



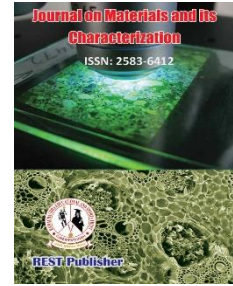
Journal on Materials and its Characterization

Vol: 4(4), December 2025

REST Publisher; ISBN: 2583-6412

Website: <http://restpublisher.com/journals/jmc/>

DOI: <https://doi.org/10.46632/jmc/4/4/3>



Enhancing the Efficiency of Optimizing Process Parameters for Micro-EDM Drilling on Inconel 625 using MOORA Method

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Abstract: Inconel 625 is a nickel-based super alloy widely used in the aerospace, automotive, and marine industries because of its excellent resistance to high temperatures, corrosion, and oxidation. Despite these advantages, its high mechanical strength, hardness, and low thermal conductivity make machining difficult, particularly in micro-electrical discharge machining (micro-EDM) drilling. Micro-EDM is a non-traditional machining process that removes material from electrically conductive work pieces by means of controlled electrical discharges between a tool electrode and a work piece immersed in a dielectric fluid. The process produces localized melting and evaporation, which gradually creates micro-grooves that shape complex and precise features. Machining Inconel 625 by micro-EDM presents challenges such as rework layer formation, heat-affected zones (HAZ), poor surface quality, high tool wear, and reduced dimensional accuracy. These problems are exacerbated in micro-drilling applications where tight parameter control is required for small geometric features. Critical process parameters include discharge current, pulse-on time, pulse-off time, gap voltage, capacitance, electrode material, dielectric properties, and EDM feed rate. Traditional trial-and-error optimization methods are inefficient for such precision-based machining. Therefore, advanced techniques such as evolutionary algorithms, neural networks, response surface methodology (RSM), and MOORA-based multi-objective optimization are used. Among the evaluated parameters, EDM feed rate achieved the highest evaluation value, while pulse-off time showed the least influence on improving machining performance.

Keywords: MCDM, Current (A), Pulse on time (μ s), Pulse off time (μ s), Gap Voltage (V), Capacitance (pF) and EDM federate (μ m/s).

1. INTRODUCTION

The micro-EDM technique uses the same material removal mechanism as the traditional EDM process. The work material and electrically conductive tool are both submerged in an electrolyte solution, and a voltage difference is generated between them. The formation on the intensity of the plasma channel voltage and for tool and work the distance between However, such a plasma channel's electrical resistance would be incredibly low. The thermo-electric energy generated between such a work as well as electrodes submerged in a conductive fluid is, in essence, the foundation of the electromagnetic discharge machining (EDM) process [1]. Genetic mechanisms and evolutionary mechanisms, such as particle swarm optimization and natural selection, reflect processes for exploring solution spaces and considering both exploitation and exploration to converge towards the global optimum, especially within neural networks. Artificial neural networks (ANNs) utilize input parameters and output from experimental data to learn complex relationships, facilitating the upgrade process through a data-driven approach. Trained neural networks, optimized with high accuracy parameters, predict outcomes without extensive testing, enabling rapid optimization [2]. The Response Surface Method (RSM) is the input parameters and between mechanical responses correlations in, meaning removal rate and such as surface roughness using mathematical models approximates. Through regression analysis, response surfaces fit experimental data, reducing the number of test trials and helping identify optimal parameters for machining processes. Full Factorial

Designs, Partial Factorial Designs, and techniques like Taguchi methods within Design of Experiments (DOE) reduce testing effort while systematically varying process parameters within determined limits to measure key machine responses [3]. Performance of process parameters is assessed through measured outcomes Material Removal Rate (MRR), Tool Wear Rate (TWR) and surface roughness etc., and scanning electron microscopy (SEM) and for quality profilometry used as advanced with quantitative techniques analysis. Once test data is collected, optimization algorithms or regression analysis techniques create models for forecasting. Neural network-based models undergo validation and testing to prevent over fitting, while genetic algorithms generate initial populations randomly, evaluating efficiency through measurements and evolving towards optimal parameter sets through successive generations via crossover and mutation [4]. RSM-based optimization utilizes regression analysis to fit response surfaces to experimental data, aiming to increase MRR or reduce surface roughness as optimization objectives, with methods like slope-based techniques or uniform search updating parameter settings within constraints for identification. A pulsed shock from the electrode transfers a layer of material thru the melting and evaporation when such workbench and the electrode is the spark gap a so-called by certain small opening will be spaced [5]. The wear on the blade electrode is very well occurring in conventional Milling (die sinking). When considering the needed feature sizes and tolerances, errors brought on by electrode deterioration in this scenario are frequently insignificant. Because mixing nano characteristics and macro features on one electrode would result in distinct wear characteristics, conventional die-sinking methods rely upon the use of one or so more sensors for sanding followed by an emitter for finishing are also not viable for machining micro features [6]. The effectiveness of the diesel engine is closely related Drilled needle tips improve the quality of holes. Perforated Geometry of needle holes Affects atomization spatial distribution of the fuel. Internal combustion engines can operate at their maximum strength and speed while emitting the fewest amounts of exhaust thanks in large part to such architecture comprising the final and final, undercutting inclination, waviness, and circularity of machine holes' entry and exit in place. Maintenance micro-drilled whole's calibre will help to increase the fuel's thorough spray characteristics and high flow coefficient [7]. One of the most well-liked and flexible non-conventional metal removal techniques is EDM. It operates by producing a succession of brief electric discharges in a dielectric-filled gap between both the work piece and tool. Liquid of the spark electrical energy is heat converted into energy, it is the surface of the work piece melts and evaporates. The dielectric flow flushes away materials eliminated as trash particles. Not only is material removed from the work piece, but also on the tip electrode wear [8]. Producing tiny parts and components with much less than 10 μm sizes (within 1 and 999 m) involves the use of micro-machining. The growing demand for reduced weight and miniaturization of items in the biotechnology, telecommunications, atmospheric and biomedical fields, electric devices, machinery, and other fields has increased the demand for micro-machining recently. There has been numerous research on microstructure and component manufacture. There are three types of material removal techniques for micro-machining: conventional, nonconventional, and hybrid [9]. Particularly when a small hole in an aerospace alloy is machined using a typical machining technique, the slicing efficiency is really poor and the drill is easily destroyed because the aerospace alloy has a low degree of stiffness and is challenging to evacuate. When using electrical discharge machining (EDM), mechanical tensions, chatter, and vibration issues during machining is not present because the electrodes as well as the work piece do not come into direct contact. Any substance that conducts electricity can be sliced, regardless matter how hard the material is. As a result, it is excellent for drilling small, blind, and deep holes. Additionally, the EDM method eliminates the spiral traces produced by standard drilling procedures. Because of its superiority in the shortest amount of time required, Micro-EDM is recognized as an effective approach for fabricating precise micro-metal holes [10]. Tool wear is an inevitable byproduct of the EDM process since sparks are produced Because the precision of machining is limited by the simultaneous removal of a piece pertain to the degradation of cutting tools in the radial and axial directions, respectively. As a result, tool wear in EDM drilling decreases for more specifically, the creation of a blind hole exacerbates this issue. Proposed a relationship seen between thermal characteristics of the ratio of tool wear and the work piece and tool composition. Numerous studies have been conducted to tackle the issues of wear rate in EDM using cylindrical tools [11]. No matter how hard the material is, EDM can remove it by using a succession of shocks on electrically conducting materials. EDM process for micro-milling applications most suitable in various geometric qualities there is a very important criterion. Complicated composites such as composite materials, steel, and aerospace super alloys. This is because no mechanical correlation exists during material removal [12]. Industrial products are increasingly in demand, both for their enhanced functionality and for their smaller size. Since the tendency in technical progress has been the shrinking of industrial products, micromachining is anticipated to become more and more significant in the manufacturing technologies of today [13]. Traditionally, EDM has been utilized to create intricate melds for injection molding or shaping. By using wire EDM, it has also been frequently utilized to cut shapes out of steel plates. The primary method used to create pinholes in regular diesel nozzles is micro-EDM. Additionally, the method is used to create gaps in propeller razors for the air transport industry. Whole widths in fuel pump components can be as small as 200 m. An ideal procedure for obtaining Micron size features good rates and no Burrs Micro-EDM. In particular, Micro-EDM is a non-contact object removal

technology it is a rapid electrical spark uses discharges. To melt and vaporize the work piece's material to remove it. The current work focuses on creating micro-sized holes utilizing micro-EDM technology [14].

2. MATERIALS AND METHOD

Current (A): Micro-EDM (Electrical Discharge Machining) to make precise, tiny holes in hard materials like metals and ceramics, drilling is a procedure. In this method, a thin electrode is used to spark the material and create a hole between the work piece and the electrode. Electrode wear, hole size, and the speed of removal of material are all impacted by the amount of current (A) employed in micro-EDM drilling. For micro-EDM drilling, the average current range is 1 to 50 microamperes. Higher currents typically lead to faster rates of material removal, but they also cause larger holes and more electrode degradation. Lower currents may produce smaller, more precise holes with less electrode wear, but they may also slow down the pace of material removal. The ideal current for a particular drilling application depends on several variables, including the drilling material, the electrode's size and shape, and the required whole characteristics.

Pulse on time (μ s): Another crucial variable in micro-EDM drilling is a pulse on time, which is also known as pulse width or pulse width. It describes the amount of time that is spent applying the electrical discharge during each pulse. The energy provided to the object and the height of both the hole produced is influenced by the pulse on time. Smaller holes with less deviation and finer surface finishes are produced by shorter pulse durations, whereas larger rounds with any more taper and worse surface finishes are produced by longer pulse durations. In micro-EDM drilling, pulse lengths typically range from a few femtoseconds to several hundred microseconds. The ideal pulse duration for a given application is dependent on a variety of factors, such as the piercing materials, the size and form of the electrode, and the specifications for the desired hole. It should be mentioned that throughout the micro-EDM drilling process, the pulse on time can be adjusted in real-time and other desired whole parameters and maximum performance.

Pulse off time (μ s): Another crucial factor in micro-EDM drilling is pulse off time, which is also referred to as a pulse cycle or off period. It outlines the time frame between subsequent electrical discharges that occur while drilling. This provides many opportunities for it electrode or the work piece to be given time to recuperate during the pulse-off period, and the fluid flow can flush the residue from the prior discharge. This keeps the machining process stable and guarantees that all discharge is reliable and effective. Longer pulse-off periods may produce larger hole sizes and poorer surface finishes, but they may also result in slower material removal levels and lower electrode wear. Faster material detection limits and smaller whole sizes can be achieved by using shorter pulse-off periods, although this may result in increased electrode wear and rougher surface finishes. The ideal pulse-off time for a given application depends on several variables, including the drilling material, the electrode's size and shape, and the required whole characteristics. The pulse-off time can be changed in real-time, just like other micro-EDM drilling settings, to enhance performance and provide the desired outcomes.

Gap Voltage (V): Another crucial factor in micro-EDM drilling is gap voltage. It speaks about the voltage difference that exists while drilling between the electrode and work piece. The quality and features of the drilled hole are greatly influenced by the gap voltage. The exact shape of the hole produced, as well as the electrical discharge's intensity, are all influenced by the gap voltage. Stronger discharges are produced by higher gap voltages, which can speed up material removal rates but can result in larger holes and rougher quality materials. Less intense discharges are produced by lower gap voltages, which can result in slower rates of material removal but smaller holes with better surface finishes.

Capacitance (pF): Capacity of electronic generator that creates the electrical storm between the electrode and the work piece is referred to as capacitance in micro-EDM drilling. The amount of capacitance has an impact on the discharge energy and duration, which has an impact on the effectiveness and the velocity of material removal of the drilled hole. A higher capacitance value may lead to a longer, more intense discharge, which accelerates the pace of material removal but may also result in larger holes and finer surface finishes.

EDM feed rate (μ m/s): The pace at which the electrode is inserted into The EDM feed rate (electrical discharge machining) is the rate at which the work piece is cut during the process. In micro-EDM drilling, the feed rate is a significant factor that can affect the characteristics and caliber of the drilled hole. Greater feed rates can speed up material removal, but they may also make large perforations as well as rougher surface finishes. Although smaller holes with better surface finishes may be produced, a reduced feed rate may result in slower rates of material removal. The ideal EDM feed rate for a given application relies on several variables, such as the drilling material, the electrode's size and shape, and the required whole characteristics. It is important to remember that the EDM feed rate can be changed while drilling to get the desired results and maximize performance.

Method: The second aspect pertains to MOORA's property of utilizing dimensionless numbers as its foundation. Ultimately, it considers all objectives and goals, comparing inequalities across the ten counties of Lithuania, each with varying degrees of prosperity and health. This analysis highlights stark differences between three affluent districts and others less fortunate. One significant factor is income disparity among districts, with labor migration being particularly pronounced in the Vilnius District, where automatic redistribution is not permitted. The emphasis lies on promoting commercialization and selective industrialization to foster development across regions [15]. Robust multi-objective optimization involves navigating constraints and conflicting attributes, with the possibility of updating notes simultaneously. This approach is particularly useful in addressing design issues across various product dimensions and making decisions amidst competing interests, such as increasing sales while reducing production costs. For instance, enhancing efficiency in automobiles might involve reducing fuel consumption and weight simultaneously, despite the associated complexities [16]. When considering Firstly, MOORA is a novel approach, contrasting with more traditional methods, and is developed with practicality in mind. Secondly, MOORA typically requires less processing time compared to other MCDM techniques. Finally, MOORA does not necessitate extensive setup, offering a stable and efficient decision-making process [17]. MOORA serves as an educational tool, aiding in the selection of college students for scholarships based on academic success. Its ability to quickly analyze and choose among applicants is beneficial to both students and institutions. Additionally, MOORA's versatility allows for handling diverse components and conducting comprehensive analyses, making it an effective green multi-criteria selection method for resolving complex decision-making problems [18]. MOORA offers a rigorous approach to resolving complex decision-making problems by considering conflicting standards and ultimately aiming to select the optimal solution. Its effectiveness in addressing various criteria makes it a valuable tool in diverse decision-making contexts, with its results often being rewarded for their efficacy [19]. The MOORA technique is versatile, serving as a means to enhance decision-making processes. It incorporates various criteria and methods to advance simultaneously. Employing MOORA involves experimenting with different approaches, proving to be an effective strategy for control [20]. Incorporating MOORA entails considering all characteristics this method is straightforward to understand and apply, recommended for decision-making across different scales and qualities. By amalgamating applicable features, MOORA facilitates precise targeting and simplifies decision-making processes [21]. MOORA, grounded in ratio analysis, addresses multi-objective optimization by simultaneously assessing multiple attributes. It proves particularly valuable in complex scenarios like supply chain management, where decision-making involves a multitude of factors such as warehouse location, supplier selection, and product design [22]. Extending MOORA allows for the identification and prioritization of failures, aiding in addressing deficiencies efficiently. By ranking failures according to their priority, this extension enhances the decision-making process, ensuring significant issues are addressed promptly. This extension augments the reliability of MOORA, providing decision-makers with logical conclusions. Comparing MOORA with conventional practices reveals its effectiveness in disaster management. By prioritizing detectable disasters, MOORA enables proactive mitigation efforts, showcasing its superiority over traditional routines. Ultimately, the decision-maker's role is crucial in leveraging the potential of MOORA to its fullest extent [23]. Recent scholarly research has focused on utilizing the latest available data to analyse techniques such as MOORA and MOOSRA. These methods are predominantly favoured as the primary choice for selection problems due to their complementary, diverse, and unconventional nature, particularly in the context of production systems. Expressing ratios is advantageous for assessing economic welfare, as it ensures uniformity in value measurement [24]. Conceptually, MOORA and MOOSRA align with other performance assessment approaches, emphasizing incremental performance evaluation. In the realm of port planning, the selection of the MOORA technique is justified based on its ability to benchmark goals and preferences effectively, crucial for simulations. Stakeholders in this domain include various governmental bodies at local, state, and central levels, alongside industrial stakeholders and consumer representatives [25]. MOORA's effectiveness in addressing decision-making challenges, particularly in complex systems like CNC machine tool operations, lies in its ability to integrate variables and navigate ambiguity inherent in decision-making contexts. By employing a subjective approach and accommodating diverse perspectives, MOORA aids decision-makers in processing information effectively. Multi-MOORA rank orders are discussed in detail, providing comprehensive insights into decision outcomes [26].

3. RESULTS AND DISCUSSION

TABLE 1. Optimizing Process Parameters for Micro-EDM Drilling on Inconel 625

	Process parameters levels 1	Process parameters levels 2	Process parameters levels 3
Current (A)	0.1090	0.0960	0.1400
Pulse on time (μ s)	0.0840	0.1100	0.0390
Pulse off time (μ s)	0.0690	0.0836	0.1530
Gap Voltage (V)	0.1170	0.0954	0.1210

Capacitance (pF)	0.0790	0.1040	0.0250
EDM feedrate (µm/s)	0.1930	0.1320	0.1760

Table 1 shows the Multi-Objective Optimization based on ratio Analysis Enhancing the efficiency of optimizing process parameters for Micro-EDM drilling on Inconel 625. Process parameters levels 1, Process parameters levels 2 and Process parameters levels 3. Current (A), Pulse on time (µs), Pulse off time (µs), Gap Voltage (V), Capacitance (pF) and EDM feedrate (µm/s) it is seen that EDM feedrate (µm/s) is showing the Highest Value Process parameters levels 1 and Pulse off time (µs) is showing the lowest value. EDM feedrate (µm/s) is showing the Highest Value for Process parameters levels 2 and Pulse off time (µs) is showing the lowest value. EDM feedrate (µm/s) is showing the Highest Value for Process parameters levels 3 and Capacitance (pF) is showing the lowest value.

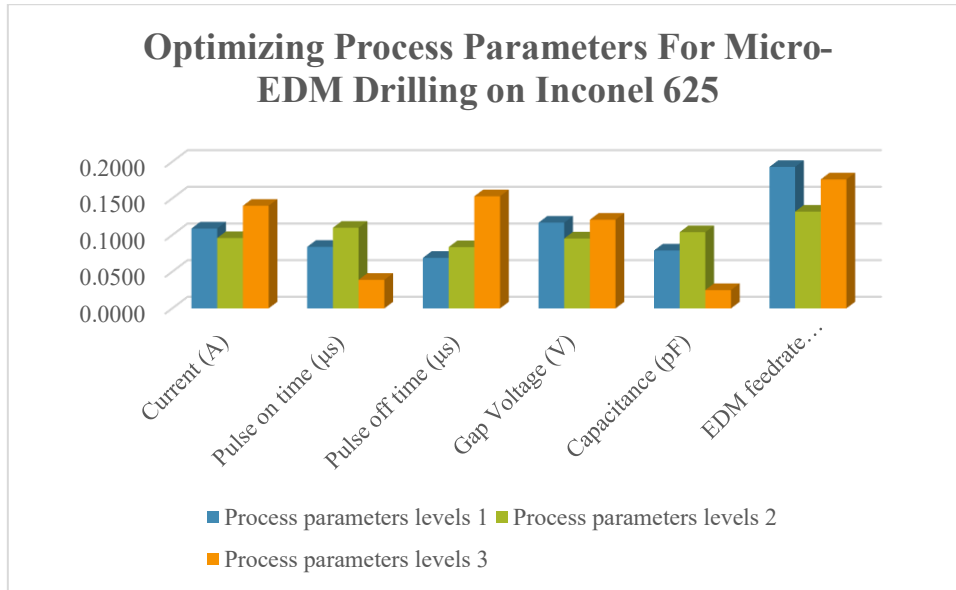


FIGURE 1. Optimizing Process Parameters for Micro-EDM Drilling on Inconel 625

Figure 1 shows the Multi-Objective Optimization based on ratio Analysis Enhancing the efficiency of optimizing process parameters for Micro-EDM drilling on Inconel 625. Process parameters levels 1, Process parameters levels 2 and Process parameters levels 3. Current (A), Pulse on time (µs), Pulse off time (µs), Gap Voltage (V), Capacitance (pF) and EDM federate (µm/s) it is seen that EDM federate (µm/s) is showing the Highest Value Process parameters levels 1 and Pulse off time (µs) is showing the lowest value. EDM federate (µm/s) is showing the Highest Value for Process parameters levels 2 and Pulse off time (µs) is showing the lowest value. EDM federate (µm/s) is showing the Highest Value for Process parameters levels 3 and Capacitance (pF) is showing the lowest value.

TABLE 2. Normalized Data

	Process parameters levels 1	Process parameters levels 2	Process parameters levels 3
Current (A)	0.3833	0.3747	0.4647
Pulse on time (µs)	0.2954	0.4293	0.1294
Pulse off time (µs)	0.2426	0.3263	0.5078
Gap Voltage (V)	0.4114	0.3723	0.4016
Capacitance (pF)	0.2778	0.4059	0.0830
EDM federate (µm/s)	0.6786	0.5152	0.5842

Table 2 shows the various Normalized Data Multi-Objective Optimization based on ratio Analysis Enhancing the efficiency of optimizing process parameters for Micro-EDM drilling on Inconel 625. Process parameters levels 1, Process parameters levels 2 and Process parameters levels 3. Current (A), Pulse on time (µs), Pulse off time (µs), Gap Voltage (V), Capacitance (pF) and EDM feedrate (µm/s) Normalized Data value.

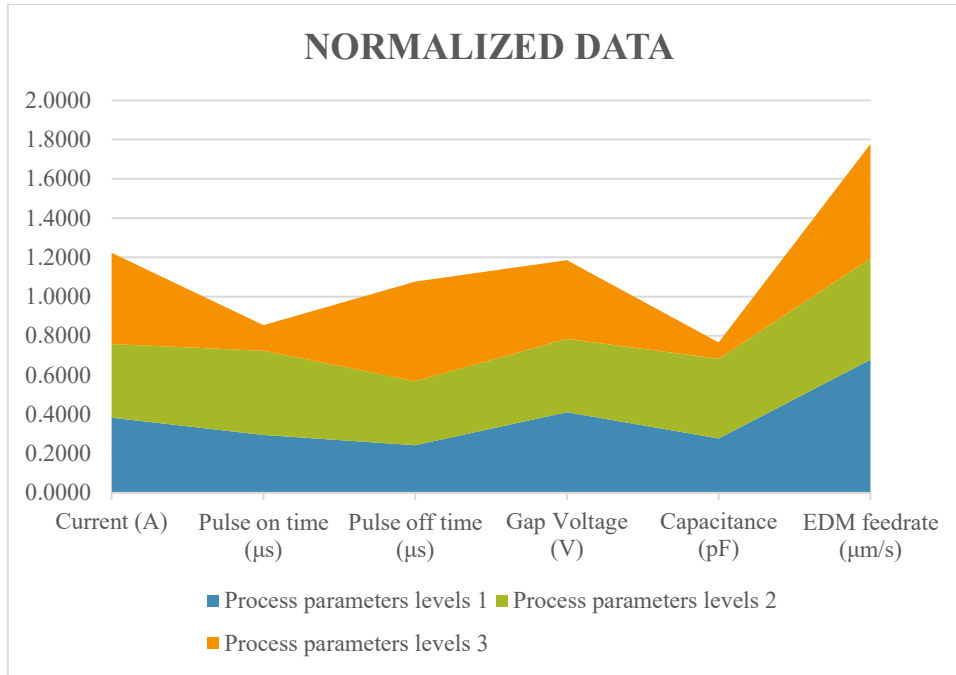


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TABLE 3. Weightages

Weightage		
0.25	0.25	0.25
0.25	0.25	0.25
0.25	0.25	0.25
0.25	0.25	0.25
0.25	0.25	0.25
0.25	0.25	0.25

Table 3 shows that the weighting matrix assigns equal importance to all criteria, with each criterion given a value of 0.25. This represents a balanced evaluation approach, in which no single factor dominates the decision-making process. Each parameter contributes equally to the overall evaluation and the final ranking result.

TABLE 4 shows the Weighted Normalized Decision Matrix

	Process parameters levels 1	Process parameters levels 2	Process parameters levels 3
Current (A)	0.096	0.093671	0.116169493
Pulse on time (µs)	0.074	0.107332	0.032361501
Pulse off time (µs)	0.061	0.081572	0.12695666
Gap Voltage (V)	0.103	0.093086	0.100403633
Capacitance (pF)	0.069	0.101477	0.020744552
EDM feedrate (µm/s)	0.17	0.128798	0.146041648

Table 4 shows the Weighted Normalized Decision Matrix Multi-Objective Optimization based on ratio Analysis Enhancing the efficiency of optimizing process parameters for Micro-EDM drilling on Inconel 625. Process parameters levels 1, Process parameters levels 2 and Process parameters levels 3. Current (A), Pulse on time (µs),

Pulse off time (μs), Gap Voltage (V), Capacitance (pF) and EDM feedrate ($\mu\text{m/s}$) Weighted Normalized Decision Matrix value.

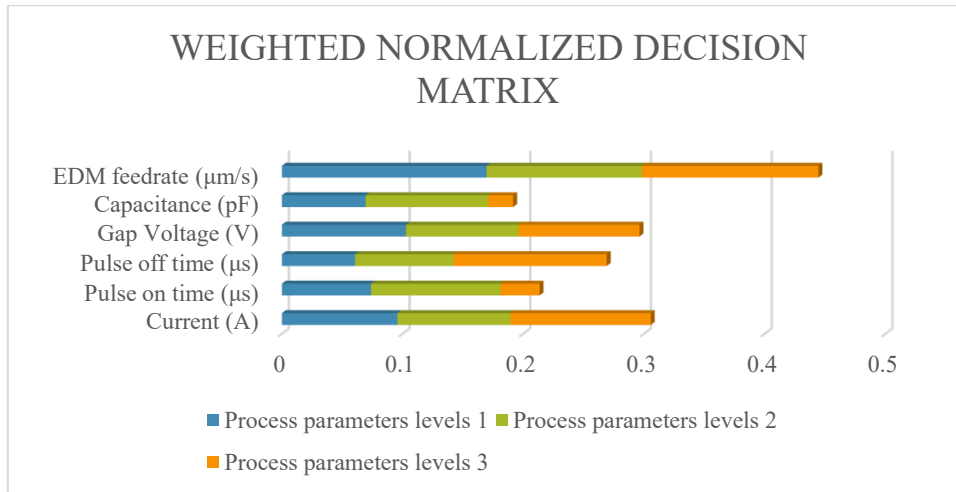


FIGURE 3 Weighted Normalized Decision Matrix

Figure 3 shows the Weighted Normalized Decision Matrix Multi-Objective Optimization based on ratio Analysis Enhancing the efficiency of optimizing process parameters for Micro-EDM drilling on Inconel 625. Process parameters levels 1, Process parameters levels 2 and Process parameters levels 3. Current (A), Pulse on time (μs), Pulse off time (μs), Gap Voltage (V), Capacitance (pF) and EDM feedrate ($\mu\text{m/s}$) Weighted Normalized Decision Matrix value.

TABLE 5. MOORA Analysis and Result

	Assessment value	Rank
Current (A)	0.0733	5
Pulse on time (μs)	0.1488	3
Pulse off time (μs)	0.0153	6
Gap Voltage (V)	0.0955	4
Capacitance (pF)	0.1502	2
EDM feedrate ($\mu\text{m/s}$)	0.1524	1

Table 5 shows the final result Multi-objective optimization based on ratio analysis enhancing the efficiency of optimizing process parameters for Micro-EDM drilling on Inconel 625. In Assessment value, EDM feedrate ($\mu\text{m/s}$) is having is Higher Value and Pulse off time (μs) is having Lower value

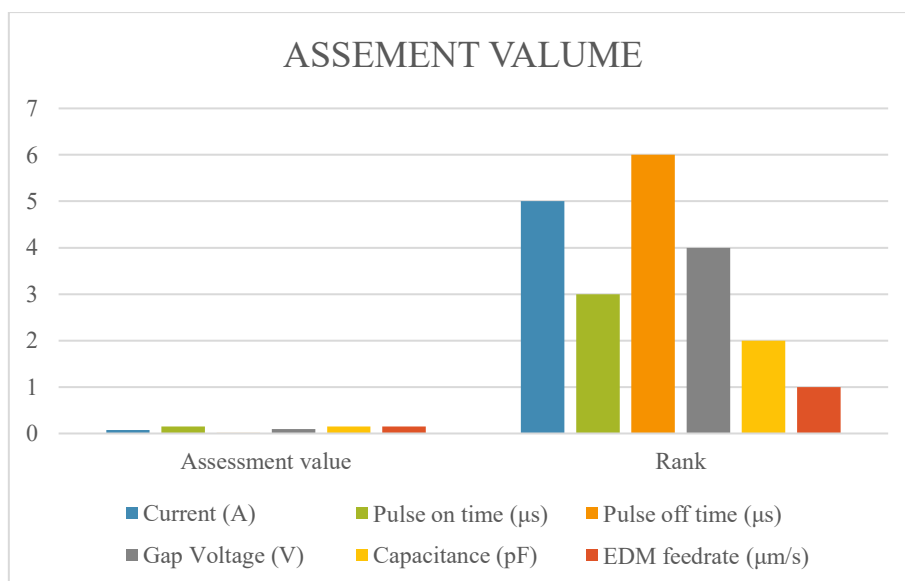


FIGURE 4. Assessment value

Figure 4 Shows the Assessment Value Multi-objective optimization based on ratio analysis enhancing the efficiency of optimizing process parameters for Micro-EDM drilling on Inconel 625. In Assessment value, EDM feedrate ($\mu\text{m/s}$) is having is Higher Value and Pulse off time (μs) is having Lower value.

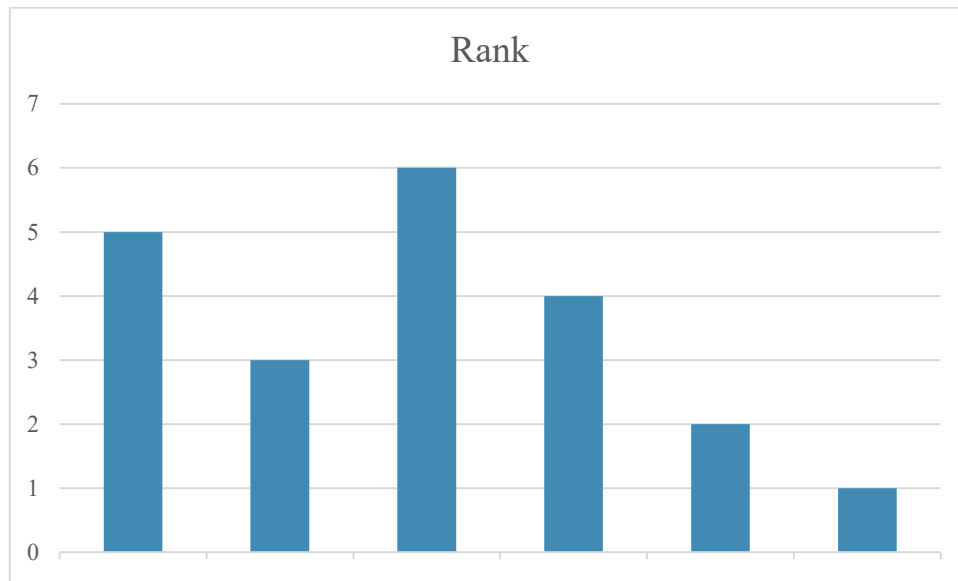


FIGURE 5. Shown the Rank

Figure 4 Shows the Ranking of Enhancing the efficiency of optimizing process parameters for Micro-EDM drilling on Inconel 625. In Assessment value, EDM feedrate ($\mu\text{m/s}$) is having is Higher Value and Pulse off time (μs) is having Lower value.

4. CONCLUSION

The micro-EDM technique uses the same material removal mechanism as the traditional EDM process. The work material and electrically conductive tool are both submerged in an electrolyte solution, and a voltage difference is generated between them. The formation on the intensity of the plasma channel voltage and for tool and work the distance between However, such a plasma channel's electrical resistance would be incredibly low. The thermo-electric energy generated between such a work as well as electrodes submerged in a conductive fluid is, in essence, the foundation of the electromagnetic discharge machining (EDM) process. Micro-EDM (Electrical Discharge Machining) To make precise, tiny holes in hard materials like metals and ceramics, drilling is a procedure. In this method, a thin electrode is used to spark the material and create a hole between the workpiece and the electrode. electrode wear, hole size, and the speed of removal of material are all impacted by the amount of current (A) employed in micro-EDM drilling. For micro-EDM drilling, the average current range is 1 to 50 microamperes. Higher currents typically lead to faster rates of material removal, but they also cause larger holes and more electrode degradation. Lower currents may produce smaller, more precise holes with less electrode wear, but they may also slow down the pace of material removal. The ideal current for a particular drilling application depends on several variables, including the drilling material, the electrode's size and shape, and the required hole characteristics. The second aspect pertains to MOORA's property of utilizing dimensionless numbers as its foundation. Ultimately, it considers all objectives and goals, comparing inequalities across the ten counties of Lithuania, each with varying degrees of prosperity and health. This analysis highlights stark differences between three affluent districts and others less fortunate. One significant factor is income disparity among districts, with labor migration being particularly pronounced in the Vilnius District, where automatic redistribution is not permitted. Current (A), Pulse on time (μs), Pulse off time (μs), Gap Voltage (V), Capacitance (pF) and EDM feedrate ($\mu\text{m/s}$). Process parameters levels 1, Process parameters levels 2 and Process parameters levels 3. the Ranking of Enhancing the efficiency of optimizing process parameters for Micro-EDM drilling on Inconel 625. In Assessment value, EDM feedrate ($\mu\text{m/s}$) is having is Higher Value and Pulse off time (μs) is having Lower value.

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