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Performance analysis of vibration-assisted Micro-EDM dressing

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Abstract

Micro-EDM dressing is one of the recent methods used to fabricate high aspect ratio arrayed micro-structures, which have a great demand in the field of biological interfaces. In this paper, different machining performances of micro-EDM dressing, both online and offline, estimated under with and without vibration conditions at a certain average energy setting. Online monitoring responses such as contributing and non-contributing pulses during machining and offline responses such as material removal rate (MRR), volume removal per discharge (VRD), tool wear ratio (TWR) and dimensional accuracy were analysed. The experimental results showed that when machining under vibration condition, effective discharge ratio, VRD, MRR and the percentage of contributing pulses were improved.

Keywords: Micro-EDM dressing, Contributing and Non-Contributing Pulses, VRD, MRR, TWR

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1. INTRODUCTION

Micro-EDM dressing has emerged as an important process for machining of very high aspect ratio arrayed features which could be used in a brain machine interface, neural interface, retina implant, cochlear implant, micro-needle for syringe etc. [1], [2]. Other variants of micro-EDM such as micro-EDM milling, and micro-wire EDM could also be used to fabricate similar features, however, these processes failed when there is a requirement of densely spaced high aspect ratio arrayed micro-features of circular cross section. In this regard, an emerging micro-EDM variant called micro-EDM dressing has already shown its excellent capability to fabricate such features.

Despite several breakthrough advantages, micro-EDM dressing has not achieved widespread acceptance in micro-fabrication industries because of its low material removal rate (MRR) and dimensional inaccuracy. This arises from the narrow discharge gap (~ 4–8 μm) which hinders the evacuation of debris effectively. This situation becomes even more worsen in absence of spindle rotation since this rotation is not feasible when fabricating arrayed micro-rods. On the other hand, static dielectric pressure at the tool-work interface also imposes a serious problem in debris evacuation. Therefore, proper measures must be taken to improve the evacuation of debris from such a narrow inter-electrode gap (IEG) and that too in absence of spindle rotation while fabricating very highly dense micro-rod (s).

To flush the debris from IEG of micro-EDM, techniques such as vibration-assistance electrode, jet flushing, magnetic field-assistance, rotating electrodes and geometrically modified electrodes were used. However, vibration assistance micro-EDM has proved to be effective [3]. Zeng et al [4] fabricated arrayed (5x5) micro-rods with good coaxiality and surface quality of length 30 μm and aspect ratio more than 8 on AgW. In the same work, they suggested machining time reduces by two folds, when the amplitude of vibration increased from 0.2 μm to 0.4 μm. Mastud et al [5] observed that percentage of normal discharge time is increased multi-fold by 2.0 and 2.7 times, respectively, with the change in the amplitude from 0.5 to 2 μm and the frequency from 3 KHz to 6 KHz. Although, a few of the above responses were explored in the past, however, determining debris removal efficiency based on all of the aforesaid features would certainly explain the stability of the vibration assistance micro-EDM dressing process more clearly.

2. Experimental details

Experiments were conducted on a DT-110 Mikrotools machine. The machine had a resolution of 0.1 μm and accuracy of 1 μm for each of the three axes. Both electrodes were submerged in dielectric fluid during micro-EDM dressing process. EDM oil was used as dielectric. An NI digitizer card (model: 5122) with 100 MS sampling rate was used to capture the signals from current and voltage probe. The current probe model was Fluke i30 and voltage probe model was Yokogawa 701938. Signals from current and voltage probes were imported via the digitizer card to the LabView software. The pulses were discriminated based on an algorithm written in LabView [6]. Experimental conditions and materials for work piece and tool are listed in Table 1. A vibration set up was developed in house and integrated with the micro-EDM machine. It consist of a fixture and a PZT actuator (P-885.55 Physic Instrumente). The PZT actuator was driven from a function generator and power amplifier. At first micro EDM-drilling was done on multipurpose micro machining setup. Then micro-EDM dressing was conducted to fabricate the micro rod. The fabricated rod was 2.1 mm in length. Machining were done with and without vibration. The amplitude and frequency of vibration were kept 8 μm and 600 Hz, respectively during experiment. The experimental set up is shown in figure 1.

3. Experimental results and discussion

Experiments were carried out to investigate the effect of vibration on the performance of the micro-EDM dressing. The next section will give a detailed discussion on the results.

3.1. Machining time

It was observed that with the implementation of vibration, the machining time reduced significantly. The effect of vibration on the machining time was more pronounced during the prolonge machining time. Figure 2 reveals that machining time reduced significantly from 25 minutes for without vibration to 13 minutes after using vibration. In case of no vibration, the

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*Author to whom correspondence should be made, Email: psaha@iitp.ac.in process becomes unstable owing to the accumulation of debris particles, which caused secondary discharge. After using vibration to the Cu tool plate, the overall flushing process improved which reduced the machining time significantly.

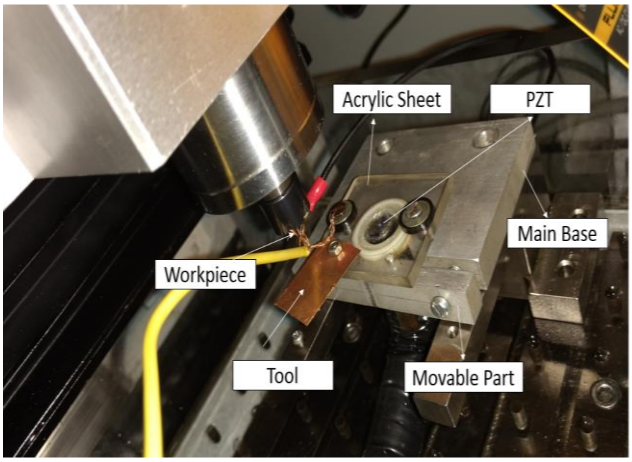

Figure 1 Developed vibration set up

3.2. Material Removal Rate (MRR)

It was observed that when vibration applied to micro-EDM dressing, MRR increased almost by 23 %. The effect of vibration on the MRR of brass rod is presented in Figure 3. The state of process became more stable upon employing the vibration-assistance micro-EDM dressing. The machining debris expelled from the IEG more efficiently and the amount of debris suspended within the dielectric fluid reduced. This phenomenon cleared up the dielectric fluid and resulted to higher plasma explosive force, that helped in accelerating the debris in a much better way. Increased in MRR while using vibration suggests that vibration induced help in better removal of material.

3.3. Tool Wear Ratio (TWR)

TWR defined as the ratio of removed material volume from tool plate having pre-drilled hole to the removed material volume from workpiece. TWR tend to decrease gradually with the vibration, as can be seen from Figure 4. Due to the assistance of vibration, the debris easily flushed away from the machined zone, reducing the arcing and hence TWR. Accumulation of debris in the machining gap, affect the gap condition. Under such machining conditions, a repetitive unwanted discharge take place at the same location. The result showed, 23 % decrease in TWR on Cu plate tool electrode.

3.4. Volume Removal Per Discharge (VRD)

VRD is defined as the volume of material removed from work piece per unit number of discharges during machining. After discriminating pulses using pulse discrimination strategy, it was found that micro-EDM dressing pulses mainly belong to normal, effective and arcing. It is well known that normal pulse contributes the material removal the most. During the vibration-assistance micro-EDM dressing, it was found that the normal pulse occured the most. This is because, well distribution of debris could recover the dielectric to the original condition in the best possible manner. In short, only a small number of normal pulses were sufficient to remove the required volume of material under vibration conditions. Figure 5 depicts that the VRD during vibration-assistance micro-EDM dressing increased to about 9%.

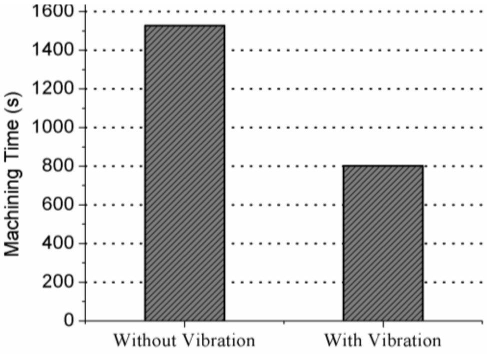

Figure 2: Effect of vibration on machining time

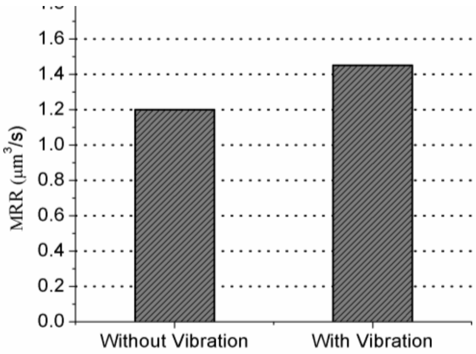

Figure 3: Effect of vibration on MRR

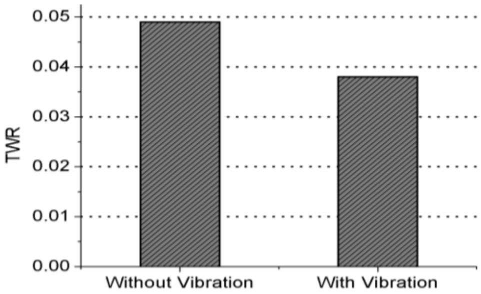

Figure 4: Effect of vibration on TWR

3.5. Machining stability

The machining stability was studied by observing and discriminating the discharging pulses, and calculating the percentage of various pulses during machining according to the pulse discrimination system. Figure 7 shows that, during the vibration-assistance micro-EDM dressing, the percentage of normal pulses increased from 29 to 52% , effective and arcing pulses decreased from 44 to 36% and 27 to 12%, respectively. Figure 6 shows one snap shot of the voltage and current signatures taken in between for vibration and no vibration condition. The signatures also reveal the existence of more number of normal pulses in case of with vibration. The above results reveal that material removal was taking place more effectively when vibration introduced. Decrease in percentage of arcing was required for better efficiency, which was possible

Table 1

Material properties

Material: Brass(Work piece, 500 µm diameter) and Copper (Tool plate, 200 µm thickness and 300 µm diameter hole)	
Experimental Conditions	
Voltage	90 V
Capacitance	10 nF
Feed rate	0.2 mm/min
Spindle speed	2000 rpm

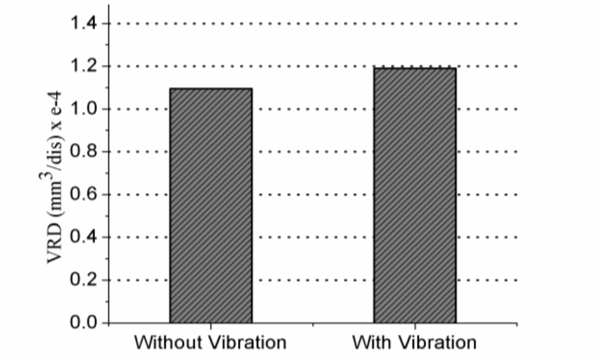

Figure 5: Effect of vibration on VRD

by the introduction of vibration-assistance. Reduction of localized debris agglomeration and short bridge formation due to the dynamic dielectric fluid flow caused by vibration is the prime reason for the occurrence of large percentage of normal pulses in case of vibration-assisted micro-EDM dressing [7].

3.6. Surface Quality and Dimensional accuracy

3.6.1 Tool Plate

It has been observed that, the surface obtained without vibration has resolidified debris and craters attached at the rims. Figure 8 (left), shows quality of micro-tool plate hole, used under no vibration condition. On the other hand, the surface obtained using the vibration assistance are smooth and free of burr-like recast layer. In addition, there are no black spots on the surface obtained using the vibration assistance micro-EDM dressing, as shown in figure 8 (right). This is due to the fact that momentum caused by vibration to the dielectric fluid help in flushing away the debris and decomposed dielectric carbon particles [8]. Micro-pre drilled hole on the Cu plate get enlarged from 300 µm to 338 µm, after micro-EDM dressing process in case of no vibration. On the other hand, this value enlarged to only 326 µm in case of with vibration, means showing good dimensional accuracy. This dimensional inaccuracy is due to the gowth of debris concentration at the top rim of tool plate in case of no vibration that leads to lower the IEG and causes an another unwanted secondary discharge [9]. From the figures, we can observe that there are more black spots in without vibration case compared to with vibration case. The black spots represent carbon deposition formed due to high temperature during machining. It implies flushing of debris is good in case of "with vibration" compared to "without vibration" case.

3.6.2 Fabricated micro-rod

During micro-EDM dressing of micro-rod without vibration, arcing and short-circuiting occured more frequently, which not ony decreased the machining performance but also affect the machined surface quality. Figure 9 (left) and (right) shows the comparision of machined surface of the micro-rods for machining without and with vibration-assistance micro-EDM dressing. Due to the more wear, took place at the top surface of Cu tool plate, approx. 8˚ taper angle was seen on the micro-rod compared to only 4˚ taper angle, in case of with vibration machining condition. Also, it was seen that the tip diameter of the micro-rod improved from 218 µm to 246 µm under the vibration condition. The overall improvement in case of vibration fabricated micro-rod is due to the fact that repeatitive suction and pumping action always retain the IEG quality even at prolonged machining time [10].

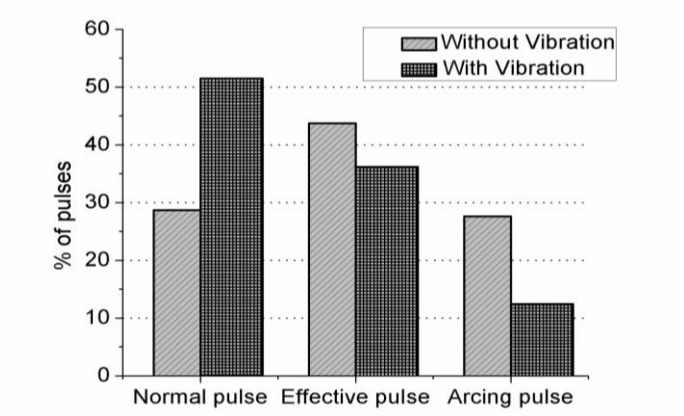

Figure 7: Effects of vibration on percentage of pulses

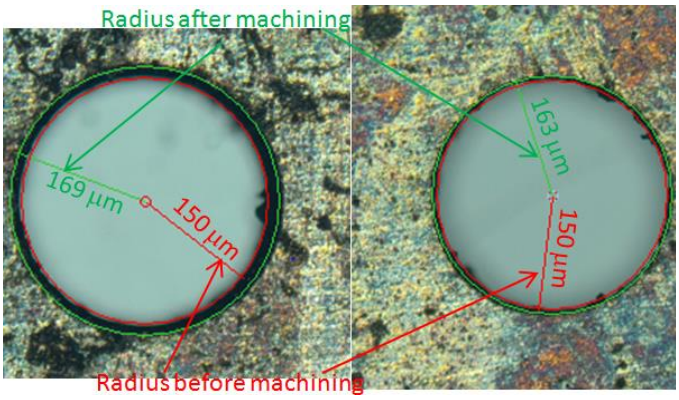

Figure 8: Effect of vibration on tool plate (Top surface)

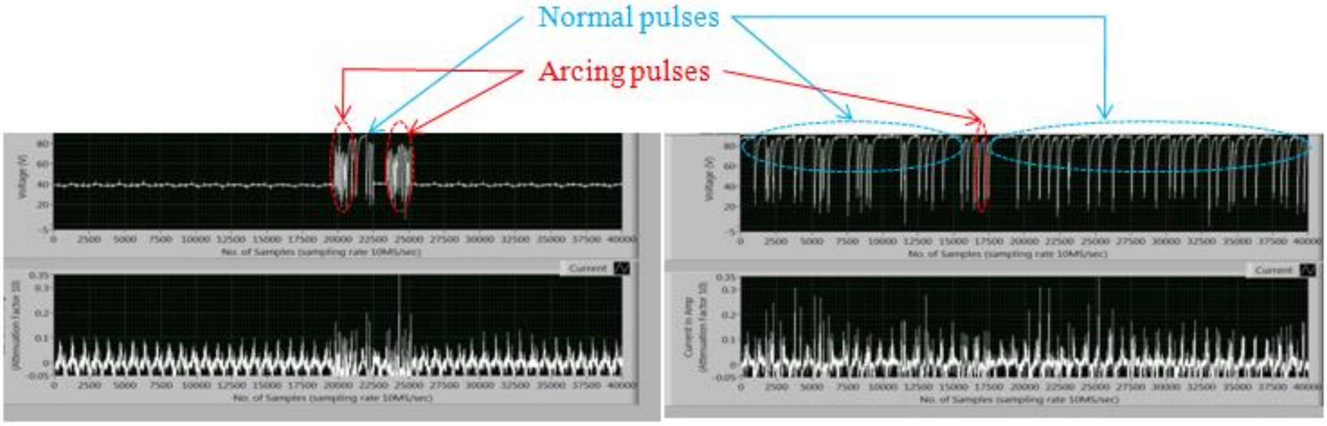

Figure 6 Voltage and Current signals for: Without Vibration (left) and With Vibration (right)

4. CONCLUSION

Micro-EDM dressing process was performed with and without vibration. By using the vibration, it was observed that:

- The decrease in machining time was 48 %
- The increase of MRR was 23 %
- The decrease of TWR was 23 %
- The increase of VRD was 9 %
- The normal pulses increased by 79 %, whereas the arcing pulses decreased by 55 %.
- Less carbon deposit along with low tool wear were observed over the tool plate
- Less debris sticked and less taper angle were observed on the fabricated micro-rod

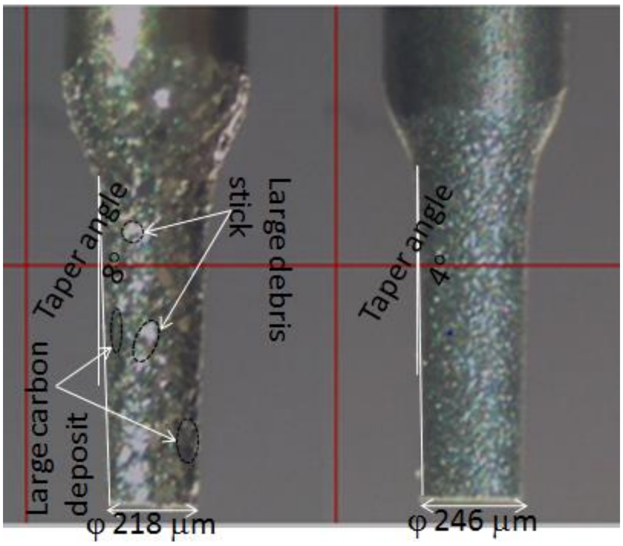

Figure 9: Effect of vibration on micro-rod (work piece) after machining

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