Multi Response Optimization of EDM of AA6082 Material using Taguchi- DEAR Method

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Abstract-Electrical discharge machining is most widely used in machining industries to make dies of complex cavities. In the present work investigation has been carried out on electrical discharge machining of AA6082 material using electrolyte copper as tool material. Experiments were conducted using Taguchi method with L9 orthogonal array. The process parameters such as peak current, pulse on time and pulse off time are chosen for experimentation. Further material removal rate, surface roughness and tool wear rate are chosen as performance characteristics for this study. The aim of this work is to find significance of process parameters on performance characteristics and also obtain an optimal combination of process parameters by Taguchi-Data Envelopment Analysis based Ranking (DEAR) multi objective optimization method.

Index Terms - Electrical Discharge Machining, Taguchi Method, DEAR Method, Peak Current, Pulse on Time, Pulse off Time, Material Removal Rate, Surface Roughness, Tool Wear Rate, Optimization

1. INTRODUCTION

In electrical discharge machining (EDM) process material is removed generally by conversion of electrical energy into thermal energy through a series of distinct electrical discharges taking place between the electrodes (tool and workpiece). These electrodes are immersed into a dielectric fluid and are separated with a small gap. Furthermore, there is no physical contact between electrodes which minimizes mechanical stresses, chatter and vibration problem during machining that enable EDM process to machine brittle material (Beri N, et al 2008.) Lin et al (2000) have applied Taguchi method with fuzzy logic for optimizing the EDM with multiple performance characteristics. The process parameters such as discharge current, pulse on time, duty factor, polarity, open discharge voltage and dielectric fluid are optimized considering multiple performance characteristics, namely, material removal rate (MRR) and tool wear rate (TWR). Wang et al (2003) discussed the development and application of a hybrid artificial neural network (ANN) and genetic algorithm (GA) methodology for modeling and optimization of EDM. Kansal et al (2006) proposed the parametric optimization of powder-mixed electrical discharge machining (PMEDM) through Taguchi method and utility concept. The process parameters such as discharge current, pulse on time, duty cycle and silicon powder added into dielectric fluid are optimized considering multiple performance characteristics, namely, MRR, SR and TWR. Mahdavinejad (2008) presented the optimization and control of EDM process using the neural model predictive control method.

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Krishna Mohana Rao et al (2008) optimized the MRR of die sinking EDM using neural networks and GA. Experiments are carried out on Ti6Al4V, HE15, 15CDV6 and M-250 by varying peak current and voltage. Lajis et al (2009) discussed the feasibility of machining tungsten carbide ceramics by EDM with a graphite electrode and obtained optimal combination of process parameters using Taguchi method. Jung and Kwon (2010) have proposed the optimization of EDM process for multiple performance characteristics using Taguchi method and gray relational analysis method. T Muthuramalingam and B. Mohan (2013) were applied Taguchi-grey relational approach based multi response optimization techniques to maximize material removal rate and to minimize surface roughness in electrical discharge machining of AISI 202 stainless steel using brass has been used as tool electrode with kerosene as the dielectric medium. V.Chittaranjan Das et al (2014) have reported the influence of process parameters such as discharge current, gap voltage, pulse-on time and duty cycle on performance characteristics material removal rate, electrode wear rate and surface roughness during rotary EDM of Ti–6Al–4V alloy. It is observed from the literature survey that little work has been carried out so far in the field of multi-objective optimization of EDM of AA6082 material. The aim of present work is to know the influence of chosen input parameters such as peak current I (A), pulse on time Ton (µs) and pulse off time (Toff) (µs) on EDM performance measures namely, material removal rate (MRR), surface roughness (SR) and tool wear rate (TWR) and also to yield optimal combination of input parameters for getting maximum MRR and minimum SR and TWR simultaneously using Taguchi- DEAR multi-response optimization method.

TABLE 1
CHEMICAL COMPOSITION OF AA6082 MATERIAL

Element	Percentage (%)
Manganese (Mn)	0.40 - 1.00
Iron (Fe)	0.0 - 0.50
Magnesium (Mg)	0.60 - 1.20
Silicon (Si)	0.70 - 1.30
Copper (Cu)	0.0 - 0.10
Zinc (Zn)	0.0 - 0.20
Titanium (Ti)	0.0 - 0.10
Chromium (Cr)	0.0 - 0.25
Aluminium (Al)	Balance

1. EXPERIMENTAL SETUP, PROCEDURE AND EQUIPMENT

Aluminum alloy AA6082 material is chosen as work material for conducting experiments. The dimension of work specimen is 100 × 50 × 13 mm^3. Table 1 shows chemical composition of work material AA6082. The properties of AA6082 material are presented in Table 2. The electrolyte copper ϕ14mm and length 70mm is selected as tool material and its properties are presented in Table 3. Process parameters such as peak current, pulse on time and pulse off time are chosen as input parameters based on literature survey. To decide ranges of chosen input parameters, pilot experiments were conducted. The chosen process parameters and corresponding levels for this study are presented in Table4. All the experiments are conducted on die sinking EDM machine model MOLD MASTERS605 using EDM Oil grade SAE240 as dielectric fluid. Experimental setup is shown in Figure 1. Taguchi L9 orthogonal array (OA), is chosen for this study for conducting all the experiments and each experimental run is repeated thrice. The experimental layout is presented in Table 5. The chosen experimental conditions are presented in Table 6. In this work, the responses chosen for multi-response optimization of EDM are MRR, SR and TWR. Furthermore MRR has been chosen as the larger-the-better responses, while SR and TWR are selected as the smaller-the-better responses. A digital weighing balance (Citizen) having a capacity of up to 300 g with a resolution of 0.1 mg is used for weighing both the workpiece and the tool before and after machining. Then, the MRR and the TWR are calculated with weight loss method. SR values of the machined surfaces are measured using Talysurf SR tester with sampling length of 0.8mm

TABLE 2
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
Proof Stress	310 MPa
Tensile Strength	340 MPa
Elongation	11%
Shear Strength	210 MPa

TABLE 3
PHYSICAL PROPERTIES OF ELECTROLYTE COPPER

Density	8.95 (g/cm^3)
Specific capacity	383 (J/kg °C)
Thermal conductivity	394 (W/m °C)
Electrical resistivity	1.673×10^{-8} Ω m
Melting point	1083°C

Figure1: Experimental setup

TABLE 4
WORKING RANGE OF THE PROCESS PARAMETERS AND THEIR LEVELS

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

TABLE 5
EXPERIMENTAL LAYOUT USING AN L_9 (3^4) OA

SNo	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. DEAR METHODOLOGY

In DEAR method, to find optimal combination of proce parameters, multi-response performance index (MRPI) value used. This MRPI value is obtained by mapping a set of origin responses.

The following steps are used to calculate MRPI value

1. The weight of response is the ratio between responses at any experimental run to the summation of response of all experimental runs. Weights are calculated using the following equations

$$W_{mrr} = \frac{MRR}{\sum MRR} \text{.....(1)}$$

$$W_{sr} = \frac{1/SR}{\sum\left(1/SR\right)} \text{......(2)}$$

$$W_{twr} = \frac{1/TWR}{\sum\left(1/TWR\right)} \text{......(3)}$$

2. Convert response data into weighted data through multiplying each response value with its own weight using the following equations

$$M = MRR \times W_{mrr} \text{.........(4)}$$

$$S = SR \times W_{sr} \text{........(5)}$$

$$T = TWR \times W_{twr} \text{.......(6)}$$

3. Divide the larger-the-better data with the smaller the-better data to get MRPI value using the following equation

$$MRPI = \frac{M}{S+T} \text{.......(7)}$$

4. RESULTS AND DISCUSSION

Experiments were conducted using L9 OA to investigate the significance of process parameters on EDM of AA6082 material. Table 7 presents the average values of experimental results. In the present work, MRR is chosen as the larger-the-better characteristic, whereas SR and TWR are selected as the smaller-the-better characteristics. From the response graphs (Figures 2–4), it was noticed that MRR, TWR, and SR are increased with increase in peak current and pulse on time. However MRR TWR and SR decrease with increase

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	Positive
Supply voltage	240 V
Machining time	5 minutes

TABLE 7
AVERAGE VALUES OF RESPONSES MRR, TWR AND SR

Exp.	I (A)	T_{on} (µs)	T_{off} (µs)	MRR (mm³/min)	TWR (mm³/min)	SR (µm)
1	8	50	35	5.4259	0.1122	3.8583
2	8	100	65	6.6666	0.2244	4.357
3	8	150	95	7.974	0.2632	4.764
4	16	50	65	15.5555	0.36	6.4798
5	16	100	95	19.74	0.42	8.3302
6	16	150	35	24.9629	0.413	9.2785
7	24	50	95	38.5185	0.4432	8.704
8	24	100	35	45.888	0.521	10.8468
9	24	150	65	47.9258	0.5611	11.9325

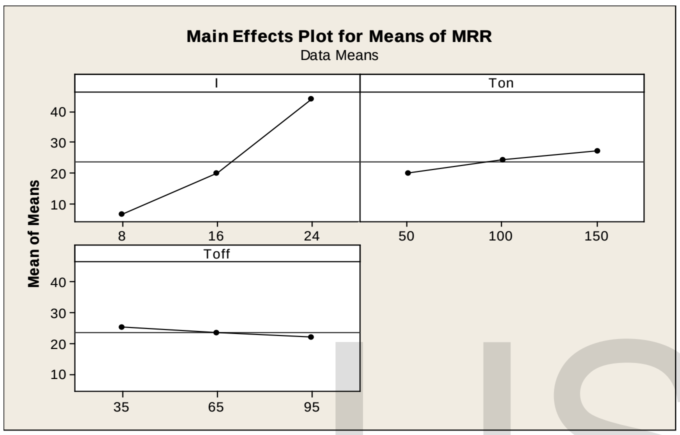

Figure2: Effect of process parameters on mean data of MRR

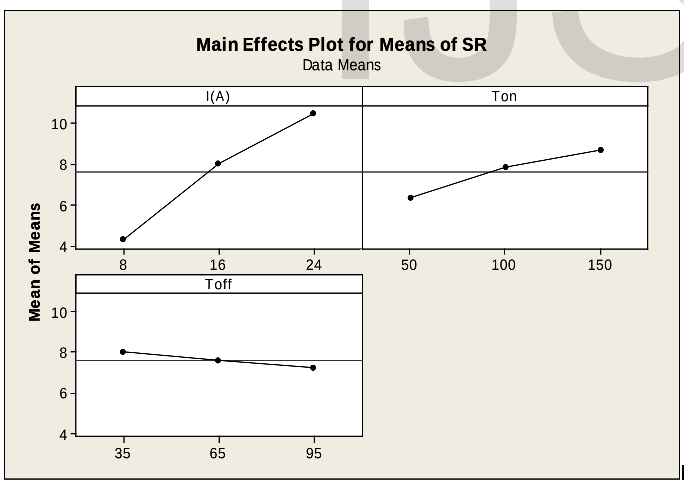

Figure4: Effect of process parameters on mean data of SR

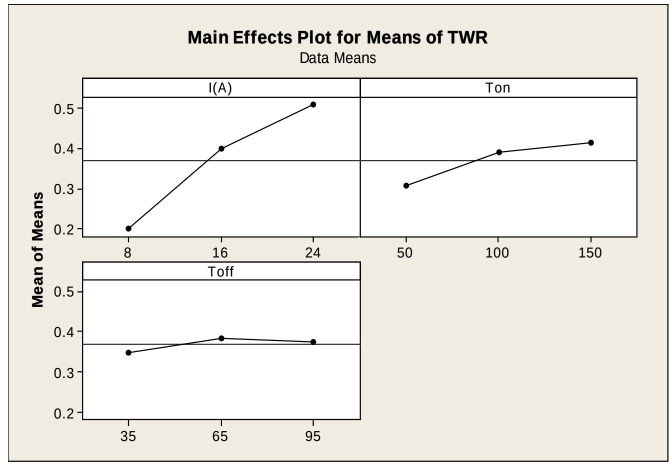

Figure3: Effect of process parameters on mean data of TWR

However, weights of responses and MRPI values are calculated using equations (1)–(7). The weighted response values are presented in Table 8 and Table 9 shows the MRPI values. Combined MRPI values of each process parameter at various levels are presented in Table10.These values are calculated through summation of all MRPI values for corresponding level of each process parameters. Highest value of MRPI for a particular process parameter indicates optimal level of that parameter. From Table 10, optimal combination of process parameters is obtained when peak current is at 24 A, pulse on time is at 150µs and pulse off time is at 35µs.

TABLE 8
WEIGHTS FOR RESPONSES MRR TWR AND SR

Exp.	I (A)	T_{on} (µs)	T_{off} (µs)	Wmrr	Wtwr	Wsr
1	8	50	35	0.02552	0.29026	0.188957
2	8	100	65	0.03135	0.14513	0.167329
3	8	150	95	0.0374	0.12373	0.1533034
4	16	50	65	0.07315	0.09046	0.1125119
5	16	100	95	0.09283	0.07744	0.08751946
6	16	150	35	0.11739	0.07885	0.07857462
7	24	50	95	0.18113	0.07348	0.08376087
8	24	100	35	0.21578	0.06251	0.0672138
9	24	150	65	0.22537	0.05804	0.06109823

Confirmation experiment has been conducted at optimal parametric setting to validate conclusions drawn from optimization using Taguchi-DEAR methodology. The response values at optimal parametric setting are as follows: MRR 49.12 mm³/min, SR 8.96 µs and TWR 0.392 mm³/min. However, MRPI value is calculated for a combination of these response values as 13.078. The MRPI value calculated for the combination of response values of confirmation experiment based on DEAR approach is found deviated from maximum MRPI value with 4.8% error. This variation lies within the acceptable tolerance value of 5%. It is also observed that peak current has most significant, pulse on time has significant and pulse off time has less significant effect on EDM process performance.

TABLE 9
WEIGHTED RESPONSES DATA OF MRPI VALUE

Exp.	I (A)	T_{on} (µs)	T_{off} (µs)	M	T	S	T+S	MRPI
1	8	50	35	0.13844	0.03257	0.72906	0.76162	0.18177
2	8	100	65	0.20899	0.03257	0.72906	0.76162	0.2744
3	8	150	95	0.299	0.03257	0.72906	0.76162	0.39259
4	16	50	65	1.13786	0.03257	0.72906	0.76162	1.49399
5	16	100	95	1.83237	0.03257	0.72906	0.76162	2.40589
6	16	150	35	2.93029	0.03257	0.72906	0.76162	3.84743
7	24	50	95	6.97684	0.03257	0.72906	0.76162	9.16051
8	24	100	35	9.90189	0.03257	0.72906	0.76162	13.0011
9	24	150	65	10.8009	0.03257	0.72906	0.76162	14.1814

TABLE 10
RESPONSES TABLE FOR TOTAL MRPI VALUES

Parameter	Level 1	Level 2	Level 3
I (A)	0.84876	7.747313	36.343
Ton (µs)	10.83627	15.6813	18.42144
Toff (µs)	17.03027	15.94982	11.95898

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