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Analysis Of Metal Removal In Vibration Assisted Micro- EDM

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Introduction

The reasons for improving the overall flushing conditions are explained in terms of the behavior of debris in a vibrating Work piece, change in gap distance, and dielectric fluid pressure in the gap during vibration-assisted micro-EDM. In addition, the effects of vibration frequency, amplitude, and electrical parameters on the machining performance, as well as surface quality and accuracy of the micro holes have been investigated. It has been found that the overall machining performance improves considerably with significant reduction of machining time, increase in MRR, and decrease in EWR. The improved flushing conditions, increased discharge ratio, and reduced percentage of ineffective pulses are found to be the contributing factors for improved performance of the vibration-assisted micro-EDM

Analytical Study of Micro-EDM with Vibrating Work piece

Mathematical Representation of the System.

Assumptions are as follows

Low frequency vibration follows a simple harmonic motion [16,17].

- The plate is completely horizontal and the vibration direction is fully perpendicular to the plate.

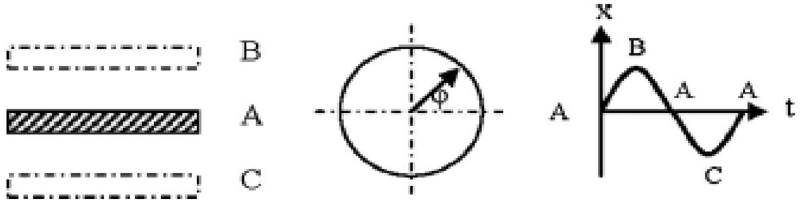


Fig. 1 Displacement-time relationship for the work piece vibration at different position of vibrating plate

Figure 1 shows the displacement-time relationship of a vibrating plate. Let the work piece vibrates at amplitude of “a” with an angular frequency “_.” From the Fig. 1, at any position of the work piece between equilibrium and maximum, the displacement of vibrating plate can be obtained as

$$x = a\sin(\omega t + \varphi)$$

Where a is vibrating amplitude (μm), ω = 2Π f is the angular frequency (rad/s), f is the vibration frequency (Hz), t is the time (s), and φ is phase angle (rad)
The velocity and acceleration of the plate at that position of can be obtained as

$$\dot{x} = a\,\omega cos(\omega t + \varphi)$$
$$\ddot{x} = -a\,\omega^2 sin(\omega t + \varphi)$$

Now, if we consider the maximum acceleration is at B and C positions, then

$$\ddot{x}_{max} = \pm a\omega^2$$

At positions B and C

$$\sin(\omega t + \varphi) = 1$$

Therefore, the equation of maximum acceleration can be written as

$$\ddot{x} = \pm a\,\omega^2 \sin(\omega t + \varphi)$$

where the ± sign indicates two opposite directions from the mean position. If the maximum acceleration along the gravitational direction is defined by "c" and $(\omega t + \varphi)$ is is replaced by α then the equation of maximum acceleration becomes

$$c = a\,\omega^2 \sin \propto$$

Gap Distance and Gap Fluid Pressure During Vibration-Assisted Micro-EDM.

Assumption is as follows.

- As the vibration frequency is much higher than that of the servo response (20 ms or 50 Hz) of this machine, the change in gap distance and gap fluid pressure can take place easily. Figure 2(a) represents the schematic diagram showing the work piece vibration in micro-EDM drilling process. Figure 2(b) shows the variation of work piece position, gap distance, and gap fluid pressure change with time during work piece vibration assisted micro-EDM drilling.

If the maximum amplitude of the work piece vibration is a, then the equivalent gap distance

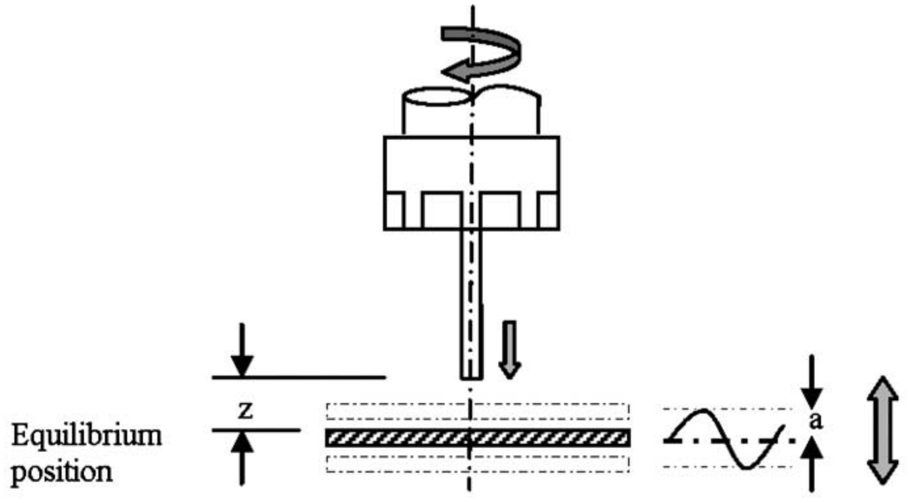
$$\Delta \text{ gap} = z \pm a$$

The position of maximum and minimum gap distance can be obtained as

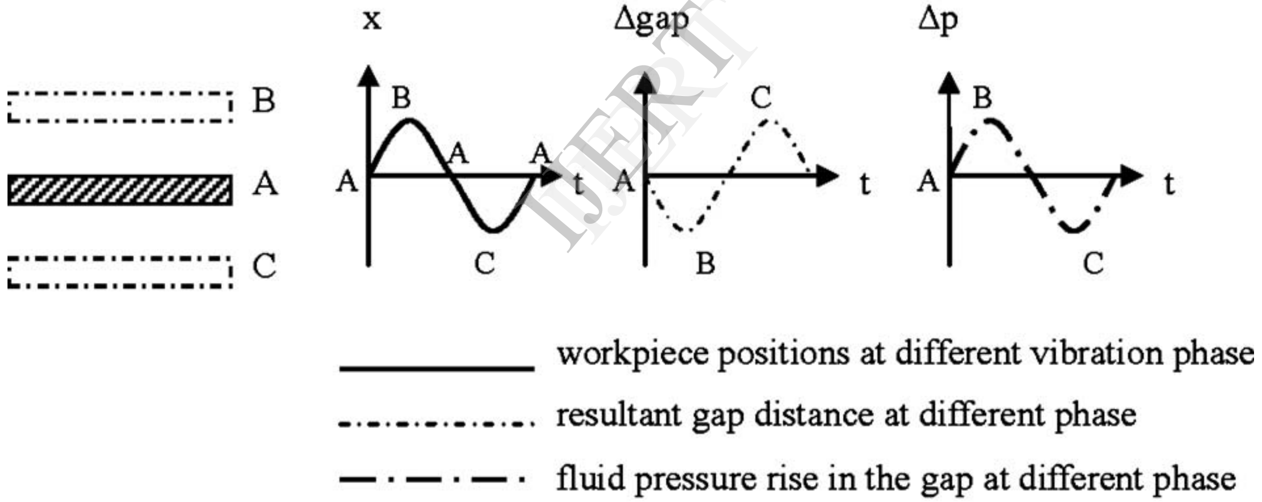
$$\Delta \text{ gap} = z + a \text{ at position C}$$

$$\Delta \text{ gap} = z - a \text{ at position B}$$

At position B in Fig. 2(b), during the upward movement of the work piece, the equivalent gap distance decreases. Therefore, there is an increase in the pressure of dielectric fluid in the gap. During the reduction of gap distance, fluid pressure increases and the fluid comes out from the side of the tool electrode, thus helping to flush the debris particles out from the deep blind hole.



(a)



(b)

Modeling of the Pressure Change in the Gap During Vibration.

Figure 3 shows the schematic diagram of stress applied on a micro fluid cell when the gap distance is reduced. If we consider a micro fluid cell of cross-sectional area “ΔA” and height “Δz” and assume that this micro fluid cell is vibrating at the same vibration, frequency, and phase of the vibrating plate, then the stress experienced by the microcell in the gap can be expressed by
[3]

$$P \cdot S + \Delta G - (P + \Delta P)S = F \qquad (9)$$

where S is the cross sectional area, ΔP is the pressure change on the micro fluid cell, ΔG is the force change due to gravity g, and F is the resultant force exerted on micro fluid cell.

$$\Delta G = (\Delta m)g,\ \Delta m = \rho \cdot S \cdot \Delta z,\ F = (\Delta m)\ddot{x}$$

Putting the values of ΔG, Δm, and F, the Eq. (9) becomes

$$P \cdot S + (\Delta m)g - P \cdot S - \Delta P \cdot S = (\Delta m)\ddot{x} \qquad (10)$$

Therefore, the change in fluid pressure ΔP can be calculated as

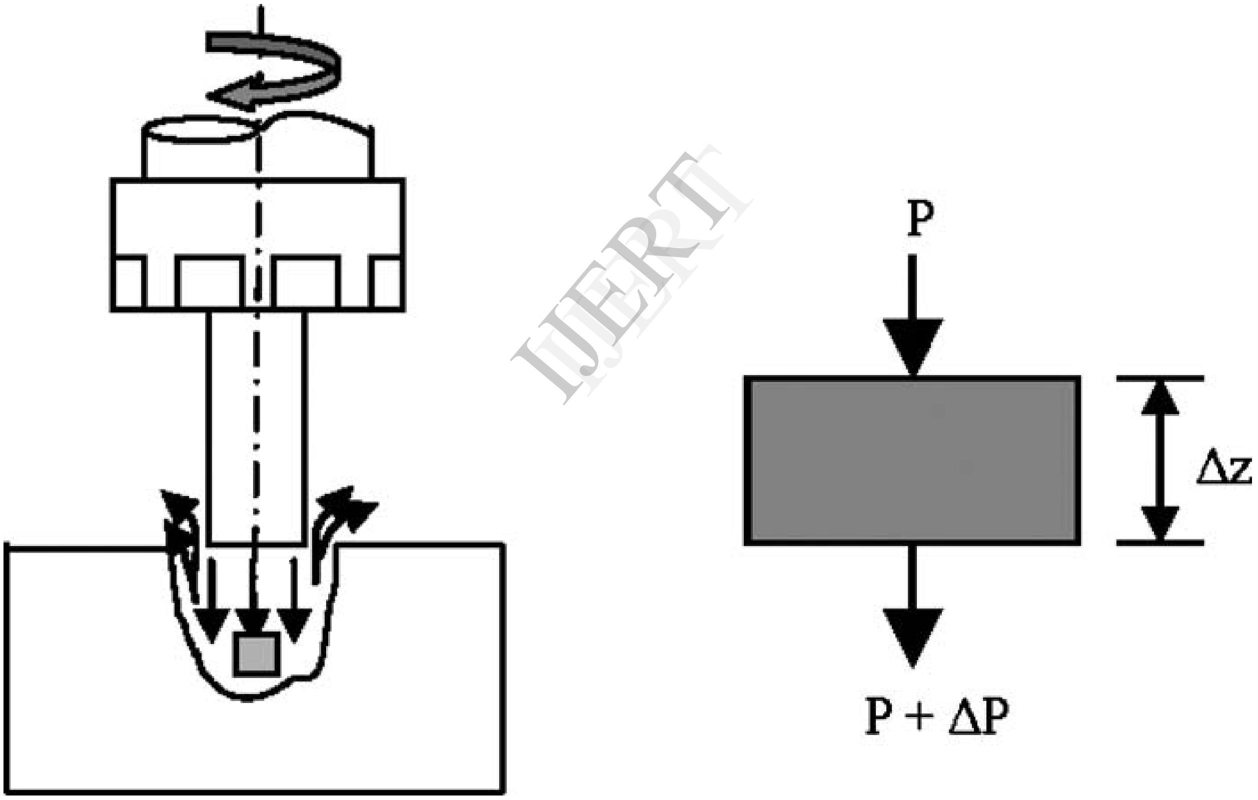


Fig. 3 Schematic diagram representing the pressures exerted in a micro fluid cell during the reduction of gap distance.

$$\Delta P = \rho \cdot \Delta z(g - \ddot{x}) \qquad (11)$$

As assumed, the micro fluid particle is vibrating at the same frequency and amplitude of the work piece, thus the acceleration of the micro fluid cell can be obtained from Eq. (4).

$$\ddot{x} = \pm a\,\omega^2 \sin(\omega t + \varphi)$$

Therefore,

$$\Delta P = \rho \cdot \Delta z\,[g \pm a\,\omega^2 \sin(\omega t + \varphi)\,] \qquad (12)$$

From Eq.(5), $c = a\,\omega^2 \sin\alpha = a\,\omega^2 \sin(\omega t + \varphi)$.Thus, Eq. (12) becomes

$$\Delta P = \rho.\ \Delta z(g \pm c) = \rho\ .\ \Delta z\ .\ g(1 \pm \frac{c}{g})$$

Putting (c/g) as Kv the equation becomes

$$\Delta P = \rho \cdot \Delta z \cdot g(1 \pm Kv) \qquad (13)$$

where Kv is the ratio of acceleration c to the gravitational acceleration “g” and the value of Kv can be obtained from the equation

$$\frac{c}{g} = \frac{a\omega^2}{g}\sin\alpha \qquad (14)$$

For simplification, putting ($\frac{a\omega^2}{g}$) as K the equation of Kv becomes

$$Kv = K\sin\alpha \qquad (15)$$

where K= ($\frac{a\omega^2}{g}$) is the centrifugal effect

Therefore, from the Eq. (13), $\Delta P = \rho \cdot \Delta z \cdot g(1 \pm Kv)$.

If Kv <1, the value ofΔP is always positive, thus the pressure does not change periodically and no vibration effect on the machining performance.

On the other hand, for Kv>1, the value of ΔP is either positive or negative depending on the movement of the plate from mean position. Thus, if Kv>1, there is periodical suction and pressure increase in the working gap, which improves the overall flushing procedure.

Verification of the Analytical Findings. The analytical findings suggest that if Kv>1 during the machining, the overall performance should be improved. Therefore, the frequency and amplitude of the vibration device was selected such way as the value of Kv is always greater than 1. At the two lower settings of vibration device used during experimental study, the value of Kv can be calculated as _considering $\sin(\omega t + \varphi) = 1$ at position B and C of Fig. 2(b)

at f = 500 Hz, a = 1.5 μm, $Kv = \frac{c}{g} = \frac{a\omega^2}{g}\sin(\omega t + \varphi)$

$= 1.507$

at f = 750 Hz, a = 0.5 μm, $Kv = \frac{c}{g} = \frac{a\omega^2}{g}\sin(\omega t + \varphi)$

$= 1.130$

As the values of Kv>1 for all the settings used in this study, the effect of workpiece vibration is supposed to be effective.

Again, from the expression of Kv

$$Kv = K\sin\alpha \text{ or } \frac{c}{g} = \frac{a\omega^2}{g}\sin(\omega t + \varphi)$$

It can be said that the value of Kv, hence overall performance of vibration-assisted micro-EDM depends on the following:

- amplitude of the vibration a
- angular velocity $\omega=2\Pi f$, thus vibration frequency “f”
- phase angle of the vibrating plate “$(\omega t + \varphi)$”

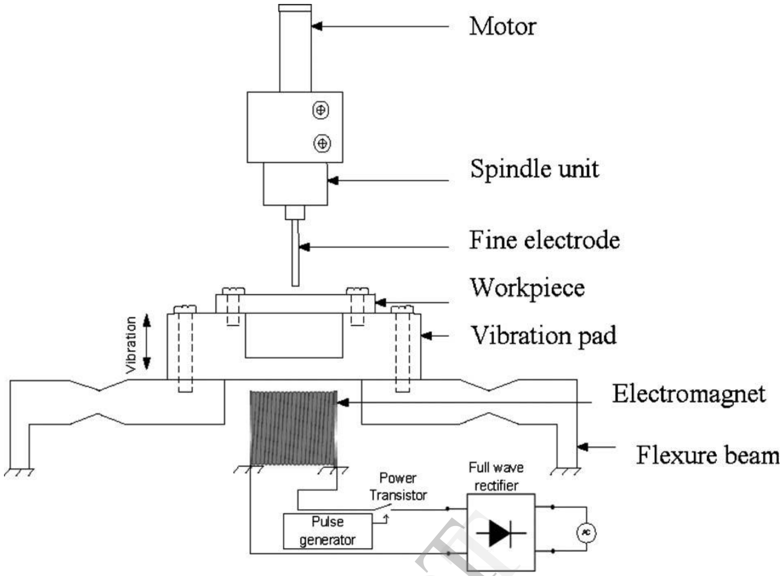


Fig. 4 Schematic diagram of the developed vibration unit

Therefore, the effect of vibration frequency and amplitude on the performance of vibration-assisted micro-EDM will be investigated in the following sections.

Vibration Unit

A simple vibration device has been designed and developed. In order to create a low frequency oscillation on the work piece (Fig.4). An electromagnet is used as the actuator. The electric power is supplied periodically to the electromagnet with the help of a power transistor switch. The on-off sequence of the power transistor is controlled by a frequency controllable pulse generator. When the switch is kept on, the electricity flowing through the circuit causes the electromagnet to be energized, which triggers a pull action on the vibration pad. The flexure beams are bent at that time. Again, the electromagnet is de-energized when the transistor switch is turned off, causing the flexure beams to release and push the vibration pad in upward direction. In this way, a low frequency vibration is induced on the work piece during micro-EDM.

Experimental Details

The workpiece used in this study was WC of grade MG18 with composition of WC–10 wt % Co and dimension of 63×27 mm2 with 1 mm, 1.5 mm, and 2 mm thickness. The tool electrode material used in this study was pure tungsten _99.9% W_ of diameters 200 _m. The tungsten electrode material is selected for its high melting point and high wear resistance. The dielectric fluid used in this study was commercially available “Total FINA ELF EDM 3” oil having relatively high flash point, high auto-ignition temperature, and high dielectric strength. The experimental conditions are listed in Table 1.

Table 1 Experimental conditions for the vibration-assisted micro-EDM of WC

Workpiece material	WC–10 wt % Co,(thickness=1, 1.5, 2 mm)
Tool electrode	W: Φ200 µm
Aspect ratio of microholes	5, 7.5, 10
Dielectric fluid	Total EDM 3 oil
Pulse generator type	RC
Voltage (V)	80, 100, 120, 140
Capacitance (pF)	1000, 2200, 4700, 10000
Resistance (kΩ)	Fixed to 1 kΩ
Vibration frequency(Hz)	0, 500, 650, 675, 700, 750
Vibration amplitude(µm)	0, 0.8, 1.2, 1.5, 1.8, 2.5

Experimental Results and Discussion

Effect of Vibration Frequency and Amplitude on Machining Performance.

The machining performance was studied in terms of machining stability, material removal rate (MRR)and electrode wear ratio(EWR). It has been found that there is a significant improvement in machining stability due to the reduction in percentage of short-circuits after applying a vibration of frequency of 500 Hz (Fig. 5(a)). However, there is a little reduction in the percentage of short-circuits for further increasing vibration frequency. Similarly, the short-circuit percentage reduces significantly after applying a vibration amplitude of 0.8 µm, continues up to 1.8 _m, and again tend to increase with the increase of amplitude(Fig. 5(b)). High amplitude tends to affect the machining stability by slightly increasing the percentage of short-circuits. It was found that during machining without vibration, the short-circuit percentage was higher at lowest settings of voltage and capacitance (Figs. 5(c)and 5(d)). Therefore, the vibration assistance is more effective when machining proceeds at lower settings of voltage and capacitance. Moreover, for the same electrical settings, the short-circuit percentage is higher during drilling higher-aspect-ratio micro holes. A comparison on the percentage of different types of pulses without and with vibration at f =750 Hz and a=1.5 µm is presented in Fig. 6. It has been observed from Fig. 6(a) that for machining a.r. 5 micro holes, the normal discharge pulses increases by about 40%, whereas the percentage of short pulses reduces by about 80% after using work piece vibration during micro-EDM. Almost similar results have been obtained in machining micro holes of a.r. 7.5 (Fig. 6(b)). The normal pulses increases, whereas other types of pulses decrease with vibration, which is an indication of stable machining. This improved machining stability plays an important role in reducing machining time and increasing MRR as well as in the reduction of EWR.

Due to the improvement in machining stability and improved flushing process, the MRR was found to increase after applying vibration in micro-EDM. It can be seen from Figs. 7(a)and 7(b) that with the increase of vibration frequency and amplitude, the MRR increases first up to a certain limit, then again tends to reduce. For aspect ratios of 5 and 7.5, the highest MRR was obtained at the frequency of 700 Hz with a reduced trend starting at 750 Hz (Fig. 7(a)). However, for machining of micro holes of a.r. 10, the highest MRR was obtained at 750 Hz, which indicates that higher value of frequency provides better performance during the micro-EDM drilling of high-aspect-ratio micro holes. However, higher vibration amplitude of the work piece may result in more frequent touching with the tool electrode, which causes short-circuiting and arcing. Moreover, it has been observed that for the same settings of vibration frequency and amplitude, the MRR is lower in the case of machining high-aspect-ratio holes.

In addition, the EWR also decreases significantly in vibration assisted micro-EDM of WC. It has been observed from Figs. 7(c) and 7(d) that with the increase of vibration frequency and amplitude, the EWR tends to decrease gradually. However, at very high frequency and amplitude, the EWR tends to increase again, which is due to the interruption of machining stability and occurrence of ineffective pulses. For almost all the aspect ratios, vibration frequency of 700–750 Hz and amplitude of 1.5–1.8 µm were found to provide improved MRR as well as reduced EWR.

One important reason for improving MRR during vibration assisted micro-EDM is the increase of discharge ratio after applying vibration. It can be observed from Figs. 8(a)–8 (d) that the discharge ratio increases noticeably with the application of vibration in micro-EDM. Moreover, it can be seen from Figs. 8(e) and 8(f) that while applying the vibration assistance, the discharge ratio improves more significantly during machining at lower discharge energy setting. At the same vibration frequency and amplitude and gap voltage of 100 V, the discharge ratio is much higher for 2200 pF capacitance than that of 10,000 pF. Therefore, vibration-assisted micro-EDM is more effective during machining at lower discharge energy.

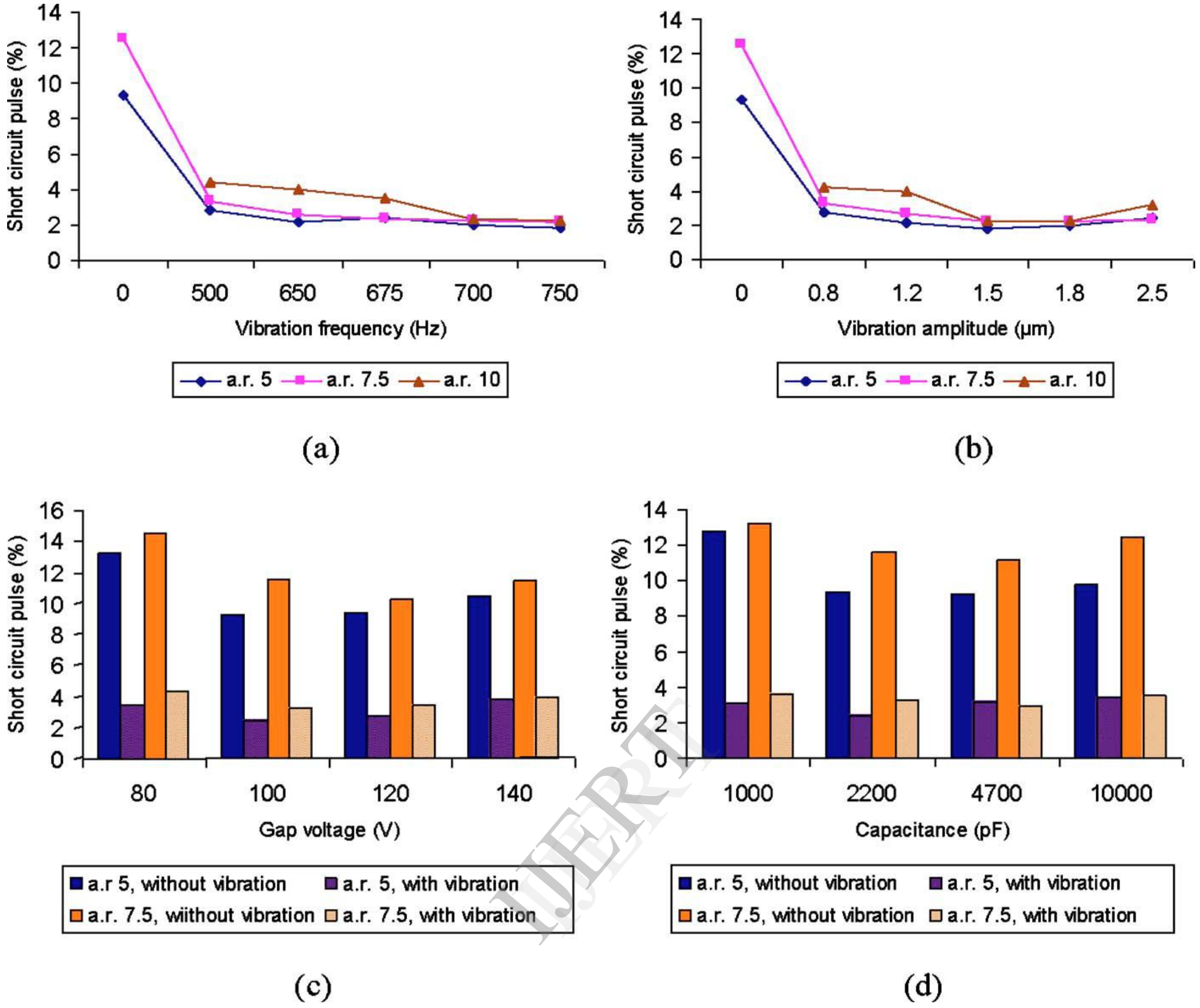
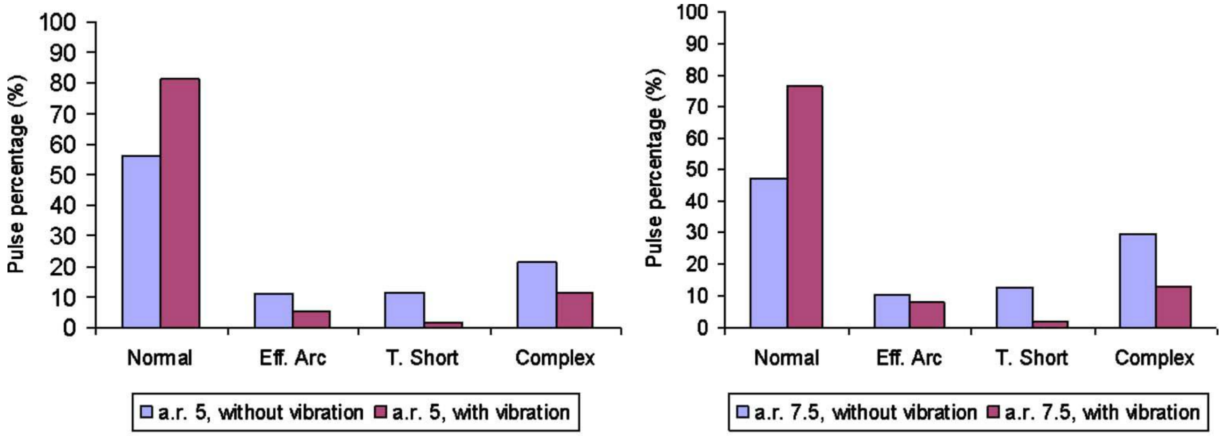


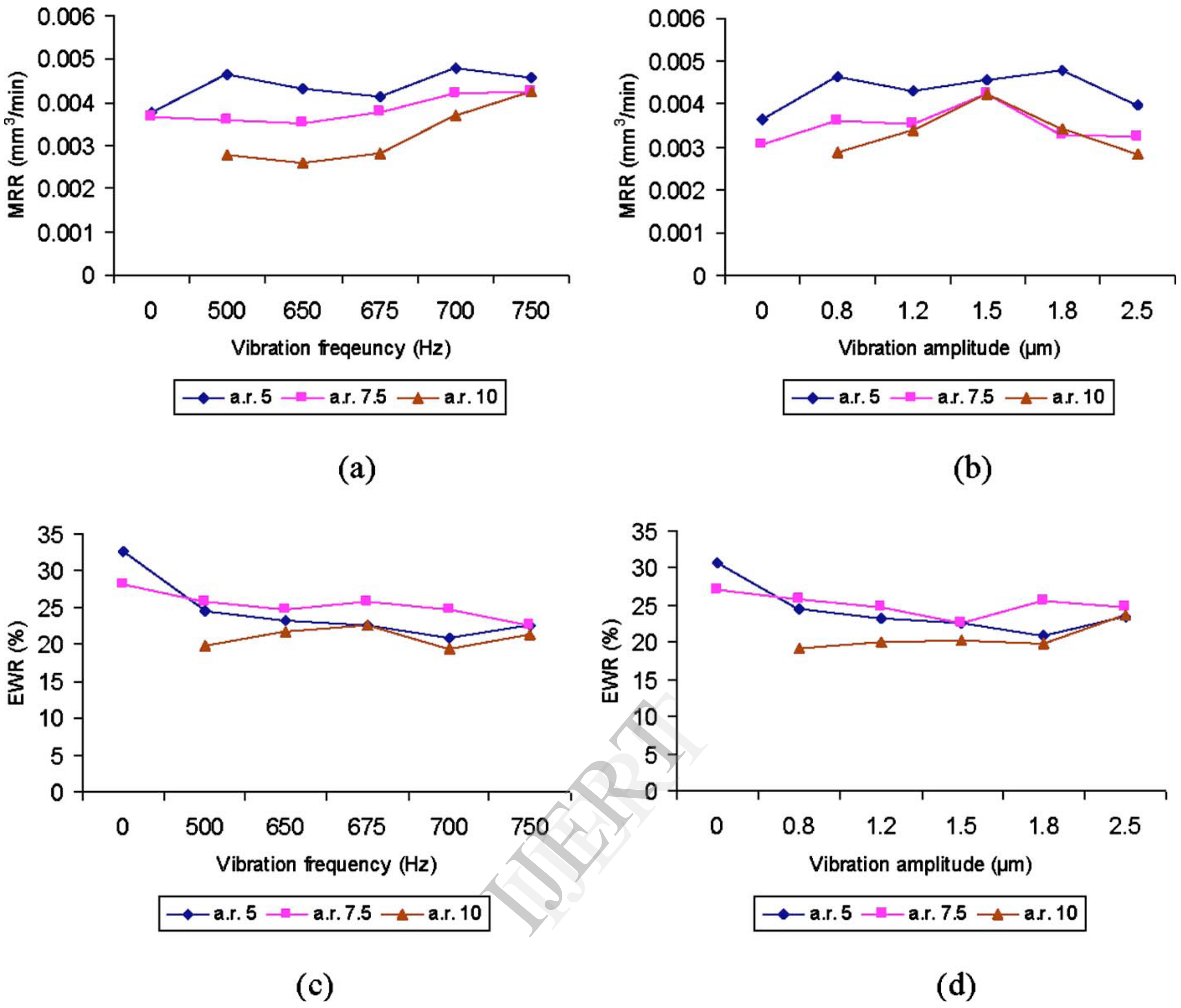
Fig. 5 Effect of (a) frequency, (b) amplitude, (c) gap voltage, and (d) capacitance on the percentage of short-circuit pulses



(a)

(b)

Fig. 6 Various pulse types in micro-EDM drilling of micro holes without and with the assistance of vibration at V=100 V and C=10 nF for(a) a.r. 5 and (b)a.r. 7.5



(a) (b)

(c) (d)

Fig. 7 Effect of frequency and amplitude on MRR ((a) and(b))and EWR((c) and (d))

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