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COMPARISION AND MULTI OBJECTIVE OPTIMIZATION OF PROCESS PARAMETERS IN ELECTRIC DISCHARGE MACHINE WITH CARBON STEEL AND MILD STEEL BY GREY THAGUCHI METHOD USING MINITAB TOOL

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Abstract : EDM is a non-traditional machining process used for machining hard and difficult-to-machine materials. In this process, a pulse discharge occurs in a small gap between the working parts and electrodes, melting and evaporating unnecessary material from the metal. In EDM, electrodes and workpieces are not mechanically connected. Instead, thermal energy is generated through a series of controlled electrical discharges between the cathode (workpiece) and the anode (electrode) submerged in an insulating dielectric fluid. This process is commonly used in the mould and die-making industry, as well as in the manufacturing of automotive, aerospace, and surgical components.

The objective of this work is to optimize the machining parameters for die sinking operation of EDM to achieve high material removal rate (MRR) and the best surface roughness (SR). Three materials, including high carbon steel, mild steel, and aluminum-6061, were used as workpieces, and a copper electrode of 10mm square-shaped tool was employed for experimentation. The input process parameters, such as discharge current (Ip), pulse on time (TON), and duty cycle, were varied to determine the output process parameters, including MRR and SR for each experimental run. The Taguchi L9 orthogonal array (OA) was implemented using the commercial tool Minitab to investigate the response to the variation of input parameters as an output with the minimum number of experimental runs. The Taguchi single-objective optimization method was used to study the effect of individual input and output parameters to optimize both input and output parameters. The results obtained from the above were used as inputs for the Grey Taguchi, a multi-objective optimization technique to determine the optimized cumulative parameters.

***IndexTerms* - pulse on time, Taguchi single-objective optimization, Grey Taguchi.**

I. INTRODUCTION

Electrical discharge machining(EDM) is a popular processing method, alongside milling, turning, and grinding. It differs from traditional metal cutting methods, utilizing electrical corrosion caused by pulse discharge between the tool electrode and workpiece electrode. The process is named EDM due to the visible sparks produced during the discharge.

EDM can be further divided into various subcategories, including WEDM, EDM piercing forming, EDM grinding and boring, EDM synchronous conjugate rotary machining, EDM high-speed keyhole machining, and EDM surface strengthening and wording. Currently, EDM technology is extensively used for processing high melting point, high strength, and high toughness materials such as quenching steel, stainless steel, die steel, cemented carbide, and for producing complex surface parts and processing molds with special requirements.

Basic Principle of Electrical Discharge Machining:

In electrical discharge machining, the tool electrode is connected to one pole of a pulse power supply while the workpiece electrode is connected to the other. Both electrodes are immersed in a liquid medium (such as kerosene, mineral oil, or deionized water) that provides insulation. An automatic feed regulator controls the tool electrode, maintaining a small discharge gap (0.01-0.05mm) between the tool and workpiece during machining.

When a pulse voltage is applied between the electrodes, the liquid medium between them is penetrated, creating a discharge channel. The channel's small cross-sectional area and short discharge time result in highly concentrated energy (10~107 W/mm). The high temperature generated in the discharge area melts or even evaporates the material, creating a small pit. After a short interval, a second pulse is discharged, and the tool electrode continues to feed into the workpiece, replicating its shape to create the desired machined surface. However, some of the energy is also released to the tool electrode, causing tool loss.

II. WORKPIECE, ELECTRODE AND PROCESS PARAMETERS SELECTION:

In this experiment, three different materials were used as work pieces: high carbon steel, mild steel, and aluminum alloy 6061. Copper was chosen as the tool material for the machining process in this study.

High carbon steel is commonly used for manufacturing tools such as drill bits, knives, saws, and metal and wood cutting tools. Mild steel is used for making pipes, machine parts, building frames, gates, and transporting water and natural gas. Aluminum alloy 6061 is widely used in aerospace components, bicycle frames, electrical fittings and connectors, and drive shafts.

Copper and copper alloys are preferred over brass for EDM due to their superior wear resistance. However, they are more difficult to machine than graphite or brass and are more expensive. Copper is highly conductive and strong, making it useful for EDM machining of tungsten carbide or in applications requiring a fine finish. Copper can produce very fine surface finishes without special polishing circuits. With the development of transistorized, pulse-type power supplies, electrolytic (or pure) copper became the preferred metallic electrode material due to its compatibility with polishing circuits and low-wear burning.

Process Parameters: The input parameters are Discharge current, Pulse on time, Duty cycle the output parameters are MRR and SR.

III. EXERIMENTAL SETUP

The experiments were conducted using the Electronica SE-35 die-sinking EDM machine, as shown in Figure 1. The EDM process begins by applying an ignition voltage of approximately 200V between the electrodes. The electrode is then positioned close to the workpiece, which results in the breakdown of the dielectric fluid (SAE450-grade EDM oil), without any physical contact between the two.

Table 1:Table OF PROCESS PARAMETERS.

Description	**Electrical discharge machine**
Model	Electronica plus
Die electric medium	EDM oil
Types of Materials Cutting	MS, SS, Al, Brass, Titanium and EN Steels.
Supply Voltage	115/230V – 50Hz
Maximum power consumption	20 VA
Supply voltage fluctuation	Not to exceed ± 10% of the operating voltage
Type of flushing	Side jet flushing
Flushing pressure	0.25 kg/cm^2
Tolerance (+/-)	Depends on the thickness of material
Accuracy (+ / -)	0.6 – 1 mm
Discharge current	1-20 amp
Pulse on time	0.5-2000 μsec

Figure 1:Tool of Electronica SE-35 die-sinking EDM machine.

IV. ANALYSIS AND OPTIMIZATION

The electrical discharge machining (EDM) experiments were conducted based on Taguchi's OA. The effects of individual EDM process parameters on the process responses (MRR and SR) have been discussed in this section. The average mean values and S/N ratio values of process responses for each process parameters at different levels were calculated from the experimental results. The main effect plots are used for investigating the effects on process responses. From the response tables, ranking of process parameters were observed. ANOVA gives the percentage contribution of each process variable on process responses. The optimal condition of process parameters is established by analysing plots and ANOVA tables.

Table 2: Taguchi's L9 OA in terms of Actual factors

Run No.	Discharge current(D)	Pulse on time(E)	Duty cycle(F)	Discharge current(D)	Pulse on time(E)	Duty cycle(F)
1	1	1	1	6	100	10
2	1	2	2	6	150	11
3	1	3	3	6	200	12
4	2	1	2	8	100	11
5	2	2	3	8	150	12
6	2	3	1	8	200	10
7	3	1	3	10	100	12
8	3	2	1	10	150	10
9	3	3	2	10	200	11

Table 2.1: ANOVA for MRR for hcs

Source	Dof	Adj. SS	Adj. MS	F-Value	P-Value	% Contribution
D	2	0.046202	0.023101	2.37	0.297	46.66
E	2	0.033153	0.016577	1.70	0.370	33.48
F	2	0.000164	0.000082	0.01	0.992	0.165
Error	2	0.019489	0.009745			19.684
Total	8	0.099009				

Table 2.2: ANOVA for SR for hcs

Source	DF	Adj. SS	Adj. MS	F-Value	P-Value	% Contribution
D	2	0.48803	0.244015	63.31	0.016	16.8664
E	2	1.53395	0.766974	199.0	0.005	53.0138
F	2	0.86380	0.431901	112.06	0.009	29.8532
Error	2	0.00771	0.003854			0.26646
Total	8	2.89349				

The average mean values and S/N ratio values of process responses for each process parameters at different levels were calculated from the experimental results for mild steel plate are as follows:

Table 2.3: Experimental results of Ra and MRR and their S/N ratio for ms

Run No.	I_P	T_{ON}		MRR	S/N ratio For MRR	SR	S/N ratio for SR
1	6	100	10	0.99	-20.087	1.55	-3.8066
2	6	150	11	0.077	-22.270	1.63	-4.243
3	6	200	12	0.029	-30.752	1.43	-3.106
4	8	100	11	0.233	-12.652	2.51	-7.993
5	8	150	12	0.226	-12.917	3.61	-11.150
6	8	200	10	0.085	-21.4116	2.11	-6.485
7	10	100	12	0.245	-12.2166	2.01	-6.063
8	10	150	10	0.210	-13.555	2.71	-8.659
9	10	200	11	0.163	-15.756	2.74	-8.755

Table 2.4: ANOVA for MRR for ms

Source	DF	Adj. SS	Adj. MS	F-Value	P-Value	%Contribution
D	2	0.032330	0.016165	26.35	0.037	61.907
E	2	0.016644	0.008322	13.57	0.069	31.87
F	2	0.002023	0.001011	1.67	0.378	3.87
Error	2	0.001227	0.000613			2.34
Total	8	0.052223				

Table 2.4: ANOVA for SR for ms

Source	DF	Adj. SS	Adj. MS	F-Value	P-Value	%Contribution
D	2	2.42442	1.21221	3.12	0.243	60.72
E	2	0.70749	0.35374	0.91	0.91	17.71
F	2	0.08349	0.04174	0.11	0.11	2.091
Error	2	0.77722	0.38861			1.94
Total	8	3.99262				

V. EXPERIMENTAL RESULTS AND MULTI OBJECTIVE OPTIMIZATION USING GREY-TAGUCHI TECHNIQUE for HCS

The first step in Grey-Taguchi analysis is the normalization of the experimental results of MRR and SR. Each response value is normalized in the range of 0 to 1. For normalizing MRR 'Higher-the-better' (equation 1) criterion and for normalizing SR 'lower-the-better' (equation .2) criterion is used.

Table 3: High carbon steel experimental results for MRR and SR

Run No.	Discharge current(D)	Pulse on time(E)	Duty cycle(F)	MRR	SR
1	6	100	10	0.0799	1.856
2	6	150	11	0.1084	2.1
3	6	200	12	0.0299	0.74
4	8	100	11	0.2250	1.73
5	8	150	12	0.0559	1.983
6	8	200	10	0.0608	0.696
7	10	100	12	0..3248	1.676
8	10	150	10	0.3007	2.156
9	10	200	11	0.1140	0.836

The results of normalized values are tabulated in Table below. Best performance was given by larger normalized values and best normalized result would be equal to 1. Calculations of normalized values for the first experimental run are shown below.

Table 3.1: Normalized data for MRR and SR for hcs

Run No.	Normalized Values	
	Material removal rate(MRR)	Surface Roughness(SR)
1	0.1664	0.2027
2	0.2661	0.0383
3	0	0.9698
4	0.6615	0.2917
5	0.0881	0.1547
6	0.1047	0.328
7	1	1
8	0.9182	0
9	0.2299	0.9041

From the normalized results, Δ_min and Δ_max values are 0 and 1for MRR.

Δ_01= X_0 (1)-X_1 (1) =1-0.1664=0.8336

ε_1 (1) = (0+0.5(1))/ (0.8336+0.5(1)) = 0.

From the normalized results, Δ_min and Δ_max values are 0 and 1 for SR.

Δ_01= X_0 (2)- X_1 (2) =1-0.2027=0.7973

ε_1 (2) = (0+0.5(1))/ (0.7973+0.5(1)) =0.3854.

Table 3.2: Response table for Grey relational grade (S/N ratio) for hcs

Level	Discharge Current (D)	Pulse on time(E)	Duty cycle (F)
1	-6.951	-4.7786	-6.2153
2	-7.6209	-6.4926	-6.2297
3	-2.1083	-5.4102	-4.2358
Delta	5.5126	1.7146	1.9939
Rank	1	3	2

ANOVA table was obtained by performing the Analysis of variance (ANOVA) in Minitab17 tool. ANOVA was used to find out the percentage contribution of each control factor. This analysis is carried out for a significance level of $\alpha=0.05$, i.e. for a confidence level of 95%. Sources with a P-value less than 0.05 were considered to have a statistically significant contribution to the performance measures. And the higher F-ratio shows more effect and more contribution of input parameter on grade. The ratio between the mean square factors to the mean square errors is called F-ratio.

Table 3.3: ANOVA for Grey relational grade for hcs using MOO.

Source	DF	Adj. SS	Adj. MS	F-Value	P-Value	% Contribution
D	2	0.25901	0.12951	4.55	0.180	66.44
E	2	0.02295	0.01147	0.40	0.713	58.87
F	2	0.05087	0.02543	0.89	0.528	13.04
Error	2	0.05698	0.02849			
Total	8	0.38981				

Figure 2 : Main effect plot for Grey relational grade(Means and S/N Ratio) for hcs

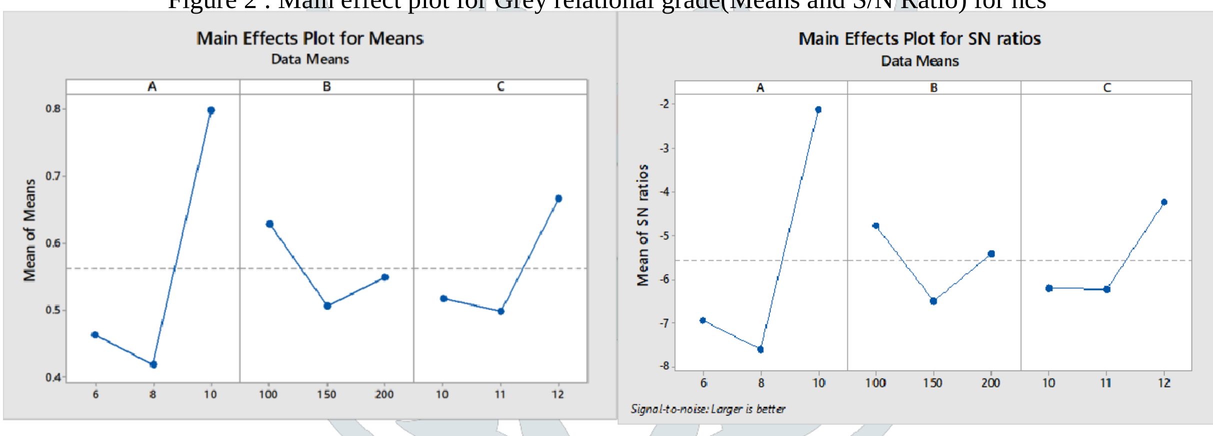


Table 4: MILD STEEL experimental results for MRR and SR

Run No.	Discharge current(D)	Pulse on time(E)	Duty cycle(F)	MRR	SR
1	6	100	10	0.99	1.55
2	6	150	11	0.077	1.63
3	6	200	12	0.029	1.43
4	8	100	11	0.233	2.51
5	8	150	12	0.226	3.61
6	8	200	10	0.085	2.11
7	10	100	12	0.245	2.01
8	10	150	10	0.210	2.71
9	10	200	11	0.163	2.74

The results of normalized values are tabulated in Table. Best performance was given by larger normalized values and best normalized result would be equal to 1. Calculations of normalized values for the first experimental run are shown below Equations.

Table 4.1: Normalized data for MRR and SR for ms

Run No.	Normalized Values	
	Material removal rate(MRR)	Surface Roughness(SR)
1	0.324	0.944
2	0.222	0.908
3	0	1
4	0.944	0.504
5	0.912	0
6	0.259	0.688
7	1	0.733
8	0.837	0.412
9	0.620	0.399

From the normalized results, Δ_min and Δ_max values are 0 and 1for MRR.

Δ_01= X_0 (1)-X_1 (1) =1-0.324=0.676

ε_1 (1) =(0+0.5(1))/(0.676+0.5(1)) = 0.425

From the normalized results, Δ_min and Δ_max values are 0 and 1 for SR.

Δ_01= X_0 (2)- X_1 (2) =1-0.944=0.056

ε_1 (2)=(0+0.5(1))/(0.056+0.5(1))=0.899

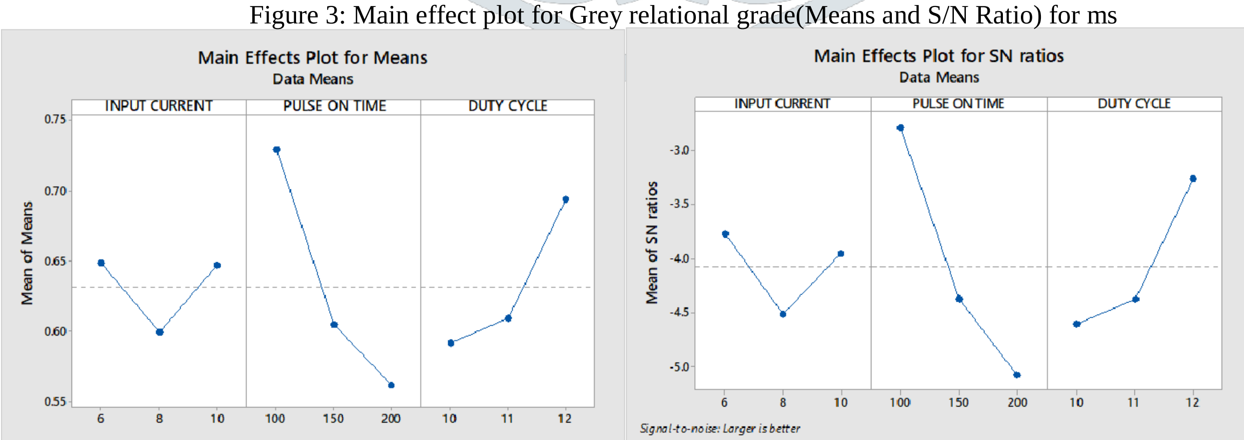
Table 4.2: Response table for GRADE -S/N RATIO for ms

Level	Discharge Current (D)	Pulse on time(E)	Duty cycle (F)
1	-3.7686	-2.7793	-4.5996
2	-4.5083	-4.3656	-4.372
3	-3.9463	-5.0783	-3.2516
Delta	0.7397	2.2990	1.3474
Rank	3	1	2

Table 4.3: ANOVA for Grey relational grade for ms

Source	DF	Adj. SS	Adj. MS	F-Value	P-Value	%Contribution
D	2	0.004642	0.002321	0.53	0.652	6.06
E	2	0.045308	0.022654	5.20	0.161	59.20
F	2	0.017873	0.008916	2.05	0.328	23.35
Error	2	0.008705	0.004352			11.37
Total	8	0.076528				

Figure 3: Main effect plot for Grey relational grade(Means and S/N Ratio) for ms



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VI . RESULT

The Experimental investigational data is normalized, and grey relational grade is obtained. It is kept to the maximum value i.e., the higher the better. Then the values are subjected to ANOVA test which provides the percentage contribution of the input parameters. The optimized value is obtained from the main effect plots for means. From the response table the input parameters are ranked to determine which input variable affects more on the output response. So, the following results are obtained after the tests.

Table 5 : OPTIMAL MATERIAL REMOVAL RATE AND SURFACE ROUGHNESS FOR HIGH CARBON STEEL

discharge current (Amp	pulse on time (µ sec)	duty cycle (%)	MRR **(mg/min)**	SR **(µm)**
10	100	12	0.3248	0.696

Table 5.1: OPTIMAL MATERIAL REMOVAL RATE AND SURFACE ROUGHNESS FOR MILD STEEL

discharge current (Amp	pulse on time (µ sec)	duty cycle (%)	MRR**(mg/min)**	SR**(µm)**
6	100	12	0.245	1.33

The effect of process parameters on output of the Electrical discharge machining process have been discussed and the optimal setting of process parameters has been obtained for maximum material removal rate (MRR) and best surface roughness (R_a) by using Taguchi technique for three different materials.

- The optimal setting parameters individually for achieving maximum MRR and best R_a at discharge current of 10 Amp, pulse on time of 100 µ sec and duty cycle of 12 %, by grey Taguchi method and Discharge current of 10 Amp, pulse on time of 100 µ sec and duty cycle of 12 % by experimental run respectively for the material of HIGH CARBON STEEL.
- The optimal setting parameters individually for achieving maximum MRR and best R_a at discharge current of 6 Amp, pulse on time of 100 µ sec and duty cycle of 12 %, by grey Taguchi method and Discharge current of 10 Amp, pulse on time of 100 µ sec and duty cycle of 12 % by experimental run respectively for the material of MILD STEEL.
- Grey Taguchi optimization technique was employed cumulatively to obtain maximum MRR and best R_a at
    - For HIGH CARBON STEEL- discharge current of 10 Amp,
        - pulse on time of 100 µ sec,
        - duty cycle of 12 %.
    - For MILD STEEL- discharge current of 6 Amp,
        - pulse on time of 100 µ sec,
        - duty cycle of 12 %.

This work also shown that optimal value is obtained for each experimental work through the ANOVA and RESPONSE METHOD by its ranking. Also, using the tool material or electrode as COPPER electrode with work materials as HIGH CARBON STEEL,MILD STEEL.