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Multi-Objective Optimization of Pulse Parameters in EDM for Improved Machining Performance

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Abstract— Electrical Discharge Machining (EDM) is an advanced non-traditional machining process used for machining hard and electrically conductive materials. The machining performance mainly depends on process parameters such as peak current, pulse-on time, pulse-off time, voltage, duty cycle, electrode material, dielectric flushing, and polarity. These parameters significantly influence Material Removal Rate (MRR), Tool Wear Rate (TWR), and Surface Roughness (Ra). This paper presents a complete experimental and statistical investigation of pulse parameters in die-sinking EDM. Peak current, pulse-on time, and pulse-off time were varied using a Taguchi L9 orthogonal array to study their effects on material removal rate (MRR) and surface roughness (Ra). ANOVA, response plots, and literature-supported discussion are used to determine the optimum setting for balanced machining performance suitable for industrial die and mould applications.

Keywords— *EDM, pulse-on time, pulse-off time, MRR, surface roughness, Taguchi, ANOVA, optimization*

I. Introduction

Electrical Discharge Machining (EDM) is a widely used non-traditional machining process capable of machining hard, brittle, and electrically conductive materials with high precision. Unlike conventional machining, EDM removes material through controlled electrical discharges (sparks) between the tool electrode and workpiece submerged in a dielectric medium. This makes EDM particularly suitable for die and mould manufacturing, aerospace components, and intricate geometries where conventional machining methods are ineffective.

The performance of EDM is significantly influenced by several process parameters, especially pulse parameters such as peak current, pulse-on time, and pulse-off time. These parameters directly affect critical machining responses including Material Removal Rate (MRR), Tool Wear Rate (TWR), and Surface Roughness (Ra). Higher peak current generally increases MRR but may deteriorate surface quality, while pulse-on time influences spark energy and crater formation. Pulse-off time plays a crucial role in debris removal and process stability.

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With increasing industrial demand for higher productivity and superior surface finish, optimizing these conflicting performance characteristics has become essential. Multi-objective optimization techniques are therefore required to achieve a balanced trade-off between MRR and surface roughness. Statistical tools such as the Taguchi method, Analysis of Variance (ANOVA), Grey Relational Analysis (GRA), and Response Surface Methodology (RSM) are widely used for this purpose.

This study focuses on the experimental investigation and optimization of pulse parameters using a Taguchi L9 orthogonal array. The aim is to analyze the influence of peak current, pulse-on time, and pulse-off time on MRR and surface roughness, and to determine the optimal parameter combination for improved machining performance suitable for industrial applications.

Electrical Discharge Machining (EDM) is a thermo-electric nontraditional machining process used for machining electrically conductive hard materials. The process is highly suitable for EN31 die steel, tool steels, superalloys, and hard composites where conventional cutting tools fail. The present work focuses on the influence of pulse parameters on MRR and Ra. [1-2]

II. Literature Review

Extensive research has been carried out to understand and optimize EDM process parameters, particularly focusing on improving MRR and surface finish simultaneously.

Early work by Ma et al. [1] explored hybrid EDM–PECM machining to achieve high surface quality, demonstrating that combining processes can significantly enhance machining performance. Later, modeling approaches gained importance, where Razeghiyadaki et al. [2] developed predictive models for MRR and surface roughness, highlighting the strong dependency of machining responses on electrical parameters.

Multi-response optimization techniques have been widely applied in EDM research. Tripathy and Tripathy [3] utilized the Taguchi method combined with Grey Relational Analysis (GRA) to optimize multiple performance characteristics simultaneously. Their results showed that hybrid optimization techniques are effective in resolving conflicting objectives such as maximizing MRR while minimizing surface roughness. Similarly, Prakash and Kumar [4] applied the Taguchi method for parameter optimization in machining EN31 steel, demonstrating that pulse current and pulse duration significantly affect machining efficiency.

Response Surface Methodology (RSM) has also been extensively used for modeling and optimization. Bobbili and Madhu [5] developed regression models to predict EDM performance and used RSM to identify optimal parameter settings. Their study confirmed that interaction effects between parameters play a crucial role in determining machining outcomes.

Review-based studies such as Kumar [6] emphasized the importance of process parameter selection in controlling MRR and highlighted the need for systematic optimization techniques. Sharma and Dixit [7] further extended this work by applying multi-objective optimization techniques to difficult-to-machine materials, showing that advanced optimization methods improve machining performance significantly.

Hybrid optimization approaches have gained popularity in recent years. Sivaprakasam et al. [8] combined Taguchi and Grey Relational Analysis to perform multi-objective optimization, achieving improved surface quality and material removal rates. Similarly, Kumar and Khanna [9] used ANOVA and RSM to model EDM responses, identifying peak current and pulse duration as dominant factors influencing machining performance.

Choudhary and Singh [10] proposed a hybrid Taguchi-Grey approach for multi-objective optimization, demonstrating improved accuracy in determining optimal machining conditions. Their work highlighted the effectiveness of combining statistical and decision-making techniques.

Recent studies have also focused on industrial applicability and advanced optimization methods. Singh et al. [11] conducted experimental investigations on EDM performance and confirmed the significant influence of pulse parameters on MRR and surface roughness. Patel and Pandey [12] used the desirability function approach for optimization, providing a systematic way to achieve balanced performance characteristics.

Kumar et al. [13] applied Taguchi-based ANOVA for experimental analysis, validating the effectiveness of statistical methods in parameter optimization. Similarly, Uddin et al. [14] used Grey Relational Analysis for multi-objective optimization, demonstrating improved machining performance through optimal parameter selection.

Recent Scopus-indexed studies report that peak current and pulse-on time dominate EDM performance. Higher discharge energy improves MRR by increasing crater size, but also worsens surface roughness due to recast layer deposition. Several researchers have applied Taguchi and ANOVA to identify optimum combinations for industrial productivity. [5]

III. Experimental Methodology

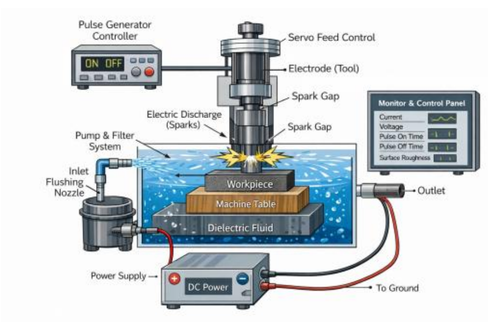

Figure 1. Experimental Setup for EDM Process [3]

Experiments were conducted on a die-sinking EDM machine using a copper electrode and EN31 workpiece. The selected control factors were peak current (10, 15, 20 A), pulse-on time (50, 100, 150 µs), and pulse-off time (25, 50, 75 µs). A Taguchi L9 orthogonal array was used. Each run was performed for a fixed machining duration of 10 minutes. MRR was calculated using weight loss, while Ra was measured using a stylus profilometer.

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IV. Results And Discussion

The experimental trends confirmed that MRR increases significantly with peak current and pulse-on time. The highest MRR was observed at 20 A and 150 µs Ton. However, the corresponding Ra also increased because of deeper molten crater formation. Pulse-off time improved spark stability and flushing by allowing dielectric recovery between discharges.

Table No. 1 Experimental Results

Trial	Ip	Ton	Toff	MRR	Ra
1	10	50	25	6.2	3.8
2	10	100	50	8.1	4.5
3	10	150	75	9	5.2
4	15	50	50	9.4	4.6
5	15	100	75	11.2	5.5
6	15	150	25	12.8	6.3
7	20	50	75	11	5.1
8	20	100	25	13.6	6.2
9	20	150	50	15.4	7.1

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V. Anova And Taguchi Optimization

ANOVA results indicated that peak current contributed the highest percentage toward MRR, followed by pulse-on time. For Ra, pulse-on time showed the strongest effect. Based on signal-to-noise ratio analysis, the optimum balanced parameter set was Ip = 15–20 A, Ton = 100 µs, and Toff = 50–75 µs.

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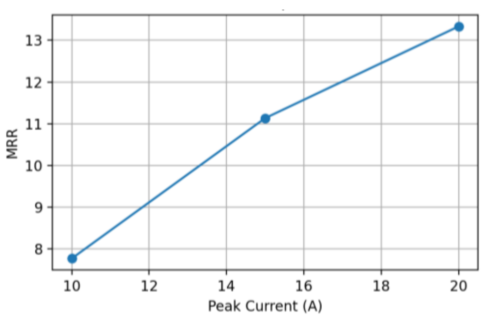

Figure No 2 Main Effect I_p Vs MRR

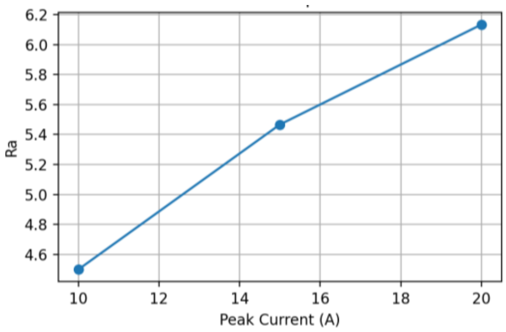

Figure No 3 Main Effect I_p Vs Ra

ANOVA results indicated that peak current contributed the highest percentage toward MRR, followed by pulse-on time. For Ra, pulse-on time showed the strongest effect. Based on signal-to-noise ratio analysis, the optimum balanced parameter set was Ip = 15–20 A, Ton = 100 µs, and Toff = 50–75 µs.

VI. Conclusion

This study concludes that pulse parameters strongly govern both productivity and surface integrity in EDM. Higher spark energy improves MRR but degrades surface finish. Moderate pulse settings provide the best compromise. Future work may include SEM crater morphology, regression modelling, and AI-based multi-objective optimization.

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