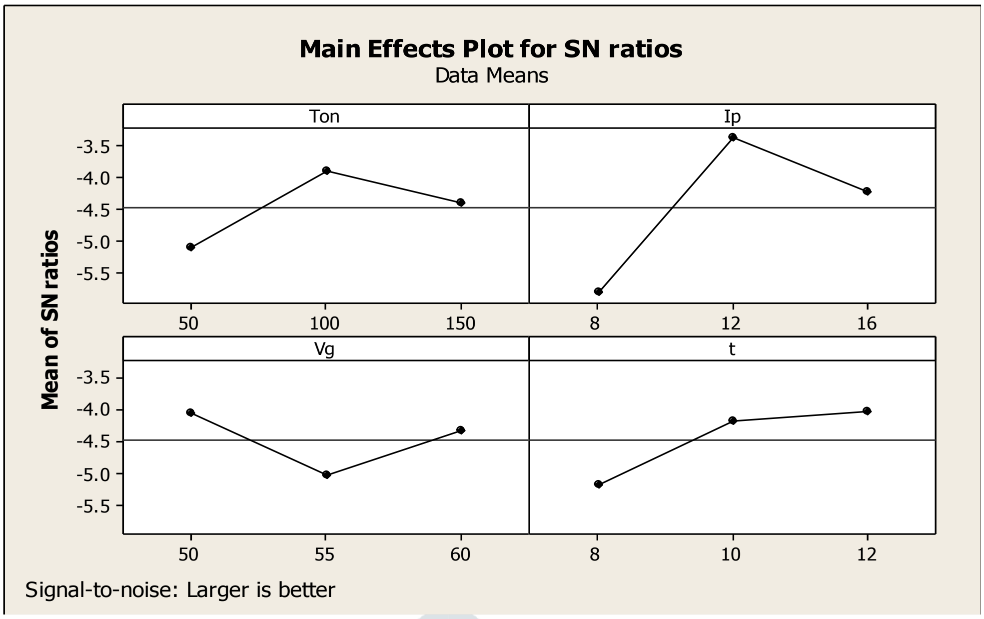

Figure 5.1 Main effects plot for means for GRG

Response table of gray relational grade (GRG) generated to find out delta and rank of input parameter for multiple performances characteristic.

Table 5.1- Response Table for grey relational grade for Graphite Electrode

Level	Ton	Ip	Vg	T
1	0.3913	0.3378	0.5735	0.4038
2	0.7094	0.7605	0.4051	0.4184
3	0.4396	0.4221	0.4318	0.5581
Delta	1.180	2.427	0.984	1.143
Rank	2	1	4	3

The ranks indicate the relative importance of each factor to the response. The ranks and the delta values (Table 5.1) for various input parameters for GRG show that Discharge Current, Pulse on Time, Duty Cycle and Gap Voltage in that order.

Table 5.2 Analysis of Variance (ANOVA) for grey relational grade for Graphite Electrode

Source	DF	SS	MS	% Contribution
Ton	2	0.0503	0.0027	18.3175
Ip	2	0.1308	0.0654	47.6329
Vg	2	0.0229	0.0114	8.3394
T	2	0.0339	0.01690	12.3452
Error	18	0.03660	0.0183	13.3284
Total	26	0.2746		

The analyses were made for the level of confidence 95% (level of significance is 5%). From analysis of Table 4.24 it could be concluded that Discharge Current and Pulse on Time has maximum influenced the multiple performance characteristic by 47.6329% and 18.3175% respectively.

6. CONFIRMATION TEST

Once the optimal level of the machining parameters is selected then estimated gray relational grade (γ^) for that that optimal parametric combination is calculated by using equation ,

$$\gamma\hat{} = \gamma m + \sum_{i=1}^{q} \gamma i - \gamma m$$

Based on equation the estimated grey relational grade (γ^) using optimal machining parameters obtained

γ^ = 0.60227+(0.7094-0.60227)+(0.7605-0.60227)+(0.5735-0.60227)+(0.5581-0.60227)

=0.79423

As the optimal parameter setting is same as that of initial parameter setting the GRG remains same in both the cases.

Table 6.1- Results of machining performance using initial and optimal parameter setting for Graphite Electrode

	Initial parameter Setting	Optimal parameter Setting (Predicted)	Optimal parameter Setting (Experimental)
Setting levels	T_{on2}, I_{p2},V_{g1},t_3	T_{on2}, I_{p2},V_{g1},t_3	T_{on2}, I_{p2},V_{g1},t_3
MRR(mm^3/min)	9.3583		9.3583
TWR(mm^3/min)	0.8817		0.8817
RO(mm)	0.155		0.155
Grey relational grade (GRG)	0.7818	0.7942	0.7818

7. CONCLUSION

1. For Multi Optimization using Graphite Electrode having Pulse on Time as 100 µs, Discharge Current as 12A,Gap Voltage as 50 V and Duty Cycle as 12 was the recommended optimum condition as per grey relational analysis where all three responses Material removal rate as 9.3583 (mm^3/min), Tool Wear Rate as 0.88172 (mm^3/min) and Radial Overcut as 0.155 mm were simultaneously considered .
2. The Grey Relational Grade for optimum setting was 0.78186 which is obtained for experiment number 13
3. From the results of ANOVA it should be concluded that Discharge Current and Pulse on Time has maximum influenced the multiple performance characteristic by 47.6329% and 18.3175% respectively.
4.

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