

Identification of Better Set of Values for Input Parameter through Multi Objective Optimization

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Abstract

Identification of input parameters and along with its range is important task to proceed with the research work especially when some specific methods in DOE like Taguchi, RSM etc. are used. It is preferable to fix the values for few parameters to identify the remaining in non-conventional machining. Once the selection of parameters is done, the immediate next task is the selection of range of its values. Most of the researchers prefer to have literature survey for this. But, along with the study of the literature, it is always preferable to have one procedure to select the suitable set of values in the orthogonal array as a support. Here, in this paper the selection of range of values for 'Pulse OFF Time' is discussed. Out of the four input parameters which are proposed to use in the experiment, three of them are assumed as static and ten experiments were conducted to determine the range for the fourth parameter. As a result of ten experiments, output parameters MRR and SR were found out for the ten unique sets of input values. Modified TOPSIS was applied on these observations and better values of T_{off} were identified considering high relative closeness of the method applied, along with the values of MRR and SR obtained initially, literature survey, limitations of the machine, to proceed further.

Keywords: - *Electric Discharge Machining, Material Removal Rate, Modified TOPSIS, Relative closeness, Surface roughness, Pulse OFF Time.*

INTRODUCTION

Electric Discharge Machining has come to practice from the 50 years or so, and has replaced many machining process like drilling, grinding, milling and other traditional operations and has become an established option in major manufacturing industries worldwide. This machining is capable of processing for hard material components and for creating geometric shapes which are 'difficult to machine' in materials like ceramics, super alloys, tool steels, composites, heat resistant steels, carbides and others, which are mostly used in various industries like nuclear, aerospace, mold making and aeronautical industries. EDM has also made its impact in a few more new fields like sports, surgical, medical, optical, instrumental and even in the automotive development segment.

It is one of the popular production systems used in creating deep complex cavities in various types of materials for machining operations like roughing and finishing. This is widely used in various industries and has become the general method for making prototypes and other relevant production parts where the production numbers are comparatively less like electronics industries, aerospace and automobiles, etc.

LITERATURE SURVEY

Many researchers have studied EDM with different inputs and obtained outputs. Each one has proceeded with some of the inputs selecting its ranges of values to get the orthogonal array for the final experimentation. Some of their findings are discussed below.

Wang et al. (1998) performed optimization of process parameters of turning of S45C steel by Taguchi method using tungsten carbide as tool. An L9 OA was selected for the process. Machining parameters like speed, feed and depth of cut are considered with the performance measure SR. The surface roughness and tool life improved considerably [1]. Marafona et al. (2000) performed optimization of MRR while machining on EDM by copper - tungsten electrodes using fractional factorial of Taguchi method. The input parameters here are current intensity, duty factor, pulse duration, ram speed, gain, gap compression, cycle time and relative withdrawal. The output parameters are MRR, SR and TWR. L18 OA was selected. It was found that the method is very useful and successful to optimize these output parameters [2].

George et al. (2004) performed optimization of EDM parameters during machining of carbon. Input parameters considered here are DC, voltage, Ton. Responses are MRR and TWR. L8 OA was selected. The optimal conditions were found to be different [3]. **Kansal et al. (2006)** performed optimization on EDM when the particle of Si was added to the dielectric. The input parameters here are PDC, DC, PD and duty cycle. L9 OA was considered for the process. It was found that current and powder concentrations are the highly significant parameters. The predicted values were verified experimentally [4].

Marafona et al. (2009) has studied the influence of black coloured layer, during which interaction of the machining parameters varies that affect RWR using Taguchi method. L18 OA was used. It was found useful to determine the interaction of inputs and to elaborate TWR [6]. **Lin et al. (2009)** has done optimization on machining parameters in magnetic force assisted EDM using Taguchi method. An L18 orthogonal array was taken. The machining parameters like machining polarity, peak current, pulse duration, high voltage auxiliary current and no-load voltage and servo reference voltage etc were selected to determine output

parameters i.e., MRR and SR. Finally, they have concluded that the magnetic force assisted EDM gives higher MRR, lower RWR and smaller SR as compared to standard EDM. [7].

Lajis et al. (2009) had analyzed the machining of tungsten carbide. Influence of each parameter with their optimal values was found. The input parameters here are DC, Ton, voltage and IT. It was found that the parameters are influential on MRR, SR and TWR. DC is an influential factor for SR and TWR, whereas Ton is for MRR [8]. **Reddy et al. (2010)** studied the AISI 304 SS. The effect of voltage, current, duty cycle and servo for TWR, SR and MRR and hardness also analyzed. Second order regression model is being developed for the study. Servo was found to be the most significant parameter for MRR and it is current for TWR. It was found that SR is affected more by current [9]. **Bhattacharya et al. (2013)** had studied the surface properties of material during PMEDM. L18 was employed. The input parameters considered here are work piece, electrode, current, dielectric fluid, Pulse ON time, powder concentration and powder type. ANOVA was used to analyze the results. Analysis of SEM along with the EDX was done at the end [10].

Rajiv K Sharma et al. (2014) have performed optimization of PMEDM process parameters working on cobalt-bonded tungsten carbide with the electrode electrolytic copper. Combination of Taguchi and GRA has been applied for the optimization of performance measures. Finally, they have observed the analytical and experimental results which are indicating the powder, pulse ON time and Discharge current as the most significant parameters [11].

Gangadharudu Talla et al (2014) conducted multi response optimization of PMEDM for the material Al/Al MMC by using GRA. They have taken MRR and SR as output parameters and have applied ANOVA for the purpose of analysis. Finally they have concluded the recommended level of process parameters [12].

Ramarao BSV et al (2016) has worked on titanium alloy as it is used in many industrial applications because of its plenty of positive aspects like corrosive resistance, high strength to weight ratio, etc. worked on finding out the best concentration of powder which is to be mixed in di-electric fluid. In their research, they have conducted 34 trail experiments and found out MRR, SR,

TWR to determine best concentration of powder and finally concluded with 5, 10 and 15g/lit [13]

Ramarao BSV et al (2016) have performed experimentation for the determination of the better combination of input process parameters. They have conducted few experiments considering Discharge current as 20Amp, Pulse ON Time 65micro seconds and Pulse OFF time 36 micro seconds and varied powder concentration from 1 - 17 g/lit [14].

Ramarao BSV et al (2017) worked on optimization and grey relation analysis when performing experimentation on PMEDM using titanium alloy. Orthogonal array was taken to design the Experiments on PM-EDM by considering the B4C as the powder, which is mixed in di-electric fluid. And the analysis has been made using Grey relational Analysis (GRA) and Taguchi method. Finally, the results are re-verified and percentage of error is calculated. And finally concluded that the best combination is A3B2C2D3 and then the predicted values of the set have been found with the average percentage of positive deviation as 6.06% [15].

Ramarao BSV et al (2018) has done multi response optimization on Powder

Mixed EDM when working on Titanium alloy by using the method Modified TOPSIS. He has conducted 27 experiments and found out the best one obtained with high relative closeness as 0.707 for the set Discharge current, Pulse ON Time, Pulse OFF time and Powder concentration [16].

Sahithi et al (2019) has conducted experimental studies by varying various parameter like cutting speeds, feed rates and depths with different Al alloys. They have used Taguchi for multi response optimization is applied to optimal process parameter on CNC lathe using coated carbide cutting tool. L9 OA was conducted with three levels and four factors and conducted optimization [17]. From the literature, it is easily understandable that most of the researchers have taken that the preferable difference between the values of Discharge Current is 5Amp which is to be used in OA of DOE.

Objective of the study

Here in this paper, three preferred values for the input parameter 'Pulse OFF Time' were identified by conducting ten experiments. Experiments were conducted considering four input parameters in the set. To start with these experiments, three

input parameters out of four i.e., Discharge current, Pulse ON time and Powder Concentration were assumed with fixed values and taken different values for Pulse OFF Time (Range from 6 μ s to 60 μ s) based on the literature and considering limitations of the machine to conduct experiments. In each experiment, MRR and SR for each unique set of input values were determined. Modified TOPSIS was applied on these output values. Based on the results of the method, better values for Toff were identified which are proposed to be utilized in DOE.

EXPERIMENTATION

Material Used

Ti-6Al-4V is selected as the material to work on and the copper electrode is used for the same. And its chemical composition is given under in table 1.

Table 1: Chemical composition of Ti-6Al-4V

Element	Percentage (Max)
C	0.014
Al	6.07
V	4.02
N	0.0036
O	0.1497
Fe	0.03
Ti	Remaining (Apx 89.7012)

B4C powder is used to mix with the di-electric fluid i.e. drinking water and its properties are given below in table 2.

Table 2: Properties of B4C

Property	Value
Density (g/cm ³)	2.51
Particle size (Micro m)	20-30
Melting point (°C)	2450-2630
Hardness (kg/mm ²)	2900-3580
Fracture toughness (MPa)	2.9-3.7
Thermal conductivity (W/m ⁰ K at 25 ⁰ C)	140
Thermal expansion 0 -100 ⁰ C/ ⁰ C	4.6 X 10 ⁻⁶
Compressive strength (MPa)	2800
Young's Modulus (GPa)	450-470

In the initial stage of the experiment, based on the literature survey and considering the limitations of the machine, it is preferable to have 12 statistical differences the between three values of the Pulse OFF Time to be used in the main experiment and here in the pilot experimentation, it was considered to take 6 statistical difference between the values for Pulse OFF Time to work on more number of experiments.

Ten experiments were conducted to find out values of Pulse OFF Time, keeping all the remaining parameters i.e., Discharge Current, Pulse ON time and Powder concentration as constant (Taken from the literature), and the parameters with their values are presented in Table 3.

Table 3: Determination of Discharge Current

Process Parameter	Value
Discharge current (Ip)	20 Amp
Pulse ON Time (T _{on})	65 µs
Powder Concentration (PC)	10 g/lit
Pulse OFF Time(T _{off})	6µs to 60µs

Material Removal Rate (MRR)

It can be measured based on its weight difference obtaining from the weight before and after processing in EDM and its relevant formula is given below - Eqn1

$$MRR = [(W_i - W_f) / (D \times t)] \times 1000 \text{---Eqn1}$$

W_i = Initial Weight in grams

W_f = Final Weight in grams

D = Density of the work piece material in gm/cm³

t = Time Period of the experiment in minutes

Surface Roughness (SR)

It is calculated based on the average roughness by comparing all the peak points and valley points to the centre line. Here, in this experimentation, the surface roughness may be calculated using Talysurf.

Determination of preferred values through Modified TOPSIS

Modified TOPSIS

This is very unique method which was developed during around 1981 by the researchers Hwang and Yoon. The basic concept is to select the ideal solution and it can be done with the identification of shortest Euclidean distance for the better one, which gives ideal and better solution from the alternatives available, which was

discussed by the prominent researcher R Venaktarao et al. (2007) worked on multi objective optimization [5].

Finding Weights

Initially, weights for the machining parameters has to be determined any method. Here, the g the Standard deviation method was selected for that and its formula is given under:

$$W_j = \frac{\sigma_j}{\sum_{k=1}^M \sigma_j}$$

Where W_j = Weights

σ_j = Std. Deviation

M = Values in number

To determine the weights of the different attributes which are selected for the problem, initially it is necessary to determine the average values of the each parameter and it will be headed as XAVE. Then obtained average values should be deducted from the original value of output values, which was shown as X-XAVE. Then, calculated the standard deviation and finally the weights are calculated and are presented in the Table 4.

Table 4: Calculation of weights

S. No.	X-X _{AVE}			(X-X _{AVE}) ²	
	MRR	SR		MRR	SR
1	-2.3121	0.7047		5.3457	0.4966
2	0.3725	0.3125		0.1388	0.0976
3	-1.2971	-0.1074		1.6824	0.0115
4	0.7979	-0.3404		0.6367	0.1159
5	-0.2571	-0.2267		0.0661	0.0514
6	0.8811	-0.3885		0.7764	0.1509
7	0.5219	-0.3296		0.2724	0.1086
8	0.8719	-0.3796		0.7602	0.1441
9	-0.3321	0.2817		0.1103	0.0793
10	0.7529	0.4735		0.5669	0.2242
X _{AVE}			SIGMA	10.3559	1.4803
			Total/N	1.0356	0.1480
			√Total/N	1.017637	0.384744
			Weights	0.725649	0.274351

Then the weights obtained here are 0.725649 is for MRR and 0.274351 is for SR.

To normalize the values of machining parameters, the square values of each parameter are calculated. The normalized values can be obtained by dividing the square roots of the sum of squares with each value. Then relative closeness can be calculated by using the following formula and its values are presented in the table 5.

$$P_i = D^- / (D^+ + D^-)$$

Table 5: Calculation of relative closeness

MRR		SR						Pi
D+	D-	D+	D-	Σ D ⁺ _i	Σ D ⁻ _i	√Σ D ⁺ _i	√Σ D ⁻ _i	
w(R-R ⁺) ²	w(R-R ⁻) ²	w(R-R ⁺) ²	w(R-R ⁻) ²					
0.0174	0.0000	0.0021	0.0000	0.0195	0.0000	0.1396	0.0000	0.0000
0.0004	0.0123	0.0009	0.0003	0.0013	0.0126	0.0360	0.1121	0.7569
0.0081	0.0018	0.0001	0.0011	0.0082	0.0029	0.0907	0.0539	0.3726
0.0000	0.0165	0.0000	0.0019	0.0000	0.0184	0.0040	0.1357	0.9715
0.0022	0.0072	0.0000	0.0015	0.0023	0.0087	0.0475	0.0934	0.6628
0.0000	0.0174	0.0000	0.0021	0.0000	0.0195	0.0000	0.1396	1.0000
0.0002	0.0137	0.0000	0.0019	0.0002	0.0156	0.0150	0.1248	0.8924
0.0000	0.0173	0.0000	0.0020	0.0000	0.0194	0.0005	0.1391	0.9962
0.0025	0.0067	0.0008	0.0003	0.0033	0.0070	0.0574	0.0837	0.5932
0.0000	0.0160	0.0013	0.0001	0.0013	0.0161	0.0363	0.1270	0.7775

RESULTS AND DISCUSSION

Any kind machining process of either conventional or non-conventional, it is preferable that the ultimate target of the machining process is to get higher rates of MRR and lower rate of SR. From the graphs which are drawn below are shown in the following Fig, it is clear that the values of MRR are better when Pulse OFF Time is at 36 μ s and then followed by 48 μ s, 24 μ s and then at 60 μ s. And then, coming to Surface Roughness, the values

are better for 36 μ s, 24 μ s and then followed by 48 μ s and then 42 μ s. From the literature, it is quite understandable that the values of Pulse OFF Time should be as much as LOW comparatively with Pulse ON time values according to the possibility.

The results obtained for MRR and SR are plotted in the graph as shown in the below Fig 1(a), Fig 1(b), Fig 2(a) and Fig 2(b).

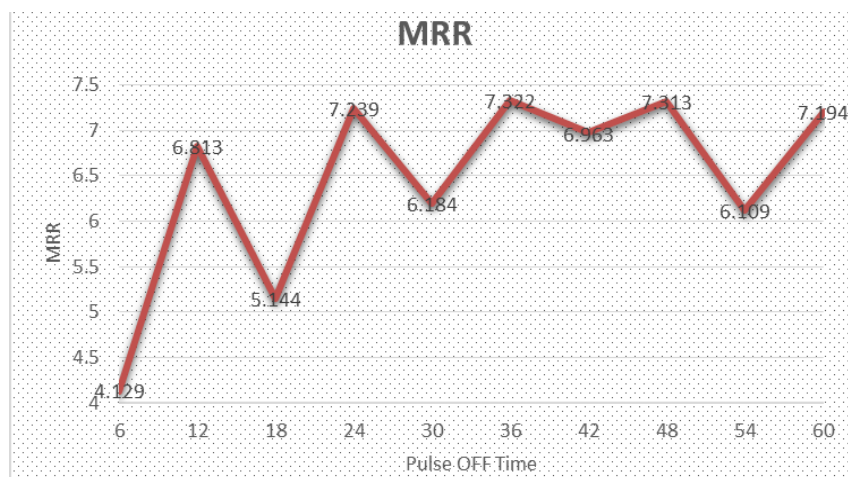


Fig 1 (a): Variations of MRR w.r.t T_{off}

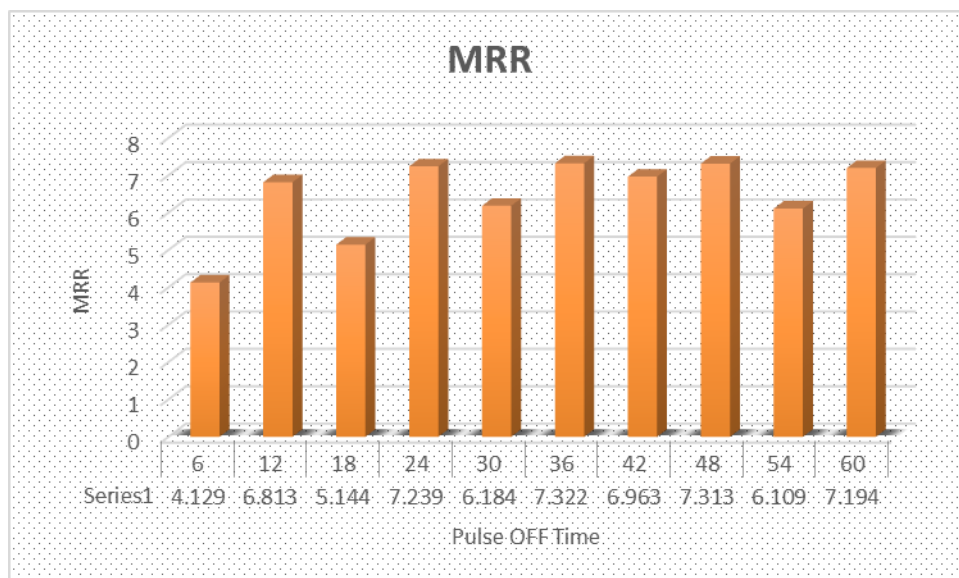


Fig 1 (b): Variations of MRR w.r.t T_{off}

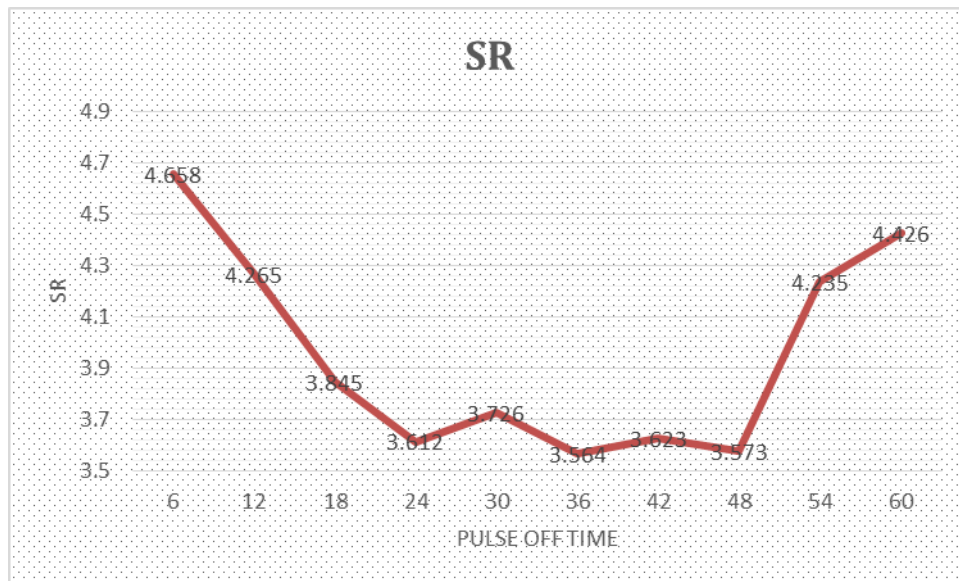


Fig 2 (a): Variations of SR w.r.t. T_{off}

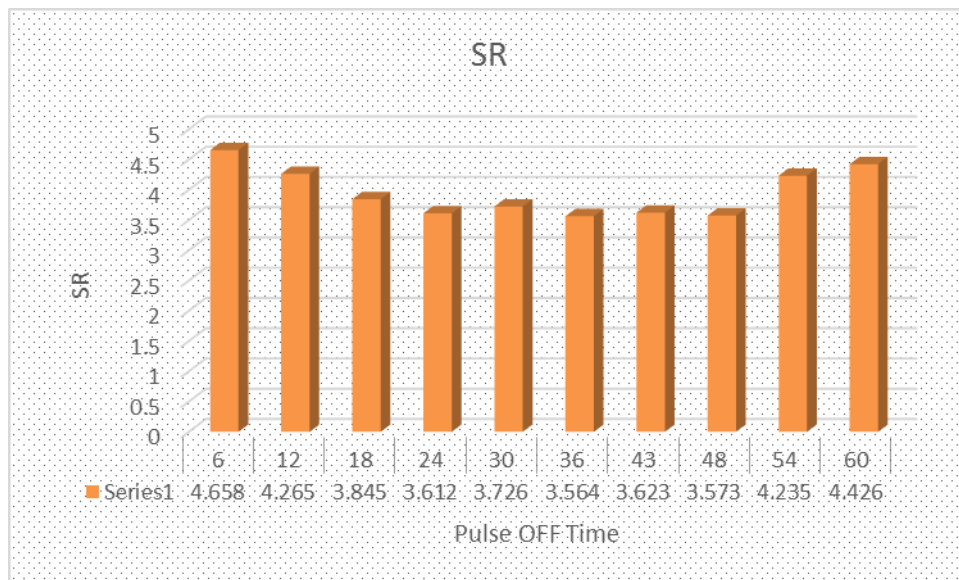


Fig 2 (b): Variations of SR w.r.t. T_{off}

From the literature, it is quite evident that the values of T_{off} should be a lower than T_{on} as it is required to have more pulse duration to get better results in terms of responses parameters.

From the graphs drawn above, it is very clear that the values of MRR and SR are better when the T_{off} is at 48 μ s (for MRR)

and 36 μ s (for SR). And the next preferred value for consideration is 24 μ s from both the above. As it was decided to have 12 numeric differences between the three levels, it is suggested to have 24 μ s, 36 μ s and 48 μ s as the three values of the orthogonal array.

And then, by observing the results of Modified TOPSIS from the table 5, it is obvious that the value of P_i i.e., relative closeness is high when Pulse OFF Time is at $36\mu s$. The values are tabulated in descending order in-terms of the relative closeness and are shown below in Table 6.

Table 6: Ranks of Relative closeness

$T_{off}, \mu s$	P_i	Rank
36	1	1
48	0.996	2
24	0.972	3
42	0.892	4
60	0.778	5
12	0.757	6
30	0.663	7
54	0.593	8
18	0.373	9
6	0	10

Then the next better value of relative closeness was found when T_{off} at $48\mu s$ and then the next better one for relative closeness was found when T_{off} was at $24\mu s$. The relative closeness is very least i.e., almost negligible when the Pulse OFF Time is at $6 \mu s$.

CONCLUSION

Considering the values of MRR and SR, it is evident that the values of $36 \mu s$, $48 \mu s$, $24 \mu s$, $60 \mu s$ and $42 \mu s$ are preferable, as

shown in the Fig. 1(a), Fig. 1(b), Fig. 2(a) and Fig. 2(b). Further, as per the result obtained by applying Modified TOPSIS, the relative closeness value is high for the pulse OFF time when it is at $36 \mu s$, and then followed by $24\mu s$, $42\mu s$ and $60\mu s$. As it was recommended earlier to have $12\mu s$ numeric difference between the values of the three levels, it is quite suitable to take $24\mu s$, $36 \mu s$ and $48\mu s$ as the three level values by keeping the obtained value with highest relative closeness value obtained from the method Modified TOPSIS as the middle value for the orthogonal array.

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