Machining on hard to machine materials with Vibration assisted EDM, micro-EDM and WEDM: State of the art review

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Abstract

Electrical Discharge Machining (EDM) is an unconventional machining process used for machining of hard-to-cut materials. Both EDM and micro-EDM processes are extensively used for producing dies and molds, complex cavities and 3D structures. In recent years, researchers have intensively focused to improve the process performance of micro-EDM and EDM processes both. This paper reviews the research work carried out by the researchers on vibration assisted EDM, micro-EDM and Wire EDM. The consolidated review of this research work enables the better understanding of the vibration assisted EDM process. This study also discusses the influence of vibration parameters such as vibration frequency and amplitude on the MRR, EWR, and surface roughness. The important issues and research gap in the respective area of research are also presented in this paper.

Keywords: EDM, Micro-EDM, WEDM, Work piece vibration, Tool vibration, MRR, EWR and Surface roughness

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1. INTRODUCTION

Electrical discharge machining (EDM) is one of the most popular non-traditional machining processes adopted in manufacturing industries due to its lower cost, dimensional accuracy, and good surface finish. It is a non-contact type non-traditional machining process. Therefore workpiece and tool remain free from any mechanical stresses. The materials that are extremely hard in nature and difficult-to-cut such as inconel, titanium and other high strength, temperature resistance nickel based alloys that are widely used in aerospace, submarine, nuclear, and rocket industries are difficult to be machined by conventional machining process. Thus, EDM process has emerged as a promising technology for the machining of these materials [1–3]. It is an electro-thermal machining process in which material removal takes place due to the melting and vaporization of the material when heat is produced by electric spark between the tool and workpiece [4, 5]. The working principle of micro-EDM is very similar to EDM. Micro-EDM is the application of EDM at a micro scale, with the size of the tool being significantly small, and the amount of the discharge energy being at a micro scale [2]. In EDM, tool and workpiece are separated by a small gap. When a DC voltage is applied across them, an intense electric field is develops in the gap. This electric field attracts the contaminants in the dielectric fluid, which concentrate on the field at the strongest point. These contaminants build a high conductive bridge across the gap as the field voltage increases. The particles in the conductive bridge across the gap get heated up and some of the particles form a spark channel between tool and workpiece. At this point, temperature and pressure both increase in the channel and a small amount of material melts and vaporizes from the tool and the workpiece at the point of spark contact [6]. After sparking, debris particles formed on the machining surface are flushed out using the dielectric medium. Removal of the debris from the electrode gap is one of the major challenges in the EDM process. Due to the melting of the metal, the debris thus formed accumulates in the gap, and poor flushing makes the process unstable and adversely affects the MRR and surface integrity of the machined surface [7]. Since the thermal energy produced is proportional to applied electrical energy, it is very important to enhance the electrical process to improve the process efficiency. Researchers have developed a number of ways to improve process efficiency such as different flushing technique, dielectric modification, application of magnetic field, dielectric types, electrode coating, etc. [6]. However, the application of these techniques is limited due to the lack of knowledge of process mechanism of EDM/micro-EDM. The vibration of the tool or workpiece in the EDM process is one of the methods used to improve the debris flushing. The application of the tool or workpiece vibration in EDM causes change in the tool gap due to the forward and backward motion of either the tool or workpiece. When the tool moves upwards, or workpiece moves downwards, the fresh dielectric is drawn inside the gap, and when tool moves downwards, or workpiece moves upwards the dielectric is forced out of the machining gap. As a result, the variation in the pressure of the dielectric inside the gap improves the flushing efficiency. This paper reviews the recent research articles that have documented the research results in vibration-assisted EDM, micro-EDM and Wire EDM.

2. EDM PROCESS PARAMETERS

The important EDM process parameter may be classified as shown in Fig.1.

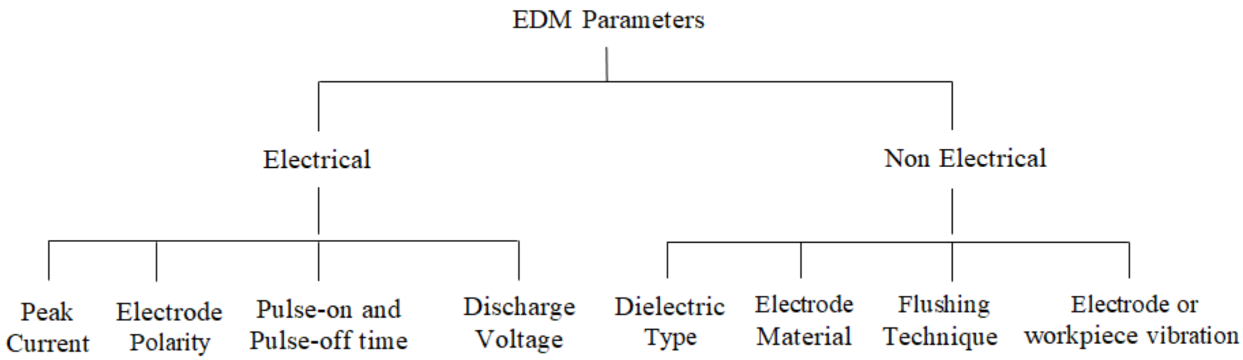

Figure: 1 Process parameters of EDM process

2.1 ELECTRICAL PARAMETERS

Peak Current: The amount of power used is the most significant process parameter in discharge machining. During each pulse-on time, current increases until it reaches a preset level, which is expressed as a peak current. Higher peak current increases material removal rate but at the cost of surface finish and tool wear [8].

Electrode Polarity: There are two types of polarity used in EDM namely positive and negative, depending upon the tool and work material, current density and dielectric fluid. Positive polarity is generally preferred when higher MRR is required. Modern power supplies insert an opposite polarity “swing pulse” at fixed intervals to prevent arcing [9]. A typical ratio is one swing pulse for every 15 standard pulses [10]

Pulse-on time and Pulse-off time: It is the time duration for which energy is supplied to the workpiece. For a larger pulse-on time more heat is applied to the workpiece, which increases the size of the crater and increases MRR. During the pulse-off time, there is no energy supplied to the workpiece and the dielectric flushes the molten metal off the machined surface [8].

Discharge voltage: In EDM, material removal takes places using an electrical spark, which is produced when the potential difference between the electrodes exceeds the breakdown voltage. Discharge voltage is related to the spark gap and breakdown strength of the dielectric fluid. To obtain the breakdown voltage, appropriate gap between the electrodes has to be maintained. This function is performed by servo tool mechanism. The most important requirements for good machining performance are gap stability and the reaction speed of the system, as the presence of backlash is undesirable [8, 10]

2.2 NON-ELECTRICAL PARAMETER

Dielectric Type: The choice of dielectric is of greater importance in micro-EDM and EDM processes. Since different dielectrics have different cooling rates and compositions, hence the re-solidified surface affects the hardness and chemical composition of the workpiece. Many researchers have investigated the effect of different types of dielectric on the stability and machining efficiency of EDM. In recent years, researchers have 117 investigated the performance of EDM process using powder mixed dielectric.

Tool Material: The material used for the tool can be copper, brass, graphite etc. The selection of the type of tool depends on the required process performance. A copper tool is used when higher MRR is required while aluminum tool gives low MRR and good surface finish.
Flushing Technique: Type of flushing used is an important parameter in the EDM process, especially in micro-EDM, because of its dimensional constraints. In EDM, dielectric not only flushes the debris off the gap, but also influences the process performance. There are many types of flushing technique used in EDM such as pressure flushing, jet flushing, and suction flushing. The selection of the appropriate flushing method is very important to obtain better machining performance.

Tool or Workpiece vibration: The vibration of the tool or workpiece is used to improve the flushing from the gap. The vibration is provided by some external means which results in improvement of process performance.

3. EDM PROCESS PERFORMANCE

The performance of the EDM process is influenced by the following parameters:
Material Removal Rate: It is the amount of material removed per unit time from the workpiece surface corresponding to the input process parameter. It is usually measured in mm3/s. Tool Wear Rate: It is defined as the percentage ratio of the amount of the tool material lost from the tool corresponding to the input process parameter.
Surface Roughness: It is the average surface deviation of the machined surface from the ideal surface. It is usually measured in micro-meter.

4. WORKING PRINCIPLE OF VIBRATION ASSISTED EDM

As mentioned in the introductory part, the formation of debris in the gap after sparking causes arcing and short-circuiting in EDM and adversely affects the process performance. In vibration assisted micro-EDM or EDM, low frequency or ultrasonic frequency vibration is provided to the tool, workpiece, or dielectric fluid by some external force. The vibration produced by external force produces pumping action of the dielectric fluid in the gap. The pressure variation produced by pumping action improves the flushing efficiency and formation of the vapor bubble in the low-pressure region. The collapsing and bursting of these bubbles brings about material removal from the metal surface. The introduction of vibration in EDM process not only improves the flushing condition, but also contributes to MRR [11]. The major difficulty in the micro-EDM process is the removal of debris from the gap. The poor dielectric circulation affects the micro-EDM performance and limits its application [2]. The conventional methods of flushing such as high-pressure flushing or jet flushing are not effective in micro-EDM due to the dimensional constraint.

5. ULTRASONIC VIBRATION-ASSISTED TOOL IN EDM

Nanu et al. [12] have presented the design of ultrasonic horn for the UVEDM process. The finite element analysis of the horn has been carried out to know the ultrasonic frequency at different points of the horn with an axial mode of vibration. It is reported that for the best experimental results, the ultrasonic horn must be synchronized with a pulse generator. The finite element analysis of the horn using ANSYS software helps in selection of correct dimension of horn to get the required longitudinal mode of vibration. Abdullah and Sahabgard [13] have investigated the ultrasonic vibration of the tool in the EDM process on a cemented tungsten carbide workpiece. They observed that ultrasonic vibration of the tool was a more dominant factor to obtain high MRR at low discharge current and small pulse time. The longitudinal vibration of the tool creates longitudinal compression and refraction wavefront, which produced pumping action, causing better debris suspension. A better dielectric fluid renewal reduced short-circuiting, and gave better stability for the operation. They observed that ultrasonic vibration induced tool oscillation. Due to this, cavitation took place adjacent to the tool tip. This effect increased the tool wear. They found that, the surface was about 10% rougher when using ultrasonic vibration because of shorter ignition delay time and higher pulse energy, Fig 2.
Zhang et al. [14] reported that the ultrasonic vibration 192 of the tool caused better dielectric circulation from the gap and improved the machining performance of EDM. With the increase in gap voltage, discharge current, and vibration amplitude there was an increase in MRR and EWR. It was due to the reason that the vibration of tool caused the formation and bursting of vapor bubble, which increased MRR from both surfaces. The maximum value of the amplitude that gave better machining efficiency depended upon the gap between the tool and the workpiece. The better machinability criteria were obtained when the vibration amplitude was equal to tool gap.

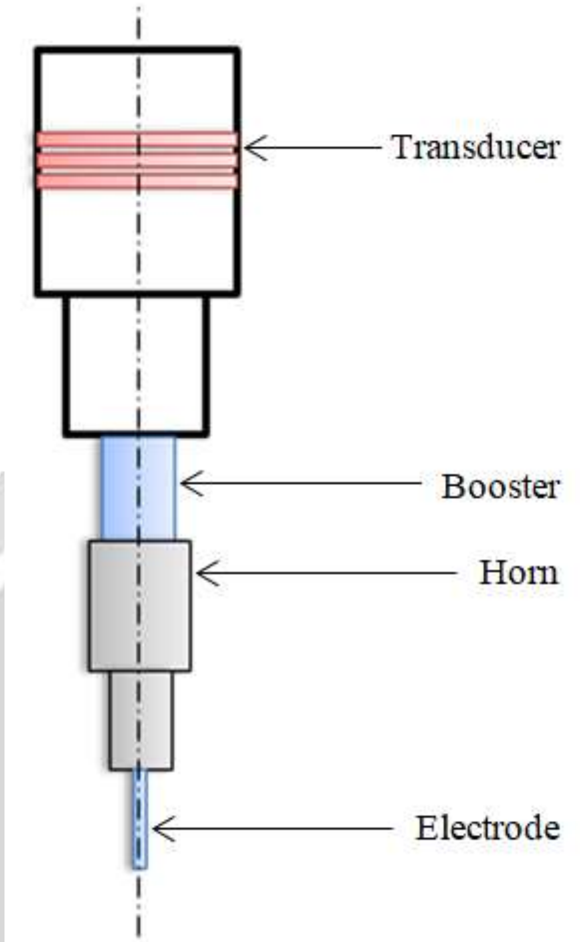

Figure: 2 Main elements of ultrasonic acoustical system [13]

Ghoreishi and Atkinson [15] have compared the effect of low and high frequency forced axial vibration, rotation of the tool and combination of these on MRR, TWR and surface roughness in die sinking electro discharge machining. It was evident from the experimental investigation that the vibrating tool increased MRR and TWR as compared to the rotary and vibro-rotary alone, regardless of surface quality. The increase in MRR is due to the fact that the vibrating tool produces pressure variations in the dielectric fluid within the gap. As a result, more molten metal is ejected from the crater and there is an enhancement in MRR. In finishing regime, the high frequency (19.900 Hz) tool vibration and rotation gives higher MRR as compared to low frequency (50 Hz) tool vibration and rotation as shown in Fig. 3

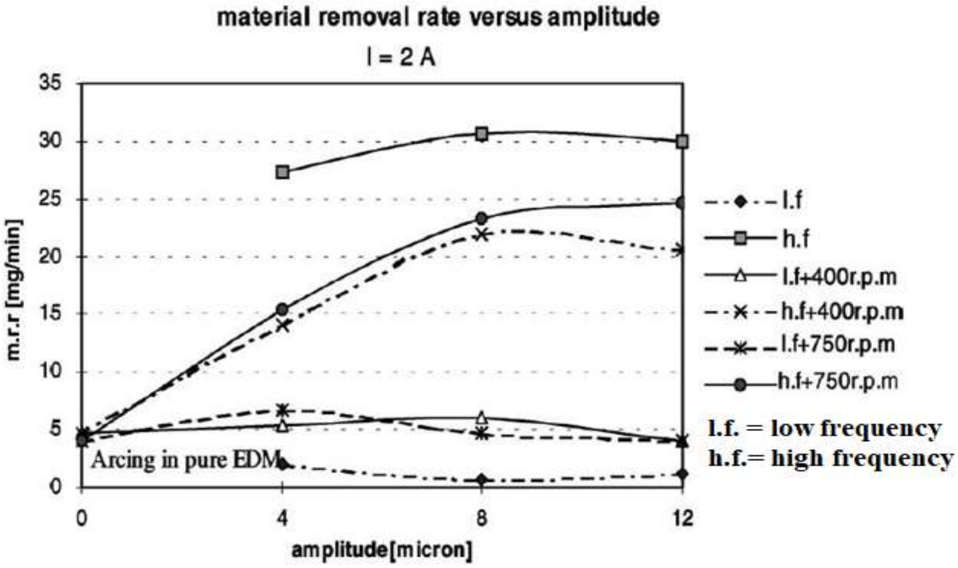

Figure: 3 MRR in finishing regime [15]

The MRR increased with the increase in vibration amplitude. In the semi-finishing regime, the vibro-rotary EDM, the MRR increased by 35 % as compared to vibratory EDM as shown in Fig. 4. The rotating tool at low pulse current and narrow gap gave a better surface finish but reduces MRR due to the shallow crater formation.

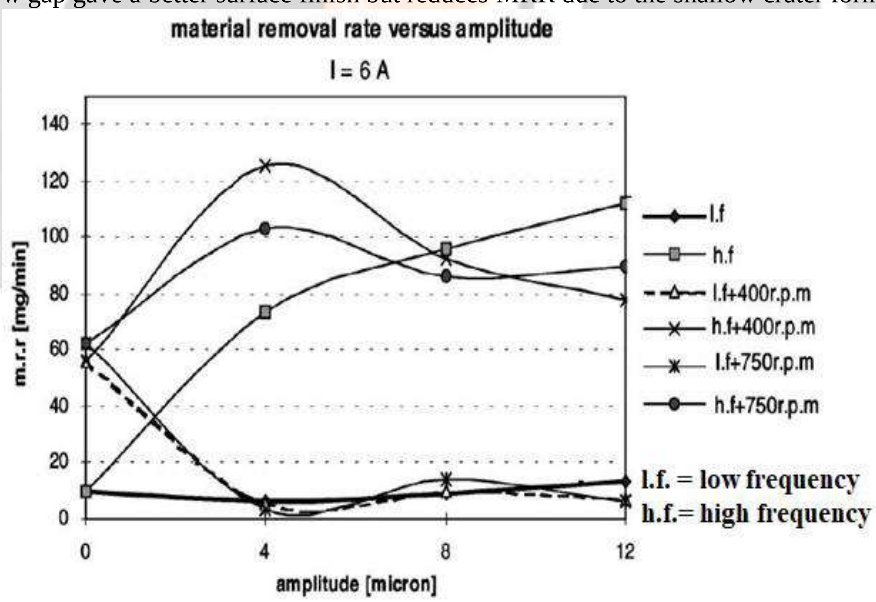

Figure: 4 MRR in semi-finishing regime [15]

6. ULTRASONIC VIBRATION-ASSISTED TOOL IN MICRO-EDM

A micro-hole is a common feature in many micro products. It is a challenging task to improve the surface integrity and the aspect ratio of hole with high MRR. The researchers applied vibration to tool to improve the process performance of the micro-EDM operation [32]. Weiliang et al. [33] have investigated the influence of ultrasonic vibration of the tool for the fabrication of a microelectrode array through theoretical analysis and experimental observations. It is evident from experiments that the machining time reduced with the increase in the voltage. When the tool vibrated with 20 kHz frequency, the machining efficiency increased two times as compared to without ultrasonic vibration. It has been observed that cavitation created by ultrasonic vibration enhances the MRR. It accelerated the ejection of molten metal, decreased the metal recasting on the metal surface of the tool, and improved the discharge efficiency four times. As a result, the best surface quality has been achieved. Wansheng et al. [34] have studied the effect of ultrasonic vibration and rotation of the tool for the deep hole drilling of titanium alloy in the micro-EDM operation. It was observed that the ultrasonic vibration of the tool caused the pressure variation of dielectric in the gap that accelerated the ejection of molten metal from the crater. It improved machining stability and efficiency. The process of cavitation resulting from dielectric pressure variation increased fusion metal ejection from the crater and reduces the recasting of metal recasting on the machined surface. In deep-hole drilling, the rotating tool enlarged the hole, produced better debris removal, and 417 improved surface finish with an increase in machining efficiency. It was observed that when capacitance varied in the range of 1000 to 5000 pF the inlet and exit diameter of the hole remained same. But, when the machining time increased, the hole entrance diameter increased due to the secondary discharge produced by debris as shown in Fig. 5. In order to reduce the over-cut effect, the hole should be machined as quickly as possible. When the tool was fed to a depth of four times of the thickness of the workpiece, the difference in diameter was reduced by 12.5 μm. With further increase in tool feed depth, there was no reduction in the difference of diameter. The introduction of ultrasonic vibration improved the flushing condition and reduced the machining time. The difference in diameter reduced to nine μm as compared to conventional micro-EDM. The smaller the capacitance at the early stage and the larger capacitance at the latter stage were beneficial to produce straight hole.

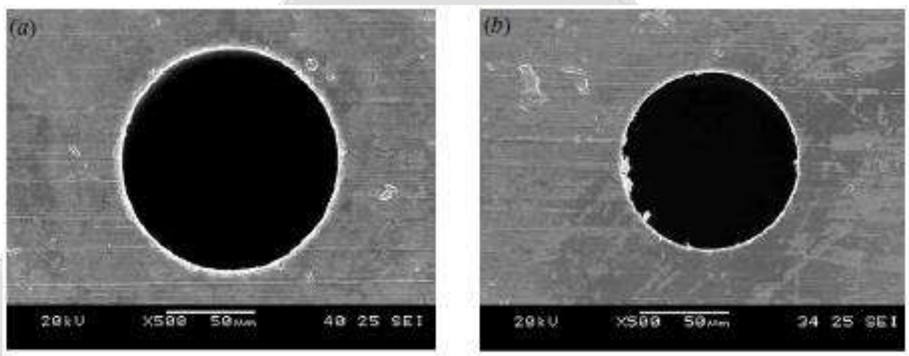

Figure: 5 Entrance and exit of a micro hole machined by micro-EDM: (a) hole entrance 122 μm (b) hole exit 106 μm [36]

7. CONCLUSIONS AND FUTURE RESEARCH WORK

The present study primarily focuses on the working principle of vibration-assisted EDM, various vibration-assisted methods and the effect of vibration parameters along with the process parameters in vibration-assisted EDM. Researchers have worked on the improvement in MRR and reduction in tool wear along with a better surface finish by applying low and high frequency vibrations to the tool or workpiece. This paper will be beneficial for the development in the research to fabricate the EDM/micro-EDM machine with vibration-assisted mechanism. The important conclusions can be drawn as follows:

1. There is an improvement in machining performance of EDM/micro-EDM when vibration is applied to either tool or the workpiece.
2. As compared to the tool vibration, the workpiece vibration setup is simpler and compact as it does not required booster and horn.
3. The higher frequency with lower vibration amplitude gives better machining performance because higher frequency with higher vibration amplitude makes the process unstable.
4. The vibration amplitude should be less than or equal to electrode gap to avoid the short circuiting because at excessively large amplitude, the tool will touch the workpiece and produce arcing and short-circuiting. The aid of vibration to the tool or workpiece in various EDM processes can become aviable technique to improve the machining performance. In this context, following is the list summarizing the future research opportunities in vibration-assisted EDM processes.

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