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Optimization of input factors of EDM using Taguchi ANOVA and genetic algorithm for machining of Aluminum 6061 Alloy

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ABSTRACT

EDM is an electro-thermal method, where electrical energy is used to produce electrical spark and volume loss chiefly take place as a result of thermal energy of spark. Objective of current work is to investigate impact of input factors such as Peak-Current (IP), Pulse-on-Time (Ton) and Pulse-off-Time (Toff) on die-sinking EDM responses such as Material Removal Rate (MRR), Tool Wear Rate (TWR) and Surface Roughness (Ra) on aluminum 6061 alloy hole drilling process with copper electrode and kerosene dielectric fluid. Selected orthogonal-array was L9 in three levels. The employed methodology was Taguchi-method, analysis-of-variance for single-objective optimization by Minitab software and genetic algorithm for multi-objective optimization using Mat-lab software with varies population size. Influence of peak-current was the most significant factor to MRR, TWR, and Ra of Aluminum 6061 machining. The optimum value for single-objective and multi-objective-optimization was selected.

Keywords— *EDM, Peak current, Pulse on time, Pulse off time, Material-removal-rate, Tool-wear-rate, Surface roughness, Minitab, Mat-lab, Taguchi, Analysis-of-variance, Genetic-algorithm, Single-objective-optimization, Multi-objective optimization, Optimum value*

1. INTRODUCTION

EDM is an electro-thermal method, where electrical energy is used to produce electrical spark and volume loss chiefly take place as a result of thermal energy of spark.[1] Die-sinking EDM is category of EDM which comprises work piece and tool that is submerged in dielectric fluid like mineral oil, de-ionized H_2O and kerosene. Both are flooded in fluid at time of production. It may need several passes because shape are usually complex. Bhatia and Gundiyatgaon, 2014 [2] There are two passes in which first passes eliminate large amounts of material and form rough texture while last pass ensures creation of best feature surface and exact quality process. Ezeddini et al., 2019 [3] carried out wire EDM of titanium-aluminum intermetallic composite work piece material with brass wire electrode using Taguchi, Responsive Surface Method (RSM) and ANOVA for optimization of surface roughness. From T_{on}, speed, startup voltage and flushing pressure, study concluded that pressure was significant factor which contributed to Ra then pulse of time, voltage and speed respectively. Mandal et al., 2019 [4] examined optimization of Ra and kerf width in wire EDM of aluminum 6061 alloy using Taguchi technique and ANOVA. From T_{on}, T_{off}, SV and WT, they proved that T_{on} and servo voltage were main significant factor which contributed to kerf width whereas T_{off} and WT were less dominating factor and pulse of time, pulse off time, wire tension and servo voltage were contributed to surface roughness. Valarmathi et al., 2019 [5] studied optimization of MRR in wire EDM of H12 steel work piece material and copper and copper-tungsten electrodes using Taguchi, ANN, GA and ANOVA and they concluded that T_{off} and flushing pressure were significant factor which contributed to surface finish improvement whereas pulse on time was substantial impact on overcut. Mishra et al., 2018 [6]investigated optimization of MRR, Ra, SCD, WLT, circularity, TA, ROC in WEDM of Inconel-625 super alloy work piece by Taguchi technique, EDS and Topsis. Mussada et al., 2018 [7]investigated optimization of RLF in Wire EDM of die steel by SEM and input factors were servo feed and wire speed and they concluded that wire speed and servo feed greatly affected RL and formation of HAZ. Parameters et al., 2018 [8] examined MRR and Ra optimization using Ip, T_{on} and T_{off} input factors in EDM of Nimonic-90 work piece by Taguchi system and they concluded that T_{on} and T_{off} were the major factor on responses. Pontevedra et al., 2018 [9] used ANOVA technique, surface plot and non-linear regression models to study optimization of MRR, EWR, ROC and Ra in WEDM of Al7075 red mud metal matrix composite and input factors such as Ip, T_{on} and GV and they concluded that Ip was the most substantial factor on output. Prasanna et al., 2018 [10] studied optimization of MRR and TWR in ED turning practice of stainless steel 304 using ANOVA using input factors of T_{on}, IP, GV and tool thickness. And they studied that T_{on} was dominant factor. Rajmohan, 2018 [11] studied optimization of Ra and MRR in WEDM of nano-SiC particle reinforced magnesium matrix composite using RSM and ANOVA and concluded that T_{on} and GV were the main influential factor on MRR. Sani et al., 2018 [12]used Taguchi technique and ANOVA to optimize MRR and Ra in

WEDM of 16MCr5 alloy steel with two types of electrodes such as diffused wire and zinc coated wire using input factors such as type of wire, T_{on}, T_{off} and IP and proved that T_{on} was greatest influential factor. Wegener et al., 2018 [13] studied MRR in EDM of hard work piece by stochastic method using input factors of tool length and tool shape which concluded that tool length was key significant factor on drilling time and tool wear but less effect on MRR. Chandramouli and Eswaraiah, 2017 [14] carried out optimization of MRR and Ra in EDM of 17-4PH steel using Taguchi and ANOVA and they proved that the influence of input factors for responses were T_{on} and IP. Niamat et al., 2017 [15] studied MRR and EWR in WEDM of Al 6061 T6 alloy by Taguchi and probability plot and concluded that T_{on} and IP were the main substantial factor on responses.

2. MATERIAL AND METHOD

In this study work, L9 orthogonal has selected and types of work piece was aluminum 6061 alloy and experiment size of 150 x 150mm and 5mm thick square plate and copper electrode were chosen for conducting the experiment. Also copper has second highest only to bulk electrical conductivity next to silver. Copper has higher strength than silver, but it has lower oxidation resistance. Employed methods for this study were Taguchi method and Genetic Algorithm.

Table 1: Physical property of Aluminum 6061 alloy

S no.	Property	Value
1	Density	2.7g/cm3
2	Thermal conductivity	162 W/m.K
3	Melting point	582-652 °C
4	Tensile strength	124–290 Mpa
5	Yield strength	55.2MPa
6	Specific heat	897 J/(kg·K)

Taguchi the DOE involves using OA to organize the factors influencing the process and the levels at which they should be fluctuates. Instead of taking to test all combinations, the Taguchi method tests pairs of arrangements.

Table 2: Ranges and levels of selected parameters

Process parameters	Symbols	Machining parameter Range and unit	Levels		
			1	2	3
Peak current	IP	1-9A	3	4	5
Pulse on time	T_{on}	5-900 µs	499	599	699
Pulse off time	T_{off}	1-60µs	29	39	49

Table 2 shows selected Die sinking Electric discharge control factors and their ranges. The selected range is based on preliminary experimental evaluation of die sinking electric discharge machine.

3. EXPERIMENTATION

In this study work, conducted experiment for aluminum 6061 alloy is in three trial experiment and experiment size of 150 x 150mm and 5mm thick square aluminum 6061 plate and copper electrode were chosen for conducting the experiment. The machining-type is 14mm diameter, and 5mm depth cavity hole. Identified dielectric fluid is kerosene as well as tool is copper tool and responses are MRR, TWR and RWR. Measurement of experimental responses calculated as follow:

$$\text{MRR} = \frac{\text{weight of work piece before machining} - \text{weight after machining}}{\text{density of work piece x machining time}}$$

$$\text{TWR} = \frac{\text{weight of tool before machining} - \text{weight of tool after machining}}{\text{density of tool x machining time}}$$

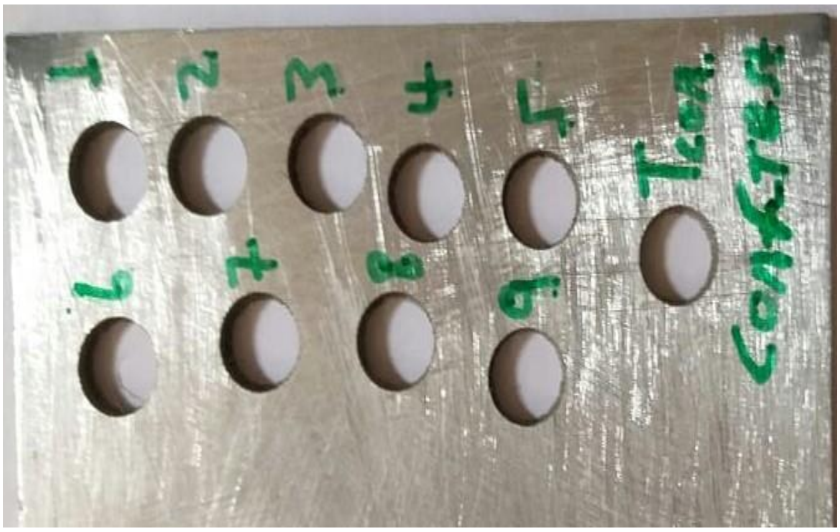

Fig. 1: Aluminum 6061 alloy experimental sample

Table 3: Aluminum alloy experimental value for MRR, TWR and Ra responses

Experiment no.	Input-parameters			Responses/Outputs		
	IP A	T_{on} µs	T_{off} µs	MRR mm3/min	TWR mm3/min	Ra µm
1	3	499	29	78.971	0.0995	0.251
2	3	599	39	82.305	0.1037	0.262
3	3	699	49	86.873	0.1095	0.287
4	4	499	39	87.835	0.1107	0.291
5	4	599	49	91.075	0.1148	0.306
6	4	699	29	88.676	0.1117	0.311
7	5	499	49	83.48	0.1052	0.298
8	5	599	29	94.643	0.1193	0.322
9	5	699	39	89.606	0.1129	0.317

3.1 Single objective optimization Using Taguchi Method

3.1.1 Taguchi analysis for MRR

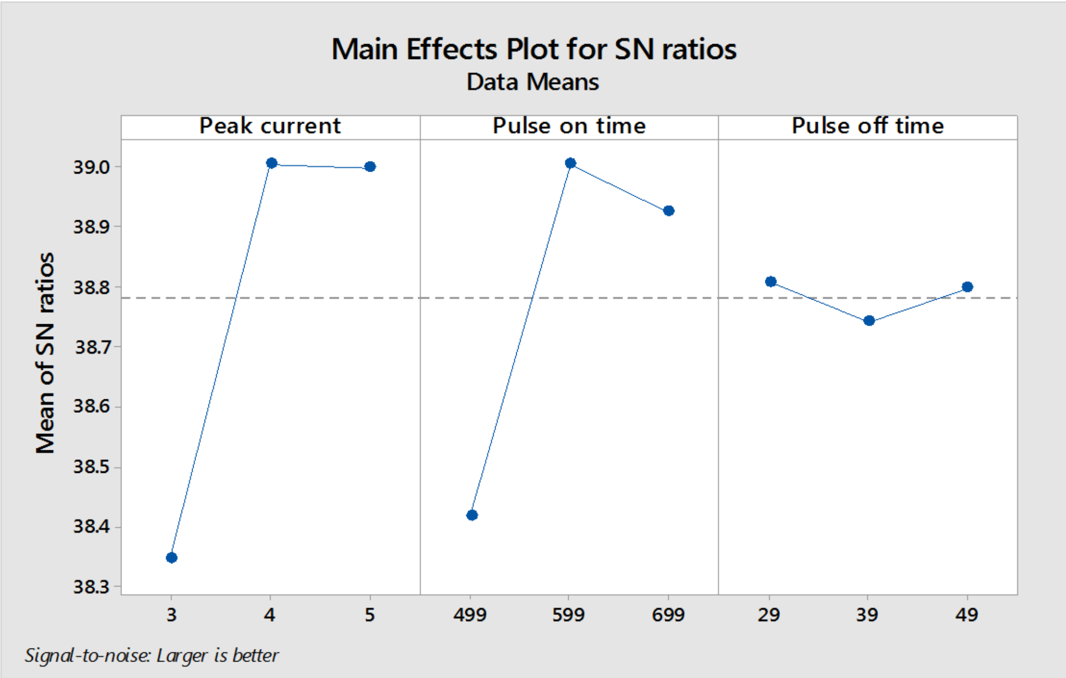

Fig. 2: Main-effects-plot of SN ratios to MRR

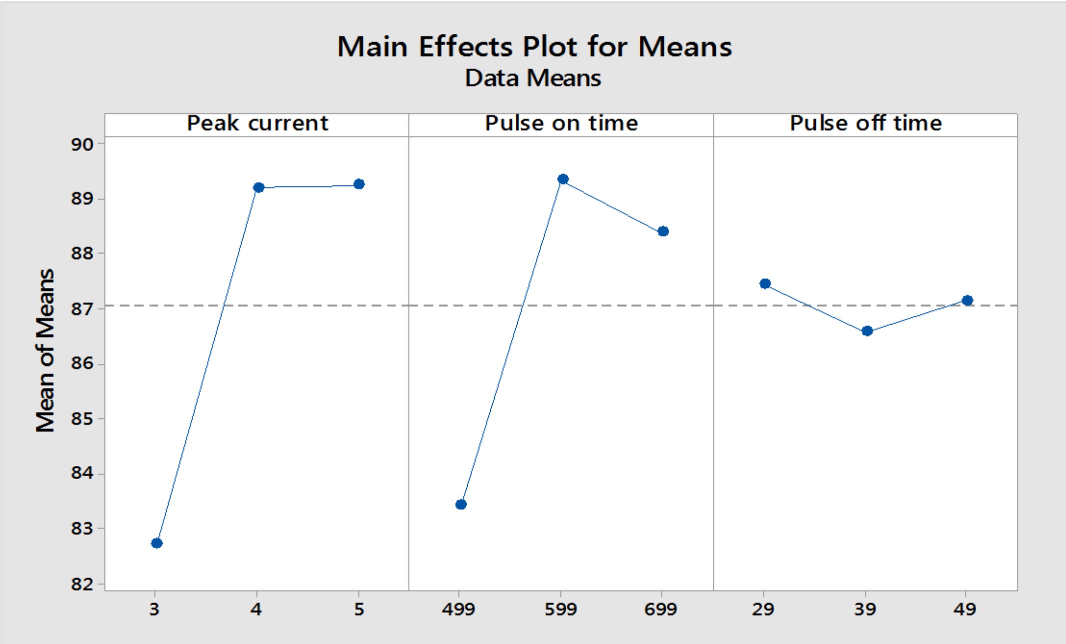

Fig. 3: Main-effect-plot of mean value to MRR of aluminum-alloy

Higher the better for MRR so that from figure number 2 and 3, it notices that MRR has highest value at IP of 5A, T_{on} 599µs and T_{off} 29µs. Therefore the optimum input arrangement value for MRR is IP (5A), T_{on} (599µs) and T_{off} (29µs).

- **Impact of input factors on MRR:** From figure 3, there is rise of MRR by increasing of IP. The rise in IP result in rise in spark energy in greater current density. This increases the heating ability of work piece intensively which creates much molten material that is. rise MRR. Initially MRR rise with Ton until level two then decrease with rise in T_{on} since at higher T_{on} more oxygen starts inflowing the machining area that generates ineffective discharge within the electrode-gap that cause smaller MRR. But initially MRR decreases with rise of T_{off} until level two then rises with rise in T_{off}.

3.1.2 Taguchi Analysis for TWR

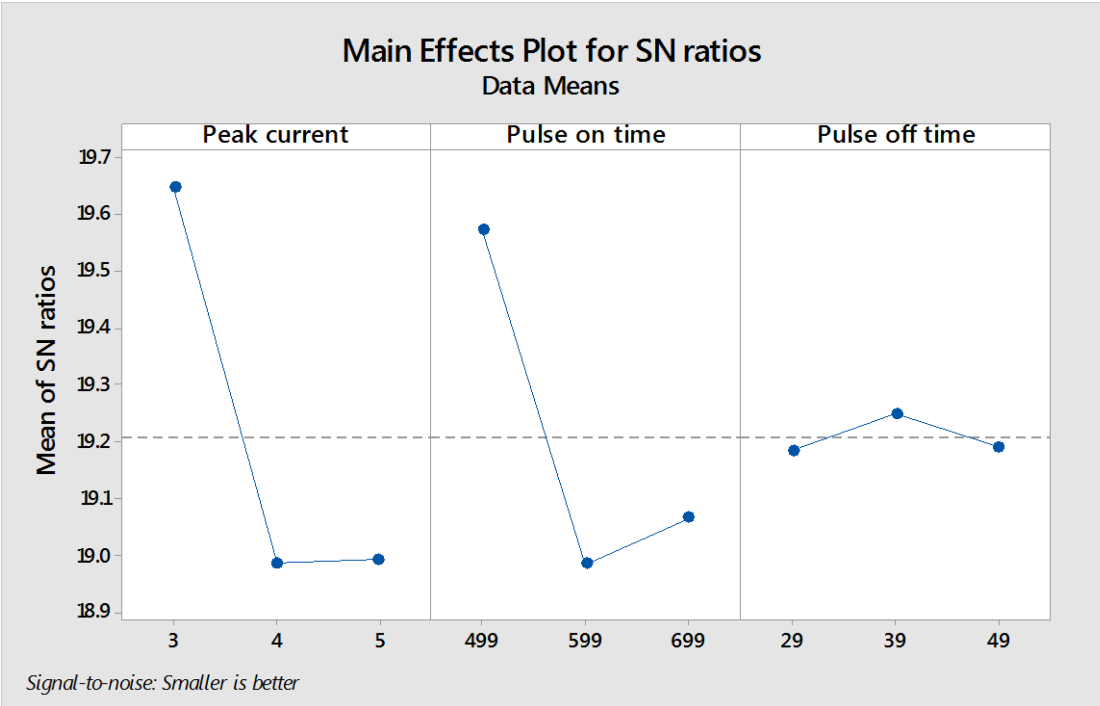

Fig. 4: Main-effects-plot of SN ratios for tool-wear-rate of aluminum alloy

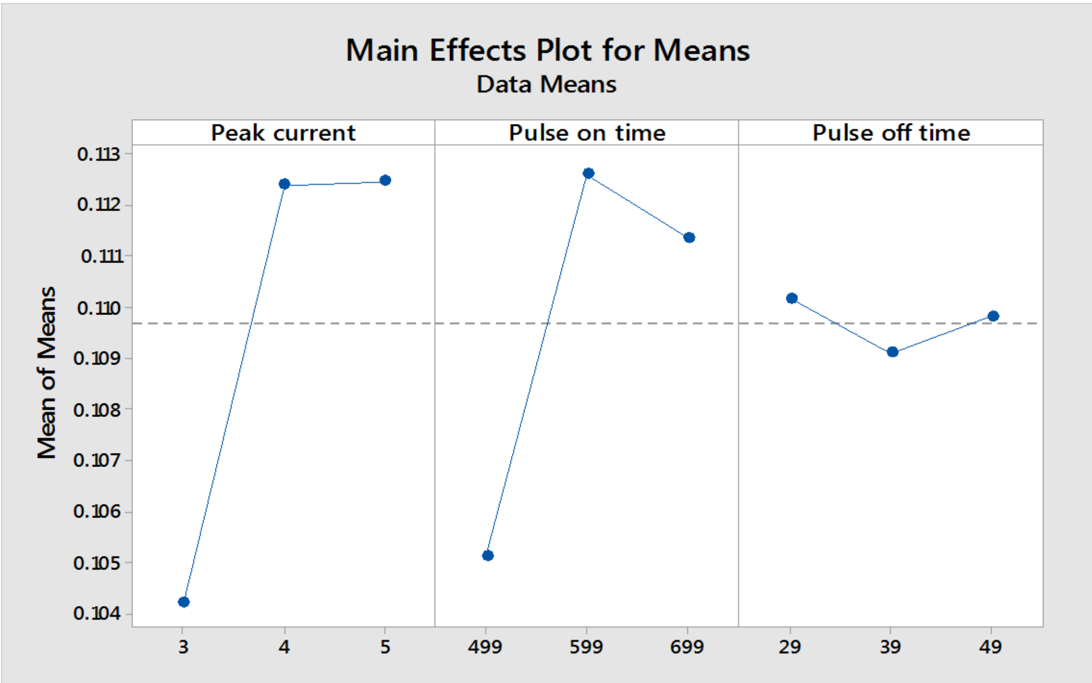

Fig. 5: Main-effect-plot of mean value for tool-wear-rate of aluminum alloy

Smaller the better for TWR so that from figure number 4 and 5, it notices that TWR has lowest value at IP of 3A, T_{on} 499µs and T_{off} 39µs. Therefore the optimum input arrangement value to MRR is IP (3A), T_{on} (499µs) and T_{off} (39µs).

- **Impact of input factors on TWR:** From figure 5, there is increase of TWR with increasing of IP. The rise in IP result in rise in spark energy result in rise in TWR. This rises the heating ability of work piece intensively which creates much molten tool material that is. rise TWR. Initially TWR rise with T_{on} until level two then decrease with rise in T_{on} since at greater T_{on} more oxygen starts inflowing the machining area that produces ineffective discharge within electrode gap that cause lower TWR. But initially TWR declines with rise of T_{off} until the level two then rise with rise in T_{off}.

3.1.3 Taguchi Analysis for Surface roughness (Ra)

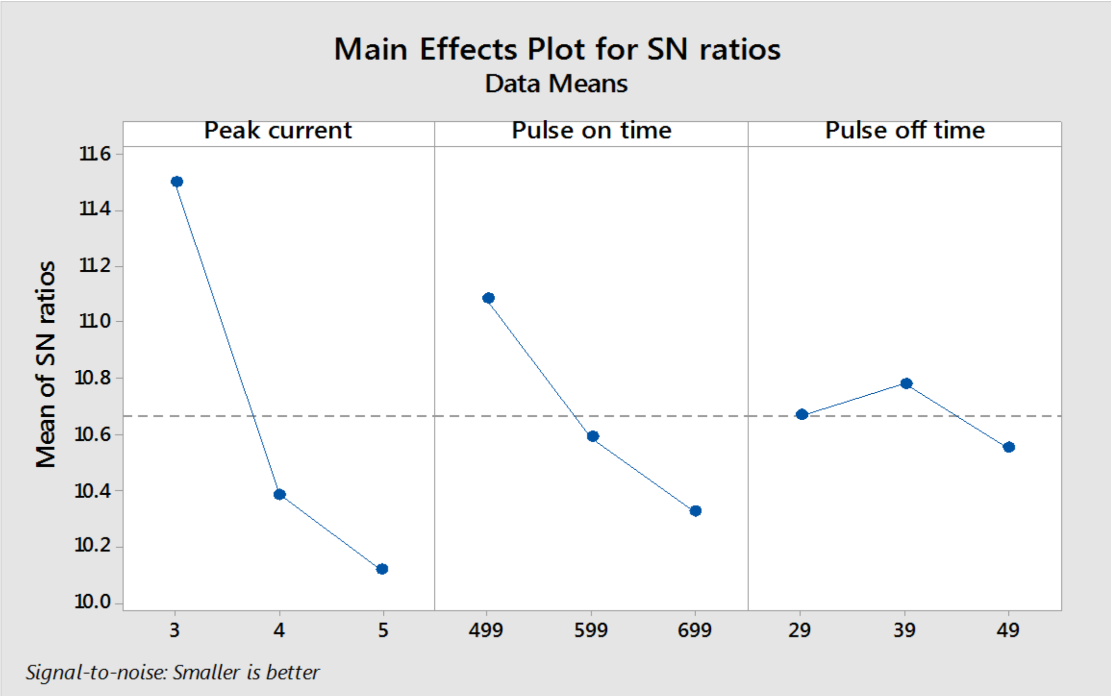

Fig. 6: Main-effects-plot of SN ratios for Ra of aluminum alloy

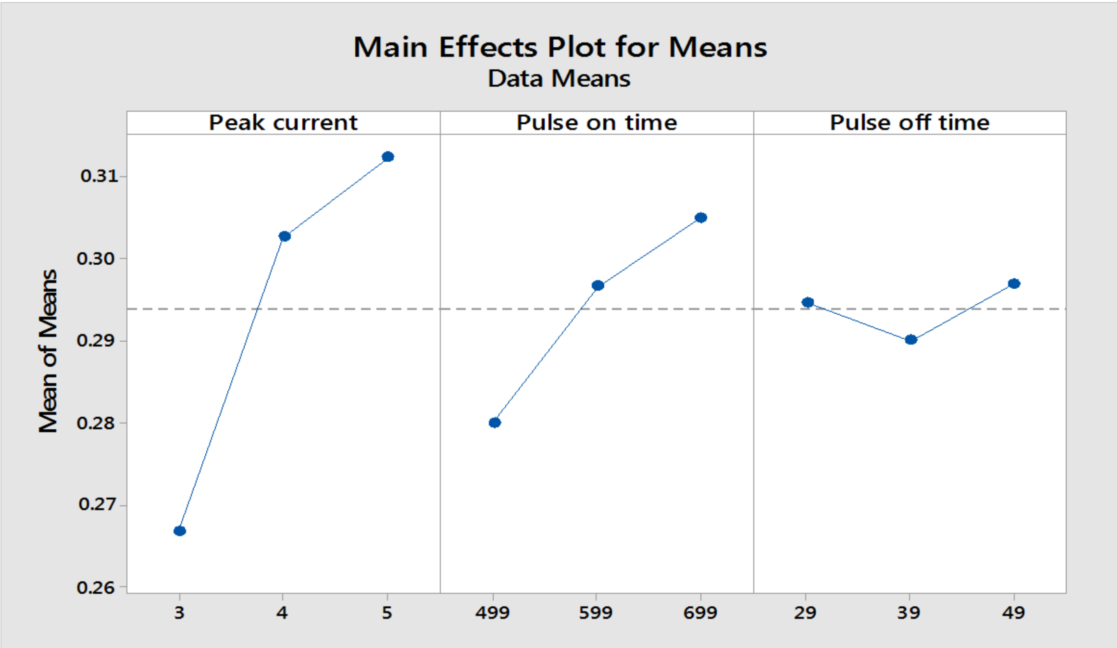

Fig. 7: Main-effect-plot of mean value for Ra of aluminum alloy

Smaller the better for Ra so that from figure number 6 and 7, it notices that Ra has lowest value at IP of 3A, T_{on} 499µs and T_{off} 39µs. Therefore the optimum input combination value to TWR is IP (3A), T_{on} (499µs) and T_{off} (39µs).

3.2 Analysis using ANOVA method

Table 4: ANOVA result for MRR

Source	DF	Seq SS	Contribution	Adj SS	Adj MS	F-Value	P-Value
IP	2	84.577	45.91%	84.577	42.2885	2.22	0.310
T_{on}	2	60.435	32.81%	60.435	30.2174	1.59	0.387
T_{off}	2	1.116	0.61%	1.116	0.5580	0.03	0.972
Error	2	38.081	20.67%	38.081	19.0405		
Total	8	184.209	100.00%				

From table 4 of MRR ANOVA result, contribution of IP is greatest substantial parameter and its involvement is 45.91% after that T_{on} and its contribution is 32.81%, but T_{off} is insignificant factor on MRR of aluminum-alloy hole-drilling

Table 5: ANOVA result of TWR

Source	DF	Seq SS	Contribution	Adj SS	Adj MS	F-Value	P-Value
IP	2	0.000134	45.78%	0.000134	0.000067	2.19	0.313
T_{on}	2	0.000096	32.73%	0.000096	0.000048	1.57	0.390
T_{off}	2	0.000002	0.61%	0.000002	0.000001	0.03	0.972
Error	2	0.000061	20.88%	0.000061	0.000031		
Total	8	0.000294	100.00%				

From table 5 of TWR ANOVA result, contribution of IP is greatest significant parameter and its involvement is 45.78% after that T_{on} its contribution is 32.73%, but T_{off} is insignificant factor on TWR of aluminum alloy hole drilling.

Table 6: ANOVA result of surface-roughness

Source	DF	Seq SS	Contribution	Adj SS	Adj MS	F-Value	P-Value
IP	2	0.003475	74.05%	0.003475	0.001737	20.49	0.047
T_{on}	2	0.000972	20.72%	0.000972	0.000486	5.73	0.149
T_{off}	2	0.000076	1.62%	0.000076	0.000038	0.45	0.690
Error	2	0.000170	3.61%	0.000170	0.000085		
Total	8	0.004693	100.00%				

From table 6 of Ra ANOVA result, contribution of IP is greatest significant parameters and its involvement is 74.05% after that T_{on} its contribution is 20.72%, but T_{off} is insignificant factor on Ra of aluminum-alloy hole-drilling

3.3 Multi-Objective-Optimization Using Genetic Algorithm in Mat-Lab

Genetic Algorithm is multi-objective-optimization technique which is very important to optimize more than one responses. Fitness function for MRR, TWR and Ra:

$$\mathrm{MRR} = 3.26 * x1 + 0.0248 * x2 - 0.014 * x3 + 59.7$$

$$\mathrm{TWR} = 0.0042 * x1 + 0.000031 * x2 - 0.000017 * x3 + 0.0752$$

$$\mathrm{Ra} = 0.022833 * x1 + 0.000125 * x2 + 0.000117 * x3 + 0.123131$$

Table 7: GA predicted result for varies population size

S no.	Optimum input factor			Optimum output responses		
	IP A	T_{on} µs	T_{off} µs	MRR mm^3/min	TWR mm^3/min	Ra µm
3. **Population size: 50**						
3.1	3	499	29	81.4492	0.102776	0.257358
3.2	3	499	29.921875	81.4362938	0.10276	0.2574659
3.3	3	499	36.935551	81.3381023	0.102641	0.2582865
4. **Population size:70**						
4.1	3	499	29	81.4492	0.102776	0.257358
4.2	3	499	39.1460624	81.3071551	0.102604	0.2585451
4.3	3	499	31.4198456	81.4153222	0.102735	0.2576411
5. **Population size: 90**						
5.1	3	499	29	81.4492	0.102776	0.257358
5.2	3	499	48.9441756	81.1699815	0.102437	0.2596915
5.3	3	499	46.5691756	81.2032315	0.102477	0.2594136

3.4 Combined-objective-function

$$\text{Combined objective function formula} = -\mathrm{MRR} * 0.5 + \mathrm{TWR} * 0.25 + \mathrm{Ra} * 0.25$$

Table 8: Combined-objective-function result for Al 6061 alloy of different population size

S no.	Optimum input factor			Optimum output responses			
	IP A	T_{on} µs	T_{off} µs	MRR mm^3/min	TWR mm^3/min	Ra µm	Combined objective function
3. **Population size: 50**							
3.1	3	499	29	81.4492	0.102776	0.257358	-40.6345665
3.2	3	499	29.92188	81.436294	0.102760328	0.257465859	-40.62809033
3.3	3	499	36.93555	81.338102	0.102641096	0.258286459	-40.57881925
4. **Population size:70**							
4.1	3	499	29	81.4492	0.102776	0.257358	-40.6345665
4.2	3	499	39.14606	81.307155	0.102603517	0.258545089	-40.56329041

4.3	3	499	31.41985	81.415322	0.102734863	0.257641122	-40.61756708
5. **Population size: 90**							
5.1	3	499	29	81.4492	0.102776	0.257358	-40.6345665
5.2	3	499	48.94418	81.169982	0.102436949	0.259691469	-40.49445867
5.3	3	499	46.56918	81.203232	0.102477324	0.259413594	-40.51114304

Based on the result of combined-objective-function without considering -ve sign, lowest-objective-function shows optimum result and combination from rest of iteration. From table 8, the lowest result is for population size 90 that is. its lowest result is -40.49445867. Thus the optimum value is MRR, TWR and Ra is 81.169982mm^3/min, 0.102436949 mm^3/min and 0.259691469µm at Ip 3A, T_{on} 499µs and T_{off} 48.94418µs respectively.

Table 9: Lowest-combined-objective-function for Aluminum 6061 alloy

Work piece type	IP A	T_{on} µs	T_{off} µs	MRR mm^3/min	TWR mm^3/min	Ra µm	Minimum objective function
Aluminum alloy	3	499	48.9441756	81.16998	0.102437	0.259691	-40.494459

3.5 Confirmation Experiment

Optimal combination of factors and their levels of Al 6061 alloy coincide with one of experiments in the Orthogonal Array (OA) for MRR, then no confirmation test is required for it. From MRR optimal combination of parameters match with L9 DOE number nine (9) at A3B2C1. So that only confirmation experiment was conducted for TWR and Ra. Therefore optimum-arrangement of parameters and their levels of aluminum alloy for MRR is at A3B2C1, TWR at A1B1C2 and Ra at A1B1C2 that is optimum result for aluminum alloy hole drilling of MRR is IP, T_{on} and T_{off} (5A, 599µs and 29µs), for TWR and Ra is (3A, 499 µs and 39 µs) respectively.

Table 10: Confirmation experiment result for Al 6061 alloy hole drilling response

S no.	Optimum input parameter combination value			Responses type	Optimum response value		Residuals	Error
	IP (A)	T_{on} (µs)	T_{off} (µs)		Experimental result	Predicted result		
1	5	599	29	MRR $_{max}$ (mm^3/min)	94.643	94.5226	0.1204	0.13%
2	3	499	39	TWR $_{min}$ (mm^3/min)	0.0967	0.09667	-1.4E-17	0.03%
3	3	499	39	Ra $_{min}$ (µm)	0.243	0.242999	5.55E-17	0.0004%

From confirmation test value table 10, experimental value of MRR, TWR and Ra is very close to the predicted value. This confirms that the experimental result of MRR, TWR and Ra is intensely correlated with predicted value. Error of MRR, TWR and Ra of aluminum alloy hole drilling is 0.13%, 0.03% and 0.0004% respectively.

4. CONCLUSION

In this study, influence of input factors such as IP, T_{on} and T_{off} on MRR, TWR and Ra of aluminum 6061 alloy hole drilling with copper tool and kerosene dielectric fluid has been discussed and for analysis of study work two type of methods employed such as Taguchi for single objective optimization and Genetic Algorithm (GA) for multi objective optimization and two software such as Mat-lab and Minitab software were applied for analysis. The main conclusion from current study are summarized below:

- IP is the most influential parameter to MRR, TWR and Ra for aluminum 6061alloy hole drilling, but its contribution is greater for Ra (74.05%) than MRR (45.91%) and TWR (45.78%). T_{on} is the second significant factor next to IP for MRR, TWR and Ra, but T_{off} is insignificant factor for MRR, TWR and Ra
- Optimum input factor in case of single-objective-optimization: Optimum input factor for MRR is at A3B2C1, for TWR at A1B1C2 and for Ra at A1B1C2.
- Optimum input factor in case of Multi-objective-optimization by GA: Optimum value for MRR, TWR and Ra is 81.1699 mm3/min, 0.102437 mm3/min and 0.2596 at A1B1C48.944 respectively.
- To increase life of electrode, low value of IP and Ton but high value of T_{off} is required to for machining of aluminum 6061 alloy because low TWR provides long tool life. Thus to decrease TWR to increase pulse off time and decrease both IP and Ton.
- To decrease Ra, low value of IP but high value of T_{on} and T_{off} is required. Thus to decrease Ra to increase T_{on} and T_{off} and decrease IP.

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