Multi-Objective Optimization of Parameters during EDM of Aluminum Alloy 6082 using Grey Relational Analysis

V.Vikram Reddy
Professor, Mechanical engineering department Jayamukhi Institute of Technological sciences Warangal T.S India-506332

M.Jawahar
Assistant Professor, Mechanical engineering department Jayamukhi Institute of Technological sciences T.S India-506332

Abstract: In the present work an optimal combination of process parameters such as peak current, pulse on time and pulse off time was obtained during Electrical Discharge Machining (EDM) of Aluminum alloy AA6082 with electrolyte copper as the too electrode using multi- response optimization Grey Relational Analysis (GRA) method. The performance characteristics namely material removal rates (MRR), tool wear rate (TWR) and surface roughness (SR) are selected for this study. Experiments are designed based on Taguchi method with L9 orthogonal array. Using Grey Relational Analysis a grey relational grade (GRG) was calculated. Further this grey relational grade is used to obtain optimal combination of the EDM process parameters considering multiple performance characteristics. Performance characteristics (MRR, TWR and SR) were estimated/predicted at optimal combination of process parameters using Taguchi based GRA. To validate these predicted values confirmation experiments were conducted at optimal parametric setting. It was noticed that the predicted values of selected performance characteristics at optimal combination of parameters are in good agreement with the experimental results. It was also observed that considerable improvement in machining performance using this approach.

Key words: Electrical Discharge Machining, Peak Current, Pulse on Time, Pulse off Time, Material Removal Rate, Tool Wear Rate, Surface Roughness, Multi- Response Optimization, Taguchi Method, Grey Relational Analysis

I.INTRODUCTION

Nontraditional machining processes are required for a number of complex applications in machining industries where traditional process cannot be used. Among the nontraditional machining processes, Electrical Discharge Machining (EDM) is perhaps the most popular one and adopted by machining industries. It is extensively used in making of complex cavities and dies. EDM is also being increasingly used to machine wide variety of exotic, high strength, temperature and corrosion resistance difficult to machine alloys irrespective of the hardness which are used in aerospace and automobile Industries (Ho and Newman, 2003). Its low machining efficiency and poor surface finish enable to pay attention by many researchers to improve its performance. It is difficult to understand, predict and optimize EDM process performance that makes it complex and difficult to model for the reason that there are so many dependent and independent variables which have direct or indirect influence on machining efficiency. Further it is required for an optimization of machining processes to reduce production cost and improve product quality. However stochastic nature of EDM process coupled with existence of non linear relation between input and output variables of the process makes many researchers paid their attention on improvement and optimization of performance measures of EDM process. Different optimization methods like Taguchi, Response Surface Methodology, Artificial Neural Network, Genetic Algorithm, Grey Relational Analysis, Fuzzy Logic, etc. by varying of different electrical and non-electrical process parameters. Raghuraman et al. (2013) have studied the influence of Current, pulse on time, and pulse off time on MRR, TWR, and SR. Further investigation was carried out for the optimal set of process parameters such as current, pulse on and off time to get maximum MRR and minimum TWR and SR considering each response separately using Taguchi method. Gopalakannan et al. (2013) explored optimal combination of parameters such as Pulse current, gap voltage, pulse on time, and pulse off time to obtain maximum MRR and minimum TWR and SR simultaneously using Taguchi based grey relational analysis. Thillaivanan et al. (2010) have presented optimization of cutting parameters such as Current and feed of EDM for minimum total machining time using Taguchi method and ANN. Assarzadeh and Ghoreishi (2013) employed RSM with rotatable central composite design scheme to plan and analyze the experiments for optimization of MRR, TWR and SR considering process parameters namely Discharge current, pulse-on time, duty cycle, and gap voltage. Tzeng and Chen (2013) developed models using back propagation neural network/GA to predict MRR, EWR and SR considering process parameters such as Discharge current, gap voltage, pulse on-time, and pulse off-time and concluded that the proposed models gives better prediction results in the experimental runs than regression models based on the RSM method. Rao et al. (2008) have developed multi perceptron neural network model using neuro solutions package and GA concept to predict optimal MRR varying Peak current and voltage. Padhee et al(2012) have adopted NSGA II in order to optimize both MRR and SR simultaneously to obtain the Pareto optimal solution considering process parameters such as Concentration of powder in dielectric fluid, pulse on time, duty cycle, and peak current. Vikram Reddy et al (2015) have reported the individual effect of process parameters such as peak current and pulse duration on performance characteristics namely MRR, TWR and SR. Experiments were conducted with PH17-4 stainless steel as work material and electrolyte copper as electrode. Vikram Reddy et al (2014) have been investigated the effect of process parameters namely peak current, pulse on time, duty factor and supply voltage on material removal rate electrical discharge machining process using response surface methodology. Experiments were conducted on EN31 tool steel with electrolyte copper as electrode. Further regression model was developed.

From the literature, it was noticed that no extensive work has been reported so far on EDM of Aluminium Alloy 6082 material using electrolyte copper as electrode. This work aims to optimize processes parameters of EDM such as peak current, pulse on time, and pulse off time to get maximum Material Removal Rate (MRR), minimum Tool Wear Rate (TWR) and Surface Roughness (SR) simultaneously by multi response optimization Grey Relational Analysis method.

II. EXPERIMENTAL SET UP, PROCEDURE AND EQUIPMENT

Aluminum alloy AA6082 material and electrolyte copper was chosen as work material and tool material respectively for conducting all experiments. The physical and mechanical properties of work material are shown in Table1. Table 2 presents physical properties of electrolyte copper material. The process parameters such as peak current, pulse on time, and pulse off time were selected for experimentation. Trial experiments were performed to decide the range of each parameter. For conducting experiments three parameters and each parameter at three levels were chosen and it is presented in Table3.

Table 1: Physical and Mechanical properties of AA6082 material

Density	2.70 Kg/m3
Specific capacity	400 (J/kg °k)
Thermal conductivity	180 W/m.K
Electrical resistivity	0.038×10^{-6} Ω m
Modulus of elasticity	70 GPa
Melting Point	555 °C
Hardness Vickers	100 HV

Table2: Physical properties of electrolyte copper

Density	8.95 (g/cm³)
Specific capacity	383 (J/kg °C)
Thermal conductivity	394 (W/m °C)
Electrical resistivity	1.673×10^{-8} Ω m
Melting point	1083°C

Table 3: Working range of the process parameters and their levels

Parameter	Unit	Level1	Level2	Level3
Peak current, I	Amps	8	16	24
Pulse on time, T_{on}	μs	50	100	150
Pulse off time, T_{off}	μs	35	65	95

Table 4: Experimental conditions

Working conditions	Description
Work piece	AA6082 (100mm×50mm×13mm)
Electrode	Electrolyte copper Ø 14mm and length 60 mm
Dielectric	Commercial EDM Oil grade SAE 240
Flushing	Side flushing with pressure 0.5MPa
Polarity	Normal
Supply voltage	240 V
Machining time	5 minutes

Table 5: Experimental layout using an $L_9\,(3^4)$ OA

Sr.No	A Peak current	B Pulse on time	C Pulse off time
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

The degrees of freedom of all three parameters are two (i.e. number of levels-1) and the total degree of freedom of all the factors is 6 (i.e. 3 × 2 = 6). The selected degrees of freedom for OA are (i.e. number of experiments – 1 = 9 – 1 = 8) must be greater than the total DOF of all the factors i.e. 6. Hence, an $L_9\,(3^4)$ OA is considered for the present study and experiments were conducted as per the OA shown in Table 5. All the experiments were conducted on EDM machine model MOLD MASTERS605 with commercial EDM oil grade SAE240 as dielectric fluid and side flushing has been used while conducting all experiments. Experimental conditions are presented in Table 4. Machining time 5 minutes was chosen to conduct each experiment. EDM performance characteristics namely MRR, TWR and SR were chosen in present study. A digital weighing balance (citizen) having capacity up to 300 grams with a resolution of 0.1mg was used for weighing the work pieces and tool electrodes before machining and after machining. Then the material removal rate (MRR) and tool wear rate (TWR) are calculated using equations (1-2).

$$MRR\left({mm^3}/{min}\right) = \frac{\Delta W}{\rho_w \times t} \;....(1)$$

$$TWR\left({mm^3}/{min}\right) = \frac{\Delta T}{\rho_t \times t} \;.......(2)$$

Where ΔW is the weight difference of work piece before and after machining (g), ρ_w is density of work material (g/mm³), ΔT is the weight difference of electrode before and after machining (g), ρ_t is density of electrode material (g/mm³) and t is machining time in minutes. Surface roughness of the machined surface was measured using Talysurf surface roughness tester. To measure the deviation of performance characteristics from the desired values S/N (Signal to Noise) ratio can be used. These S/N ratios are categorized into three types based on the type of characteristics like higher the better (HB), lower the better (LB) and nominal the better (NB). The main objective in EDM process is to increase MRR and to reduce SR and TWR. Hence higher the better was applied for MRR whereas the lower the better for SR and TWR has been applied.

For higher the better,

$$S/_N \; ratio = -10 \log \left(\frac{1}{n}\right) \sum \frac{1}{Y_{ij}^2} \ldots\ldots\ldots (3)$$

For lower the better,

$$S/_N \; ratio = -10 \log \left(\frac{1}{n}\right) \sum Y_{ij}^2 \ldots\ldots\ldots (4)$$

Where n is the number of replications for each experiment and Y_{ij} is the response values. Table6 depicts the average values of MRR, TWR and SR and corresponding S/N ratios.

Table6: Average values of MRR, SR and TWR and corresponding S/N ratios.

Exp .no.	Process parameters			MRR		TWR		SR	
	I (A)	T_{on} (µs)	T_{off} (µs)	Mean (mm^3/min)	S/N Ratio	Mean (mm^3/min)	S/N Ratio	Mean (µm)	S/N Ratio
1	8	50	35	5.4259	14.6894	0.1122	19.0001	3.8583	-11.7278
2	8	100	65	6.6666	16.4781	0.2244	12.9795	4.3570	-12.7838
3	8	150	95	7.9740	18.0335	0.2632	11.5943	4.7640	-13.5594
4	16	50	65	15.5555	23.8377	0.3600	8.8739	6.4798	-16.2312
5	16	100	95	19.7400	25.9069	0.4200	7.5350	8.3302	-18.4132
6	16	150	35	24.9629	27.9459	0.4130	7.6810	9.2785	-19.3496
7	24	50	95	38.5185	31.7134	0.4432	7.0680	8.7040	-18.7944
8	24	100	35	45.8880	33.2340	0.5210	5.6632	10.8468	-20.7060
9	24	150	65	47.9258	33.6114	0.5611	5.0192	11.9325	-21.5346

In the present work to get an optimal combination of process parameters a grey relational approach is used. Using this method multiple performance characteristics can be transformed into single grey relational grade. Further the step by step procedure is as follows.

Step1: Normalizing the raw data (S/N ratios obtained from the Taguchi analysis). Yij is normalized as Xij (0≤ Xij ≤1) as follows to avoid the effect of adopting different units and to minimize the variability.

For higher the better characteristic,

$$X_{ij} = \frac{\left(Y_{ij} - \min(Y_{ij})\right)}{\left(\max(Y_{ij}) - \min(Y_{ij})\right)} \ldots\ldots\ldots (5)$$

For lower the better characteristic,

$$X_{ij} = \frac{\left(\max(Y_{ij}) - Y_{ij}\right)}{\left(\max(Y_{ij}) - \min(Y_{ij})\right)} \ldots\ldots\ldots (6)$$

Where Xij is normalized S/N ratio value, Yij is the value of S/N ratio attained by the Taguchi analysis and min (Yij) and max (Yij) are minimum and maximum S/N ratio values correspondingly.

Step2: Grey relational coefficient is then calculated as

$$GC_{ij} = \frac{\left(\Delta_{min} + \Psi \Delta_{max}\right)}{\left(\Delta_{ij} + \Psi \Delta_{max}\right)} \ldots\ldots\ldots (7)$$

where GC_{ij} is the grey relational coefficient.

Since multi response characteristics consist of both higher the better and lower the better hence Ψ is assumed as 0.5. Δ_{min} and Δ_{max} are the minimum and maximum absolute difference that is a deviation from target value. This can be treated as quality loss.

Step3: Averaging the grey relational coefficients.
Step4: Then grey relational grade (Gi) is calculated as

$$G_i = \frac{1}{m}\sum GC_{ij} \dots\dots (6)$$

Where m is the number of response variables. Higher value of grey relational grade indicates the stronger relational degree between ideal sequence and present sequence. Ideal sequence is the best response in the machining process. Higher grey relational grade specifies closer to the optimal response in the process.

III. RESULTS AND DISCUSSION

Table6 shows S/N ratio values for MRR, SR and TWR. Table7 shows normalized S/N ratio values and deviation of sequences for MRR, SR and TWR. Further these values are transformed into grey relational coefficients. Distinguishing coefficient has been taken as 0.5. Then grey relational grade (GRG) has been evaluated as said earlier. The rank of each experimental run is revealed based on grey relational grade and is presented in Table8. The higher grey relational grade value indicates better multi-response characteristics.

Table7: Normalized S/N Ratios and Deviation Sequences

Exp No	Current (A)	Pulse on Time (μs)	Pulse off Time (μs)	Normalized S/N Ratios			Deviation Sequences		
				MRR	TWR	SR	MRR	TWR	SR
1	8	50	35	0.0000	0.0000	0.0000	1.0000	1.0000	1.0000
2	8	100	65	0.0945	0.4306	0.1076	0.9055	0.5694	0.8924
3	8	150	95	0.1767	0.5297	0.1867	0.8233	0.4703	0.8133
4	16	50	65	0.4834	0.7242	0.4592	0.5166	0.2758	0.5408
5	16	100	95	0.5928	0.8200	0.6817	0.4072	0.1800	0.3183
6	16	150	35	0.7005	0.8096	0.7772	0.2995	0.1904	0.2228
7	24	50	95	0.8996	0.8534	0.7205	0.1004	0.1466	0.2795
8	24	100	35	0.9800	0.9539	0.9155	0.0200	0.0461	0.0845
9	24	150	65	1.0000	1.0000	1.0000	0.0000	0.0000	0.0000

Table8. Grey Relational Coefficients and Grey Relational Grade

Ex. No	Current (A)	Pulse on Time (μs)	Pulse off Time (μs)	Grey relational coefficient			Grey Relational Grade	Rank
				MRR	TWR	SR		
1	8	50	35	0.3333	0.3333	0.3333	0.3333	9
2	8	100	65	0.3557	0.4675	0.3590	0.3940	8
3	8	150	95	0.3778	0.5153	0.3807	0.4246	7
4	16	50	65	0.4918	0.6444	0.4803	0.5388	6
5	16	100	95	0.5511	0.7352	0.6110	0.6324	5
6	16	150	35	0.6253	0.7242	0.6917	0.6840	4
7	24	50	95	0.8327	0.7732	0.6414	0.7491	3
8	24	100	35	0.9615	0.9155	0.8554	0.9108	2
9	24	150	65	1.0000	1.0000	1.0000	1.0000	1

Table9: Optimal Factor and its Level Combination

Level	1	2	3	Δ(Max-Min)	Rank
Current	0.3839	0.6184	0.8866*	0.5027	1
Pulse on time	0.5404	0.6457	0.7028*	0.1624	2
Pulse off time	0.6427	0.6442*	0.6020	0.0407	3

The mean grey relational grade value of the selected process parameters for each level is shown in Table9. These values were calculated by averaging values of each level group at all the levels of process parameters. Since GRG specifies the level of relationship between reference sequence and obtained sequence. However higher value of average GRG indicates stronger relationship between them. It indicates optimal level of process parameters. The higher Δ (Maximum-Minimum) value designates the significant nature on determining response in the process. It was observed that peak current is most significant factor, and then follows pulse on time and pulse off time having significant affect on the electrical discharge machining process. It was noticed from Table9 that the optimal combination of process parameters is when peak current (I) at 24A (level 3), pulse on time (T_{on}) at 150 μs (level3), and pulse off time at 65 μs (level2). Further each response value is predicted at optimal combination of process parameters as follows based on grey relational analysis.

$$\text{Predicted response} = \text{average of } I_3 + \text{average of } T_{on_3} + \text{average of } T_{off_2} - 2 \times \text{mean of response } (Y_{ij})$$

At optimum process parametric setting ($I_3 - T_{on_3} - T_{off_2}$) confirmation experiment was conducted to validate the predicted values. Comparison of Predicted values with Experimental values of each response and corresponding percentage error were presented in Table10.

Table 10: Comparison of Predicted values with Experiment values

	Optimal process parameters		% of error
	Predicted	Experiment	
Level	$I_3 - T_{on_3} - T_{off_2}$	$I_3 - T_{on_3} - T_{off_2}$	
MRR (mm^3/min)	49.4724	47.9258	-3.22
TWR (mm^3/min)	0.5503	0.5611	1.92
SR (μm)	11.9138	11.9325	0.15

It was observed from the Table10 that predicted values are in good agreement with experimental values.

IV CONCLUSIONS

In the present study, Taguchi L9 orthogonal array with grey relational analysis has been used to optimize the multiple performance characteristics such as material removal rate, tool wear rate and surface roughness during EDM of AA6082 material. It is found that peak current is most significant factor then pulse on time and pulse off time based on largest Δ value that was shown in response table9. The optimal combination of process parameters were achieved by GRA. Confirmation experiment was conducted at optimal parametric setting. Further predicted response values are in good agreement with corresponding experimental results.

REFERENCES

[1] Assarzadeh, S, Ghoreishi, M "Statistical modeling and optimization of process parameters in electro-discharge machining of cobalt-bonded tungsten carbide composite (WC/6%Co)". *The Seventeenth CIRP Conference on Electro Physical and Chemical Machining, Procedia CIRP*, 6: pp 464–469 (2013).

[2] V.Chittaranjan Das, C.Srinivas "Optimization of multiple response characteristics on EDM using the Taguchi method and grey relational analysis"*International Journal of research In Mechanical engineering & technology* Vol. 3, No. 2, April-May 2014

[3] Gopalakannan, S, Senthilvelan, T, Ranganathan, S "Statistical optimization of EDM parameters on machining of aluminum Hybrid Metal Matrix composite by applying Taguchi based Grey analysis", *Journal of Scientific & Industrial Research,* 72(6) pp 358-365 (2013).

[4] Ho, K.H, Newman, S.T " State of the art electrical discharge machining (EDM)" *International Journal of Machine Tools and Manufacture,* 43(13) pp1287–1300 (2003).

[5] Padhee, S. Nayak, N. Panda, S.K. Dhal, P.R. Mahapatra, S.S "Multi-objective parametric optimization of powder mixed electro-discharge machining using response surface methodology and non-dominated sorting genetic algorithm" *Sadhana-Academy Proceedings in Engineering Sciences*. Vol.37(2) pp223–240 (2012).

[6] Raghuraman, S "Optimization of EDM parameters using Taguchi method and Grey relational analysis for Mild steel IS 2026", *International Journal of Innovative Research in Science, Engineering and Technology*, Vol.2(7) pp 3095-3104 (2013).

[7] Rao, G.K.; Janardhana, G.R.; Rao, D.H.; Rao, M.S "Development of hybrid model and optimization of metal removal rate in electric discharge machining using artificial neural networks and genetic algorithm". *ARPN Journal of Engineering and Applied Sciences*, 3(1): 19-30 (2008).

[8] Thillaivanan, A, Asokan, P, Srinivasan, K.N, Saravanan, R, Optimization of operating parameters for EDM process based on the Taguchi method and Artificial neural network, *International Journal of Engineering, Science and Technology*, 2(12), pp 6880–6888 (2010).

[9] Tzeng, C.J.; Chen, R.Y "Optimization of Electric Discharge Machining Process Using the Response Surface Methodology and Genetic Algorithm Approach" *International Journal of Precision Engineering and Manufacturing,* 14(5) pp 709-717 (2013).

[10] V. Vikram Reddy_ P. Madar Valli A. Kumar Ch Sridhar Reddy, Influence of Process Parameters on Characteristics of Electrical Discharge Machining of PH17-4 Stainless Steel, *Journal of Advanced Manufacturing Systems* Vol. 14, No. 3 pp189–202 (2015), DOI: 10.1142/S0219686715500122.
[11] V. Vikram Reddy_ P. Madar Valli, Ch Sridhar Reddy, P.Rangaiah, Mathematical Modeling of Process Parameters on Material Removal Rate in EDM of EN31steel Using RSM Approach *International Journal of Research and Innovations in Science and Technology* Vol.1, Issue.1, pp49–53 (2014).