# Optimization of wire electrical discharge machining (WEDM) process parameters using hybrid optimization approaches Taguchi and response surface methodology

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## Abstract

This research explores the optimization of wire electrical discharge machining (WEDM) process parameters by using optimization methodologies of Taguchi and response surface methodology (RSM). The study focuses on improving the efficiency and precision of WEDM, a widely used procedure in the production of intricate and hard materials. It involves analyzing the influence of various control factors, such as pulse-on time, pulse-off time, wire tension and speed. The key objective is maximizing material removal rate (MRR) and minimizing surface roughness (SR) as well as kerf width (KW). Through an amalgamation of Taguchi's experimental design principles and the prediction capacity of RSM, an in-depth understanding of the WEDM parameter effect is achieved. The study enhances the production process's effectiveness, catering to the growing demand for more accurate and faster production in the engineering industry. The results validate the adaptability and robustness of the hybrid approach in optimizing WEDM process parameters.

**Keywords:** Wire Electrical Discharge Machining, Response Surface Methodology, Control Factors, Material Removal Rate, Surface Roughness.

## 1. Introduction

In the past years, advancements have unfolded in the creation of innovative and unusual substances. This progress has consequentially propelled the adoption of unconventional methodologies over traditional machining procedures[1]. The industry has markedly noticed a surge in the usage of Wire Electrical Discharge Machining (WEDM) processes in recent times[2].

This uptick can largely be accredited to its unique benefits in dealing with conductive material machining. Key among them is its striking resilience to the hardness of materials, backed by its proficiency in executing intricate cuts with impressive precision. This makes WEDM an incredibly versatile and robust technology in modern machining[3].

Significant advancements have been made in wire electrical discharge machining (WEDM) technology to accommodate a variety of manufacturing needs, most notably, within the context of the precision die industry. Essentially, WEDM is a thermoelectrical process that uses a series of discrete sparks to erode material from a given workpiece. Its functional dynamic places a wire electrode (tool) near the workpiece, with a thin layer of dielectric fluid, often deionized water, forming a barrier between the two. Not only does this fluid layer keep the wire and workpiece separate, but it also maintains a steady feed to the machining zone to remove the eroded particles. One of the core mechanics of WEDM is the precise movement control of the wire, instrumental to achieving a specific three-dimensional shape and accuracy of a workpiece. Control devices, power supply, working table, and dielectric flow, along with the schematic diagram of WEDM, are all demonstrated in Fig. 1. A key takeaway from Fig. 1 is the importance of the wire's accurate positioning against the object. This significance is exacerbated by the complex oscillations the wire repeatedly experiences due to the electro-discharge against the workpiece, making holding the wire in a designated position critical. Commonly, a pin guide is employed to secure the wire at the upper and lower sections of the workpiece. Moreover, in most scenarios, a wire is typically used once and then disposed of. However, multiple concerns need to be meticulously addressed to further increase the working precision of the machine[2]. The present work is planned to review the parametric analysis of WEDM operation with the applications of Taguchi method, response surface methodology (RSM) and combined with other optimization techniques.

### 1.1 Taguchi Method

Taguchi method plays a crucial role in the optimization of process parameters. It's a robust statistical approach that enhances the quality and performance of various processes[4]. Favored for its time-saving ability in complex engineering and manufacturing procedures, it uses orthogonal arrays to scrutinize the effects of disparate variables. The method excels at decreasing the flux and recognizing best conditions systematically. This optimization process is efficient enough to boost the quality of end-product, making it a preferred option for intricate fields.

### 1.2 Response Surface Methodology

Response Surface Methodology (RSM) is a collection of statistical techniques used for modeling and optimizing processes[5]. It explores the relationships between several explanatory variables and one or more response variables, enabling the identification of optimal conditions and improving process performance by fitting a polynomial equation to experimental data.

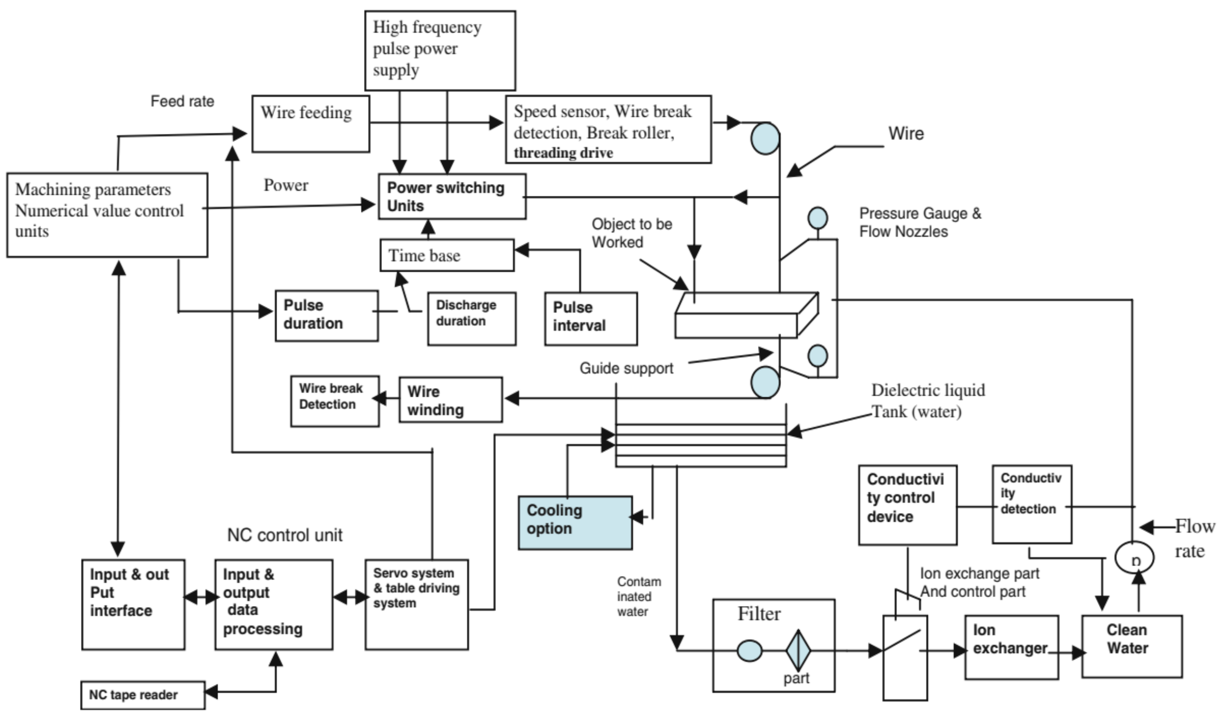


Fig. 1 Typical diagram of WEDM[6]

## 2. Literature review

Shivade and Shinde [7] have effectively enhanced parameters like Material Removal Rate (MRR), dimensional distortion, gap current, and machining duration during the Wire Electrical Discharge Machining (WEDM) process on AISI D3 grade of tool steel. Their optimization strategy was firmly established on the Grey Relational Analysis (GRA) process. Their research significantly contributes to precision manufacturing, particularly in complex geometries where precise, consistent, and high-quality machining is crucial. In their research, Conde et al. [8]scrutinized multiple factors that could lead to dimensional anomalies specifically in small radius circles. Their findings interestingly indicated that the primary cause of the observed concavity effect in the manufactured piece was in fact attributable to the phenomenon known as wire lag. This wire lag effect seemed to dominate the other potential causes they investigated, clearly indicating its significance in the understanding and controlling of such dimensional variations. Huang et al. [9] explored how different machining parameters can impact three specific elements in the machined product. These elements were the width of the gap, the overall roughness of the surface, and most notably, the depth of the so-called "white layer" on the workpiece surface. Their experimental investigation aimed to shed light on the complex relationships between working parameters and their effect on the final quality of machined pieces.

Ugrasen et al. [10] introduced an efficient strategy for determining the ideal cutting condition for achieving the desired surface finish, volumetric Material Removal Rate (MRR), and machining accuracy when working with High Carbon-High Chromium (HCHCr) workpiece materials. The said method centers around ensuring that the mechanical process achieves top-level precision and effectiveness. To optimize the process, they employed the highly regarded Taguchi method. This methodology is renowned for its effectiveness in refining complex engineering and industrial processes. Their applied approach bears promise for advancing machining practices by maintaining excellent surface finishes and machining accuracy. Their research may potentially recalibrate the standards of the machining industry. Dabade and Karidkar [11] examined the machining conditions concerning Material Removal Rate (MRR), surface roughness, kerf width, and dimensional deviation during Wire Electrical Discharge Machining (WEDM) of Inconel 718. Their findings brought to light that pulse-on-time, a significant factor within the process, profoundly impacted all the output variables. Their observation creates crucial knowledge about this technique, shedding light on how intimately connected and affected the process is by the pulse-on-time, ultimately providing foundations for improvements and optimized outcomes. Rajurkar and Wang [12]delve into the phenomena of wire rupture by utilizing a thermal model. One central focus of their study is an exhaustive experimental exploration conducted with the objective of determining the fluctuation in machining performance outputs such as Material Removal Rate (MRR) and Surface Finish (SF). Additionally, this research meticulously investigates the interactive impact of differing machining parameters on these outcomes, ensuring a comprehensive understanding of the workings involved. This in-depth analysis and its findings hold significant implications for the broader field.

Tarng et al. [13] employed a system based on neural network principles. Their focus was to identify the optimal configurations for various elements involved in machining processes. The components they experimented with include pulse duration, pulse interval, peak current, open circuit voltage, servo reference voltage, electric capacitance, and table speed. They aimed to find out how manipulating these elements could influence the prediction of cutting speed and surface finish in machining operations. Analyzing the impact of the Wire Electric Discharge Machining (WEDM) process on ZrSiO4P/6063 Aluminium metal matrix composite (MMC) was the focus of a study by Garg and Sharma[14]. The duo employed the Response Surface Methodology (RSM) to create a mathematical model that would assess the dimensional deviation. This entailed conducting experiments using four key process parameters - TON, TOFF, peak current, and servo voltage. To determine the ideal process parameters, they used a desirability function approach. In their comparative study, Lok and Lee [15] investigated the machining performance focusing on the Material Removal Rate (MRR) and quality of the surface finish. They conducted experimental processing on two high tech ceramic materials under varying cutting conditions, utilizing Wire Electrical Discharge Machining (WEDM). The results derived from these observations were used to determine the impact of different cutting conditions on the material's performance and finish. The study conducted by Scott et al. [16] utilized the factorial design method to pinpoint the most effective blend of control parameters in Wire Electrical Discharge Machining (WEDM). Performance evaluation considered both the rate of metal removal and the smoothness of the final surface. According to their variance analysis, three factors were identified as crucial in controlling both variables: discharge current, pulse length, and pulse repetition rate. These aspects greatly influence the speed of metal extraction and the resulting surface quality.

## 3. Discussion

Wire Electrical Discharge Machining (WEDM) process parameters optimization via the utilization of Taguchi and Response Surface Methodology (RSM) has led to observable gains in machining efficiency and precision. Numerous studies underscore the effect of major control elements. Such elements include pulse-on time, pulse-off time, wire tension, and speed. These studies suggest a direct influence on the Material Removal Rate (MRR), Surface Roughness (SR), and kerf width (KW).

Recent investigations, such as those conducted by Shivade and Shinde[7], emphasize the use of Grey Relational Analysis (GRA) as an effective strategy. This strategy has shown considerable improvement in MRR and the area of dimensional accuracy, particularly for structures with complex geometries. The significance of precise control in reducing dimensional anomalies is central to the conclusions presented by Conde et al. [8]especially in relation to the factor of wire lag. Furthermore, the research by Huang et al. [9] offers an enlightening view on how certain machining parameters impact gap width, surface roughness, and the extent of the "white layer." This understanding underscores the delicate equilibrium necessary in setting parameters to achieve optimal results.

In the optimization of HCHCr workpiece machining conditions, Ugrasen et al. [14]employed the Taguchi method. This implementation demonstrated the method's effectiveness in obtaining a high surface finish, as well as machining accuracy. In agreement with these findings, Dabade and Karidkar [11] highlight the pulse-on time as having a central role in determining machining results for Inconel 718. This aligns well with the research conducted by Rajurkar and Wang regarding the thermal model for wire rupture and its ensuing effect on MRR and surface finish.

A more complex approach to optimizing numerous machining parameters at the same time has been presented by Tarng et al. This research uses neural network modeling, a method that enhances predictive accuracy for cutting speed and surface finish data. Similarly, Garg and Sharma [14]applied RSM to model dimensional deviation in ZrSiO4P/6063 Aluminum MMCs. They revealed the value of the method in adjusting process parameters for optimal results.

Finally, employing the factorial design method, Scott et al. identifies discharge current, pulse length, and pulse repetition rate as critical factors. This research underlines the requirement for meticulous control in WEDM to achieve the intended machining performance and quality. These studies collectively verify the effectiveness of a hybrid approach, combining Taguchi and RSM for WEDM process optimization. This approach has enormous potential for the improvement of machining efficiency and precision across diverse materials and applications.

## 4. Conclusions

The hybrid optimization approach utilizing Taguchi and Response Surface Methodology (RSM) demonstrates substantial potential in refining Wire Electrical Discharge Machining (WEDM) processes. This study highlights the critical control factors—pulse-on time, pulse-off time, wire tension, and speed—that significantly impact Material Removal Rate (MRR), Surface Roughness (SR), and kerf width (KW). The integration of Taguchi's experimental design with RSM's predictive capabilities provides a comprehensive framework for optimizing these parameters. The reviewed literature indicates that precise control over machining parameters can markedly enhance machining efficiency and quality. For instance, the application of Grey Relational Analysis (GRA) and the Taguchi method has proven effective in achieving higher MRR and better surface finishes. Additionally, understanding phenomena like wire lag and the effects of pulse-on time on machining outcomes provides deeper insights into the intricacies of the WEDM process. The findings validate the robustness and adaptability of the hybrid optimization approach. This methodology not only improves the precision and efficiency of WEDM but also caters to the evolving demands of the engineering industry for more accurate and rapid production methods. Thus, the combination of Taguchi and RSM presents a powerful tool for advancing WEDM technology, ensuring its continued relevance and effectiveness in modern manufacturing.

## 5. Future Scope

Future research can expand the hybrid optimization approach by integrating advanced techniques like machine learning and artificial intelligence to further enhance predictive accuracy and process control in WEDM. Exploring the application of these methodologies to a wider range of materials and more complex geometry can provide deeper insights into their effects. Additionally, real-time monitoring and adaptive control systems could be developed to dynamically adjust machining parameters, ensuring optimal performance. This would significantly improve WEDM's applicability in high-precision industries, such as aerospace and biomedical engineering, driving innovation and efficiency in manufacturing processes.

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