

**OPTIMIZATION AND EXPERIMENTAL INVESTIGATION OF EDM
PARAMETERS FOR ENHANCING MATERIAL REMOVAL RATE AND SURFACE
FINISH ON ALUMINIUM T061 USING GRAPHITE ELECTRODE WITH
TAGUCHI APPROACH**

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Abstract

In most industries, Manufacturing with machining plays a greater role because the formation of parts need surface finish during the machining process. The non-conventional machining processes are only method to machine hard materials. Electric Discharge Machining (EDM) is one of such processes used for removing the material in hard materials. it is non tradition by means of thermal energy instead of cutting force. In this study, experiments are carried out to find the optimum values of the parameters for addressing the issue of surface roughness in aluminium parts produced with graphite electrode in EDM.

The experiments are carried out on ZNC-250 die-sink electric discharge machine for drilling of Aluminium T061 work piece using Graphite rod as electrode. Experiments are designed using full factorial design of experiment (DOE) and run with L9 array various combinations of process parameters value. Taguchi optimization techniques were carried out to identify most important parameter having maximum impact on the surface roughness. In order to understand the response of the system, experiments were conduct out at three levels of Current (I), Pulse-on Time (T_{on}), Pulse-off Time (T_{off}) and Servo Voltage (V).

From the measured value of Surface Roughness (SR), it is found that the surface finish deteriorates with increase in current. Current is found to be the highest effect factor which has highest upshot on the Surface Roughness followed by pulse off time and last by pulse on time.

Keywords: - Surface Roughness, Material Removal Rate, Pulse on time, Pulse off time, Current, Taguchi Optimization Technique.

1 Introduction and Motivation

In production, metal forming and machining are the two main processes. In metal forming, the shapes are produced by material displacement without material removal, whereas the desired shape is obtained in the machining processes by removing extra material from the initial stock. In most of the industry, manufacturing with machining contributes to a greater extent as even the formed parts require finishing by material removal.

Electric discharge machining (EDM) is one of the most widely used non-conventional machining processes. Electro Discharge Machining (EDM) is an electrically thermal non-conventional machining process, where electrical energy is used to generate an electrical

spark and removal of material mainly due to the thermal energy of the spark EDM is now developed into the most important accepted technologies, since many complicated 3D shapes can be machined using an uncomplicated size tool electrode. In the manufacturing industry, electro-discharge machining (EDM) is commonly used for the production of mold and die components. This machine is used because the ability of the machining process is very accurate in creating complex or simple shapes within parts and assemblies. The cost of machining is much more due to the machine for its initial investment and maintenance, but it is a highly desirable machining process when high accuracy is required.

EDM has been substituting traditional machining operations. Now today EDM is a popular it is one of the main methods used in die production and there is no direct physical contact between the electrodes so that no mechanical stresses developed on the work piece. Electric discharge machining is also known as thermal erosion process where tool and work piece do not come in to the contact with each other during machining process. The progression of events constitutes the process of material erosion from the work surfaces.

2 Review of Literature

Hung (2007) explored the feasibility of applying the EDM approach to silicon carbide particle-reinforced cast Aluminium matrix composite. In order to predict the effect of process parameters on MRR, re-cast sheet, and SR, they built a statistical model [6]. The presence of SiC particles has been revealed to result in decreased MRR. This is because the Aluminium matrix is insulated and protected from vaporization by these particles. MRR and recast layer depth have been stated to be mainly regulated by input power and the current alone dominates the machined surface finish.

Shahzad (2013) investigated the effect of process parameters like pulse on time, discharge current and diameter of electrode on material removal rate (MRR), tool wear rate (TWR) and over cut. The experiment were done using AISI P20 tool steel as workpiece and U-shaped copper tool as electrode with internal flushing system. The S/N ratios was used for minimizing the TWR and maximizing the MRR and Taguchi method was used for optimization of the process parameters [12]

Guu, Y.H. (2017). A review of electronic discharge machine research shows that it is a important machining process both process of electrical and thermal occur simultaneously, and that most significant areas of interest in electronic discharge machining research are enhancing the machining performance such as surface roughness and electrode material removal rate by different ways [5].

Hocheng (2011) conducted a preliminary analysis of the SiC / Al composite MRR and surface roughness. For single and continuous discharge, material removal characteristics were tested. The study starts with a single discharge and a relationship between the crater size and the given discharge parameters has been found. Two heat conduction models were used for the calculation of the crater size [10]. The material removal rate has been greatly enhanced, as expected. For efficient machining of SiC / Al, broad current and short on-time is recommended.

Karthikeyan (2003) focused on the mathematical simulation of Aluminium-silicon carbide particulate composites for electric discharge machining. They studied the effects on the MRR, TWR, and SR of the percentage volume of SiC, current and pulse length. With an increase in the current, the MRR rises and with an increase in the percentage volume of SiC and the pulse length decreases [7]. With an increase in the current and the percentage amount of SiC, the TWR increases but decreases with an increase in the length of the pulse. With an increase in the current, the percentage volume of SiC and the pulse length, the surface roughness increases.

RiazAhamed (2009) worked on applying (EDM) did a study, focused on optimization of electrical discharge machining process parameter for maximization of material removal rate during machining of NiTi alloy [1]. They revealed that work electrical conductivity, gap current and pulse on time were important parameters that have an effect on the material removal rate. The optimized surface roughness obtained based on optimum setting of input parameter.

Kathiresan (2010) studied EDM using a copper electrode. Studies showed that the current and %age weight of silicon carbide significantly affected the MRR and surface roughness [7]. With an increase in the current and decrease in the %age weight of silicon carbide, the MRR increases. With a reduction in the current and an improvement in the %age weight of silicon carbide, the surface finish increases. In comparison with Aluminium 6061, Mouangue Nanimina et al. investigated machining efficiency characteristics on AMMC strengthened with 30 % Al₂O₃. To evaluate their effects on the reinforced MMC's MRR and TWR, main process parameters such as current, pulse on and pulse off were varied. A high peak current and on time value has been shown to increase Al6061 MRR rapidly rather than AMMC while decreasing with the increase in off time. At low peak current and on-time, instrument wear was greater than off-time.

Velmurugan (2018) investigates the impact on the machining of hybrid Al6061 metal matrix composites reinforced with 10 % SiC and 4 % graphite particles by parameters such as current, pulse on time, voltage and flushing pressure on MRR, tool wear rate and SR. With an increase in current, pulse time, and flushing pressure of the dielectric fluid, the metal removal rate of the composite increases as it decreases with an increase in voltage. With the rise in current and voltage, the tool wear rate of the formed composite increases and decreases with the increase in pulse time and flushing pressure of the dielectric fluid. During electrical discharge machining, the surface roughness of the composite increases with an increase in current, pulse duration, voltage and flushing pressure [13].

Non-conventional manufacturing processes are characterized as a group of processes that extract excess material through different techniques or combinations of these energies involving mechanical, thermal, electrical or chemical energy, but do not use sharp cutting tools as they need to be used for traditional manufacturing processes. With chip forming, material removal may occur or even no chip formation may take place. The key attraction of EDM over conventional machining methods, such as metal cutting using various instruments

and grinding, is that this technique uses a thermoelectric approach to erode undesired materials from the work piece through a series of discrete electrical sparks between the work piece and the electrode.

In AJM, for example, chips are of microscopic size and electrochemical machining material removal occurs due to atomic level electrochemical dissolution in the case of electrochemical machining material removal. As in traditional machining processes, material in the form of chips is often extracted by applying forces to the work material with a wedge-shaped cutting tool that is harder than the machining material.

Sandhu HS, Mehta V, Manchanda J, Phull GS (2015) concluded that negative polarity performs higher material removal rate and it has lesser tool wear when graphite electrodes are used. It was also analyzed that the discharge current and the pulse on time have a direct impact on the material removal rate and the surface roughness, being the highest values of material removal rate and surface roughness [11].

Muthuramalingam (2020) gave a review on the influence of electrical process parameters in EDM process. This study examines an overview of the EDM method, the modeling of process parameters and the effect of process parameters on performance measurements such as material removal rate, surface roughness, and electrode wear rate, such as input electrical variables, pulse shape and discharge energy.

Kumar (2021) analyzed the work to maximize the Material Removal Rate (MRR) and minimize the Surface Roughness (SR) value. Discharge current (I), source voltage (V), pulse-on time (Ton) and pulse-off time (Toff) are the process parameters considered in their experimental work. They have applied the Taguchi method and ANOVA analysis based on DOE and Taguchi to optimize the two process performance factors mentioned above, that is SR and MRR [12].

In order to achieve the best (optimum) desired outcome under the given specified experimental conditions, optimization is used for results. The most important aim of the decision is either to minimize the effort / time needed or to maximize the product's desired results / benefits or economic benefits. The conventional method of selection of combinations of parameters in EDM does not provide adequate or desirable results. EDM process parameter optimization has been treated as a single-objective optimization process and a multi-objective problem for optimization. Experiment design (DOE) approach such as the Taguchi process is used to actually minimize the experimental runs [9]. According to this, electrical discharge machining (EDM) is the best tool for optimizing process parameters-pulse on time, pulse off time, current, voltage etc.

3 Experimentation and Data Analysis

To achieve the desired objective or objective when researching specific fields of interest, some kind of suitable approach or technique would be required to achieve that mission. It is therefore examined, according to the reviewed literature that statistical or mathematical techniques have proven to be the researchers' best option for many years to optimize their

findings or to predict the nature of various parameters with the output value [8]. These approach can include design of experiment, analysis of variance (ANOVA), correlation approach, Taguchi technique procedure, regression technique, and many more. For optimization or to obtain the best set of results, these techniques are extremely important because without such techniques, it is tedious to assume the effect of various parameters on the output values with accuracy (Tobias, 1965).

The experiment is planned for various combinations of cutting variables using fractional (Taguchi experiment design) and total factorial experiment design (DOE). Variance analysis (ANOVA), correlation and regression technique are used to study the output characteristics as per DOE (Soni 2015) at different conditions.

4 Proposed plan of work (Methodology)

It can be analyzed from the literature review that there are several independent parameters in the machining process that impact the surface roughness (SR). After the machining process, the surface roughness will be measured using the surface roughness tester MITUTOYO SURFTTEST 210.



Figure1: Surface Tester

In this study In order to reduce the surface roughness (SR) in Aluminium 6061 T6 with the aid of adjusting the input parameters-current, voltage and pulse on time and pulse off time for operation on the EDM, with graphite electrode tool. Applying Taguchi method for analysis and optimization of variables.

The materials to be used in experiment are given below:

Table-1: Material required in experiment

S.NO.	Object	Material
1.	Tool (Electrode)	Graphite
2.	Work piece	Aluminium 6061 T6

5 Tool (Electrode) Material:

The exceptional features of Graphite make it the ideal substrate for electrodes. In manufacturing and other uses, such as mould making, general engineering and micro machining, graphite is mainly used for electrical discharge machining (EDM).

- Fast and simple machining, no deburring
- Increased removal rate and high wear resistance compared with copper
- Lightweight with a 4 times lower density than copper
- Elevated thermal stability and high thermal shock resistance

It can be seen from the literature review that the graphite electrodes have resulted in the smoothest surface roughness. It appears that the greater the electrical conductivity, the greater the flow of current. Consequently, it affects the roughness of the work piece. The larger currents were used, the higher the acquired surface roughness value.

6 General Characteristics Aluminium 6061 T6:

In many of the manufacturing operation, especially involving Aluminium 6061T6 , shearing is one the fastest process to reduce the raw stocks into desired lengths and other dimensions. The shear edges needs to be sharp and capable of retaining sharpness even after long periods of use. The material properties that are generally of most interest when choosing the optimum material for a particular cutting application include:

- Wear resistance
- Toughness or shock resistance
- High working capacity
- Anti corrosive
- Low cost and easily available

Table-2: Chemical Composition of Aluminium 6061 T6

S.NO.	Element	Composition %
1.	Aluminum	95.8-98.6
2.	Chromium	0.04 – 0.35
3.	Copper	0.15-0.4
4.	Iron	Max 0.7
5.	Magnesium	0.8-1.2
6.	Manganese	Max 0.15
7.	Silicon	0.4 – 0.8
8.	Titanium	Max 0.15
9.	Zinc	Max 0.25
10.	Remaining	Max 0.15

Table-3: Mechanical properties of Aluminium 6061 T6

Density g/cm ³	Elastic modulus (E), GPa	Coefficient of thermal expansion, $\mu\text{m}/^\circ\text{C}$	Thermal conductivity, W/Mk	Hardness	Tensile strength, MPa
2.70	68.9	23.6	151-202	95	124-290

7 Experimental setup:

As per objective of the complete set of experimental work will be performed on Electric Discharge Machine available in the workshop of department of Mechanical Engineering

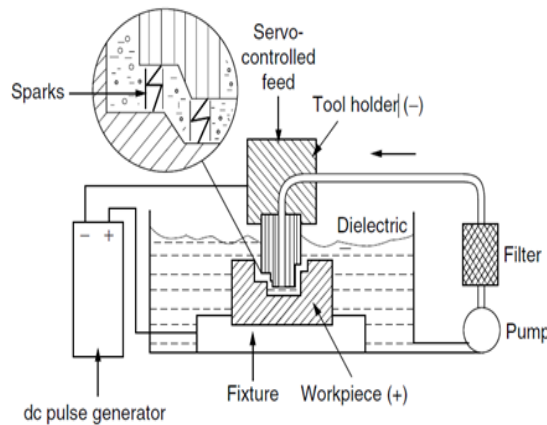


Figure 2: Line Diagram of Experimental Setup

8 Measurement of Independent parameters:

This implies to analyse the effect of surface roughness experimentally. The experimental phase will be conducted by adjusting the various process variables -current, voltage, pulse on time and pulse off time; for each, three levels will be taken.

Table-4: Input Variables

Sr.No.	Symbols	Input Variables	L 1	L2	L3	Units
1.	T _{on}	Pulse on time	50	70	90	micro sec
2.	T _{off}	Pulse off time	5	10	15	micro sec
3.	V	Servo Voltage	2	2	2	Volt
4.	I	Current	2	4	6	Amp

For measuring the surface roughness various parameters will be arranged as shown in table.

Table-5: Surface Roughness verses T_{on} and T_{off}

I = 2 amp	5 (T_{off})	10 (T_{off})	15 (T_{off})
50 (T_{on})	2.685	2.272	2.132
70 (T_{on})	2.7592	2.430	2.243
90 (T_{on})	2.832	2.641	2.378

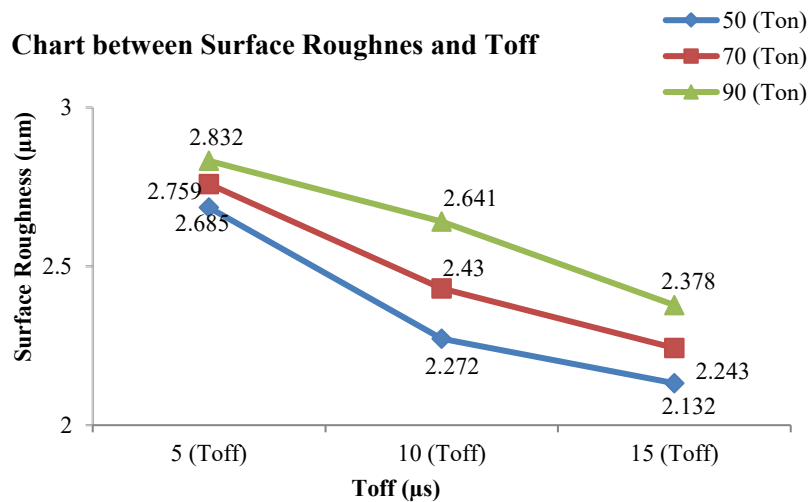


Figure 3-Changes of Surface roughness with pulse on time (T_{on}) and pulses off time (T_{off}).

The figure 3 shows the combine upshot of pulse on time (T_{on}) and pulse of time (T_{off}) on surface roughness. As shown in figure 3 at current (I) is 2 ampere and 50 micro sec pulse on time, when is pulse off (T_{off}) time changing from 5 micro sec to 15 micro sec the surface roughness changes from 2.378 micro m to 2.132 micro m respectively. Similarly it is having same effect when pulse on time (T_{on}) is 70 micro sec and 90 micro sec hence it may be concluded that as pulse off time (T_{off}) increase as surface roughness decrease and pulse on time (T_{on}) is increase then the surface roughness is also increases.

Table-5: MRR verses T_{on} and T_{off}

I = 2 amp	5 (T_{off})	10 (T_{off})	15 (T_{off})
50 (T_{on})	1.884	2.432	3.561
70 (T_{on})	1.534	2.2245	3.345
90 (T_{on})	1.261	2.012	3.0645

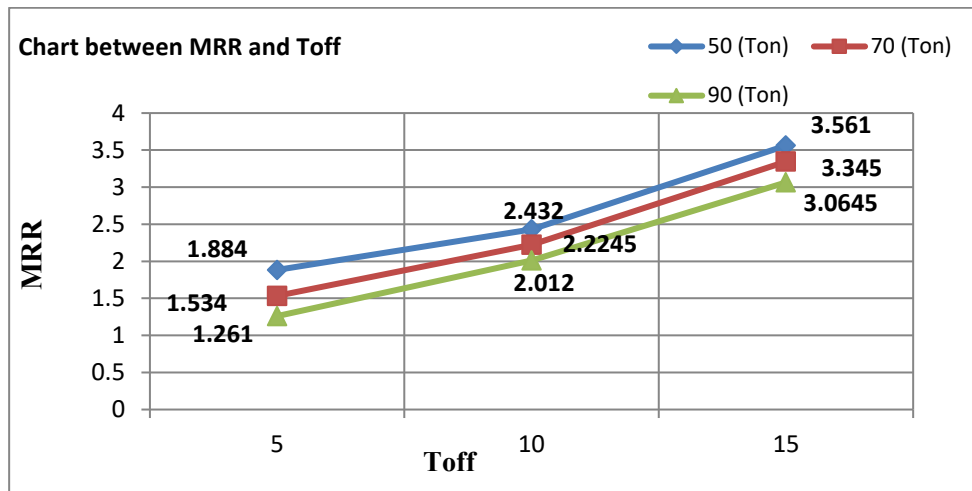


Figure 3-Changes of MRR with pulse on time (T_{on}) and pulses off time (T_{off}).

The figure 3 shows the combine upshot of pulse on time (T_{on}) and pulse of time (T_{off}) on MRR. As shown in figure 3 at current (I) is 2 ampere and 50 micro sec pulse on time (T_{on}), when is pulse off (T_{off}) time changing from 5 micro sec to 15 micro sec the MRR changes from 1.884 gm/min to 3.561 gm/m respectively. it is having the effect when pulse on time (T_{on}) is 50 micro sec and 90 micro sec MRR is reduce hence it may be concluded that as pulse off time (T_{off}) increase as MRR Increase and pulse on time (T_{on}) is increase then the MRR is decrease.

Table-6: surface roughness verses T_{on} and T_{off}

$I = 3$ amp	5 (T_{off})	10 (T_{off})	15 (T_{off})
50 (T_{on})	3.609	3.239	2.921
70 (T_{on})	3.759	3.344	3.029
90 (T_{on})	3.892	3.521	3.167

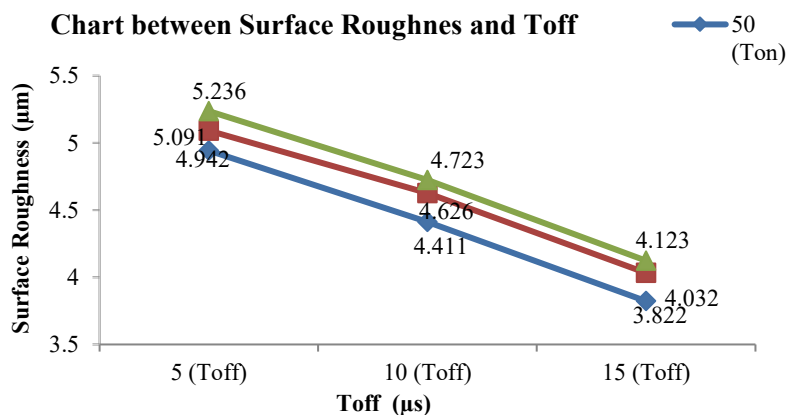


Figure 4-Changes of surface roughness with pulse on time (T_{on}) and pulses off time (T_{off}).

The figure 4 shows the combine upshot of pulse on time (T_{on}) and pulse off time (t_{off}) on surface roughness. As shown in figure 4 at current (I) is 3 ampere and 50 micro sec pulse on time, when is pulse off (T_{off}) time changing from 5 micro sec to 15 micro sec the surface roughness changes from 3.690 micro m to 3.124 micro m respectively. Similarly it is having same effect when pulse on time (T_{on}) is 70 micro sec and 90 micro sec hence it may be concluded that as pulse off time (T_{off}) increase as surface roughness decrease and pulse on time (T_{on}) is increase then the surface roughness is also increases.

Table-6: MRR verses T_{on} and T_{off}

I = 3 amp	5 (T_{off})	10 (T_{off})	15 (T_{off})
50 (T_{on})	4.8625	6.233	7.131
70 (T_{on})	4.262	5.4305	6.323
90 (T_{on})	3.592	4.336	5.741

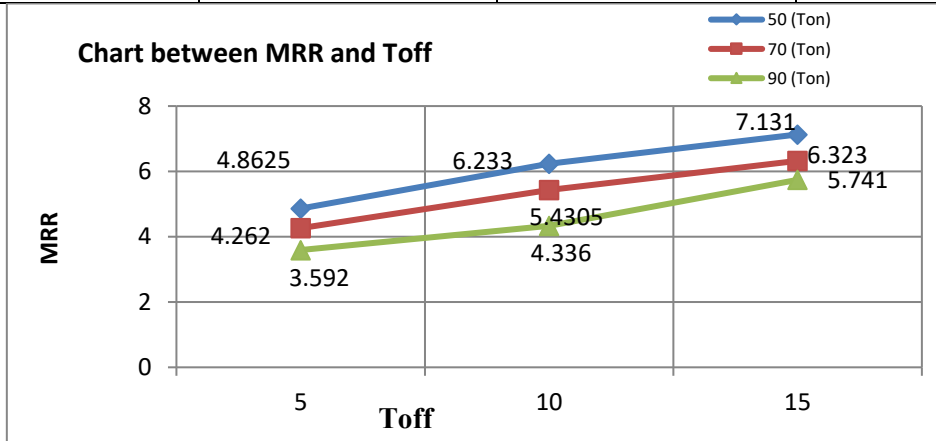


Figure 4-Changes of MRR with pulse on time (T_{on}) and pulses off time (T_{off}).

The figure 4 shows the combine upshot of pulse on time (T_{on}) and pulse of time (T_{off}) on MRR. As shown in figure 3 at current (I) is 3 ampere and 50 micro sec pulse on time (T_{on}), when is pulse off (T_{off}) time changing from 5 micro sec to 15 micro sec the MRR changes from 4.8625 gm/min to 7.131gm/m respectively. it is having the effect when pulse on time (T_{on}) is 50 micro sec and 90 micro sec MRR is reduce hence it may be concluded that as pulse off time (T_{off}) increase as MRR Increase and pulse on time (T_{on}) is increase then the MRR is decrease

Table-7: Surface Roughness verses T_{on} and T_{off}

I = 4 amp	5 (T_{off})	10 (T_{off})	15 (T_{off})
50 (T_{on})	4.942	4.411	3.822
70 (T_{on})	5.091	4.626	4.032
90 (T_{on})	5.236	4.723	4.123

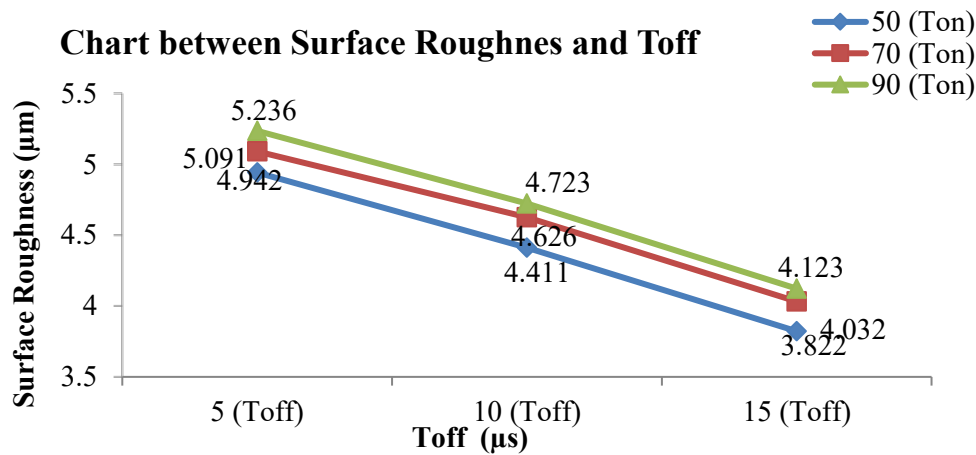


Figure 5-Variation of surface roughness with pulse on time (T_{on}) and pulses off time (T_{off}).

The figure 5 shows the combine effect of pulse on time (T_{on}) and pulse off time (t_{off}) on surface roughness. As shown in figure 5 at current (I) is 4 ampere and 50 micro sec pulse on time, when is pulse off time (T_{off}) changing from 5 micro sec to 15 micro sec the surface roughness changes from 4.423 micro m to 4.122 micro m respectively. Similarly it is having same effect when T_{on} is 70 micro sec and 90 micro sec hence it may be concluded that as pulse off time (T_{off}) increase as surface roughness decrease and pulse on time (T_{on}) is increase then the surface roughness is als increases.

For measuring the MRR various parameters will be arranged as shown in table.

Table-7: MRR verses T_{on} and T_{off}

$I = 4 \text{ amp}$	5 (T_{off})	10 (T_{off})	15 (T_{off})
50 (T_{on})	11.875	13.911	16.822
70 (T_{on})	9.989	12.915	15.632
90 (T_{on})	7.936	10.723	14.134

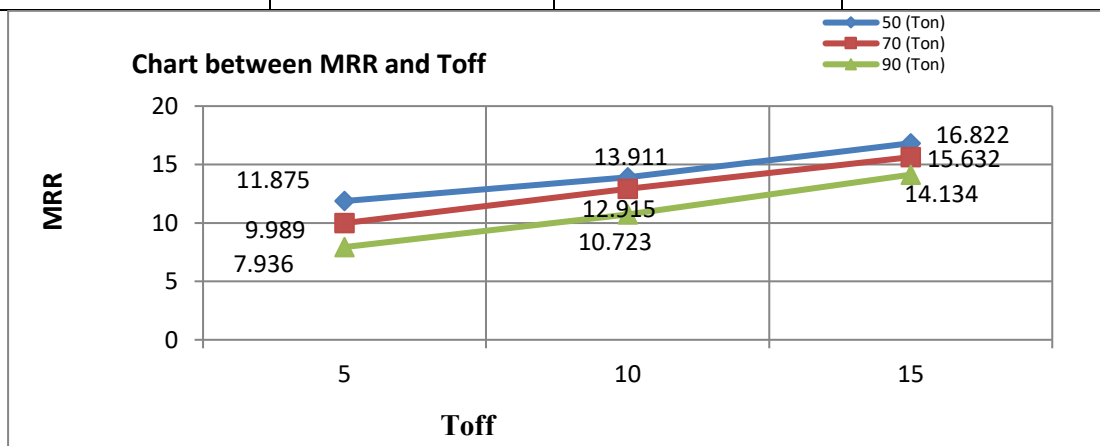


Figure 5-Variation of surface roughness with pulse on time (T_{on}) and pulses off time (T_{off}).

The figure 5 shows the combine upshot of pulse on time (Ton) and pulse of time (Toff) on MRR. As shown in figure 3 at current (I) is 3 ampere and 50 micro sec pulse on time (Ton), when is pulse off (Toff) time changing from 5 micro sec to 15 micro sec the MRR changes from 11.875gm/min to 16.822gm/m respectively. it is having the effect when pulse on time (Ton) is 50 micro sec and 90 micro sec MRR is reduce hence it may be concluded that as pulse off time (Toff) increase as MRR Increase and pulse on time (Ton) is increase then the MRR is decrease

Table- 8 surface roughness verses Ton and Toff for taguchi optimization

S.No	I	T _{on}	T _{off}	Surface roughness	S/N Ratio
1	2	50	5	2.378	-7.5242
2	2	70	10	2.685	-8.5789
3	2	90	15	2.430	-7.7121
4	3	50	10	3.609	-11.1477
5	3	70	15	3.344	-10.4853
6	3	90	5	3.167	-10.0130
7	4	50	15	4.123	-12.3043
8	4	70	5	4.942	-13.8781
9	4	90	10	4.626	-13.3041

9 Taguchi Analysis:

Taguchi techniques are used extensively in engineering design (Ross1996 & Phadke1989). The Taguchi methodology contains system style, parameter style, and tolerance style procedures to realize a strong method and result for the simplest product quality (Taguchi 1987& 1993). The most trust of Taguchi's techniques is that the use of parameter style (Ealey Lance A. 1994), that is an engineering method for a product or method design that focuses on determining the parameter (factor) settings, manufacturing the simplest levels of a high quality characteristic (performance measure) with minimum variation. Taguchi approach to design of experiments is simple to be adopted and applied for users with limited data of statistics

10 Linear Model Analysis: SN ratios versus current, pulse on time, pulse off time

It can be seen by the collected data that all the controlled parameters i.e. current, pulse on time and pulse off time, calculate S/N ratio because minimum surface roughness given batter surface finish quality and its plots are generated for S/N ratio using MiniTab-17 software. The first category “smaller is better” was selected to find out the optimum parameters for

minimization of surface roughness which is the required condition for machined parts with good surface quality.

Table 9 : Analysis of Variance for SN ratios

Source	DF	Seq SS	Adj SS	Adj MS	F	P
Current	2	40.9310	40.9310	20.4655	65.84	0.015
T _{on}	2	0.8364	0.8364	0.4182	1.35	0.426
T _{off}	2	1.0934	1.0934	0.5467	1.76	0.362
Residual Error	2	0.6217	0.6217	0.3108		
Total	8	43.4825				

S = 0.5575 R-Sq = 98.6% R-Sq(adj) = 94.3%

The experimental results were analyzed with Taguchi optimization technique by Minitab-17 software, which used to identifying the factors which is most significantly affecting the outout measures such as surface roughness. The results of the ANOVA with the surface roughness are shown in table 9. The unique sets of results have been find out by analysis of variance by which high significant process parameter can be analyzed. it can be seen that the current is the highest statistically significant factor with the F-value = 65.84 and lowest statistically significant factor with p-value = 0.015, while the effect of T_{on} has not been found significant with F-value = 1.35, and p-value = 0.426). Unique sets of results depend upon the R-square from table 9, R-Square = 98.6%) which is highly significant value.

Table 10: Response Table for Signal to Noise Ratios

Level	Current (I)	Pulse on time (T _{on})	Pulse off time (T _{off})
1	-7.938	-10.325	-10.472
2	-10.549	-10.981	-11.010
3	-13.162	-10.343	-10.167
Delta	5.224	0.655	0.843
Rank	1	3	2

The table 10 shows the respective rank value for each factor that the current (Rank 1) is the highest affecting factor which has strongest upshot on the surface roughness followed by pulse off time (Rank 2) and last by pulse on time (Rank 3).

11 Main Effects Plot for SN ratios

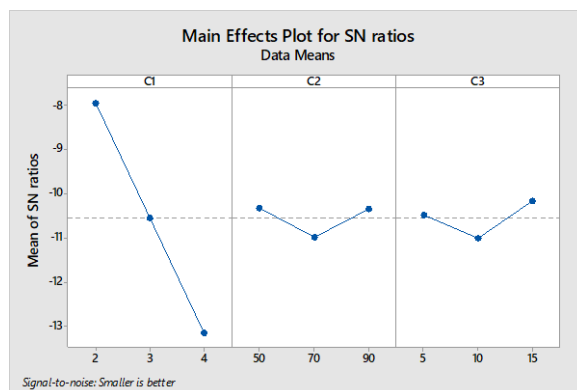


Figure -6 S/N Ratios verses process parameters (current, pulse on time, pulse off time) plots. The main effect plots of S/N ratio as shown in Fig.6 shows that in order to obtain optimum value for for Surface Roughness, Current should be set to as 4 Amp and the pulse on time should be 70 and pulse off time i.e. 10 micro sec micro sec.

Table- 8 MRR verses T_{on} and T_{off} for taguchi optimization

S.No	I	T_{on}	T_{off}	MRR	S/N Ratio
1	2	50	5	1.884	5.501618
2	2	70	10	2.2245	6.944648
3	2	90	15	3.0645	9.727193
4	3	50	10	6.233	15.89394
5	3	70	15	6.323	16.01846
6	3	90	5	3.592	11.10673
7	4	50	15	16.822	24.51755
8	4	70	5	9.989	19.99044
9	4	90	10	10.723	20.60633

9 Taguchi Analysis:

Taguchi techniques are used extensively in engineering design (Ross1996 & Phadke1989). The Taguchi methodology contains system style, parameter style, and tolerance style procedures to realize a strong method and result for the simplest product quality (Taguchi 1987& 1993). The most trust of Taguchi's techniques is that the use of parameter style (Ealey Lance A. 1994), that is an engineering method for a product or method design that focuses on determining the parameter (factor) settings, manufacturing the simplest levels of a high quality characteristic (performance measure) with minimum variation. Taguchi approach to design of experiments is simple to be adopted and applied for users with limited data of statistics

10 Linear Model Analysis: SN ratios versus current, pulse on time, pulse off time

It can be seen by the collected data that all the controlled parameters i.e. current, pulse on time and pulse off time, calculate S/N ratio because maximum MRR given batter result and its plots are generated for S/N ratio using MiniTab-17 software. The first category “larger is better” was selected to find out the optimum parameters or maximization of MRR which is the required condition for machined parts with higher mrr.

Table 9 : Analysis of Variance for SN ratios

Source	DF	Adj SS	Adj MS	F	P
Current	2	162.189	81.095	58.12	0.017
T _{on}	2	11.053	5.526	3.96	0.202
T _{off}	2	19.851	9.925	7.11	0.123
Residual Error	2	2.791	1.395		
Total	8	195.883			
S = 1. 1.18124 R-Sq = 98.58% R-Sq(adj) = 94.3%					

The experimental results were analyzed with Taguchi optimization technique by Minitab-17 software, which used to identifying the factors which is most significantly affecting the outout measures such as MRR. The results of the ANOVA with the MRR are shown in table 9. The unique sets of results have been find out by analysis of variance by which high significant process parameter can be analyzed. it can be seen that the current is the highest statistically significant factor with the F-value = 58.12 and lowest statistically significant factor with p-value = 0.017, while the effect of T_{on} has not been found significant with F-value = 3.96, and p-value = 0.202). Unique sets of results depend upon the R-square from table 9, R-Square = 94.30%) which is highly significant value.

Table 10: Response Table for Signal to Noise Ratios

Level	Current (I)	Pulse on time (T _{on})	Pulse off time (T _{off})
1	7.391	15.304	12.200
2	14.340	14.318	14.482
3	21.705	13.813	16.754
Delta	14.314	1.491	4.555
Rank	1	3	2

The table 10 shows the respective rank value for each factor that the current (Rank 1) is the highest affecting factor which has strongest upshot on the surface roughness followed by pulse off time (Rank 2) and last by pulse on time (Rank 3).

11 Main Effects Plot for SN ratios

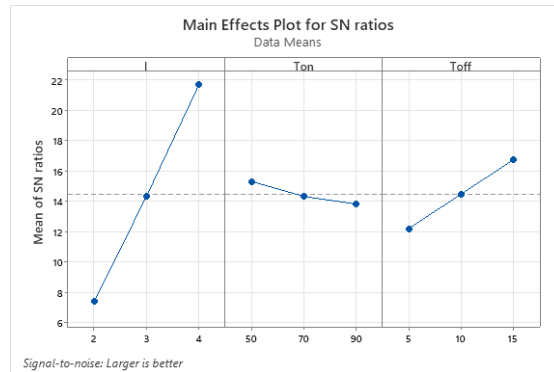


Figure -6 S/N Ratios verses process parameters (current, pulse on time, pulse off time) plots

The main effect plots of S/N ratio as shown in Fig.6 shows that in order to obtain optimum value for for surface roughness, Current should be set to as 4 amp and the pulse on time should be 50 and pulse off time i.e. 15 micro sec micro sec.

12 Conclusion

The analysis of the output parameters and experimental results for three levels of current, pulse on time and servo voltage were carried out. These techniques give the relation between input parameter and output parameter.

As per analysis for the surface roughness the value of current is increase with increasing the pulse on time (T_{on}) surface roughness is also increase mean while the value of pulse off time (T_{off}) will also increase at the same time the value of surface roughness is decreasing.

The current (Rank 1) is the highest effecting parameters which has highest effect on the surface roughness then pulse off time (Rank 2) and lowest on time (Rank 3).

From the measured value of Surface Roughness (SR), it is shows that the surface finish deteriorates with increase in current. Current is found to be the highest effecting parameters which has highest effect on the surface roughness followed by pulse off time and last by pulse on time

The analysis of the output parameters and experimental results for three levels of current, pulse on time and servo voltage were carried out. These techniques give the relation between input parameter and output parameter.

As per analysis for the MRR the value of current is increase with increasing the pulse on time (T_{off}) MRR is also increase mean while the value of pulse on time (T_{on}) will also increase at the same time the value of MRR is decreasing.

The current (Rank 1) is the highest effecting parameters which has highest effect on the MRR then pulse off time (Rank 2) and lowest pulse on time (Rank 3).

From the measured value of MRR, it is shows that the MRR deteriorates with increase in current. Current is found to be the highest effecting parameters which has highest effect on the MRR followed by pulse off time and last by pulse on time

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