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*Review*

## Micro-Electrical Discharge Machining of Inconel 718: Challenges and Future Prospects

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### Abstract

Inconel 718 is a super alloy composed of nickel and chromium, widely used in engineering applications due to its exceptional thermomechanical properties. However, its high work-hardening behavior and low thermal conductivity render conventional machining processes inefficient and challenging, particularly at the microscale. Micro-electrical discharge machining (micro-EDM) has emerged as a promising non-traditional technique for fabricating micro-features in Inconel 718. However, issues continue to arise, including difficulty in maintaining debris evacuation during machining, process stability concerns, and low material removal rates (MRR) and poor surface quality. This review presents micro-EDM of Inconel 718 and the challenges associated with machining using micro-EDM, and then examines how various vibration-assisted strategies have been developed to improve both process stability and efficiency. The review of vibration assist mechanisms on process performance in terms of MRR, total machining time, and surface finish has been discussed. Finally, this review synthesizes the data obtained from the various experiments performed thus far to establish a comprehensive understanding of how vibration assists in stabilizing and increasing the efficiency of the micro-EDM process. Furthermore, while identifying current gaps in the literature, this review suggests potential areas for future development to enhance the process performance and productivity of micro-EDM in micro-scaled machining of Inconel 718.

### Keywords

Micro-EDM, Inconel 718, Machinability characteristics, Vibration-assisted micro-EDM

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## 1. Introduction

The demand for miniaturized components is primarily driven by application-specific needs and the goal of reducing material usage without compromising performance. Micro-features such as holes and slots are vital in aerospace, biomedical, electronic, optical, and automobile sectors due to their low vibration, minimal thermal distortion, high dimensional stability, and cost efficiency. Miniaturization also enhances device speed and enables new applications [1,2]. Micro manufacturing encompasses processes for producing such components and is broadly classified into Micro-Electro-Mechanical Systems (MEMS) and non-MEMS technologies. While MEMS fabrication involves etching, chemical deposition, and patterning, non-MEMS processes include electrical discharge machining (EDM), photochemical machining, micromechanical cutting, embossing, and laser machining. Among these, accurate micro-hole production is crucial, though each unconventional machining method presents distinct benefits and challenges. The selection of the appropriate nontraditional machining process requires consideration of several criteria, such as higher material removal rates (MRR), minimum electrode wear, good surface finish and less power requirement, etc. For instance, the laser offers the freedom to change the hole diameter with higher production rates, and it can create holes in the workpiece with a diameter as small as 0.005 mm [3]. However, laser energy causes thermal damage on machined surface and leads to poor assembly tolerances [4]. For efficient utilization and optimized machining performance, strategic selection of the most appropriate process for a particular application is often required. For the fabrication of micro-sized holes, among the nontraditional machining processes, micro-EDM is usually preferred for processes in which high aspect ratio, accurate dimensions, even in complex geometries and lower cost are the primary requirements. micro-EDM is the widely adopted technique in industries for the machining of all types of conductive material, irrespective of their hardness characteristics. Micro-EDM can be used to machine three-dimensional cavities in addition to micro-sized holes and shafts with a minimum achievable diameter of 5  $\mu\text{m}$  [5].

### *Significance of machining of Inconel-718:*

Materials with special metallurgical properties, such as titanium alloys, nickel-based alloys, tool steels or other superalloys, are suitable for applications that require high resistance to heat and corrosion. These materials possess superior mechanical strengths, relying on their excellent creep resistance at elevated working and service temperatures, high work hardening capabilities, and significant corrosion resistance to be the preferred choice in aerospace, marine, gas turbine, and nuclear applications [6]. Despite its well-recognized advantages, Inconel 718 is characterized by poor machinability, which presents considerable challenges during manufacturing operations [7]. Therefore, it is essential to develop sustainable machining strategies when cutting these hard-to-cut materials, particularly because of their significance in critical applications and the associated costs and desire for sustainability. The super alloy Inconel 718, which contains nickel-chromium, is an extremely useful material in many fields, including aerospace engines, marine systems, nuclear technology, gas turbines and oilfield equipment, due to its mechanical properties. Inconel 718 offers a combination of high strength, excellent resistance to creep, and superior wear and corrosion properties that provide an advantage when used in extreme conditions [8]. Unfortunately, the same qualities that make Inconel 718 an excellent material for these types of applications also make machining the material using conventional methods (e.g., turning, milling, grinding, or broaching) very difficult. Inconel 718 exhibits very high work hardening characteristics, maintains a high tensile strength under heat, and has low thermal conductivity. This results in a large amount of heat being generated near the cutting area, creating high compressive stresses at the interface between the tool and the workpiece [9]. As a result, this high level of heat creates significant wear on the edges of the cutting tools as well as results in significant notch wear, flank wear and plastic deformation at the cutting edge. Additionally, the elevated temperatures of the tool tip result in a poor machined surface and rapid tool wear [10,11]. Therefore, machining Inconel 718 has been a critical issue for manufacturers for several decades.

Efforts were made to machine Inconel 718 with traditional methods; however, the significant temperature rise at the tool-workpiece interface during grinding negatively impacts product quality while quickly degrading the grinding wheel [12]. This problem can be minimized to some extent by using super-abrasive grinding wheels, but these wheels are very expensive and result in high manufacturing costs [13]. An attempt has been made for turning of Inconel 718 using the ceramic cutting tool. The findings show that the high temperature generated at the tool tip due to friction and plastic deformation causes rapid tool wear, especially notch wear and catastrophic failure of ceramic cutting tools [14]. The machining of Inconel 718 with CBN (cubic boron nitride) tools, at a cutting speed of 300 m/min, produces a very high temperature near the tool nose region of around 13000 C. This high temperature results in a significantly high stress concentration at the tool tip, which plastically deforms the cutting edge [15,16]. When the same material is machined at a much slower cutting speed (40 m/min in this case), the highest temperature measured was between 480-5800 °C, but with significantly lower production efficiency and increased production cost [17,18]. In conventional machining, grinding is the only accepted method for machining hard-to-cut materials, yet it is restricted to applications where a good surface finish is required [19].

The technical difficulties associated with machining of Inconel 718 using conventional machining have made non-traditional machining increasingly important. The non-traditional machining is capable of overcoming the problem associated with conventional machining for the machining of Inconel 718 or other hard-to-cut materials of complex geometries, along with improved process performance, such as high MRR, reduced tool wear, and high dimensional accuracy. EDM is one of the most widely used non-conventional machining processes for machining hard-to-cut

materials with complex shapes, due to its lower cost, ease of machining, and high accuracy [20]. It is a non-contact machining process, hence neither the electrode nor the workpiece is subjected to cutting forces or mechanical stresses during machining [21]. Micro-EDM is the application of EDM in the micro field. Micro-EDM can be considered an ideal process for the fabrication of burr-free micro holes of high aspect ratio [22]. Currently, EDM is a preferred machining process for all types of hard and brittle conductive materials, as well as some ceramic materials, due to its ability to produce a less work-hardening effect, reduce mechanical stress, and cause less metallurgical damage [23]. The precision and surface finish of micro-EDM machining are extremely excellent despite its low machining efficiency. This property enables the machining of thin and flexible parts, as well as the creation of deep grooves and holes, since there is no mechanical contact between the workpiece and the tool in EDM [9]. One of the most effective techniques for machining Inconel 718 is thought to be micro-EDM.

## 2. Micro-EDM Principle and Discharge Mechanism

Micro-EDM operates on the same basic principle as EDM but uses extremely short, low-energy pulses ( $10^{-6}$ – $10^{-7}$  J) to remove very small volumes of material while both the tool and workpiece are immersed in a dielectric fluid. The Figure 1 shows how EDM works when an electric spark is produced between the cathode tool electrode and the conducting anode, which is submerged in a dielectric liquid. The discharge process includes four phases: During ignition, a high open-circuit voltage breaks down the dielectric, establishing a stable discharge voltage ( $\approx 15$ – $30$  V) after the ignition delay time ( $t_n$ ). This is followed by plasma channel formation, as the current rapidly rises to the preset peak value. Discharge will build up until the discharge current is high enough that the voltage drops significantly, and a large amount of electrical energy is stored during the pulse-on time ( $t_e$ ) and dissipated after the pulse ends within a very short time. During the discharge phase, the electrical energy is converted to thermal energy, which melts and vaporizes a very small amount of the workpiece material. At the point when discharge stops and the pulse off period ( $t_o$ ) begins, the voltage goes to zero and the discharge current, allowing for the collapsing of the plasma path established during the ignition phase. This allows the melted material to solidify, the dielectric fluid, cleaning up the melted material interface area and restoring the dielectric fluid's insulation properties. Repetition of these controlled pulses results in gradual material removal without direct contact between the tool and workpiece [24].

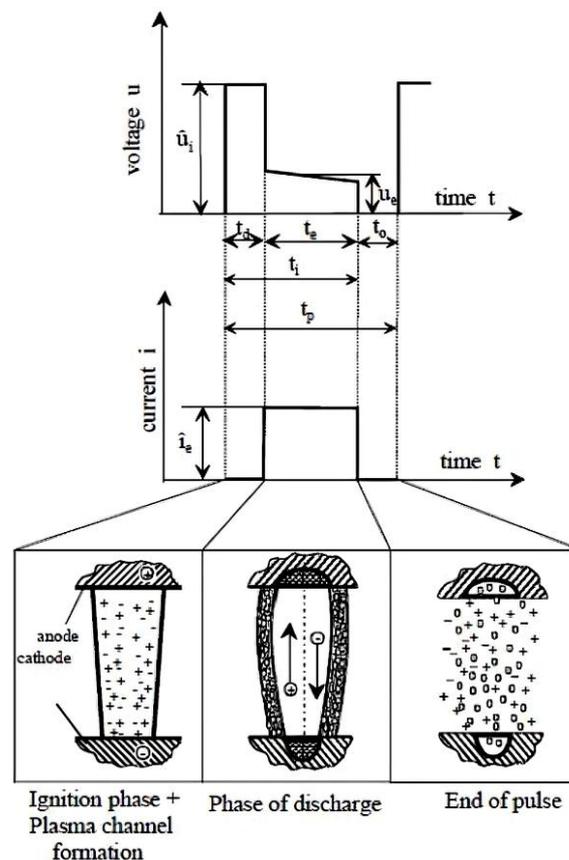


Figure 1. The phases of electrical discharges in EDM/micro-EDM [24].

## 3. Mechanism of Debris Formation and Flushing in Micro-EDM

The mechanism of material removal in micro-EDM relies on converting electrical energy into heat energy. Material melting and vaporization constitute the two main modes of material removal in micro-EDM [25]. The material debris

formed due to material melting and vaporization, is flushed out using a dielectric fluid. Apart from the removal of formed contaminants from the gap, the dielectric also serves many important functions, such as avoiding process instability and electrode wear. It also acts as an insulator through which controlled discharges occur. It absorbs and carries away the heat generated due to the spark between the electrodes [26]. Soni [27] and Murray et al. [28] have shown that eroded particles typically have a spherical shape, which can be either solid or hollow. The debris may have dents or cracks on its surface due to collision with other debris particles. Pulse current has very little influence on the size of the eroded particles [27,29]. Thus, the effectiveness of debris flushing is crucial to the success of micro-EDM machining. Hence, the mechanism of debris flushing is very crucial to understand in micro-EDM.

### 3.1 Flushing Mechanism and Its Impact on Machining Characteristics on Micro-EDM of Inconel 718

Flushing is a crucial factor in micro-EDM for precision machining. An efficient flush requires specific parameters, such as flushing pressure and the speed of dielectric fluid flow within the gap separating the electrodes [30]. The large electrode gap could result in negative process behaviour due to poor ignition, whereas a too small electrode gap might result in process stability. Several studies have experimentally examined the specifics of EDM flushing. Wang et al. [31] examined how flushing pressure affects the MRR by varying the flushing pressure up to 0.03 and found an increase in MRR when the pressure increased [32]. Lee et al. [33] varied the flushing pressure between 0.02 and 0.05 MPa and reported the possibility of flushing of the plasma channel. However, they were unable to prove the flushing of the plasma channel at high pressure. Li et al. [34], Cetin et al. [35], and Masuzawa et al. [36] studied the effect of flow rate on MRR using a bunched electrode. They found that the increasing flow rate increases the MRR. For flow speeds exceeding 0.03 m/s, a reduction in MRR was observed, attributed to a decrease in discharge efficiency. The increase in flow velocity increases the MRR, but when velocity exceeds a certain limit, there is a decrease in MRR recorded due to poor electrical discharge between the electrode gaps. The higher inlet velocity increases the tool wear rate (TWR) as it minimizes the deposition of carbon on the surface of the electrode. For macro-sized holes, periodical flushing can be used through the hollow electrode to evacuate debris from the gap. However, this technique is not applicable for the machining of micromoles, and there is a need for a new technique to flush out the debris effectively [37].

### 3.2 Effect of Process Parameters on Micro-EDM of Inconel 718

The process performance of micro-EDM of Inconel 718 is strongly influenced by key electrical and flushing parameters, which significantly influence the MRR, surface integrity, and process stability. Discharge energy, primarily controlled by pulse-on time and peak current, has been identified as the most influential factor affecting the performance characteristics of micro-EDM. The experimental study by Choubey and Maity [6] reported that pulse-on time affects both MRR and surface roughness during micro-EDM of Inconel 718, highlighting a clear trade-off between productivity and surface quality. Higher pulse-on time and current levels increase MRR due to greater energy input per spark; however, they concurrently degrade surface quality through increased crater size and redeposition phenomena [6,30]. Pulse-off time also plays a critical role; insufficient pulse-off duration leads to unstable discharges and short-circuiting, whereas longer pulse-off intervals improve debris, evacuation but reduce machining efficiency by lowering discharge frequency [30]. These effects are strongly influenced by the low thermal conductivity of Inconel 718, which promotes localized heat accumulation and limits efficient heat dissipation. Thermal erosion, melting and re-solidification, secondary discharges, carbon deposition from dielectric decomposition, and geometrical degradation of micro-electrodes [6]. Studies using statistical modelling and optimization methods have further confirmed that interactions between pulse-on time, discharge current, and time interval control both the discharge frequency and the thermal characteristics of the spark gap, thereby affecting not only MRR but also surface morphology and tool wear behaviour [20]. While the general trends in the effects of micro-EDM parameters on Inconel 718 are evident, quantitative outcomes vary markedly between studies due to differences in machine setup, dielectric environment, and electrode geometry, highlighting the need for cross-study standardization and comprehensive optimization frameworks.

## 4. Challenges in Machining of Inconel 718 Using Micro-EDM

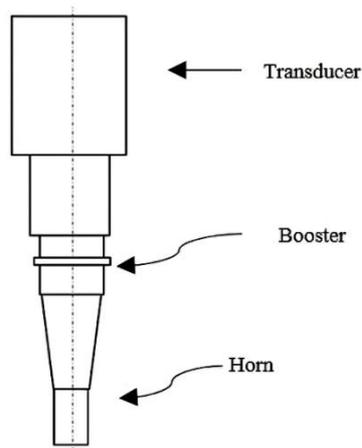
Micro-EDM is affected by many inherent limitations that have an impact on process efficiency and stability. During machining, the accumulated gas and debris on the machined surface can create challenges due to the micron-scale inter-electrode distance in dielectric fluid. As a result, a model of the process is difficult to produce, and control of the operation presents further difficulties. The rate of material removal (or machining) is often low, limiting the applications of the micro-EDM process for bulk machining applications [38]. Microelectrodes have a tendency to bend or break, reducing accuracy and productivity. Flushing is necessary for effective debris removal; however, due to the small size of the inter-electrode gap, it can be difficult for flushing to clear debris effectively [39]. The excessive force used to flush can create instability in the process. Additionally, the amount of tool wear experienced and the low machining rate result in extended process times [40]. The limitations become more pronounced when machining hard-to-machine Inconel-718, as this alloy exhibits extremely low thermal conductivity compared with materials commonly processed through EDM, such as aluminium, copper, and various steel alloys, which significantly affects process efficiency [41]. Its conductivity, approximately 6-6.7 W/m·K at room temperature, is far lower than that of highly conductive metals like copper (398 W/m·K) [41,42]. The primary reason for this behaviour is due to its very high nickel and chromium content, which dramatically lowers the average phonon path length, hence limiting heat transport

throughout the material. As it relies on multiple pulses of electricity, creating very high levels of thermal energy required to melt and vaporize the work material, heat must be dissipated effectively to maintain the stability of the process. Inconel 718 low thermal conductivity limits the extent of heat that can be removed from a discharge zone, leading to a sudden rise in localized temperature and thermal instability while machining it [41,42]. One direct consequence of this inefficient heat transport is the formation of a pronounced recast layer on the machined surface. During EDM, part of the molten material re-solidifies, and the slow cooling rate associated with poor thermal conductivity increases the thickness and defect severity of this layer [41-43]. The resulting recast layer can adversely influence surface finish, microstructural integrity, and functional performance. Prolonged exposure to elevated temperatures, caused by heat accumulation, further enhances the likelihood of recast layer development and may produce altered metallurgical characteristics that are undesirable for critical applications [41-43]. Further, the rapid wear of the electrodes and reduced life of the tools can be attributed to the low thermal conductivity of the electrode material. The concentration of thermal energy at the cutting tool due to remote heating results in increased localised temperature and a corresponding increase in the rate of wear of the tool electrodes, which results in a reduced operational lifetime of the tools [41-43]. In low-thermal-conductivity materials such as Inconel 718, as the plasma channel temperature increases, the material softens thermally, which ultimately requires frequent tool replacement, increasing machining costs and reducing productivity. Along with this, the inefficiency of thermal energy dissipation leads to thermal stress in the part because of rapid and uneven temperature changes that occur during the heating and cooling cycles. As a result, thermal stress can cause cracks to develop in the machine parts, whether they are micro or macroscopic, especially if they are thin-walled or have complex geometry [41-43]. All these factors contribute to making the low thermal conductivity of Inconel 718 a significant limitation to achieving a stable, efficient and high-quality EDM performance and ultimately, a limitation in terms of the machinability of Inconel 718 in EDM machining processes [42-44].

To address these challenges, researchers are exploring various options to enhance processes through improved efficiencies, thereby meeting the challenges associated with machining. In this context, Li et al. [45] found considerable improvement in their results when utilizing the concept of bubble-assisted flushing in their deep-hole drilling experiments on SiC and stainless steel. Alternatively, Meena et al. [46] evaluated various flushing techniques developed for deep micro-hole drilling in micro-EDM. Many researchers [47-50] have investigated the effect of various coatings on electrodes with different types of electrodes on machining characteristics, but all of these approaches can suffer from issues such as coating delamination, incompatible materials, bubble fractures induced by debris, and limitations associated with geometry, all of which limit their applications to deep micro-hole drilling.

## 5. Vibration-Assisted Micro-EDM Strategies

The efficient removal of eroded particles from the inter-electrode gap is crucial in micro-EDM of Inconel 718 to ensure process stability throughout machining and achieve optimal process performance. In this context, recent studies have demonstrated that integrating vibration into the tool and workpiece significantly enhances process stability, increases the MRR and reduces surface roughness (SR), and improves overall machining accuracy. Many researchers have proved that the application of vibration of the tool, workpiece, or dielectric in micro-EDM resulted in process stability, increased MRR, reduction in SR, as well as process performance. In micro-EDM integrated with ultrasonic vibration, a setup of ultrasonic resonant components [51], including a pulse generator, transducer, booster, horn, and sonotrode, causes the tool or workpiece to vibrate at an ultrasonic frequency. The various components of the ultrasonic resonant system are shown in Figure 2. The electrical pulses from the generator are transferred to the transducer, which converts the electrical pulses into mechanical vibration, which is then transferred to the tool through the booster and horn. The booster controls the intensity of vibration amplitude, and the horn communicates the necessary vibration amplitude to the tool mounted at the horn's tip efficiently. Conversely, if vibration is applied at the surface of the workpiece, the low vibration frequency can be used.



**Figure 2.** Schematic representing the main elements of the ultrasonic acoustic system employed in vibration-assisted micro-EDM.

Recently, many researchers incorporated low to high-frequency vibration at the tool and observed an enhancement in the machining characteristics of the micro-EDM process. Zeng et al. [52] reported that the efficiency of the machining was boosted by two times when ultrasonic vibration was present. Studies show that ultrasonic vibration-induced cavitation enhances the MRR, facilitating greater molten metal ejection and minimizing metal recast on the tool surface, and quadrupling the efficiency of electrical discharge. According to Zhao et al. [53], the tool's high frequency caused the dielectric pressure in the gap to vary, thus promoting faster ejection of molten metal from the crater. It increased the stability and effectiveness of the machining process. By increasing the velocity of the dielectric and consequently the debris, Mastud et al. [54] found that vibration inhibits the accumulation of impurities in the machining region. Schubert et al. [55] found that low-frequency vibration more accurately reflects actual conditions than high-frequency vibration. The researchers concluded that the low-frequency vibration applied to the workpiece led to a 10-40% increase in machining speed. The studies by Tong et al. [56] and Singh et al. [57] focused on ultrasonic vibration-assisted micro-EDM. Their finding reveals that high-frequency workpiece vibration significantly improved machining performance. Hao et al. [58] reported that high-frequency vibration of the workpiece stabilized the spark discharge, thereby improving machining effectiveness. According to Gao et al. [59], boosting the voltage in aided EDM results in greater vibration amplitude and improved dielectric circulation within the gap.

Sundaram et al. [60] show that the vibrating workpiece serves two purposes in micro-EDM. They concluded that the high-frequency vibration of the workpiece increased MRR by generating cavitation, while the dielectric medium's pumping action enhanced flushing from the gap. In aided micro-EDM, Prihandana et al. [61,62] looked at the impact of powder concentration. They claimed that the shorter machining times and stabilization of the machining process were caused by the higher conductivity of the dielectric fluid, caused by powder particles. Using a probe-type vibrator/horn, Liew et al. [63] and Ichikawa et al. [64] implemented the ultrasonic vibration in the dielectric medium. By ultrasonically vibrating the dielectric fluid with carbon nanofibers, better stirring results. The stirring effect caused nanofibers to spread evenly in the dielectric and increased discharge frequency, which resulted in a larger MRR. Unune and Mali [65] investigated the effect of low-frequency vibration applied to the workpiece and reported a significant improvement in MRR with a slower rate of tool wear. According to Singh et al. [66], shaking of the workpiece during micro-EDM decreased short-circuiting between the electrode gap and improved machining efficiency. In the vibration-assisted micro-EDM technique, Chern and Chaung [67] fabricated a custom vibrating worktable to impart vibration to the workpiece. Workpiece vibration experiments were run both with and without rotating the tool. The number of craters created during the micro-EDM process, which overlapped due to the rotating tool and vibrating workpiece, increased the surface finish of the drilled hole. It was due to the gap's improved dielectric circulation. In comparison to pure micro-EDM, the vibrating workpiece boosted the spark efficiency, which enhanced the surface polish with higher feed. Table 1 summarizes the effect of vibration on micro-EDM performance.

**Table 1.** Summary of micro-EDM studies aided by vibration.

Vibration parameters	Improvement in MRR	Effect on TWR	Effect on SR	Reasons	References
Ultrasonic, high-frequency vibrating tool	Enhanced two times	–	–	Cavitation, enhanced flushing	[52]
Low-frequency workpiece	10%–40% enhancement	–	–	High machining stability	[55]
High frequency workpiece vibration	Significant enhanced	Reduced TWR	Notable improvement	Stable discharge	[57]
Ultrasonic vibration of dielectric fluid	Improvement in MRR	–	–	US vibration & Nanofiber dispersion	[63,64]
Low frequency of workpiece vibration	Improved	Reduced	–	Better debris suppression	[65]
Workpiece vibration	–	–	Improved	Improved dielectric flow	[67]

In continuation of the above research, several researchers have applied vibration-assisted techniques to micro-EDM of Inconel 718 for the enhancement of machining performance. Table 2 summarizes the reported machining configurations; modes of vibration application, investigated process parameters, and their corresponding effects on performance indicators like MRR, TWR, accuracy, etc. The findings of the reviewed literature highlight consistent performance trends and enable an objective evaluation of the advantages of vibration-assisted micro-EDM over conventional micro-EDM.

The literature reports that the integration of vibration in micro-EDM results in notable improvements in machining performance, i.e. enhanced MRR, reduced tool wear, and improved dimensional accuracy. However, existing studies indicate that most researchers have not adhered to standardized or generalized guidelines when selecting vibration-related parameters for experimental investigations. Micro-EDM itself is an inherently complex thermo-electrical phenomenon due to the simultaneous involvement of numerous input parameters. The hybridization of EDM with auxiliary techniques such as vibration assistance further amplifies this complexity by introducing additional variables, i.e., vibration frequency, amplitude, and mode of application. This lack of parameter selection introduces significant variability in reported outcomes and restricts the reproducibility and meaningful comparison of results across studies. As a result, the interaction of these parameters makes it challenging to separate the effects of each on the performance

parameters of a micro-EDM process, including MRR, tool wear rate, surface characteristics, and dimensional accuracy. Therefore, it is necessary to develop computational models that can systematically identify and correlate critical input parameters with process responses. Developing a quantitative understanding of how process parameters interact while also providing guidance on selecting and optimizing parameters is essential for improving vibration-assisted micro-EDM process control and achieving better machining results [68-71].

**Table 2.** Comparative summary of vibration-assisted micro-EDM of Inconel 718.

Machining Mode	Vibration Application	MRR	TWR	Additional Performance Metrics	Key Findings	References
Ultrasonic-assisted micro-EDM	Ultrasonic vibration to the tool	Consistent MRR improvement relative to non-assisted EDM	Reduced abnormal tool wear due to improved flushing	Better dimensional accuracy by reducing recast layer thickness and optimizing SR by 74.8% and 65.7%, respectively	Performance improvement attributed to cavitation and debris evacuation	[72]
Drilling micro-EDM	Ultrasonic vibration to the tool	MRR increased with ultrasonic vibration compared to conventional micro-EDM	TWR reduced under ultrasonic vibration	Hole taper and radial overcut decreased	Ultrasonic vibration enhanced debris flushing and discharge stability	[73]
Micro-WEDM	Low-frequency workpiece vibration (a few tens Hz)	Increased compared to without vibration	Reduced tool wear	Increased kerf width and reduction in electrode workpiece adhesion	Low-frequency vibration improved flushing, increased MRR and reduced SR	[66]
Hole-sinking micro-EDM	Ultrasonic vibration to the workpiece	Higher ultrasonic power resulted in higher MRR	Lower TWR observed at optimized Ton and ultrasonic	Hole taper reduced; improved surface morphology	Optimal performance reported at 3 A gap current	[57]

## 6. Conclusion

This review highlights the current state of micro-EDM of Inconel 718, with a particular emphasis on the inherent machining challenges, process characteristics, and emerging trends. Based on the prior studies, it is evident that micro-EDM of Inconel 718 has progressed significantly; however, further innovation in process optimization and hybrid techniques is required to fully exploit its potential. The major challenges in machining Inconel 718 using micro-EDM are the expulsion of debris from the machining zone, as it significantly affects the machining performance. To address this problem, a brief review of the hybrid micro-EDM technique, which utilizes a vibrating tool or workpiece, was presented. The vibrating workpiece setup is comparatively simpler than electrode vibration, as it requires a less complex vibration arrangement and eliminates the need for an ultrasonic acoustic system. This micro-EDM, aided by vibrations, significantly enhances the capabilities of micro machining. The vibration of the tool or workpiece in micro-EDM is attributed to the increased working fluid velocity and its improved capacity to eject debris particles from the gap. Further, the improved relative velocity of the dielectric within the gap eliminates the abnormal discharges and promotes a steady machining process. Since micro-EDM is a complex process that involves a large number of interacting process parameters, the integration of tool or workpiece vibration additionally increases the complexity. Consequently, future research should focus on the development of robust numerical model capable of identifying and optimizing critical process parameters to achieve the desired machining outcome. Such efforts would provide guidelines for researchers and facilitate the broader industrial adoption of such hybrid micro-EDM techniques for machining of Inconel 718 and other such hard-to-machine alloy.

## Conflict of Interest

The authors declare no conflicts of interest.

## Generative AI Statement

The authors declare that no Gen AI was used in the creation of this manuscript.

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