

Investigations of process parameters on surface finish of aluminium component produced by die sink electric discharge machining process

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Electric discharge machining (EDM) is one of the unconventional machining methods used to create slots, holes, and complex structures, irrespective of the hardness of the material. Die sink EDM is a productive and an economical manufacturing process that yields parts with higher grades of surface finish. Surface roughness of the component has been greatly influenced by peak current, pulse ON time and pulse OFF time. Improper combinations of these process variables will lead to decrease in surface quality. The aim of the study is to evaluate the influence of various process parameters used in die sink EDM to obtain a good surface finish in the fabricated aluminium component. Peak current, pulse on time, and pulse off time are the process parameters that have been considered for the study. Taguchi technique has been used to accomplish parameter optimization with an L9 orthogonal array, and analysis of variance has been utilized to determine the optimum parameter combination and its influence. The optimal value has been determined and it has been found that the peak current, followed by the pulse off time, and the pulse on time, have a substantial impact on the surface roughness.

Keywords: Electric discharge machining, Peak current, Pulse ON time, Pulse OFF time surface finish, Analysis of variance

1 Introduction

The working principle of EDM machining process is spark generation. It is basically the removal of material between two conductors based on erosion and vaporization. While one electrode serves as a work piece, the other acts as a tool. Workpiece and the tool has been used in the EDM machine should possess conductive properties. Wire EDM, hole drilling EDM, and die sink EDM are the three main classifications of EDM¹. The work piece material melts as a result of the electric sparks that are created between the tool electrode and the work piece, increasing the temperature of the Inter Electrode Gap (IEG) to a temperature of 12000°C. Dielectric fluid flushing such as kerosene oil, hydrocarbon oil, and de-ionized water removes the chips from the machining zone at the IEG. EDM often transforms a metallic surface to a matte finish. This is because, it removes material in the form of microscopic particles known as debris².

The quality, productivity, and cost of the machined parts are directly influenced by the dielectric fluid utilized in the EDM machine. Dielectric fluid has been chosen solely based on its quality, price, and ecological impact. The rate of removal of material and the surface quality of the finished part will be greatly influenced by

the fluid. Hydrocarbon oil, kerosene oil, and deionized water are the three forms of dielectric fluids that have been utilized in EDM machines³. When using an EDM machine, the tool's shape is replicated onto the workpiece, however there is a need for boundary between them for spark creation. If this spacing has been kept higher, it would result in a poor surface finish. Therefore, in order to obtain a matte finish, it is required to maintain a smaller spacing between the tool and workpiece. The electrode utilized in the process primarily consists of two parts such as a tool holder and a tool. The choice of material will be determined by its surface roughness, cost, rate of tool wear and capability to be machined. Copper and graphite are most often used tools⁴.

EDM machines are equipped with a unit that regulates and keeps track of the machining parameters, including axis and gap motions. Due to its favourable effects on the surface roughness (SR), copper or graphite is typically employed as the electrode tool material in this procedure with hydrocarbon dielectric⁵. The dielectric has been filtered to remove the suspended particles before being reintroduced into the cooling system, where it carries the debris and degraded material with it. The electrode needs to be reshaped in order to perform the finishing operations during the die-sinking EDM

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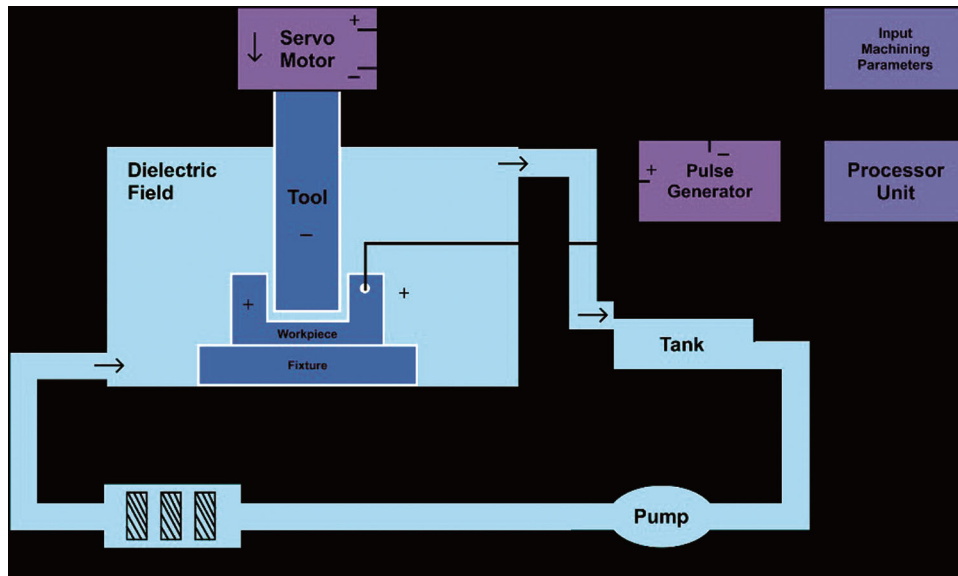


Fig. 1 — Schematic representation of die-sinking EDM.

process. A schematic representation of the die-sinking EDM is shown in Fig. 1.

Singh *et al.*⁶ have comprehended the multi-response electrical machining (EDM) in super-alloy, Inconel-718. The study focused on optimizing and discovering the ideal combination of process variables, such as discharge current, pulse-on duration and dielectric fluid pressure. Based on an L9 orthogonal array, nine different investigations each using wounded metal as the electrode were carried out. A productivity statistic called Material Removal Rate (MRR) was used to gauge how well the EDM process works. The combination of 22 A discharge current, 200 μs pulse-on time, and 0.4 kg/cm^2 flushing pressure shown to be the best for machining. The results clearly show that the pure tungsten electrode may be utilized in EDM as a tool for cutting Inconel 718 at high discharge currents (18A-22A) and high pulse-on times (50-200 μs) without experiencing any rupture.

Sultan *et al.*⁷ have addressed a response surface method with an attempt to forecast the rate of material removal, electrode wear, and surface roughness in a die-sinking EDM process. A Box-Behnken design with three variables and three levels has been used to discover the critical experimental conditions. A copper electrode with a tubular cross-section have been utilized to drill holes in an EN 353 steel alloy workpiece during the testing to change the pulse on time, pulse off time, and peak current. The ideal values for MRR, tool wear rate (TWR), and SR are respectively 17.62 mm^3/min , 6.47 mm^3/min , and 4.54 μm , achieved at 100.77 μs , 25.43 μs , and 45 A,

respectively, for the parameters pulse on time, pulse off time and peak current.

Ashok Kumar *et al.*⁸ has employed die sinker EDM to create micro-holes with a diameter of 0.7 mm (700 μm) in SS316 materials. Taguchi L9 Orthogonal Array has been used to create the experiment model, and the process parameters considered are current, time-ON, and time-OFF. Material removal rate and tool wear rate have been considered as response performances. The ideal ratio for material removal rate has been found to be 0.8 A, pulse ON time of 6 μs and pulse OFF time of 8 μs . The ideal pairing for tool wear rate is current of 0.4 A, pulse ON time of 6 μs , pulse OFF time of 6 μs . The contribution percentage for pulse ON time is 39.27% for MRR and 56.21% for TWR. Verma *et al.*⁹ have investigated the impact of input parameters on the machining properties of copper electrode-powered EDM for titanium Grade-V alloy. The control parameters considered are fluid pressure, current, gap voltage, and pulse on time. It has been found that the material removal rate increases with higher Peak current, gap voltage, and pulse-on-time values, but it decreases with higher dielectric fluid flow pressure. Peak current, gap voltage, and pulse on time rise with increase in surface roughness, but dielectric fluid flow pressure increases with a rise in surface roughness.

Sharif *et al.*¹⁰ has aimed to study the input parameters of electrical discharge machining (EDM) and its influence on the process characteristics. The study has been chosen to combine two sophisticated materials,

using copper-impregnated graphite as the electrode and stainless steel 316 L as the workpiece. Analysis of Variance (ANOVA) and mathematical modeling has been established for optimizing Material Removal Rate (MRR), Electrode Wear Rate (EWR), Surface Roughness (SR), and Dimensional Accuracy (DA). The results obtained shows that all variable responses were most significantly influenced by the peak current. Sudhir Kumar *et al.*¹¹ has employed DS - EDM for the machining of AISi420 steel with the copper electrode. It has been performed to maximize MRR and reduce EWR by optimizing the machining control variables. By combining the Taguchi methodology with the GRA method, the measured machining performance of the MRR and EWR has been investigated. The experimental configuration results stated that the multi-performance characteristics were affected in the order of pulse current, followed by gap voltage and by pulse ON time.

Dikshit *et al.*¹² have established an empirical mathematical model for surface roughness and Material Removal Rate (MRR) to study the effects of die-sinking EDM parameters, such as peak current, pulse on time, and pulse off time on Inconel 625. A quadratic model has been chosen for the empirical mathematical modelling, and central composite design has been used to arrange the layout of the experiments. ANOVA have been used to test the model's suitability using the F-test and p-test. Peak current and pulse on time have been found to be the most important factors in MRR, according to an ANOVA analysis. Surface roughness has been mostly influenced by pulse on time and pulse off time. Surface roughness constantly grows with an increase in pulse on time, whereas MRR first increases with an increase in pulse on time. Sahoo *et al.*¹³ have investigated to determine the optimum process parameters for machining of Inconel-625 alloy work piece with copper electrode on die sink electrical discharge machine. Machining performance features including material removal rate (MRR) and tool wear rate has been studied. Experiments have been conducted based on Taguchi L9 orthogonal by considering the parameters such as altering pulse on time, flushing pressure, and peak current in three levels. The (MRR) and (TWR) are revealed to be mostly affected by peak current (contributing 78%) and pulse on time (contributing 18%), respectively.

Vikas *et al.*¹⁴ have employed the Taguchi technique to maximize the MRR of two different materials namely EN19 and EN41, by considering parameter values for current, voltage, pulse on time, and pulse

off time, which were treated as input process parameters. From the result, it has been found that highest MRR for EN19 for current of 24 amps, voltage of 40 volts, pulse on time of 400 s, and pulse off time of 2300 s, whereas the same for EN41 are 24 amps, 40V, 400 s, and 2100 s, respectively. Bhosle *et al.*¹⁵ have conducted gray relational analysis to identify a particular optimal parameter setting for micro-electrical discharge machining during the drilling process of the Inconel 600 alloy. Tungsten carbide tools has been used to drill tiny holes by considering the efficient process parameters such as voltage, capacitance, feed rate, pulse-on time, and pulse-off time. The performance metrics that were measured the rate of material removal, taper angle, over-cut, and diametral variance at the entry and exit of a micro hole. The ideal machining performance for maximum material removal rate, minimal taper, over-cut, and diametral variation have been obtained for 175V voltage, 1000 pF capacitance, 20 m/s EDM federate, 15 s pulse length, and 50 s pulse interval.

Rengasamy *et al.*¹⁶ have developed a metal matrix composites (MMC) using stir casting to strengthen aluminium 4032 with reinforcement particles such as Zrb2 and Tib2 in various weight percentages (0,2,4,6,8) at room temperature. Adopted copper electrode for machining, input parameters considered are pulse on time, pulse off time, and current. Taguchi L25 orthogonal array has been used to determine the optimal process parameters. The percentage of contribution by each parameter has been investigated using the analysis of variance (ANOVA). The input parameter value of approximately 8% composites, pulse on time, pulse off time, and current of approximately 7.0 (s), 7 (s), and 26 (Amps) respectively yields the output parameter values of about 0.190 (g/min), 0.005 (g/min), and 2.155 (g/min), which are the most influential process parameters in obtaining minimum material removal rate, tool wear rate, and depth. Sahoo *et al.*¹⁷ have explored process factors including discharge current, pulse-on-time, and duty cycle with the performance metrics like metal removal rate (MRR) and electrode wear rate (EWR). In a die sinking EDM, experiments have been carried out on tungsten carbide using a copper electrode. Mathematical model and empirical connections between process parameters and process responses has been demonstrated with response surface methodology. The peak current has been discovered to be the primary component affecting both the MRR and EWR.

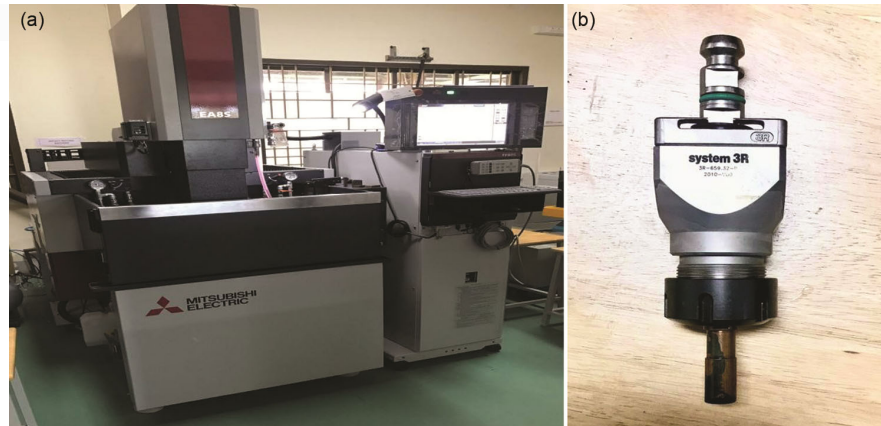


Fig. 2 — (a) Mitsubishi electric die-sink EDM, and (b) Cutting tool holder with tool.

Table 1 — Properties of copper electrode material

Electrode Material	Density (g/cc)	Specific Heat (KJ/Kg.K)	Thermal Conductivity(W/mK)	Electrode Resistivity ($\mu\Omega$ -cm)	Vicker Hardness (MPa)	Poisson Ratio
Copper	8.96	0.39	401	1.673	369	0.34

Table 2 — Process parameters and their levels

Factors	Level 1	Level 2	Level 3
Peak current, PI (Amps)	5	15	25
Pulse on time, P On (μ s)	35	39	48
Pulse off time, P Off (μ s)	16	32	45

Findings showed that the least EWR have been attained at 6 A discharge current, 10 s pulse on time, while the maximum MRR was at 10 A discharge current, 50 s pulse on time, and 8 duty cycle.

The literature review indicates that machining of component using DS-EDM still needs to be explored thoroughly; thus, emphasis to evaluate the various process and machining parameters influencing the surface roughness of the DS-EDM machined components. The process parameters such as peak current, pulse OFF time and pulse ON time on surface roughness, and machining time have to be studied for wide application of the process. There is a distinct reason behind this process and response parameters, which needs an experimental study to analyze the trend and behaviour of process variables.

The present study determines the effects of three different process variables, namely, peak current, pulse ON time and pulse OFF time on material removal, surface roughness, and machining time of aluminium component. The factors affecting the behaviour of process variables has been analyzed and these parameters have been studied and controlled. The most influential parameter is to be found by performing the regression analysis using Taguchi methodology.

2 Materials and Methods

The study was carried out using a Mitsubishi Electric EA8S Die sinks EDM as shown in Fig. 2 (a). Aluminium substrate is a unique metal-based copper clad laminate offering good thermal conductivity, electrical insulation properties and improved machinability. The electrode for machining the workpiece should have high wear resistance. So, Aluminum substrate of dimension 120 x 70 x 3 mm was used as the work material and tool made up of copper with dimension of 14 mm was employed as an electrode, and hydrocarbon oil as the dielectric. Flushing was employed to remove the debris. The cutting tool holder used in the experiment is shown in Fig. 2(b). Whole measuring of 0.679 mm in depth and 14 mm in diameter was chosen as the final geometry to be machined. Copper electrode properties are specified in the Table 1. The peak current, pulse on time, and pulse off time which have a substantial effect on surface roughness and machining time which was considered for the experimental work. Selected process variables and their levels are shown in the Table 2.

Process parameter optimization has been performed not only to increase productivity but also to reduce the

Table 3 — L9 Orthogonal array

Ex. No	Variables					
	A	B	C	PI (Amps)	P on (μs)	P off (μs)
1	1	1	1	5	35	16
2	1	2	2	5	39	32
3	1	3	3	5	48	45
4	2	1	2	15	35	32
5	2	2	3	15	39	45
6	2	3	1	15	48	16
7	3	1	3	25	35	45
8	3	2	1	25	39	16
9	3	3	2	25	48	32

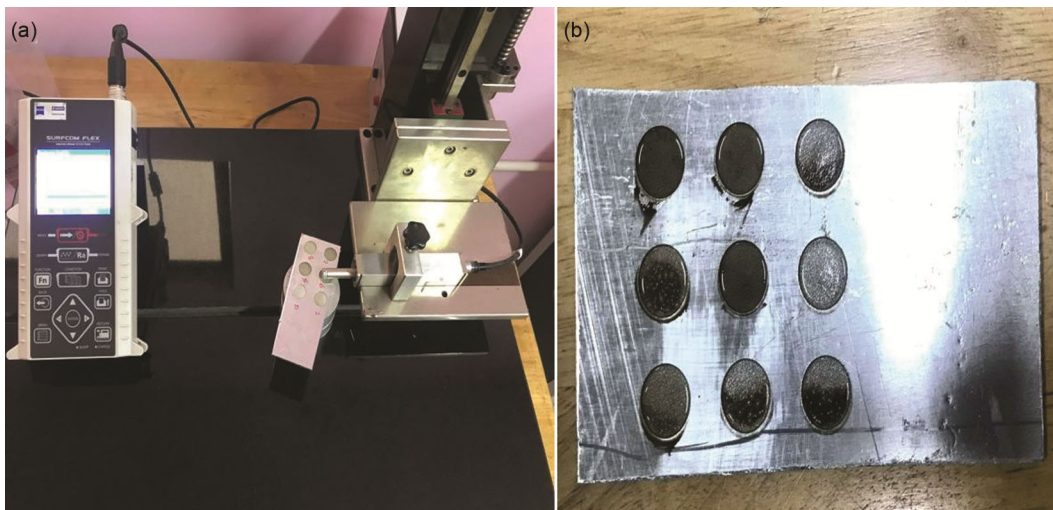


Fig. 3 — Surface roughness measurement.

awareness of changes in environmental issues, including various noise characteristics. Fundamentally, the parameter setting in the conventional technique is ambiguous and difficult to use. There are more process parameters; hence more experiments must be performed. Taguchi technique has been used as a special layout to evaluate with a constrained number of experiments. Where for a set of process parameter, the signal-to-noise ratio (SNR) can be calculated through Taguchi technique. The comprehensive evaluation of signal-to-noise ratio is necessary to optimize a Multiple Performance Characteristics (MPC). The number of levels matching each of the criteria was used to determine which Orthogonal Array (OA). Since there are two Degrees of Freedom (DOF) for each of the factors, a total of six freedom levels are obtained (i.e., $3 \times 2 = 6$). The chosen OA freedom levels must be larger than the sum of all factor levels of freedom. The DOF is 8. (i.e., number of experiments-1). L9 is thus taken into consideration for the study and is provided in Table 3. Average surface roughness, mean surface roughness,

and machining time were used to gauge the effectiveness of the operation. With the help of Surf-com Flex surface roughness measurement apparatus as shown in Fig. 3 and a diamond point stylus with a 4 mm evaluation length, the surface roughness was measured. Surface roughness value was provided in the Table 4.

The experiment design and analysis were carried out using the Taguchi technique. The smaller the best in the signal-to-noise ratio was chosen to measure the surface and processing quality. This is considered to minimize the surface roughness of the machined aluminium surface. Larger the Signal to Noise ratio, lower the impact. The signal-to-noise (S/N) ratio was calculated for each factor level combination. The formula for the smaller-is-better S/N ratio is shown in Eq. (1).

$$S/N = -10 \log (\Sigma(Y_2)/n) \quad \dots(1)$$

where, Y = responses for the given factor level combination and n = number of responses in the factor level combination.

Table 4 — Measurement of surface roughness

Ex. No	Process parameters			Time (min)	Ra (μm)	Rz (μm)
	PI (Amps)	P on (μs)	P off (μs)			
1	5	35	16	12.35	2.275	14.214
2	5	39	32	19	2.321	14.312
3	5	48	45	24.34	2.473	15.19
4	15	35	32	3.39	5.933	30.809
5	15	39	45	3.37	6.546	36.693
6	15	48	16	2.25	6.147	32.572
7	25	35	45	3.16	7.093	37.203
8	25	39	16	1.39	6.828	34.656
9	25	48	32	2.08	6.949	37.368

3 Results and Discussion

Working efficiency of EDM machine decreases due to a short circuit when debris builds up in the IEG during machining. This has been overcome by using the flushing mechanism to remove the particles. High-pressure dielectric fluid flushing is necessary to destroy the ionization bridges in the IEG to prevent metal particle buildup and adhesion¹⁸. The recast layer on the material will be formed as a result of several electrical sparks between the electrodes in the dielectric fluid. The recast layer's surface, which is extremely hard, brittle, and in-homogeneous, was formed while the metallurgical structure and properties were altered. The recast layer formed by the EDM process will result in increased surface roughness and decreased fatigue strength, as well as micro cracks and microvoids¹⁹.

The flushing and debris-cleaning steps in the machining process are extremely hard. This will result in a decrease in the machine rate and IEG. To resolve this, a new jump operation for the tool must be implemented. By doing this, the IEG will be increased and the flushing techniques will have enough time to remove the debris²⁰. Increase in jump height increases debris particle removal and reduces dimensional error caused by lateral discharge. The die sink EDM machine's parameters, which are used to evaluate the machining process, can be divided into two categories such as process parameters and performance parameters. Process parameters include discharge current, duty cycle, voltage, pulse on time, pulse off time, arc gap, electrode diameter, over-cut, jump height and jump speed. On the other hand, surface roughness, material removal rate, and tool wear rate comprises of the performance parameters²¹.

Taguchi technique is one of the experimental designs based on factors and levels, and it uses an efficient,

systematic, and straightforward approach to validate the best settings. The orthogonal array serves as the fundamental Taguchi design to generate less variety by developing quick, effective, and economic results with the aid of a degree of freedom. Quality control, statistics, engineering, and research are just a few of the many fields in which the Taguchi design is applied²². The significance of each independent variable in the model has been determined using the Analysis of Variance (ANOVA) test. Typically, the ANOVA test was run with a probability factor of less than 0.05 and at a 95 percent confidence level. A probability value of less than 0.05 should be considered acceptable, whereas a probability value of more than 0.05 denotes non-significant elements that should not be included in the factors used to determine the responses. Following the elimination of the non-significant components, an analysis of variance test was carried out to determine the new function²³.

The signal-to-noise ratio has been used to determine how far performance feature deviates from the target value. With minimal variance, it successfully and accurately represents the important characteristics. To obtain the higher quality characteristics from the experimental data, the S/N ratio was employed to locate the required signal and detect the undesirable random noise value. Performance factors serve as the basis for choosing the S/N ratio²⁴.

By employing a surface roughness tester to determine the response parameters such as surface roughness and recording the machining time from the observed data, the experimental process was verified. The statistical analysis was completed using Taguchi technique, and the minimum signal-to-noise ratio was considered. The experimental results are displayed in Table 5. It was determined that peak current, followed by pulse OFF and pulse ON time had an impact on the

Table 5 — Experimental results and S/N values , Mean of surface roughness

Ex. No	Input Variables			Time (min)	Ra (μm)	Rz (μm)	S/N RA1	MEAN 1
	PI (Amps)	P on (μs)	P off (μs)					
1	5	35	16	12.35	2.275	14.214	-20.7886	9.613
2	5	39	32	19	2.321	14.312	-2.7968	11.8777
3	5	48	45	24.34	2.473	15.19	-24.4158	14.001
4	15	35	32	3.39	5.933	30.809	-25.2109	13.3773
5	15	39	45	3.37	6.546	36.693	-26.6919	15.5363
6	15	48	16	2.25	6.147	32.572	-25.6576	13.6563
7	25	35	45	3.16	7.093	37.203	-26.8255	15.8187
8	25	39	16	1.39	6.828	34.656	-26.1965	14.2913
9	25	48	32	2.08	6.949	37.368	-26.8394	15.4657

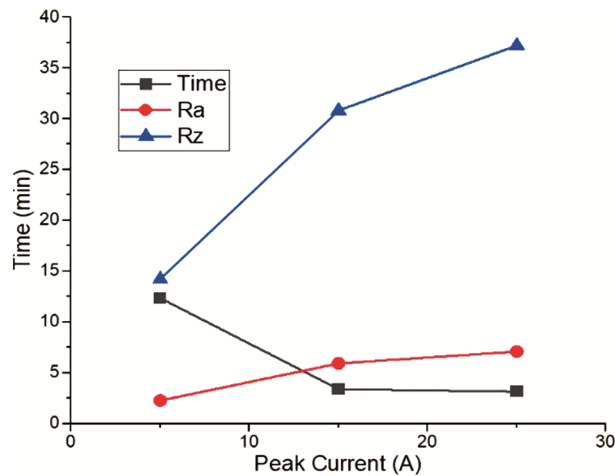


Fig. 4 — Peak current versus Ra, Rz and time.

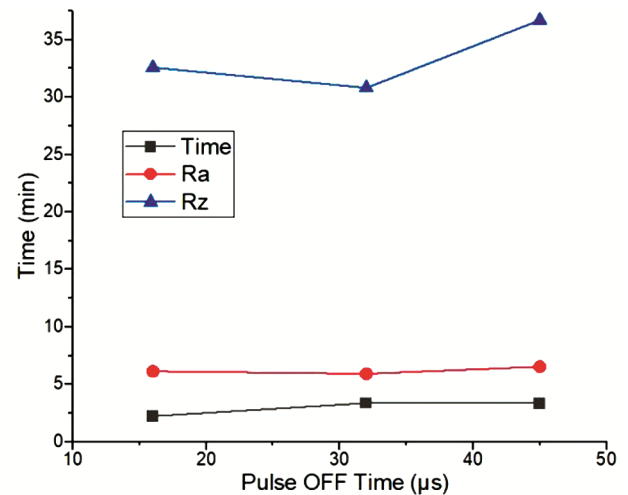


Fig. 5 — Pulse off- time versus Ra, Rz and time.

surface roughness of the substrate. Lower values of peak current showed minimal surface roughness in the material. The discharge energy enhances with peak current value of 25A leading to an increase in cutting speed as interpreted from Fig. 4.

At higher values of peak current, the gap condition may become unstable with improper combination of time ON and time OFF, voltage and servo feed setting. This might be caused by a spark that is more intense at a higher current level, causing larger craters and more material getting eroded, as a result, producing a rough surface on machine work. Surface roughness drastically increases at higher frequencies because of lower pulse off-times. This is because, especially whenever the distance between the electrode and the workpiece is small in size, higher average current flows during the period resulting in greater quantities of heat and products that can only be partly eliminated by the electrolyte during the pulse off-time. Reduced pulse-off times may cause wire breakage and increases the surface roughness of the machined surface as shown in Fig. 5.

Increased pulse off-time promotes linear dissolution and decreases material removal from the broader region of the workpiece by removing Joule heat from the machining zone, preventing bubble formation, and making sludge removal easier. Material Removal Rate (MRR) increases with peak current and pulse on time (Pon), on the other hand it decreases with increase in pulse off time (Poff) and peak current. MRR increased as Pon increase, and at the expense of Poff. In general, surface roughness increased with an increase in Pon and peak current, whereas surface roughness dropped with an increase in Poff. With a decline in Poff and a rise in Pon, surface roughness surged. It was discovered that surface roughness elevated in correlation with increased peak current and decreased Poff. However, there is no change in trend seen in surface roughness for increasing pulse OFF time. Surface roughness increases on increase in Pulse ON Time as shown in Fig. 6.

In general, on-time must be shorter than off-time in order to completely eliminate reaction products generated during the previous half-cycle and maintain

the IEG's ready for the subsequent half-cycle. The electrochemical dissolution of the anode occurs during on-time. Higher pulse on time melts more amount of material, the molten material spells around the machined surface and thus forms larger globule of debris and causing higher surface roughness. Thus, pulse ON time should be optimized for better surface finish. The surface roughness will not vary greatly as a result of the identical pulse-on-time and pulse-off-time trends, but the machining time will grow linearly as the time increases.

3.1 Taguchi analysis: Ra versus PI, P On, P Off

It was discovered that the levels of peak current and peak voltage utilised during machining strongly impact the nature of the sparking, which in turn influences the nature of the machined surface. Voltage across electrodes is absent during pulse OFF time. A lower value of Poff for a particular pulse duration results in an increase in pulse on time, which causes more discharges and an increase in sparking efficiency and cutting rate. But an extremely low Poff value results in wire breaks and an unstable discharge situation. It is preferable to increase Poff when sparking becomes unstable because this enables a lower pulse duty factor, which minimizes the average gap current. During pulse ON time,

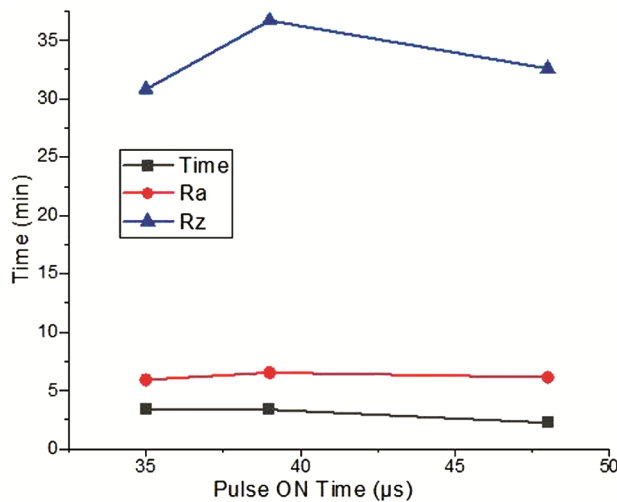


Fig. 6 — Pulse on-time versus Ra, Rz and time.

voltage is applied across the wire electrode and workpiece. A single pulse discharge energy increases with an increase in pulse ON time, resulting in an increased cutting rate.

The linear model analysis was performed against the average surface roughness. From Table 6, it is observed that peak current with P-value 0 (less than alpha = 0.05) is the most influential parameter on surface roughness followed by pulse Off and pulse ON time. The minimum average surface roughness combination is denoted as A1B1C1 as shown in Fig. 7, with optimum parameter values of 5A of peak current, 35 µs of pulse On time and 16 µs of pulse OFF time.

It is found that peak current is the most predominant factor affecting surface roughness (Ra), followed by pulse OFF time and pulse ON time as per the ranking as shown in Table 7. Largest signal-to-noise ratio would reflect the best response resulting in lowest Ra value (positive impact).

3.2 Taguchi analysis: Rz versus PI, P On, P Off

Pulse discharge increase as the peak current (PI) increases. The gap condition may become unstable at larger PI values, if the Ton, Toff, voltage, and servo feed parameters are not properly combined. In order to convert an unstable discharge situation into a stable condition, the PI value must be decreased.

The pulse off-time is the period of time that must lapse for the dielectric to reionize. This gives the molten material enough time to cool and solidify before being washed out of the spark gap. Sparks will tend to be unstable if the pulse off-time is too short, which will lead to more short-circuiting. On the other hand, a longer pulse off-time increases machining time but might offer the stability needed for an EDM process to succeed.

When the pulse off-time is insufficient compared to the pulse on-time, the advancing servo motor will retract and cycle erratically, slowing down the operation. The stability and speed of the cut will be impacted by the pulse interval. Theoretically, machining operations will proceed more rapidly and the shorter will be the delay. However, in order to stop persistent sparking at one point, the pulse interval must be longer than the deionization

Table 6 — Linear model analysis: SN ratios (Ra) versus PI, P On, P Off

Source	DF	Seq SS	Adj SS	Adj MS	F	P
PI	2	160.282	160.282	80.1412	11561.50	0.000
P On	2	0.138	0.138	0.0689	9.95	0.091
P Off	2	0.564	0.564	0.2818	40.66	0.024
Residual Error	2	0.014	0.014	0.0069		
Total	8	160.998				

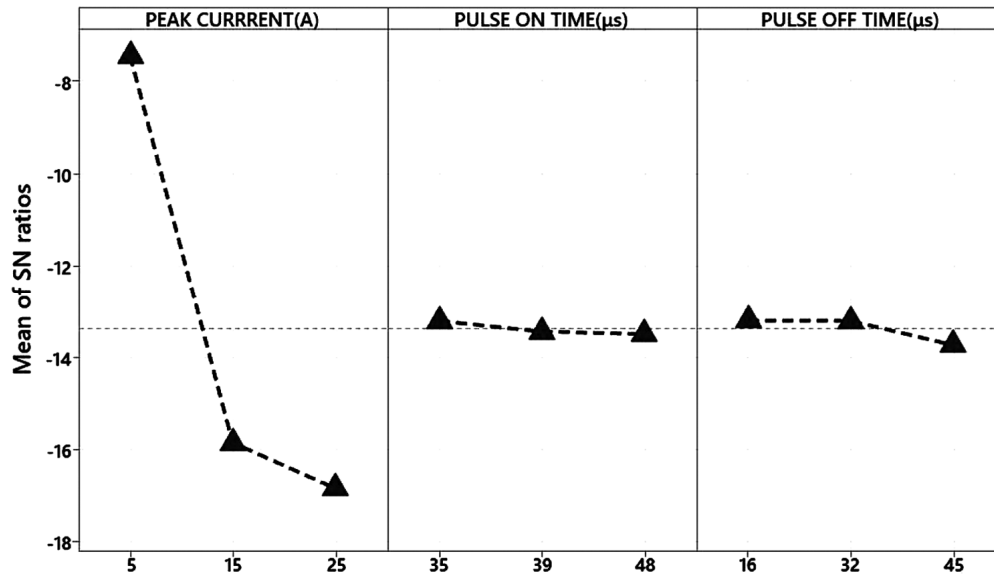


Fig. 7 — Main effects plot for S/N ratios obtained for Ra.

Table 7 — Response table for signal to noise ratios for Ra

Level	PI	P On	P Off
1	-7.439	-13.207	-13.200
2	-15.853	-13.440	-13.206
3	-16.847	-13.492	-13.734
Delta	9.408	0.285	0.534
Rank	1	3	2

Table 8 — Linear model analysis: SN ratios (Rz) versus PI, P On, P Off

Source	DF	Seq SS	Adj SS	Adj MS	F	P
PI	2	115.318	115.318	57.6590	265.27	0.004
P On	2	0.239	0.239	0.1195	0.55	0.645
P Off	2	1.000	1.000	0.5002	2.30	0.303
Residual Error	2	0.435	0.435	0.2174		
Total	8	116.992				

Table 9 — Response table for signal to noise ratios for Rz

Level	PI	P On	P Off
1	-23.27	-28.08	-28.01
2	-30.44	-28.40	-28.11
3	-31.22	-28.45	-28.78
Delta	7.95	0.37	0.74
Rank	1	3	2

duration. Based on ANOVA results as provided in Table 8 and 9, it is found that peak current followed by pulse OFF time and pulse ON time had a notable impact on the measured mean surface roughness (Rz). According to the results of the linear model analysis against the mean surface roughness depth, the peak current will have the greatest influence with p-value 0.011 (less than alpha=95%), trailed by the pulse off time and the pulse on time with p-values of

0.303 and 0.645 respectively, as determined by the ANOVA analysis. Combination A1B1C1 as shown in Fig. 8 has the lowest mean surface roughness depth with optimum values of 5A of peak current, 35 μs of Pulse On time and 16 μs of Pulse Off time.

3.3 Taguchi Analysis: Time versus PI, P On, P Off

When a proposed mathematical analysis was conducted in relation to the machining time as

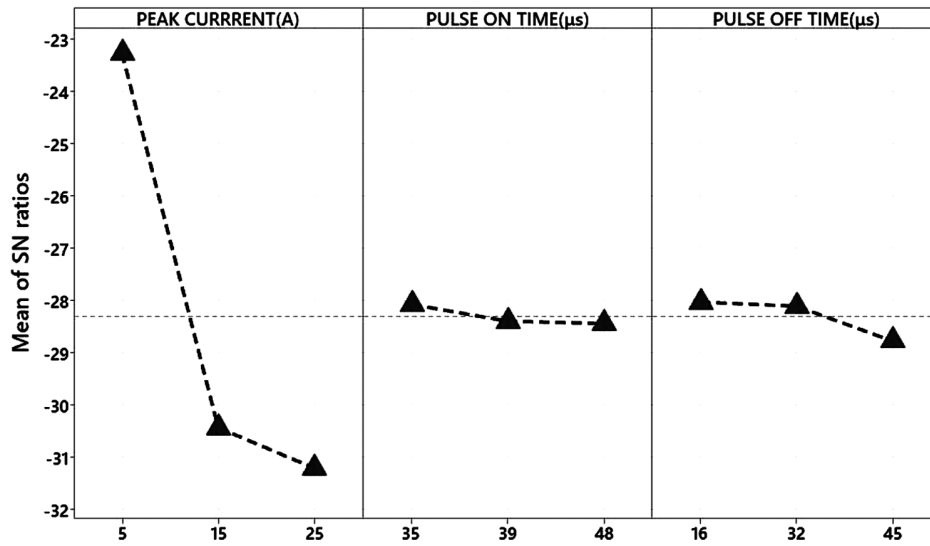


Fig. 8 — Main effects plot for S/N ratios obtained for Rz.

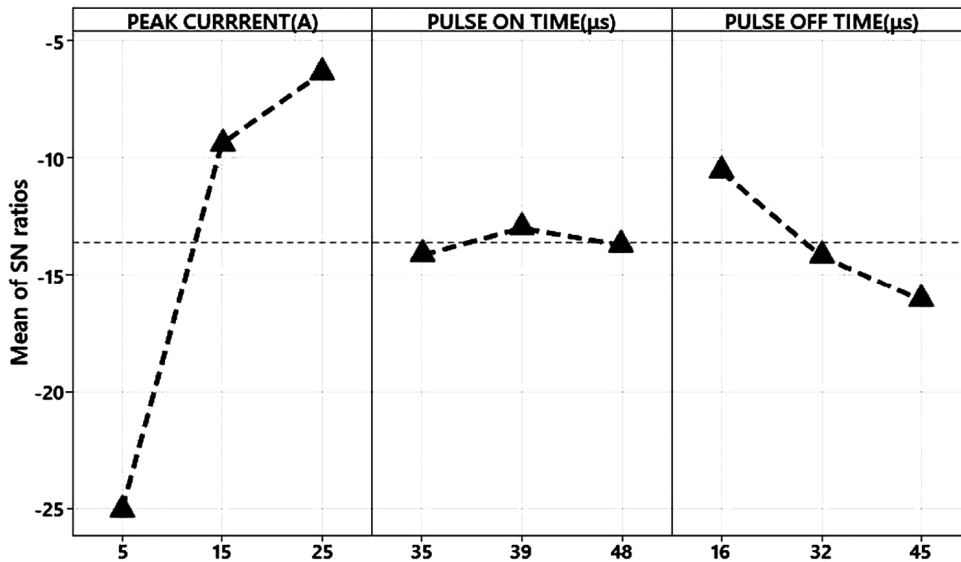


Fig. 9 — Main effects plot for S/N ratios obtained for time

provided in Table 10 and 11, it was discovered that the peak current would have the greatest influence with p-value of 0.004, followed by the pulse off time and the pulse on time having p-values of 0.05 and 0.55 respectively, as determined by the ANOVA. A3B1C1 as shown in Fig. 9 is the combination with the shortest machining time. The optimum values interpreted include 25A, 35μs and 16μs of peak current, pulse OFF and pulse ON time.

It concludes that the peak current is highly influencing the surface finish and machining time. Significant change in surface roughness due to longer pulse durations and higher peak currents, which

increases the thermal energy produced throughout the manufacturing process. The bigger substance melts when the thermal energy is dispersed around the electrode. The electrode of an EDM is prevented from dissipating the heat energy to an inclusive area around it toward the alloy cross-section by an increase in the spark gap set voltage. Additionally, the energy is distributed across the aluminium workpiece consecutive layers with a stronger pulse in terms of both time and current. The surface roughness that was created during the experimental operation will be reducing due to the lack of machining time for the heat to dissipate into the alloy.

Table 10 — Linear Model Analysis: SN ratios (Time) versus PI, P On, P Off

Source	DF	Seq SS	Adj SS	Adj MS	F	P
PI	2	601.175	601.175	300.588	235.94	0.004
P On	2	2.015	2.015	1.008	0.79	0.558
P Off	2	46.999	46.999	23.499	18.45	0.051
Residual Error	2	2.548	2.548	1.274		
Total	8	652.737				

Table 11 — Response Table for signal to noise ratios for Time

Level	PI	P On	P Off
1	-25.045	-14.144	-10.579
2	-9.400	-12.996	-14.180
3	-6.405	-13.710	-16.091
Delta	18.640	1.148	5.512
Rank	1	3	2

4 Conclusions

The process variables of DS-EDM which has been considered for the study are peak current, and pulse on and off times and average surface roughness, mean surface roughness depth, and the time taken to finish the machining process of the material aluminium has been considered as response variables. This process have been carried out on the Mitsubishi Electric die sink EDM machine EA8S. Taguchi design, and ANOVA have been used to determine the optimum process parameter.

The peak current was determined to be the primary affecting factor depending on the ANOVA table during the linear model evaluation against the surface roughness and, machining time. The pulse of time and pulse on time was discovered to be the next most important factors. Combination A3B1C1 has the shortest machining time and combination A1B1C1 has the lowest surface roughness value.

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