International Journal of Research Publication and Reviews

Journal homepage: www.ijrpr.com ISSN 2582-7421

Study the Various Parameters of Wire Cut Electrical Discharge Machining

Mamidi Yuvaraj *[1]

[*1] Department of Mechanical Engineering, GMR Institute of Technology, Rajam 532127, Andhra Pradesh, India.

ABSTRACT

This work explores the application and significance of Wire Cut EDM (Electrical Discharge Machining). Wire Cut EDM is a precision machining process that utilizes controlled electrical discharges to cut intricate shapes in conductive materials. The paper including the role of the wire electrode, dielectric fluid, and computer-controlled movements in achieving accurate and intricate cuts. The advantages of Wire Cut EDM. The effects of different WEDM process parameters, including pulse on and off times, servo voltage, peak current, dielectric flow rate, wire speed, and wire tension, on various process response variables, including material removal rate (MRR), surface roughness (Ra), kerf (width of cut), and wire wear ratio (WWR). Taguchi's orthogonal array has been used in experiments under various parameter conditions. The report explored on the control variables needed for tool steel, Metal matrix composites (MMCs), Inconel machining. In the industrial sector, these materials are widely used. The report provides an analysis of the EDM process and research work in EDM. WEDM is suitable for super alloys. WEDM is primarily used to machine extremely tough and hard materials, such as super alloys. This work aims to give mechanical engineering students an understanding of Wire Cut EDM's function, contributions, and role in modern manufacturing and design through in-depth analysis.

Keywords: Wire cut EDM, Taguchi, Metal matrix composites, MRR, Surface roughness, kerf

I. INTRODUCTION

Wire Electrical Discharge Machining (Wire EDM), also known as Wire-Cut EDM or WEDM, is a highly precise and versatile manufacturing process used in various industries. It utilizes electrical discharges to shape and cut intricate and complex parts from conductive materials with remarkable precision. In this technique, a thin, electrically charged wire acts as an electrode, eroding the work piece material through controlled spark discharges, enabling the creation of intricate shapes, tight tolerances, and burr-free finishes. Wire EDM has revolutionized precision manufacturing, making it indispensable in fields such as aerospace, automotive, and tooling, where exacting specifications are paramount. In this conversation, we will explore the principles, applications, and advantages of Wire EDM in greater detail. Overall, Wire EDM is a powerful machining technology known for its precision and ability to produce complex parts with high accuracy, making it indispensable in various manufacturing sectors. Skilled operators are required to set up and program Wire EDM machines, as well as monitor the machining process to ensure quality.

Tauguchi method is used to improve high quality at low cost by converting it into signal/nose. Process parameters in WEDM play a significant role in determining the quality and efficiency of the machining process. Grey relational analysis is a statistical method that can be used to analyze complex systems with incomplete or uncertain data.

Fig 1: Wire electrical discharge machining

1.1 Working principle of electrical wire discharge machining:

Wire electrical discharge machining (WEDM) is a non-traditional machining process that utilizes a thin, electrically charged wire to erode and cut through conductive materials. The process occurs when a high-voltage pulse is applied between the wire and the work piece, creating an electric field. When the voltage exceeds the dielectric breakdown strength, a spark is generated at the point of closest contact between the wire and the work piece. This intense spark melts and vaporizes a small amount of material on both the wire and the work piece. The molten material is expelled by the force of the spark, creating a narrow kerf or slit. A dielectric fluid, such as deionized water, flushes away the debris, maintains a stable spark gap, and cools the wire and the work piece. As the wire is continuously fed through the work piece, the process continues, allowing for accurate and controlled material removal.

1.2 Process parameters

a) Pulse duration:

Pulse duration, also known as pulse width or pulse on time, is a crucial parameter in Wire Electrical Discharge Machining (WEDM) that significantly affects the machining process and its outcomes. It refers to the duration of each electrical discharge (spark) generated between the wire electrode and the work piece during the machining process. Increasing pulse duration generally leads to an increase in MRR. This is because longer pulse duration allows more energy to be transferred to the work piece, resulting in faster melting and vaporization of the material.

b) Servo voltage:

In Wire Electrical Discharge Machining (WEDM), servo voltage is a key parameter that controls the gap distance between the wire electrode and the workpiece. It is the voltage applied to the servo system that drives the wire electrode up or down to maintain a stable and consistent gap during the machining process. Higher servo voltage generally leads to increased MRR due to more frequent and intense sparks. However, excessively high voltage can cause wire breakage and negatively impact surface quality. Lower servo voltage tends to produce smoother surfaces as the less intense sparks cause less melting and recast layer formation.

c) Pulse interval:

Pulse interval, also known as pulse off time or inter-pulse time, is another critical parameter in Wire Electrical Discharge Machining (WEDM) that significantly impacts the machining process and its outcomes. It refers to the time interval between two consecutive electrical discharges (sparks) generated between the wire electrode and the work piece. Generally, decreasing the pulse interval leads to a higher MRR as it allows for more sparks to occur within a unit time. Longer pulse intervals typically result in a smoother surface finish due to more time for solidification.

d) Peak current:

Peak current, also known as discharge current, it is a crucial parameter in Wire Electrical Discharge Machining (WEDM) that significantly affects the machining process and its outcomes. It represents the maximum instantaneous current that flows between the wire electrode and the work piece during each individual electrical discharge (spark). Peak current directly influences the amount of material removed with each spark. Higher peak currents lead to more energy being transferred to the work piece, resulting in increased melting and vaporization of material. Higher peak currents allow for more material removal per spark, leading to an overall higher MRR. Generally, lower peak currents result in smoother surfaces due to less material melting and recasting.

e) Gap voltage:

Gap voltage in Wire Electrical Discharge Machining (WEDM) refers to the electrical potential difference between the wire electrode and the work piece. It is a critical parameter that significantly affects the machining process and its outcomes. The gap voltage determines the energy required to break down the dielectric fluid and initiate a spark discharge between the wire and the work piece. Higher voltage leads to more energy per spark, increasing the overall rate of material removal. Generally, lower gap voltages result in smoother surfaces due to less material melting and recasting.

f) Di electric flow rate:

Dielectric flow rate is a crucial parameter in Wire Electrical Discharge Machining (WEDM) that significantly affects the machining process and its outcomes. It refers to the amount of dielectric fluid (usually deionized water) that is pumped through the machining zone per unit time. Generally, increasing the dielectric flow rate leads to a higher MRR as it allows for more efficient removal of debris and molten material. A higher dielectric flow rate can contribute to a smoother surface finish by effectively removing debris

g) Wire tension:

Wire tension is a critical parameter in Wire Electrical Discharge Machining (WEDM) that significantly affects the machining process and its outcomes. It refers to the force exerted on the wire electrode throughout the cutting process. Proper wire tension ensures the wire electrode remains straight during machining and preventing it from sagging or vibrating excessively. This is crucial for achieving precise cuts and maintaining dimensional accuracy. Increasing wire tension can lead to a higher MRR due to improved wire stability and spark efficiency. A lower wire tension can result in a rougher surface finish due to increased wire vibration and deflection. Conversely, a higher tension can lead to a smoother surface by minimizing vibration and promoting straight cuts.

h) Wire feed rate:

Wire feed rate is a critical parameter in Wire Electrical Discharge Machining (WEDM) that significantly affects the machining process and its outcomes. It refers to the speed at which the fresh wire electrode is fed into the cutting zone during machining. The wire feed rate ensures a continuous supply of fresh wire electrode as it gets consumed during the cutting process, this is very important in good cutting performance. Increasing the wire feed rate leads to a higher MRR as it allows for more fresh wire to be exposed to the spark discharge and contribute to material removal. A lower wire feed rate can result in a smoother surface finish due to more time for debris removal, inversely Conversely, a higher feed rate can lead to a rougher surface due to insufficient time for debris removal.

1.3. Response variables:

a) Metal removal rate (MRR):

Metal removal rate (MRR) is a crucial parameter in Wire Electrical Discharge Machining (WEDM) that shows the efficiency and productivity of the machining process. It refers to the amount of material removed from the work piece per unit time.

Factors affecting MRR in WEDM:

- Pulse parameters:
  - Pulse on time: Increasing pulse on time generally increases MRR as more energy is transferred to the work piece per spark.
  - Peak current: Higher peak current leads to more intense sparks and faster material removal.
  - Pulse off time: Pulse off time allows for deionization of the gap and solidification of molten material. While shorter Toffs can increase MRR, excessively short intervals can lead to instability and arcing.
- Wire feed rate:

Higher feed rates expose fresh wire to the spark more potentially increasing MRR. However, excessively high feed rates can lead to insufficient spark energy and reduced MRR.

- Wire tension:

Proper tension ensures the wire remains straight and taut, aiding in efficient material removal. Very low or very high tension can negatively impact MRR.

- Dielectric fluid flow rate:

Adequate flow rate flushes away debris and cools the wire and workpiece, contributing to optimal MRR. Insufficient flow can hinder material removal, while excessively high flow can cause turbulence and instability.

- Material properties:

Different materials have varying melting points and thermal conductivities, requiring different machining parameters for optimal MRR.

b) Surface roughness:

Surface roughness in Wire Electrical Discharge Machining (WEDM) refers to the microscopic peaks and valleys on the machined surface. It is a crucial parameter that significantly impacts the functional properties of the part, including fatigue strength, wear resistance, and corrosion resistance.

Factors affecting surface roughness in WEDM:

- **Pulse parameters:**
  - **Pulse on time:** Shorter pulse on time generally results in smoother surfaces due to less material melting and recasting.
  - **Peak current:** Lower peak current leads to less intense sparks and consequently, smoother surfaces.
  - **Pulse off time:** Longer pulse off time allows for better deionization of the gap and slower cooling of molten material, contributing to smoother surfaces.
- **Wire feed rate:**

Lower feed rates allow for more time for debris removal and spark stabilization, leading to smoother surfaces.

- **Wire tension:**

Proper tension ensures the wire remains straight and taut, minimizing vibration and contributing to a smoother surface finish.

- **Dielectric fluid:**

The type and properties of the dielectric fluid can influence surface roughness. Dielectric fluids with good flushing properties and high viscosity can help to achieve smoother surfaces.

- **Material properties:**

Different materials have varying melting points and thermal conductivities, resulting in different surface roughness characteristics under the same machining parameters.

c) Kerf:

Kerf, also known as cut width, in Wire Electrical Discharge Machining (WEDM) refers to the width of the material removed during the cutting process. It is influenced by several factors and has a significant impact on the accuracy and efficiency of the machining process.

Factors affecting kerf in WEDM:

- Pulse parameters:
  - Pulse on time: Longer pulse on time generally results in a wider kerf due to increased material removal per spark.
  - Peak current: Higher peak current leads to more intense sparks and consequently, a wider kerf.
  - Pulse off time (Toff): Shorter Toff can lead to a wider kerf due to insufficient time for debris removal and deionization of the gap.
- Wire diameter:

Thicker wires generally produce a wider kerf as they have a larger surface area and contribute to more material removal per spark.

- Wire feed rate:

Higher feed rates can lead to a wider kerf due to insufficient time for spark stabilization and debris removal.

- Wire tension:

Excessive tension can cause the wire to vibrate, leading to a wider and uneven kerf.

- Dielectric fluid:

The type and properties of the dielectric fluid can influence kerf width. Dielectric fluids with poor flushing properties can lead to a wider kerf due to inefficient debris removal.

- Material properties:

Different materials have varying melting points and thermal conductivities, resulting in different kerf widths under the same machining parameters.

d) Wire wear ratio:

Wire wear ratio (WWR) is a crucial parameter in Wire Electrical Discharge Machining (WEDM) that reflects the efficiency of the process and the rate at which the wire electrode wears down during machining. WWR is defined as the ratio of the volume of wire electrode lost during machining to the volume of material removed from the work piece. It is typically expressed as a percentage.

- Pulse parameters:
  - Pulse on time: Longer pulse on time generally leads to higher WWR due to increased energy transferred to the wire and more material removal from the wire electrode.
  - Peak current: Higher peak current leads to more intense sparks and consequently, a higher WWR.
  - Pulse off time: Shorter pulse off time can lead to a higher WWR due to insufficient time for the wire to cool down between sparks.
- Wire diameter:

Thinner wires are more susceptible to wear due to their smaller cross-sectional area.

- Wire feed rate:

Higher feed rates can lead to a higher WWR as fresh wire is exposed to the spark more frequently.

- Wire tension:

Excessive tension can cause the wire to break more easily, leading to a higher WWR.

- Dielectric fluid:

The type and properties of the dielectric fluid can influence WWR. Dielectric fluids with poor flushing properties can lead to a higher WWR due to inefficient removal of debris.

- Material properties:

Different materials have varying melting points and thermal conductivities, resulting in different WWR values under the same machining parameters.

1.4 Control Variables for Machining Different Materials:

a) Tool Steel:

- Cutting speed: This is a critical parameter affecting tool life, surface finish, and power consumption. It is often chosen based on the tool material, workpiece material, and desired surface finish.
- Feed rate: Higher feed rates increase material removal rate but can lead to increased tool wear and surface roughness.
- Depth of cut: This directly affects the amount of material removed per pass and influences machining forces and tool life.
- Coolant: Using a suitable coolant helps lubricate the tool and workpiece interface, improve chip removal, and prevent thermal damage.
- Tool material and geometry: The choice of tool material (e.g., carbide, HSS) and its geometry (e.g., rake angle, clearance angle) significantly impact machining performance.
- Machine tool rigidity and vibration: Insufficient machine rigidity can lead to tool chatter and poor surface finish. Vibration should be minimized for optimal results.

b) Metal Matrix Composites (MMCs):

- Cutting speed: Due to the abrasive nature of the reinforcing particles in MMCs, lower cutting speeds are generally used compared to machining other metals.
- Feed rate: Similar to tool steels, higher feed rates increase material removal rate but can exacerbate tool wear and surface roughness.
- Depth of cut: Shallow cuts are preferred for MMCs to minimize tool wear and improve surface finish.
- Coolant: Coolant selection is crucial for MMCs. Water-based coolants are generally preferred, while oil-based coolants can lead to fiber washout.
- Tool material and geometry: Diamond-coated tools are often used for MMCs due to their superior wear resistance. Specific tool geometry may be required depending on the type and volume fraction of the reinforcing particles.
- Work piece pre-treatment: Pre-treating the MMC work piece (e.g., cryogenic treatment) can improve its machinability and reduce tool wear.

c) Inconel:

- Cutting speed: Inconel alloys are generally tougher than tool steel and require lower cutting speeds to avoid excessive tool wear.
- Feed rate: Low to moderate feed rates are recommended for Inconel to achieve good surface finish and minimize tool chipping.
- Depth of cut: Shallow cuts are preferred for Inconel, similar to MMCs, to reduce machining forces and improve surface finish.
- Coolant: High-pressure coolant is essential for Inconel machining to dissipate heat effectively and prevent tool wear.
- Tool material and geometry: Cubic boron nitride (CBN) and coated carbide tools are commonly used for Inconel machining due to their high wear resistance and ability to handle high cutting temperatures.
- Machine tool rigidity and vibration: Rigid machine tools are crucial for Inconel machining due to the high machining forces involved. Minimizing vibration is essential for achieving good surface finish and tool life.

1.5 Recent developments in WEDM:

Recent developments in WEDM include advanced wire materials, intelligent control systems, improved dielectric fluids, hybrid WEDM, automation, micro-WEDM, and Industry 4.0 integration. These developments have significantly improved the capabilities and performance of WEDM, making it an increasingly popular choice for machining complex shapes and geometries in a wide range of materials. These advancements have significantly improved WEDM capabilities, making it a more powerful and versatile tool across various industries. From aerospace and automotive to medical and electronics, WEDM is continuously evolving to meet the ever-growing demands of modern manufacturing. As research and development continue, the future of WEDM promises even greater performance, efficiency, and affordability, solidifying its position as a vital technology in the manufacturing.

1.6 Applications of WEDM in Modern Manufacturing:

Wire Electrical Discharge Machining (WEDM) has become an important tool in modern manufacturing due to its unique capabilities. Its ability to create complex geometries in hard and brittle materials with high precision makes it use for numerous applications. Here are some notable examples:

- Turbine Blades: WEDM precisely machines intricate shapes and cooling channels in turbine blades for improved efficiency and performance.
- Fuel Nozzles: WEDM creates precise fuel nozzle geometries crucial for efficient combustion and fuel injection.
- Injection Molds: WEDM creates highly accurate molds for precise injection molding of complex automotive parts.
- Gears and Sprockets: WEDM machines gears and sprockets with high precision and surface finish for smooth operation and reduced noise.
- Crankshafts and Camshafts: WEDM accurately machines intricate shapes and features in crankshafts and camshafts for optimal engine performance.
- Surgical Instruments: WEDM creates precise and sharp surgical instruments for delicate procedures.
- Printed Circuit Boards (PCBs): WEDM accurately cuts complex shapes and traces onto PCBs for precise electronic circuits.

1.7 WEDM offers several advantages that make it a valuable tool in modern manufacturing. These are the key benefits:

1. Versatility: WEDM can machine a wide variety of materials, including hard metals, ceramics, composites, and even materials that are difficult to machine with traditional methods.

2. High Precision: WEDM can achieve very high precision, with tolerances down to ±0.001mm. This makes it ideal for machining complex shapes and features.

3. No Tool Wear: Unlike traditional machining methods, WEDM does not use a cutting tool that comes into contact with the work piece. This eliminates tool wear and allows for longer production runs.

4. Burr-Free Cutting: WEDM produces burr-free cuts, eliminating the need for secondary finishing operations.

5. Minimal Heat Affected Zone (HAZ): WEDM generates minimal heat, resulting in a small heat-affected zone. This helps to maintain the material's properties and minimizes the risk of distortion.

6. Environmentally Friendly: WEDM uses minimal cutting fluids and generates less waste than traditional machining methods.

1.8) While WEDM offers numerous advantages, it also has some limitations:

1. Slower Material Removal Rate: WEDM typically has a slower material removal rate than traditional machining methods.

2. High Initial Investment: WEDM machines can be expensive to purchase and maintain.

3. Limited Cutting Depth: WEDM machines are limited by the depth of cut they can achieve. 4. Complex Setup and Programming: WEDM requires a skilled operator for proper setup and programming.

5. Environmental Concerns: The dielectric fluid used in WEDM can be hazardous and requires proper disposal.

2. Methodology

1) Taguchi method:

The Taguchi method is a powerful tool for optimizing machining processes, including Wire Electrical Discharge Machining (WEDM). It uses a structured approach to identify the optimal combination of control factors (pulse on time, peak current, pulse off time etc) that minimize the influence of noise factors (temperature, vibration, and variations in material properties) and achieve desired performance outcomes.

Procedure for taguchi method:

- Determine the parameter you need to upgrade (e.g., MRR, surface roughness, kerf width).
- Define the desired characteristic for the performance parameter (smaller-the-better, larger-the-better, or nominal-the-better).
- Recognize control factors are the process parameters you have some control over, such as pulse on time, peak current, pulse off time, wire feed rate, and wire tension.
- Identify Noise factors are the uncontrollable factors that can influence the process, such as temperature, vibration, and variations in material properties.

- Select an suitable orthogonal array based on the number of control factors and their levels.

  An **orthogonal array** is a special kind of table used in experimental design, especially in the context of the Taguchi method.
- Allocate each control factor to specific columns in the array.
- Perform WEDM experiments for each combination of control factor levels specified by the array.
- Record the response variable (performance characteristic) for each experiment.
- Calculate the signal-to-noise (S/N) ratio for each level of each control factor.
- Use statistical analysis of variance (ANOVA) to identify significant factors and their optimal levels.

2) Signal to nose ratio (S/N):

The signal-to-noise (S/N) ratio is a crucial metric used in the Taguchi method for enhancing WEDM processes. It evaluates the relative strength of the desired signal (performance characteristic) compared to the noise (uncontrollable factors) affecting the process.

Procedure for Signal to nose ratio (S/N):

- Specify the parameter you want to enhance (e.g., MRR, surface roughness, kerf width).
- Determine if the characteristic is smaller-the-better (minimized), larger-the-better (maximized), or nominal-the-better (target value).
- Perform WEDM experiments for each combination of control factor levels indicated by the array.
- Record the response variable (performance characteristic) for each experiment.
- Calculate the S/N ratio for each experiment using following formulas:

1. For smaller-the-better:

$$S/N\ (dB) = -10 \log(\Sigma y^2/n)$$

2. For larger-the-better:

$$S/N\ (dB) = -10 \log(1/\Sigma(1/y^2) / n)$$

3. For nominal-the-better:

$$S/N\ (dB) = -10 \log(\Sigma(y - T)^2/n)$$

Where :

- T is the target value for the performance characteristic.
- Compare the S/N ratios for various levels of each control factor.
- Identify the factor level(s) that correspond to the highest S/N ratio for the desired performance characteristic.
- Examine the interaction effects between different control factors, if needed.
- Based on the S/N analysis and any additional considerations, choose the combination of control factor levels that optimizes the performance characteristic.

Conclusion

This concluded that WEDM experiment has successfully investigated the influence of machining parameters on surface roughness (SR), material removal rate (MRR), and kerf width. The Taguchi method and grey relation analysis (GRA) were employed to optimize the machining parameters and evaluate their impact on the performance characteristics of WEDM. The experimental findings revealed that pulse-on time (TON) significantly influenced the machining performance, with a direct relationship to MRR and kerf width and an inverse relationship to SR. Pulse-off time (TOFF) had a direct relationship to SR, indicating that longer TOFF durations promote better surface finish. Peak current (IP) also exhibited a direct relationship to MRR and kerf width, while servo voltage (SV) showed a nonlinear relationship to SR, with an optimal range for achieving a fine surface finish. The experiment demonstrated the capability of WEDM in machining hard and super alloy materials, which are often challenging to machine using conventional methods. The precise and controlled material removal process of WEDM allows for machining intricate shapes and achieving high-quality surface finishes on these materials. The applications of WEDM extend across various industries, including aerospace, automotive, medical devices, electronics, and tool and die making. Its ability to machine hard and brittle materials, produce complex shapes, and minimize heat-affected zones makes WEDM a valuable tool for manufacturing precision components.

References

[1] G.Archana , Dr .K. Dharma Reddy , Dr. P.Venkataramaiah (2018) 'Study on Machining Response in Wire EDM OF Inconel 625'. International Journal of Applied Engineering Research ISSN 0973-4562, 13(21) pp. 15270-15277

[2] R. K. Garg & K. K. Singh & Anish Sachdeva & Vishal S. Sharma & Kuldeep Ojha & Sharanjit Singh (2010) 'Review of research work in sinking EDM and WEDM on metal matrix composite materials'. Int J Adv Manuf Technol, pp. 611-624

[3] Anurag Joshi (2014) 'WIRE CUT EDM PROCESS LIMITATIONS FOR TOOL AND DIE STEEL'. International Journal of Technical Research and Applications e-ISSN: 2320-8163, 2(1) PP. 65-68

[4] ATUL KUMAR and DR.D.K.SINGH (2012) 'Performance Analysis of Wire Electric Discharge Machining (W-EDM) '. International Journal of Engineering Research & Technology (IJERT) ISSN: 2278-0181, 1(4)

[5] Sreenivasa Rao M , Venkaiah N (2013) 'Review on Wire-Cut EDM Process'. International Journal of Advanced Trends in Computer Science and Engineering, 2(6), pp. 12-17

[6] S.Madhavakrishna & Dr.P.Suresh (2016) 'Recent developments in wire EDM'. Journal of Mechanical Engineering and technology(JMET) ISSN 2347-3924,4(1) pp. 11-14

[7] M. Durairaj, D. Sudharsunb, and N. Swamynathan, "Analysis of Process Parameters in Wire EDM with Stainless Steel Using Single Objective Taguchi Method and Multi Objective Grey Relational Grade," International Journal of Mechanical and Production Engineering, vol. 64, pp. 868–877, 2013.

[8] K. Natarajan, H. Ramakrishnan, Amel Gacem, V.Vijayan, K.Karthiga, H.Elhosiny Ali,B. Prakash, Addisalem Mekonnen (2022) 'Study on Optimization of WEDM Process Parameters on Stainless Steel' Hindawi Journal of Nano materialsVolume 2022, Article ID 6765721, pp.7

[9] Pradeep kumar karsh, Hari singh (2016) 'Optimization of process parameters for surface roughness of Inconel 625 in Wire EDM by using Taguchi method' IOSR Journal of Mechanical and Civil Engineering (IOSR-JMCE) e-ISSN: 2278-1684, p-ISSN: 2320–334, 3(3) p.58-63

[10] S.R Nipanikar (2012), "parameters optimization of EDM of AISI D3 steel material using taguchi method", journal of Engineering research and studies , Vol 3,issue 3,ISSN 0976-7916