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AN ULTRASONIC ASSISTANCE IN WIRE SPARK EROSION MACHINING FOR FABRICATING CYLINDRICAL SHAPES COMPONENTS: A REVIEW

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ABSTRACT

Nowadays, wire spark erosion of machining process has the capability to cut cylindrical shapes components by integrating rotary spindle on the machine worktable. However, this process has disadvantages in terms of low cutting rate due to the disruption of pulses caused by the rotating workpiece. This drawback become the point of study by researchers to apply ultrasonic vibration to this process. Therefore, this paper presents a comprehensive review of ultrasonic vibrations for wire spark erosion machining for fabricating cylindrical shapes parts. This review paper has been carried out in terms of current state of the process, ultrasonic excitement targets, effect of ultrasonic vibration and its parameters along with the potential research gap in this area.

Keywords: ultrasonic-assisted machining, cylindrical shapes machining, wire electrical discharge machining (WEDM), spark erosion machining.

1. INTRODUCTION

Ultrasonic vibration assistance is widely used in machining processes including spark erosion machining. Spark erosion machining consists of two well-known process namely die sinker electrical discharge machining (die sinker EDM) and wire electrical discharge machining (WEDM). Excitement of ultrasonic vibration in EDM and WEDM show significant beneficial results.

Khatri *et al.* [1] highlighted in die-sinker EDM that the effects of ultrasonic vibration is capable to minimizes arc and open circuit pulses which subsequently improves the machining stability. Pachaury and Tandon [2] have pointed out that by using ultrasonic tool vibrations in EDM, the surface integrity could be improved with the elimination of recast layer.

Guo *et al.* [3] is the earliest researcher that reported in integration of the ultrasonic vibration technology to WEDM in which it is found that this combination could enhance the rate of cutting and the surface finish of the machined parts while at the same time could also counteract the wire breakage. According to Guo *et al.* [3], the interferences of ultrasonic vibration during the erosion of WEDM facilitates the formation of multiple-channel discharges and increase the utilization ratio of the energy as much 15% due to the increase in discharge frequency. Henceforth, this leads to the improves in cutting rate of the surface roughness.

This view is supported by Han *et al.* [4] who investigated the effects of ultrasonic vibration for WEDM with different thickness of Ti6Al4V as materials and they reported that the cutting rate is improved by the increase of ultrasonic vibration up to 10% when comparing the cutting without ultrasonic vibration. They found that the kerf width is raised by increasing the ultrasonic amplitude since the machining spark gap varies with the workpiece vibration in horizontal direction. Simultaneously, it quickens the slurry circulation in the spark gap that consequently improved the material removal rate.

There are many advantages that could be obtained by integrating the ultrasonic vibration in the erosion process due to the enhancement in flushing, creation of cavitation, which causes the discharge to be easier for breakdown during the machining process [5, 6].

Large majority of research only focusses on ultrasonic vibration for EDM and WEDM, but currently the WEDM process has the capability to be extend to the machining of cylindrical shapes components. The advancement of ultrasonic vibration for machining cylindrical shape components in WEDM is supposedly to be in line with growing of WEDM technology. Therefore, this present study will explore the review on investigation of ultrasonic vibration assistance in fabrication for cylindrical shapes components in wire spark erosion machining.

2. CURRENT STATUS

In the aspect of fabricating cylindrical shape workpiece by WEDM process, the ultrasonic vibration has been introduced only to the dielectric bath and electrode wire, while the vibration exerted on workpiece is still not successfully tested as reported by Hsue *et al.* [7] due to the existence of short pulses and unstable spark discharge during the machining.

Hsue *et al.* [7, 8] has developed an ultrasonic assistance to the micro WEDM machine with integration of rotating workpiece. The name of this process is called as ultrasonic-assisted wire electrical discharge grinding (WEDG) which is used for machining curled micro electrodes for EDM drilling application. The objectives of their studies are to enhance the machining capability and surfaces integrity through debris removal processes improvement. Hsue *et al.* [7] employed 42.8kHz of ultrasonic vibration through a stainless-steel horn shaft

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which act as transducer that is driven by piezoelectric actuator.

Meanwhile, a study by Mohammadi *et al.* [9] investigated on excitement to the electrode wire with the effectiveness of ultrasonic vibration. This process is known as ultrasonic-assisted wire electrical discharge turning (UA-WEDT) which is used for machining macro scale of cylindrical shape components. A groove wire holder is used as guider for electrode wire to travel toward the machining zone and that electrode wire vibration is amplified by a concentrator.

The ultrasonic system proposed by them comprises of an ultrasonic generator, a transducer, a conical concentrator and an electrode wire holder. The electrical generator could produce ultrasonic waves of the maximum output power as much as 1200W [9, 10] and it is suggested that 200W is the best outputs power for ultrasonic vibration in their study. According to their results, the ultrasonic effect is insignificant for output powers lower than the stated value. If the power is too high, it could trigger short circuit and wire breakage that subsequently interrupted the process.

The amplitude of vibration can be controlled through adjustment of output power. By using power of 200W, the maximum amplitude obtained is as much as 10 µm. Between the two wire guides, a round stainless-steel bar with a WC head (wire holder) is installed, transmitting ultrasonic vibration from the ultrasonic transducer to the wire. Figure-1 shows the experimental setup for the ultrasonic-assisted machining of WEDT and Figure-2 shows the ultrasonic-assisted machining of WEDG. Both of these types of process used wire guide and are used for machining cylindrical shapes components.

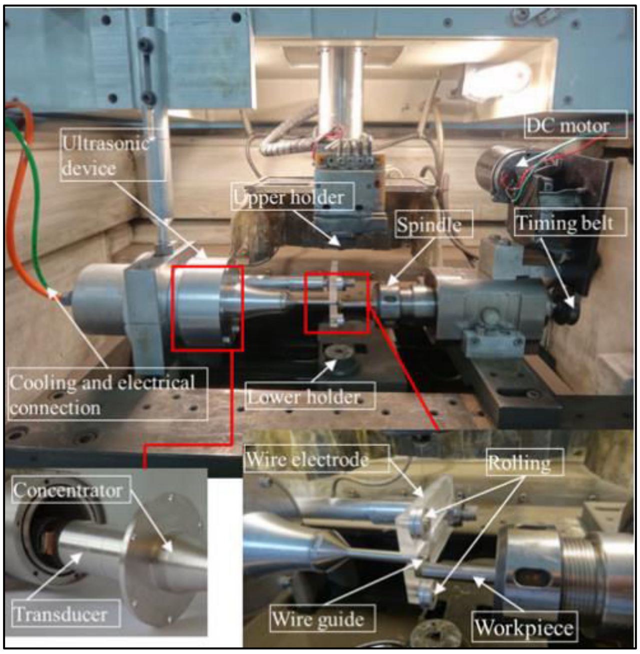

Figure-1. Spindle and ultrasonic head in WEDT [10].

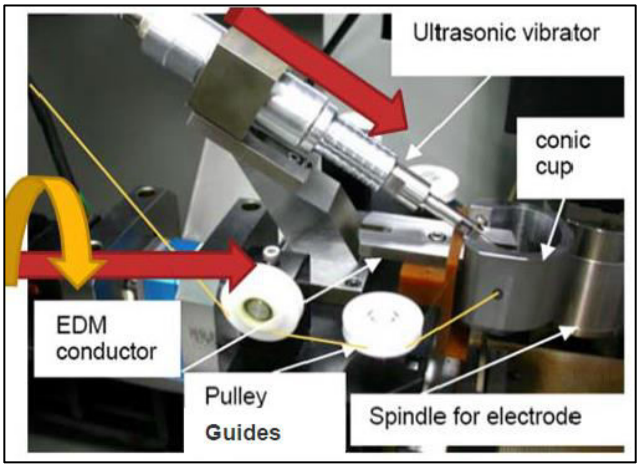

Figure-2. Ultrasonic vibration assisted mechanism setup for the WEDG [8].

3. ULTRASONIC VIBRATION TO DIELECTRIC FLUID

Hsue *et al.* [8] analyzed the result of ultrasonic vibration when it excites to the dielectric fluid. The tip of ultrasonic transducer is submerged into kerosene dielectric fluids of a small conic container to improve the debris removal processes in machining. A container with a diameter of 40 mm is chosen to provide fine shock-wave reflection effects and the ultrasonic transducer is aligned with an inclined angle at 45˚. Sufficient kerosene fluid is constantly resupplied by a flushing nozzle and the level is maintained continuously during the machining. The workpiece is machined down from 0.5 mm to 80 µm with five passes of cuts. Hsue *et al.* [7] found that the micro-sized of workpiece consumed only 65.5 minutes with ultrasonic-assistance machining compared to conventional machining which consumed 95 minutes with the same servo control that saves about 32% of machining time (Figure-3).

The excitement of ultrasonic assisted machining to dielectric bath produced fine shape geometry at the last step compared to the early step of the cylindrical shaft as presented in Figure-3. This is probably occasioned from well flushing behavior at the last stage due to the wave of vibration by ultrasonic vibrator is restricted and reflected in the small space between oil-cup and the target electrode.

4. ULTRASONIC VIBRATION TO THE ELECTRODE WIRE

Mohammadi *et al.* [9] and Hsue *et al.* [7] an employed ultrasonic assisted WEDT through vibration to the electrode wire. Mohammadi *et al.* [10] applied the resonance condition of vibration through wire holder (wheel-shaped) made by the combination of stainless-steel bar with tungsten carbide as the wire guide material. The electrode wire travelling in the groove is at 0.1 mm depth slot of wire holder while it vibrates under the resonance condition transmitted by the transducer in a longitudinal direction. The machining is initiated by a spindle

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submerged in a tank of deionized water [11]. Figure-4 shows the visual graphic of wire guide and the workpiece.

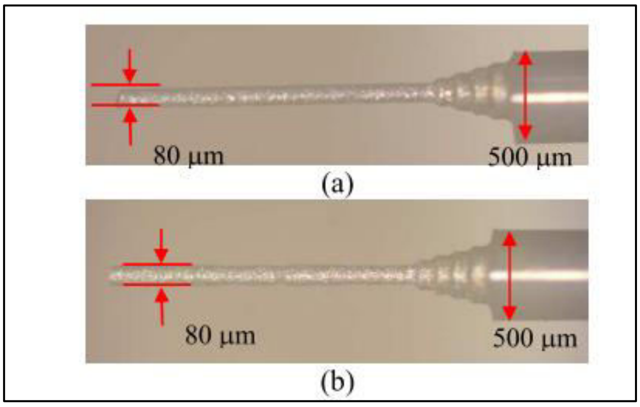

Figure-3. Comparison of shapes quality between (a) conventional and (b) ultrasonic assisted machining to dielectric bath in fabricated 80 µm diameter of tungsten carbide rod [7]

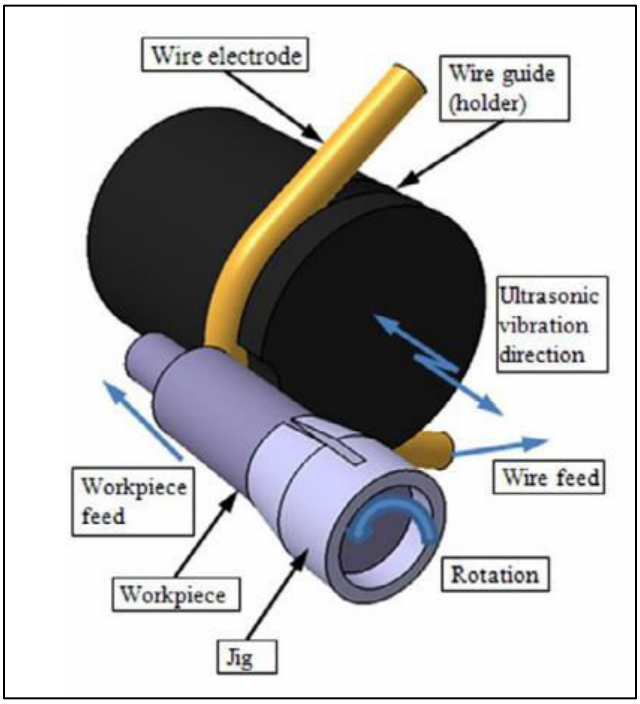

Figure-4. Application of ultrasonic WEDT to the electrode wire through wire guide [10]

Hsue *et al.* [7], transmitted ultrasonic vibration to the wire via the ultrasonic tip head that is connected to the wire segment in between of the narrow slit. The tungsten carbide with grain size of 600 nm WC material is used with the initial micro sized workpiece of 0.5 mm in diameter. By comparing with the conventional micro-WEDM, introducing the ultrasonic vibration to the wire led to improving the surface integrity and machining time. Figure-5 shows comparison of the machining micro-sized workpieces with three types of condition namely without employing ultrasonic vibration, excitement to dielectric fluid and excitement to the electrode wire. Other than that, the straightness of the machined surface attained by ultrasonic vibration on electrode wire look better than the excitement to the dielectric fluid.

As shown in Figure-5, by employing the ultrasonic to machining zone, the machining process produced fine surface texture either to the electrode wire or dielectric fluid. When comparing the excitement of ultrasonic either to the electrode wire or dielectric fluid, ultrasonic assisted to the electrode wire provides better surface texture compared to the dielectric fluid.

Mohammadi *et al.* (2013) stated the MRR is increased by the exciting electrode wire with vibration. This situation happened due to reduced friction between the electrode wire and wire guide that improvised the flushing and dielectric circulation which subsequently forced the material to be ejected from the molten crater with ultrasonic periodic suctions.

This sliding friction effects is found to impacting the excitement of ultrasonic vibration either for parallel or perpendicular due to the sudden alteration in the vector of the force [12, 13]. Other than that, Mohammadi *et al.* [9] highlighted that proper debris suspension and removal from the spark gap along with sufficient dielectric fluid renewal also play a part to the MRR increment.

Longitudinal compressive and rarefaction wave front, micro bubbles and intensive ejecting micro streams are generated because of the longitudinal ultrasonic vibration of the wire which is also supporting the forceful and quicken mass transfer of the spark gap as well as acting as the pump [14].

In the crater size aspect, Mohammadi *et al*. [14] found that there is a growing in width and depth of the discharged crater when exciting the electrode wire with ultrasonic vibration, but the discharged crater length is found to be reduced. These phenomena happened due to the plasma discharge column that glides over the workpiece and produced craters aligned with the vibration direction.

The crater constantly prolongs the relative motion either from ultrasonic or from the workpiece rotation. In conclusion, the application of relative motion with the ultrasonic vibration causes the plasma discharge column to effortlessly slides over the workpiece in the direction of the ultrasonic vibration. This conveys there is an increment in the surface area of the crater and the crater becomes deeper for a certain amount of energy per discharge [14]. This means that the crater surface area is increased, and for a certain amount of energy per discharge, the crater becomes deeper.

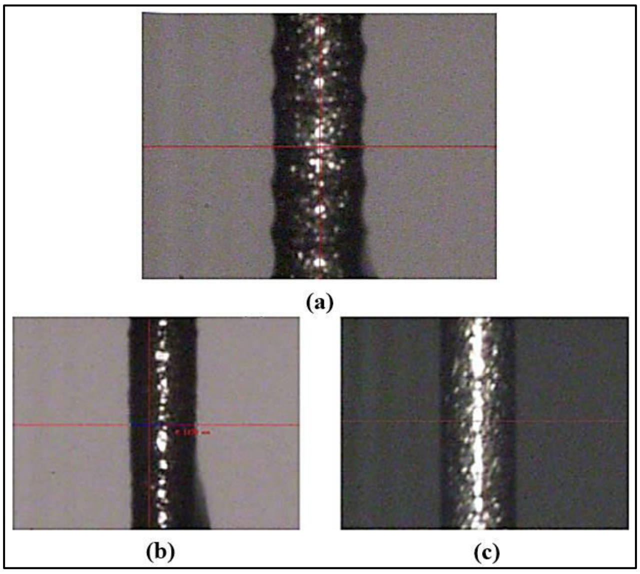

Figure-5. Comparison of the machining micro-sized workpieces between (a) without employing ultrasonic vibration (b) ultrasonic vibration to dielectric fluid (c) ultrasonic vibration to the electrode wire [8]

5. EFFECTS OF ULTRASONIC PARAMETERS AND IT'S INTERACTION

5.1 Frequency and Amplitude

Wire spark erosion machining with the assistance of ultrasonic vibration is discovered to be more stable compared to without an assistance of ultrasonic vibrations. By referring to the pulse waveform, majority of voltage pulses managed to become normal spark type variations under the ultrasonic effect [9]. Figure-6 shows the dissimilarities of gap voltage pulse shape between the application of ultrasonic and without application of ultrasonic in different machining parameters setting.

The behavior of this ultrasonic vibration in wire spark erosion machining can be explained by the suction of high frequency on the overheated molten crater at the plasma channel of the workpiece surface. This leads to the molten puddle evacuation that impacted the mechanism of material removal which subsequently improves the removal process with fewer resolidified layer on the machined workpiece surface [15-17].

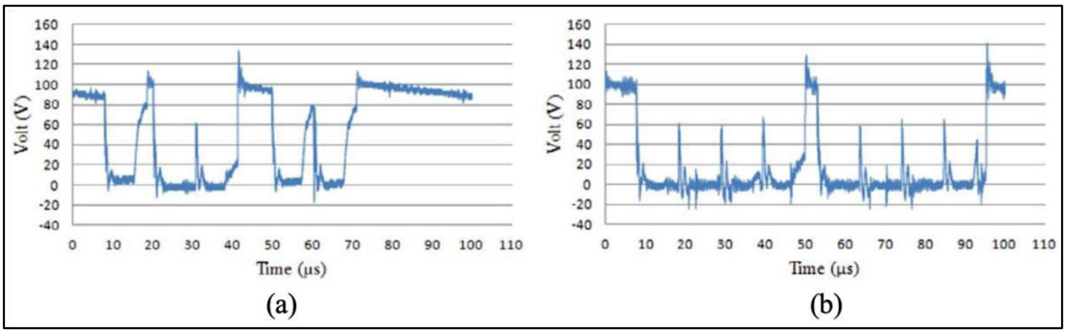

Figure-6. Comparison of the voltage pulses waveform between (a) WEDT and (b) ultrasonic-vibration WEDT [9].

The effects of amplitude to the MRR is determined to be statistically significant when comparing with the 95% confidence, but statistically insignificant to the surface roughness. By increasing the amplitude from 9.5 to 15.5 µm, the MRR is increased until the amplitude is at 12.5 µm but then decreased until amplitude is at 15.5 µm [11]. This is because of the improvement in flushing and cavitation creation that leads the discharge to breakdown easier [15-19]. Extremely high ultrasonic amplitude can cause short pulses and wire breakage occurrences along with the decrease of the MRR value.

5.2 Ultrasonic Vibration and Power-Voltage on MRR

According to Mohammadi *et al.* [10], ultrasonic vibration is deduced to possess a major effect to the MRR in different machine power supply mode which are finishing and roughing at ultrasonic vibration excitement through electrode wire. During the rough-cut state, the effect of the ultrasonic vibration is more significant because of a fewer friction between the electrode wire and the wire guide, enhanced flushing condition and it is also an excellent material suction. Although high pulse current and voltage are used in the rough-cut state, the effect of the ultrasonic vibration is more significant because of the additional enhancement of flushing conditions. Other than that, the effects of ultrasonic parameter which is amplitude is discovered to has statistical significant interaction effects with machining voltage parameter [9].

5.3 Ultrasonic Vibration and Time-Off on MRR

According to Mohammadi *et al.* [9], the MRR increases with longer pulse off-time when the electrode wire vibrates at ultrasonic level. These phenomena occurred because the ultrasonic vibration can facilitate to eliminate the accumulated excessive eroded material from the machining gap and replenished fresh dielectric fluid in the gap for the following spark. When longer pulse-off time is applied, practically MRR will be decreased which leads to the formation of cavitation that subsequently boosts the MRR. However, the MRR will not decreased when there is a usage of ultrasonic vibration.

5.4 Ultrasonic Vibration and Spindle Speed on MRR

Mohammadi *et al.* [20] and Janardhan and Samuel [21] reported that the spindle speed gave great impact to the erosion competency that causes erosion material removal rate to be decreased along with the high spindle speed. However, by introducing ultrasonic vibration to electrode wire in WEDT, the material removal rate is found to be increased probably because of the vibration and deviation of wire that has been restricted by the proposed wire guiding block that subsequently improved the debris flushing condition [9].

6. CONCLUSIONS

Despite the benefits of ultrasonic assisted in wire spark erosion machining, the studies are limited to the straight turning and only low radial in feed can be set due to the installation of wire holder transducers. This setup is restricted with the flexibility of this process in machining free-form geometrical features.

Moreover, the drawbacks in the inconsistency of the ultrasonic tool size makes the ultrasonic energy that is transmitting from the bulky size of transducer to the thin electrode wire to be wasted.

In addition, the excitement of ultrasonic assisted vibration in WEDT only covers on excitement to electrode wire and inside the dielectric bath. None of the previous studies investigated excitement to the workpiece in wire spark erosion machining even though excitement the ultrasonic vibration to the workpiece in WEDM process demonstrates better in material removal mechanism and improves the machined surface textures.

In term of parametric study to the performance measures, the range ultrasonic parameter such as the frequency and amplitude and its interaction with cutting parameter are not properly discovered. Additionally, little is known about the effects of ultrasonic parameters to the machined surface quality not to mention the deep study into multi objective optimization. Most of the research is just focused on performing the comparative study between conventional and ultrasonic assisted machining only focused on single objective optimization like MRR.

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