

# Optimization of Machining Parameters in Electrical Discharge Machining of Steel Using Taguchi Method

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**Abstract:** This study explores the influence of key electrical discharge machining (EDM) parameters—discharge current, pulse-on time (Ton), pulse-off time (Toff), and dielectric pressure—on the machining performance of stainless steel using a flat base copper tool. Material removal rate (MRR) and surface roughness (SR) were analyzed as output responses, with experiments designed using an L18 orthogonal array and validated through Analysis of Variance (ANOVA). The results reveal that discharge current and Ton significantly affect both MRR and SR. Higher discharge currents increase spark intensity, leading to elevated temperatures that enhance material removal through melting and vaporization, but also result in rougher surface textures. Conversely, increasing Ton reduces MRR due to the expansion of the plasma channel, while contributing to higher SR owing to extended heat application. Dielectric pressure aids in clearing debris from the machining zone, thereby improving process stability, though its direct impact on MRR and SR is less pronounced. Toff was observed to have minimal influence on both responses. These findings highlight the importance of optimizing discharge current and Ton to balance efficiency and surface quality, ensuring reliable machining performance. The insights gained provide valuable guidance for enhancing EDM processes in industrial applications.

**Keywords:** Electric Discharge machining; Material Removal rate; Surface roughness; ANOVA.

**Abbreviations:** MRR: Material Removal Rate, TWR: Tool Wear Rate, SR: Surface Roughness

## I. INTRODUCTION:

Electrical Discharge Machining (EDM) has emerged as a critical process in modern manufacturing, especially for machining hard-to-cut and intricate materials. As a non-conventional process, EDM does not rely on mechanical cutting forces but instead uses a series of electrical discharges to erode material from the workpiece [1], [2]. This makes it indispensable in industries such as aerospace, automotive, and medical

device manufacturing, where precision and surface integrity are paramount [3]. EDM's ability to handle materials with high hardness and thermal resistance sets it apart from conventional machining methods. However, the process efficiency and quality heavily depend on the appropriate selection of process parameters, which underscores the necessity for parameter optimization [4].

The EDM process is governed by several critical parameters, including discharge current, pulse-on time, pulse-off time, and dielectric pressure. Each of these factors interacts with the others, creating a complex machining environment that affects Material Removal Rate (MRR) and Surface Roughness (SR) [5]. For instance, while higher discharge currents typically enhance MRR, they can also degrade SR due to larger craters formed on the workpiece surface [6]. Similarly, improper pulse-on and pulse-off times can lead to unstable machining conditions, affecting both productivity and surface integrity. The interdependence of these parameters complicates the optimization process, making it essential to employ robust statistical methods to identify optimal machining conditions.

In recent years, the Taguchi method has gained significant traction for optimizing machining parameters due to its simplicity and effectiveness in analyzing multi-variable processes [7]. By utilizing orthogonal arrays, this method reduces the number of experiments required while ensuring comprehensive coverage of parameter interactions. Combined with Signal-to-Noise (S/N) ratio analysis, the Taguchi method provides a robust framework for distinguishing between variations caused by noise factors and those influenced by control factors [8]. While many researchers have explored the Taguchi approach in EDM, most studies focus on limited parameters, leaving gaps in understanding the holistic

interaction of factors like dielectric pressure and pulse-off time [9].

Stainless steel, particularly grade 316, is a widely used material in industries due to its excellent mechanical properties and corrosion resistance. However, machining stainless steel poses unique challenges because of its tendency to work-harden and its low thermal conductivity, which can lead to heat accumulation during machining [10]. EDM provides a viable solution for machining such materials, but achieving an optimal balance between MRR and SR remains challenging. The interaction between machining parameters and material-specific properties necessitates a systematic investigation to ensure high-quality machining outcomes.

While previous studies have explored the effects of discharge current and pulse-on time on EDM performance, limited attention has been given to the combined influence of dielectric pressure and pulse-off time. Dielectric pressure plays a critical role in flushing debris from the machining zone, which directly impacts both SR and machining stability [11]. Additionally, the lack of multi-objective optimization frameworks in existing literature often limits the applicability of findings to real-world scenarios [12]. Addressing these gaps requires a comprehensive experimental approach that integrates advanced statistical tools to validate results and ensure practical relevance.

This study aims to optimize EDM parameters for machining stainless steel 316 using the Taguchi method and S/N ratio analysis. By investigating the effects of discharge current, pulse-on time, pulse-off time, and dielectric pressure on MRR and SR, this research seeks to provide a detailed understanding of parameter interactions. The use of an L18 orthogonal array ensures efficient experimentation, while ANOVA and regression analysis validate the statistical significance of findings. The ultimate goal is to establish a robust framework for optimizing EDM performance, with broader implications for machining other hard-to-cut materials. This study not only addresses existing research gaps but also lays the foundation for future advancements in EDM parameter optimization.

## II. METHODOLOGY AND WORK PLAN

The experiments were conducted using stainless steel 316 as the workpiece material. Stainless steel 316, also referred to as 18-8 stainless steel, is widely used in

industrial and engineering applications due to its high corrosion resistance, excellent strength, and ability to withstand harsh environments. The chemical composition of stainless steel 316 includes 18% chromium and 8–10% nickel, which contribute to its superior corrosion-resistant properties. The material's density, hardness, thermal conductivity, and coefficient of thermal expansion make it a challenging yet rewarding material for machining via EDM.

The tool material selected was flat copper with a diameter of 4 mm. Copper was chosen for its excellent electrical and thermal conductivity, which ensures stable spark generation and efficient heat dissipation during machining. The flat geometry of the tool also aids in achieving uniform energy distribution across the workpiece surface, contributing to consistent machining performance.

### a. *Mechanical Properties:*

Stainless steel 316 exhibits excellent mechanical characteristics that make it a highly reliable material in demanding applications. Its density is approximately 7.99 g/cm<sup>3</sup>, providing a good balance between strength and weight. The material demonstrates a yield point of 332 MPa and a tensile strength of 673 MPa, which allow it to endure significant mechanical stress before deformation. The modulus of elasticity is 165 GPa, indicating its ability to withstand deformation under load, while the strength at break is measured at 586 MPa, showcasing its resilience under high-tensile forces. Additionally, stainless steel 316 offers remarkable elongation at break, with a stretchability of 35.5 mm, making it suitable for applications requiring ductility.

### b. *Chemical properties: -*

The chemical composition of stainless steel 316 is precisely engineered to enhance its corrosion resistance, durability, and thermal stability. Chromium (Cr) constitutes 18% of the alloy, playing a vital role in forming a protective oxide layer that resists oxidation and corrosion. Nickel (Ni), accounting for 10%, provides toughness and improves corrosion resistance, especially in acidic environments. Manganese (Mn) and Silicon (Si), at 2% and 0.75%, respectively, act as deoxidizers, contributing to improved mechanical properties. Molybdenum (Mo) is present at 1.66%, enhancing resistance to pitting and crevice corrosion, particularly in chloride environments. The material contains trace amounts of

Carbon (C) at 0.08%, Nitrogen (N) at 0.10%, Sulfur (S) at 0.03%, and Phosphorus (P) at 0.045%, all of which improve machinability and weldability. The remaining balance is iron (Fe), which provides the alloy's foundational structure and strength.

c. *Pilot Study:*

The pilot study was conducted to understand the effects of the machining parameters—pulse-on time (Ton), pulse-off time (Toff), discharge current, and dielectric fluid pressure—on the machining responses: Material Removal Rate (MRR) and Surface Roughness (SR). These output responses were computed by systematically varying one parameter at a time while keeping the others constant, allowing for precise evaluation of individual effects. During the pilot research, a computerized EDM system was employed to ensure consistent and repeatable machining conditions. Stainless steel 316 was used as the workpiece material, and a flat copper tool was utilized to conduct the experiments. The dielectric fluid, kerosene, was circulated continuously to maintain thermal stability and to flush debris from the machining zone.

d. *Experimental Methodology*

The following procedure was adopted during the pilot study:

- **Parameter Selection:** The four key machining parameters considered were:
  - **Pulse-On Time (Ton):** The duration for which the current flows during one machining cycle.
  - **Pulse-Off Time (Toff):** The pause interval between successive discharges.
  - **Discharge Current:** The level of electrical current applied during machining.
  - **Dielectric Fluid Pressure:** The pressure at which the dielectric fluid circulates through the machining zone.
  - **Systematic Variation:** In each experimental run, one parameter was varied while keeping the others constant. For example, Ton was incrementally increased while Toff, discharge current, and dielectric pressure were held fixed.
- **Data Acquisition:** After each machining cycle, the Material Removal Rate (MRR) was calculated by measuring the weight loss of the workpiece, while Surface Roughness (SR) was evaluated using a portable surface roughness tester.
- **Graphical Analysis:** Iterating the process for all parameters resulted in a series of graphs that illustrated the influence of each parameter on MRR and SR. These graphs provide a clear understanding of the trends and relationships between input parameters and output responses. Table 1 is a result of utilizing the values obtained.

Table 1. Pilot Study Input and Output Responses Values

S.NO	Current (A)	Pulse on time (µSec)	Pulse off time (µSec)	Dielectric pressure (kg/cm <sup>3</sup> )	Material removal rate (mg/min)	Surface roughness (µm)
1.	7	6	6	1	5.8	2.83
2.	11	6	6	1	115.6	9.21
3.	15	6	6	1	194.7	19.12
4.	19	6	6	1	345.3	19.84
5.	23	6	6	1	520.1	23.62
6.	23	6	6	2	920.5	19.35
7.	23	6	6	3	1055.6	16.24
8.	23	6	6	4	1185.2	15.75
9.	23	6	6	5	1325.1	15.73
10.	23	2	6	5	1615.4	10.59
11.	23	3	6	5	1519.2	11.41
12.	23	4	6	5	1483.5	11.95
13.	23	5	6	5	1424.7	15.68
14.	23	5	2	5	512.4	19.03
15.	23	5	3	5	514.1	19.15
16.	23	5	4	5	516.9	18.93

17.	23	5	5	5	515.4	19.08
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e. Influence of Input Parameters on Responses

The study reveals that MRR increases with higher discharge current. This behavior is attributed to the enhanced intensity of the sparks generated at elevated current levels, which leads to a rise in localized temperatures. Consequently, material is effectively removed through melting and vaporization mechanisms. This correlation between current and MRR demonstrates that higher energy input facilitates a more efficient removal of material, as evidenced in the graphical results. In contrast, surface roughness (SR) also increases with rising current levels. This is because the greater spark intensity associated with higher currents generates more substantial discharge energy, leading to deeper craters on the machined surface. Hence, while higher currents improve MRR, they also degrade surface quality by increasing SR. Lower current values are associated with smoother

surfaces, indicating that current must be carefully optimized to balance MRR and SR.

Material removal in EDM primarily occurs due to the successive melting and vaporization of material, which creates crater volumes on the workpiece. From the pilot study, a clear relationship between pulse-on time (Ton) and MRR was identified. As Ton increases, the spark intensity diminishes, resulting in a wider plasma channel and a subsequent reduction in MRR. Therefore, maintaining an optimal Ton value is crucial to achieving efficient material removal. Longer pulse-on times also result in increased SR due to extended current flow, which amplifies surface irregularities. This deterioration in surface quality underscores the importance of selecting an appropriate Ton value during machining experiments. Without optimization, prolonged Ton can compromise both MRR and SR, leading to suboptimal machining performance.

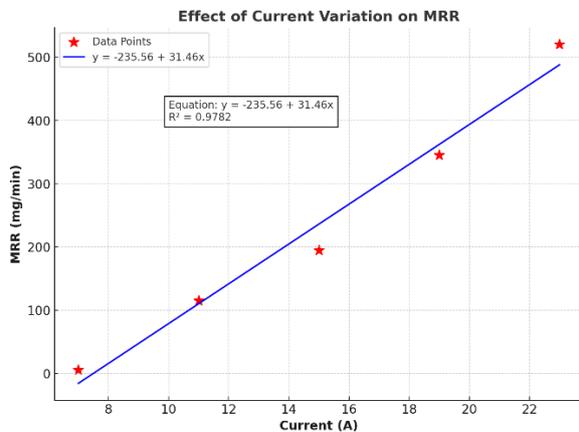


Fig. 1. Graph b/w MRR and Current.

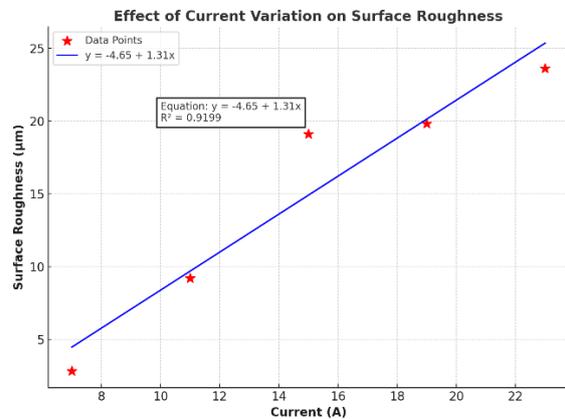


Fig. 2 Graph b/w SR and Current

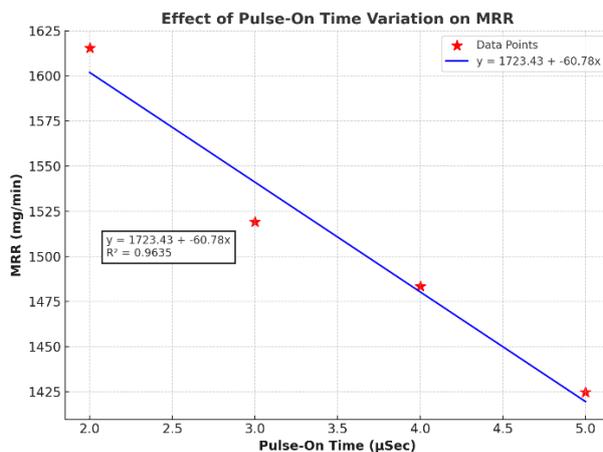


Fig. 3 Graph b/w MRR and Pulse on time.

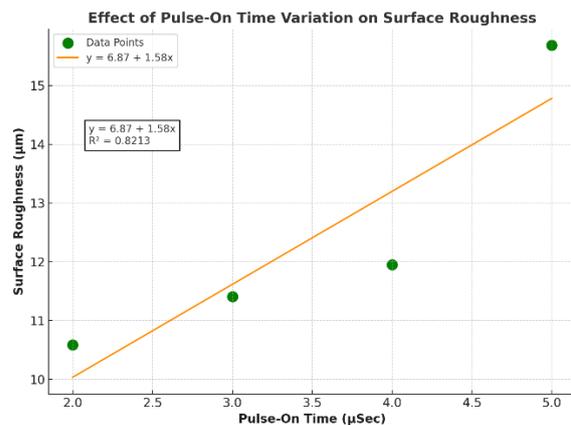


Fig. 4. Graph b/w SR and Pulse on time.

### III. RESULTS AND DISCUSSION

The performance of Electrical Discharge Machining (EDM) depends on several critical parameters, including discharge current, pulse-on time (Ton), pulse-off time (Toff), and dielectric pressure. Among these, discharge current exerts the most significant influence on the Material Removal Rate (MRR). As discharge current increases, the intensity of the spark becomes greater, resulting in a substantial rise in localized temperatures. This, in turn, facilitates efficient material removal through the processes of melting and vaporization. In contrast, other parameters such as Toff have a comparatively minimal impact on MRR. Additionally, the study revealed that an increase in Ton leads to a decline in MRR due to changes in energy transfer dynamics and the widening of the plasma channel.

Material removal in EDM is primarily governed by spark energy. At lower values of Ton, the spark energy is concentrated in a small region, leading to higher MRR. However, as Ton increases, the energy density diminishes, which reduces the efficiency of material removal. This behavior is associated with the expansion of the plasma channel at higher Ton values, which dilutes the energy available for machining. The observed trends are illustrated in Figures 5 and 6, which provide the main effects plots for means and S/N ratios, respectively. These plots clearly demonstrate that discharge current and Ton are the most influential factors affecting MRR, while the effects of Toff and dielectric pressure are relatively minor.

The analysis further indicates that discharge current directly correlates with MRR, as higher currents

enhance the spark intensity, allowing greater heat generation and more efficient material removal. Conversely, an increase in Ton reduces MRR due to the broader plasma channel, which lowers the concentration of spark energy. Dielectric pressure plays a secondary role in improving MRR by flushing debris from the machining zone and preventing the re-solidification of molten material. This stabilizes the machining process but has less impact compared to discharge current and Ton. On the other hand, Toff has a negligible effect on MRR, as its primary role is to allow the dielectric fluid to replenish and reset the machining zone for subsequent discharges.

The surface roughness (SR) results, analyzed using Analysis of Variance (ANOVA), reveal that discharge current and Ton also significantly affect SR. Higher discharge currents lead to deeper craters on the machined surface, resulting in increased surface roughness. Similarly, extended Ton values exacerbate surface irregularities due to prolonged heat application and increased material removal volume per discharge. Dielectric pressure, while playing a stabilizing role, marginally improves surface quality by efficiently removing debris and reducing the formation of recast layers. Toff again shows minimal influence on SR, highlighting its limited role in controlling surface quality. This study systematically evaluates the interplay between machining parameters and their effects on MRR and SR. The experimental results indicate that discharge current and Ton must be carefully optimized to achieve the desired balance between efficient material removal and acceptable surface quality. While dielectric pressure helps maintain process stability, Toff demonstrates negligible contributions to these responses.

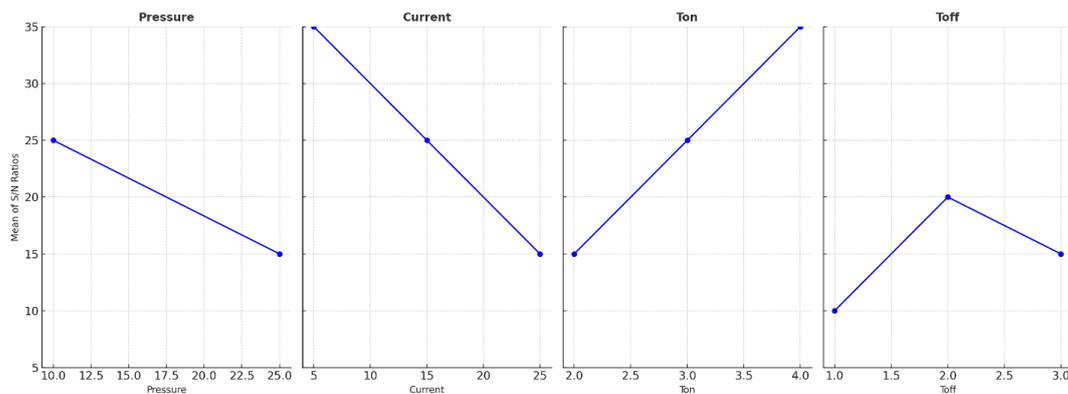


Fig.5 Main effect plot for mean.

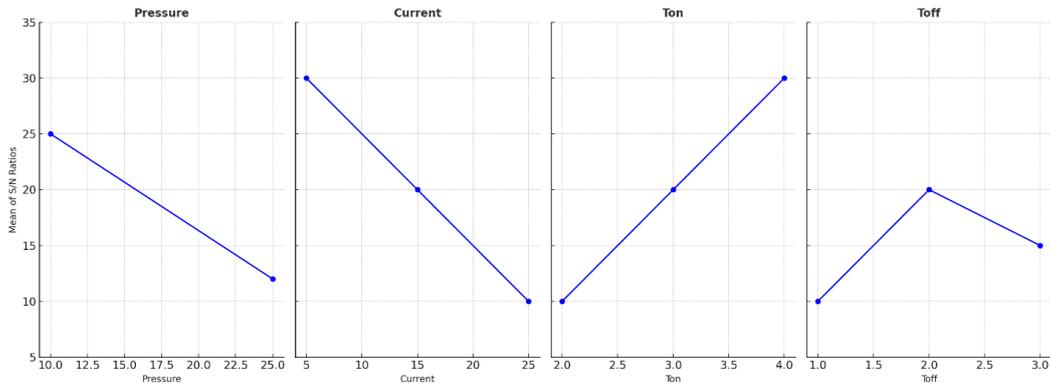


Fig.6 Main effect plot for S/N Ratio: -

#### IV. CONCLUSION

The investigation into the MRR and SR of stainless steel using a flat base copper tool in an EDM process highlights the critical influence of discharge current and Ton. The study employed an L18 orthogonal array with Minitab software for experimental design, and the results were validated using ANOVA. It was observed that higher discharge currents significantly enhance MRR by intensifying the spark, leading to greater material removal through melting and vaporization. However, these higher currents also result in rougher surfaces due to deeper craters formed on the workpiece. Similarly, increasing Ton diminishes MRR due to reduced spark energy density and widens the plasma channel, while simultaneously increasing SR due to prolonged exposure to heat. Dielectric pressure contributes to process stability by efficiently clearing debris, though its overall impact on MRR and SR is less pronounced. Toff remains the least influential parameter for both responses, primarily serving to regulate the dielectric replenishment process. These findings underscore the importance of parameter optimization to achieve high-quality machining outcomes with a balance of efficiency and precision.

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