

# A Review on Parametric Optimization of WEDM Technique for OHNS Steel

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## Abstract

*In this study, the Wire Electrical Discharge Machining (WEDM) process for OHNS (Oil Hardened Non-Shrinking) steel, a high-performance material frequently used in the production of dies, punches, and precision tooling components, is optimized parametrically and validated experimentally. A continuously moving wire electrode and a sequence of electrical discharges are used in WEDM, a non-traditional machining method, to erode material and produce intricate and precise profiles, particularly in materials that are challenging to machine. Using a Taguchi L9 orthogonal array design, a structured experimental approach will be used to gather data under controlled conditions. This approach helps to reduce the number of experiments while offering important insights into the behaviour of the process. To ascertain the impact and interplay of different process parameters on the output responses, the experimental results will be statistically examined using Analysis of Variance (ANOVA). Additionally, the process's robustness under various conditions will be assessed using Signal-to-Noise (S/N) ratios. To guarantee the accuracy and repeatability of the findings, confirmation experiments will be used to validate the optimized parameters that were determined by the analysis. The purpose of this study is to help with the accurate and efficient machining of OHNS steel using WEDM by providing insightful suggestions for industrial applications where precision, surface integrity, and productivity are critical. The findings will serve as a reference for engineers and manufacturers to fine-tune WEDM processes for high-performance tool steels. This study's main goal is to identify the ideal combination of process variables that result in better machining performance, specifically wire tension, servo voltage, pulse on-time, and pulse off-time. Critical response characteristics like surface roughness, material removal rate (MRR), and dimensional accuracy will be used to evaluate the machining process's quality.*

**Keywords:** WEDM, OHNS, pulse on-time, pulse off-time, servo voltage, wire tension, MMR, ANOVA

## INTRODUCTION

### Wire Cut Electrical Discharge Machining

“Wire Cut-Electrical Discharge Machining” (WEDM) tool electrode is a wire. The wire electrode has been continuously supplied to create controlled, fast, and repetitive sparks that remove material from workpiece. The workpieces and wire electrode have been cooled by the dielectric fluid, which also eliminates the removed material. Sparks are then put out using the dielectric. The wire electrode and the workpiece could be electrically conductive, which has an important requirement.

The wire electrode in WEDM is fed from reel, and passes through workpiece material; it is extracted by the take-up reel, as shown in Figure 1. The wire is progressively advanced to compensate for tool wear during cutting. Wire electrodes are precisely positioned between the workpiece and the material to be cut via a series of sparks in WEDM.

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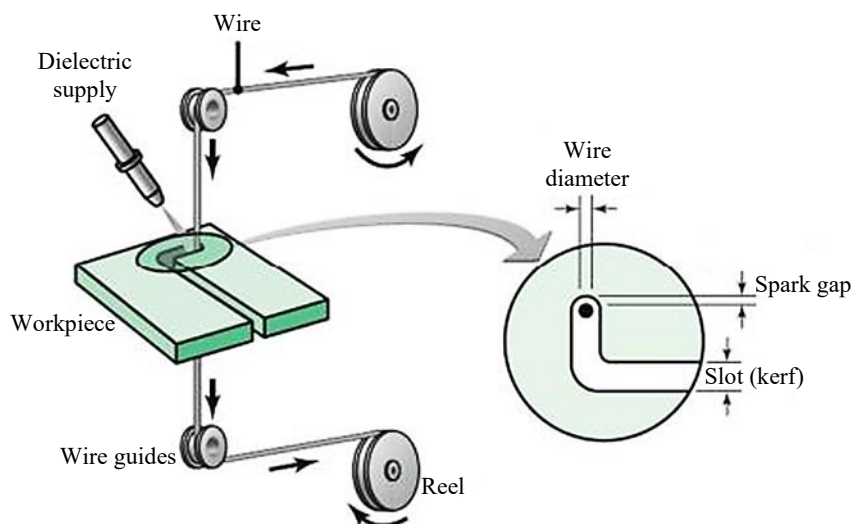
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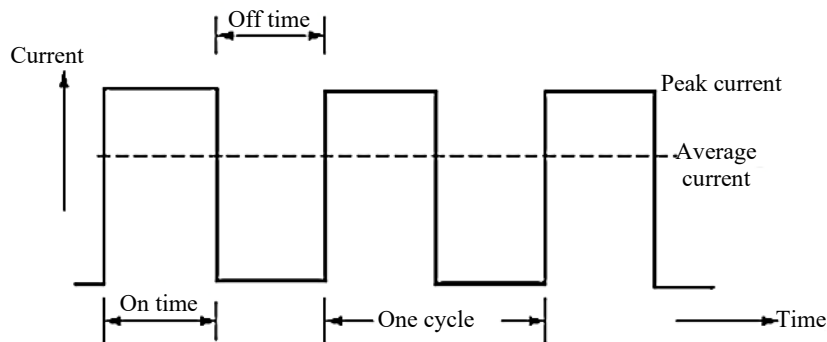
**Figure 1.** WEDM process setup illustration.

Sparks were produced among wire electrode and workpiece in a small area filled with dielectric fuel or de-ionized water using high frequency pulses. Tiny materials are eroded by heat from sparks because they melt and vaporize off work component. Erosion of the wire electrode happens through this process. Dirt and machined materials are removed from the surface by a jet of dielectric fluid that passes through flushing nozzles at top and bottom of setup. WEDM machines were initially used to cut tiny structures, but with the utilization of many controlled machines, complex 2D profiles might now be produced without the need for a WEDM machine, any certain type of electrodes. This method is perfect for creating close-fitting pieces because of its precision and small kerf width. Generally speaking, a wire electrode has travelling copper/brass wire with a diameter between 0.001 and 0.012 in. Through careful placement and wire tension, an incredibly small kerf is created. Without the use of a special tool, this arrangement enables cutting of intricate apertures as well as exact radial curves inside and outside. Due to its low cost, the wire is typically used only once. Engineered materials can be cut into many different shapes. Thickness of the workpiece varies between a few and several millimetres. Punches, dies along with stripper plates could be employed to cut any of conductive, hardened tool materials. Interior shapes are frequently created using mirror-image profile work as well as a beginning hole.

Often, workpieces can be cut and stacked simultaneously. After the operation, virtually no burrs are left on edges of finished workpiece. Since WEDM provides no limitations on the processing of even the most complex and challenging metals, it has its applications in automotive, aerospace, medical, pharmaceutical, electrical, telecommunication, packaging, and even in military sectors. Examples of applications in aircraft include turbine blades, gas turbine engine stator parts, compressor wheels, and turbine rotor discs. Brush assemblies, pulleys and plates, motor housings, brass terminals, bearing retainers, and shifting levers are among the automotive applications.

### **Mechanism of metal Removal**

Extremely high temperatures are produced by high-intensity discharges that melt and vaporise the workpiece and tool electrode, which leads to metal removal. Between the workpiece and the tool, a series of electric pulses with a frequency of 5 kHz and a voltage of about 20 to 120 V are supplied, spaced by a spark gap of 0.01 to 0.5 mm (Figure 2). The particles are removed by the voltage pulses produced by RC generators. When voltage pulses are given, the dielectric medium breaks down to a depth of approximately 10 m. This is caused by electrons moving from the cathode to the anode, which are provided by the electric field, and by wandering electrons that are present in the tool gap. These stray electrons have a tendency to collide with the dielectric's neutral atoms, producing more electrons and positive ions that go in the direction of the anode and cathode.



**Figure 2.** Timings of pulse currents in WEDM.

### Wire Electrode Material in WEDM

The material's thermal conductivity, melting point, and the length and strength of the electrical pulses all affect the electrode wear and the rate at which material is removed from the workpiece. Similar to traditional machining, some EDM materials are better at cutting and wearing than others; as a result, electrode materials have to possess the following attributes:

- Excellent electrical conductor,
- Accurate, consistent diameter,
- High melting point,
- High tensile strength,
- Good thermal conductivity, and
- Capable of effectively removing metal from the workpiece.

Because there are fewer options, like brass or copper, the wire selection in WEDM is significantly simpler. These days, wire EDM offers a greater selection of electrodes than sinkers. Currently, the market offers wires for machining, greater speed, tapering, and milling PCDs and carbides in addition to utility grades and cost-effective wires.

### LITERATURE REVIEW

Dayakar *et al.* investigated on Electrical discharge machining (EDM) which takes on a unique form with wire EDM [1]. Maraging steel featured extremely low carbon steel with greater strength and material toughness. The material removal rate (MRR) and surface roughness (Ra) are the machining output responses of the Taguchi optimization technique for WEDM of maraging steel 350 that is presented in this study. The sturdy design of Taguchi plans the machining process. The analysis is carried out using analysis of variance (ANOVA) for the findings. Through Taguchi analysis, the ideal circumstances are achieved for this job.

Naresh *et al.* dealt with ANFIS model's results which were separated from experimental values, and it was discovered that the output characteristics' predicted values and actual values correspond quite well [2].

*Relationships:* The coefficient of determination ( $R^2$ ) and average error (%) for surface roughness were found to be 0.9891 and 2.04 respectively, while the coefficient of determination ( $R^2$ ) and average error (%) for material removal rate were found to be 0.9738 and 1.70% respectively. The coefficient (R) of both MRR and surface roughness was almost 0.9945, which is nearly equal to one. With an accuracy of 98.3 and 98.75%, respectively, predictive modelling of MRR and SR was done using experimental data.

Owhala *et al.* investigated on an experimental work which introduced a novel idea for Wire-EDM turning operations on materials that are challenging to cut [3]. Wire-EDM, a non-traditional technology, is regarded as an effective and cost-effective tool for electrically conductive advanced alloy and

composite machining. Because the machine's task rotating axis is unavailable for turning operations, the Wire-EDM is put together using a well-engineered and produced rotary mechanism that maintains a runout precision of 15  $\mu\text{m}$ . The three independently regulated process parameters are wire feed rate (WF), pulse-on time (Tonne), and rotating speed of the workpiece (RPM). In contrast, the productivity and component quality are indicated by the performance measures, material removal rate (MRR) and average surface roughness (Ra), respectively. The alloy Ti-6Al-4V is used for the workpiece.

Daneshmand *et al.* worked on the LI8 orthogonal array, Taguchi's approach, and Minitab@16.1.1 software has all been used for the design of experiments (DOE) [4]. The studies were carried out in the voltage range of 10–20 A for discharge current and 80–250 V for voltage. The results show that tool wear, workpiece wear, and surface roughness increase with increasing voltage and discharge current. Additionally, as the pulse on time grows, tool wear rises initially before falling off, while surface roughness and material removal rate both decreases. The results also indicate a decrease in tool wear rate, material removal rate, and surface roughness with increasing pulse off time.

Seshaiah *et al.* investigated on the WEDM method which is used by the majority of industrial sectors due to its ability to generate goods at a superior economic rate and in a relatively short development cycle [5]. The WEDM technique removed mechanical stresses during machining by eroding the metal sample's shape away from the wire. Using RSM, the impact of several WEDM operating factors, such as wire speed, wire tension, discharge current, dielectric flow rate, and pulse on and off duration, has been examined with respect to the parameter known as stainless steel 304 material removal rate (MRR). If the best combinations of operational variations are employed, the MRR will be maximised and a greater surface finish will be obtained.

Arunadevi and Prakash conducted a study; the primary goals of this article were to decrease the Surface Roughness (SR) and increase the Material Removal Rate (MRR) value [6]. To investigate the output parameters and accomplish the goals, five input factors, such as pulse-on, voltage, pulse-off, bed speed, and current, are taken into account. The Artificial Neural Network (ANN) mathematical model is used to do performance analysis of the experimental results, and the R-square value is used to assess the model. The Artificial Neural Network model outperforms the linear regression model in terms of accuracy and quality of data. It is difficult to discover the optimum solution for every goal at the same time in real-world situations. When all the objectives are taken into account, Pareto optimum solutions are non-dominated ones. Thus, the Pareto optimum principle is used in this work to discover the solution for multi-objective optimisation.

Deshwal *et al.* conducted a study; for the purpose of the current research, the H-13 hot die-hard material, which has dimensions of 103.70 mm $\times$ 13.95 mm, has been employed as a work section substance [7]. Brass wire electrode with a standard diameter of 0.25 mm is used as the electrode. The influence of four parameters on cutting rate and surface roughness is taken into consideration: TONNE, TOFF, WF, and voltage. Minitab 15 programming is used to conduct experiments and analyse data using the Taguchi Plan of Technique. Observations indicate voltage is the most notable limitations on SR where Tonne and Toff are less important and also noted that MRR augments with boost in Tonne and WF and reduces on ascending of Vg and Toff.

Marelli *et al.* conducted an investigation on the experiments conducted using Taguchi L27 Orthogonal array. When conducting experiments, factors including peak current, gap voltage, pulse on and off times, and gap voltage are taken into account [8]. Performance qualities may be optimised by adjusting the machining settings appropriately. The optimisation process is carried out to achieve the highest Material Removal Rate and optimal Surface Roughness. The ideal combination of machining settings is found via Grey relational analysis. The most important component for both MRR and surface roughness is revealed by an ANOVA. The findings indicate that the machining parameter Pulse ON time has a more significant influence on the performance parameters.

Gupta and Dubey investigated on good responsiveness of NiTi in medical and other applications which is largely due to its net form and efficient machining [9]. Variations in the input parameters, namely pulse on time (Tonne), pulse off time (Toff), and peak current (Ip), were used to assess the results in terms of material removal rate (MRR) and surface roughness (SR). The Wire-EDM experiments were designed and planned using Taguchi's L27 mixed orthogonal array (L27 OA). Following the results, it was determined that Tonne was the most highly effective parameter for both the MRR and the SR.

Kumar *et al.* investigated on wire electric discharge machine (WEDM) which is used to machine EN 31 alloy with independent parameters like pulse on time (Tonne), pulse off time (Toff), discharge current and wire speed to find out the changes in the dependent parameters, i.e. material removal rate, tool wear rate and surface roughness [10]. Using molybdenum wire as the electrode, an experiment was carried out on EN 31 flat steel as the workpiece. An orthogonal array of Taguchi L9 is used to design the experiment. The fuzzy anticipated outcomes and the experimental results were compared.

Razeghiyadaki *et al.* worked on axisymmetric rectangular domain which was used to measure the material removal rate, and a rectangular domain including all discharges at the end of prior craters was taken into consideration for surface roughness [11]. The findings of the heat equation simulation, which used a finite element technique, indicated that taking into account the material's immediate evaporation from the workpiece and the impact of the residual heat produced by each spark would produce more realistic results. The newly presented models were confirmed by good agreement with previously published data, showing that immediate evaporation and residual heat give more accurate predictions of the EDM process.

Naeim *et al.* created regression models and related prediction plots which provide a trustworthy means of estimating the impact of process parameters, allowing for the optimisation of those parameters' impacts on surface roughness and material removal rate, two responses [12]. The trade-off between the impact of important process parameters on surface roughness and material removal rate is clearly shown by the results. This highlights the requirement for a strong multi-objective optimisation method to determine the optimal process window for producing high-quality surfaces while maintaining the highest feasible material removal rate.

Naveen *et al.* investigated that Particle swarm optimisation was utilised to optimise the weighting factors of the network in the neural power programme, and a feed forward artificial neural network model was created to maximise the rate of material removal and surface roughness [13]. When everything was said and done, the model produced root mean square errors for MRR and SR of 0.0053881 and 0.0038324, respectively. Additionally, 22.11 mm<sup>3</sup>/min and 2.33 m, respectively, were the optimised MRR and SR achieved.

Researchers optimised parameters for manufacturing operation considering the Taguchi approach and with AVOVA and found the percent contribution of each significant parameters affecting the particular manufacturing method [14–16]. The design of experiment and response surface method was used for optimization of plasma transferred arc welding techniques [17].

## RESEARCH GAP

An in-depth study was performed to assemble the body of knowledge regarding the WEDM process and an attempt was made to comprehend the fundamental requirements of the industries' expanding demands, which include high production rates and precise and accurate components. The survey's findings included the following: researchers had compared the effectiveness of different tool wire electrodes when cutting tool and die steels and had documented a limited amount of work for productivity and performance improvement of the WEDM process. They also compared the approaches used to achieve optimal conditions. While most researches took into account limited input factors, there are additional parameters that might affect the process. In this study, a metaheuristic algorithm was used

in an attempt to find the ideal circumstances. The goal of the research is to optimise the response characteristics by adjusting the process parameters (cutting speed, pulse on-time, pulse off-time, input current, wire feed, wire tension, servo volt, and servo feed rate). Three factors went into selecting each of the aforementioned process parameters:

1. Literature and any possible gaps in research.
2. Customer feedback from many real-time apps and its prerequisites.
3. Predicated on several pilot experiments carried out prior to choosing parameters and their range to satisfy diverse industry applications.

## CONCLUSION

Wire Electrical Discharge Machining (WEDM) has been extensively studied, especially in relation to optimizing process parameters for material removal rate, cutting speed, and surface finish. Adaptive control systems are used in numerous studies to address wire-related errors. Improving cutting speed, MRR, and surface finish while lowering wire consumption and breakage is a major future challenge in machining efficiency. The ideal parameter settings are usually found experimentally and vary depending on the material. The goal of this study is to minimize manufacturing time by concurrently optimizing these die cutting settings. There is room for more research in this area because there is not much information available on WEDM in pharmaceutical applications.

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