Springer

KSME

Journal of Mechanical Science and Technology 25 (5) (2011) 1231~1234
www.springerlink.com/content/1738-494x
DOI 10.1007/s12206-011-0307-1

Effect of low-frequency vibration on workpiece in EDM processes †

Gunawan Setia Prihandana[1,*], Muslim Mahardika[1], M. Hamdi[2,3] and Kimiyuki Mitsui[4]

[1]*Department of Mechanical and Industrial Engineering, Gadjah Mada University, 55281, Yogyakarta, Indonesia*
[2]*Department of Engineering Design and Manufacture, University of Malaya, 50603 Kuala Lumpur, Malaysia*
[3]*Centre of Advanced Manufacturing and Material Processing, University of Malaya, 50603 Kuala Lumpur, Malaysia*
[4]*Department of Mechanical Engineering, Keio University, 3-14-1 Hiyoshi, Kohoku-ku, Yokohama, 223-8522, Japan*

(Manuscript Received September 7, 2009; Revised January 5, 2011; Accepted January 14, 2011)

Abstract

High-frequency vibration aided EDM has become one of the ways to increase material removal rate in EDM process, due to the flushing effect caused by vibration. However, utilizing high-frequency vibration, especially in ultrasonic range consumes a lot of setup cost. This work presents an attempt to use a low-frequency vibration on workpiece of stainless steel (SS 304) during EDM process. The workpiece was vibrated with variations of low-frequency and low-amplitude. The results show that the application of low-frequency vibration in EDM process can be used to increase the material removal rate, and decrease the surface roughness and tool wear rate.

Keywords: Electrical discharge machining; Low-frequency vibration; Material removal rate; Tool wear ratio; Surface roughness

1. Introduction

Electrical Discharge Machining (EDM) is a non-contact machining process, which electrically removes material from any conductive workpiece. This is achieved by applying high-frequency pulsed current to the workpiece through a tool electrode immersed in a dielectric fluid which subsequently melts and vaporizes the workpiece material [1-4]. Unlike the traditional machining method, EDM offers many advantages, for instance, it can be used to machine very complex shape by using a simple tool electrode. In addition, the ease of machining in EDM process is only depending on the λ•θ•ρ theory, which is the product of thermal conductivity (λ), melting point (θ) and electrical resistivity (ρ) of workpiece material [5].

As a product of electrical discharge, debris are created and accumulated in the sparking gap between the tool electrode and the workpiece. If the amounts of debris in the machining gap are too large, reduction of resistance occurs and encourages the formation of abnormal discharges, which leads to significant tool wear and slows down the material removal rate [6].

Development of flushing methods has been the focus of research in the last decade to enhance the debris removal from the sparking gap [7, 8]. The study on the effect of high-frequency vibration of the tool electrode on EDM has been undertaken since the mid 80s, and some promising results have been acquired [1, 6, 9-15]. While most experiments have been done by applying high-frequency vibration, especially in ultrasonic vibration to the tool electrode, die sinking or wire EDM, vibrating the workpiece has proven to increase the machining efficiency as well [9, 10]. These studies indicated that the introduction of high-frequency vibration into EDM process has significant results in improving machining efficiency due to the enhanced flushing effect. Researchers mainly focused on vibrating the tool within ultrasonic range to enhance the flushing effect. However, ultrasonic vibration system requires extensive tool setting and expensive devices are needed.

Previous researches in micro-EDM assisted low-frequency vibration of tool electrode by using small PZT (Piezoelectric Transducer) has proven to effectively remove debris and inhibit adhesion between electrodes and gave remarkable reduction of machining time [7, 8]. Since the energy per discharge pulse in micro-EDM process is much smaller than in EDM process, the low-frequency vibration can effectively increase the material removal rate [7, 8].

In this paper, the experiments were conducted in EDM process with the application of low-frequency vibration by applying a shaker to the workpiece. Unlike in EDM orbiting mechanism, where the electrode making a planetary motion to produce an effective flushing action only on the orbiting plane which are X and Y planes [16, 17], while vibration on the workpiece forces the debris out of the sparking gap by reciprocating tool motion in the direction of feed which is in Z direction. Moreover, the workpiece vibrates up and down in a controlled frequency and amplitude. In addition, the remark-

† This paper was recommended for publication in revised form by Associate Editor Seockhyun Kim

* Corresponding author. Tel.: +62 274 521673, Fax.: +62 274 521673
E-mail address: g_prihandana@yahoo.com

able feature of this method is that the shaker does not vibrate the tool, as in other previous researches, but vibrates the workpiece. The workpiece was attached to the shaker in order to provide vibration to the workpiece. The other benefit of workpiece vibration instead of tool vibration is that it is much simpler and more compact. This paper discusses the effect of low-frequency vibration on material removal rate, surface roughness and tool wear rate.

2. Experimental setup

A Sodick A30R EDM Mark-20 series was used for this experiment. It was conducted using copper rod with a diameter of 12.5 mm as the tool electrode, and stainless steel (SS 304) as the workpiece. The dimension of the workpiece was 20 mm × 20 mm × 10 mm. The machining depth was 3 mm, and the low-frequency vibration was applied to the workpiece.

The low-frequency vibration was generated by the shaker (VS-30-03, IMV Corporation). It was driven by a power amplifier (VA-ST-03, IMV Corporation) which was connected to a function generator as the device that set the frequency and amplitude. Fig. 1 shows the experimental setup of the experiment.

Table 1 describes the machining conditions used in this experiment. In each experiment, the material removal rate, tool wear rate and surface roughness were measured to determine the machining quality. Surface roughness (Ra) of the bottom surface of the cavity was measured using Mahr perthometer.

3. Result and discussion

3.1 Effect of vibration on material removal rate

The comparison between normal EDM and vibration-aided EDM with the same machining conditions at frequencies 300 Hz, 400 Hz and 600 Hz for 0.75 μm and 1 μm in amplitudes are presented in Figs. 2 and 3.

Experimental results showed that the tool vibration induced by low-frequency vibration action has a relatively significant effect in terms of metal removal rate when compared to normal machining. The vibration of workpiece enhances the flushing effect, and creates better dielectric circulation between the tool electrode and workpiece. During the down-movement of the workpiece, the amount of sparking gap increases and allows the entrance of clean dielectric fluid. When the workpiece is lifted up, it pumps the contaminated dielectric fluid and debris away from the gap. As the workpiece is vibrating, discharge energy is more intense as the tool electrode and the workpiece are brought closer more frequently, creating more discharges compare to when machining without vibration.

For 0.75 μm in amplitude at frequencies of 300 Hz, 400 Hz and 600 Hz, the highest material removal rate acquired is at frequency 600 Hz, as can be seen in Fig. 2. At lower amplitude, vibration of the workpiece is more stable than at higher amplitude and this will give enough gaps to create better flushing of debris. At the same amplitude, 300 Hz produces a lower penetration rate compared to 400 Hz, resulting in a lower material removal rate. The highest material removal rate is achieved at a frequency of 600 Hz. At that particular frequency, the penetration rate is increased and 0.75 μm amplitude improves the stability of the machining process, resulting in the increment of the material removal rate.

However, at an amplitude of 1 μm and frequency of 400 Hz, highest material removal rate is achieved, as shown in Fig. 3.

Table 1. Machining conditions.

Parameter	Value
Discharge Current (A)	9
No-load Voltage (V)	90
Tool polarity	+
Vibration amplitude (μm)	0.75, 1.00
Vibration frequency (Hz)	0, 300, 400 and 600

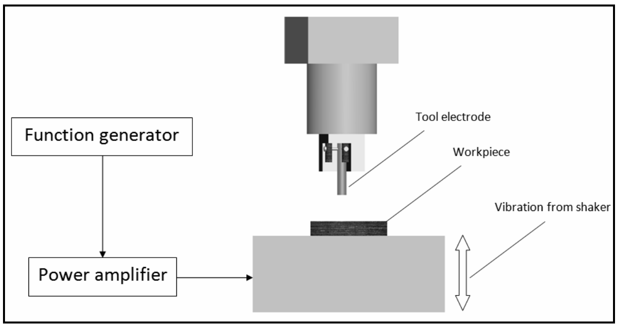

Fig. 1. Experimental setup.

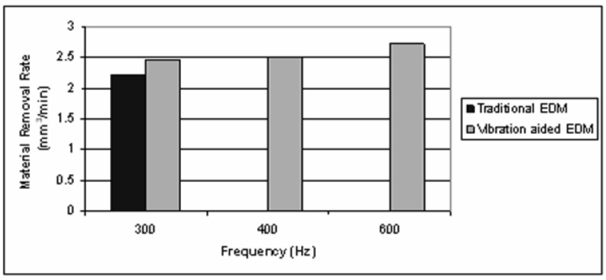

Fig. 2. The effect of low-frequency vibration to the material removal rate at amplitude 0.75 μm.

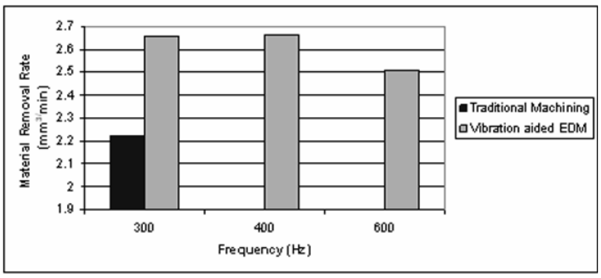

Fig. 3. The effect of low-frequency vibration to the material removal rate at amplitude 1 μm.

Material removal rate at frequency 400 Hz is higher than that at frequency 600, since at frequency 600 Hz, the 1 μm magnitude of amplitude is too large and it is affecting the machining stability, resulting in longer machining time and lower material removal rate.

3.2 The effect of low-frequency vibration to the surface roughness

Figs. 4 and 5 show the effect of frequency vibration at 0.75 μm and 1 μm of amplitudes to the surface roughness. The experimental results were obtained from the average of three repetitions at frequencies of 300 Hz, 400 Hz and 600 Hz.

Experimental result shows that by the application of vibration, the workpiece surface roughness produced is reduced. Based on Figs. 4 and 5, the best surface roughness achieved is at frequency 300 Hz and amplitude 0.75 μm. When vibration was applied at frequency 300 Hz and at amplitude 0.75 μm, the surface becomes very smooth as lower frequency and lower amplitude settings produce smaller craters resulting in better surface roughness. From the experimental result, it can be concluded that low vibration amplitude at low frequency contributes to a better surface roughness.

3.3 The effect of low-frequency vibration to the tool wear rate

The effect of vibration on tool wear rate is also investigated. Figs. 6 and 7 present the tool wear rate resulting from the experiment at amplitude 0.75 μm and 1 μm. Based on the experimental results, it can be seen that the tool wear rate tends to increase gradually with the increase of material removal rate as shown in Figs. 6 and 7.

However, at frequency of 400 Hz and amplitude of 1 μm, the tool wear rate produced was lower compared to the one at frequency of 300 Hz, even though the frequency of 400 Hz gives higher material removal rate, as can be seen in Fig. 7. This can be explained that during the machining of holes, although the machining process does not proceed further, the material is continuously removed from the tool electrode, resulting in extensive electrode wear leaving the drilling incomplete. Therefore, even though the frequency of 300 Hz produces lower material removal rate, the tool wear rate was higher compared to frequency of 400 Hz, which has higher material removal rate.

4. Conclusions

The results of applying low-frequency vibration shows that most of the material removal rate obtained from the machining with low-vibration are higher than in machining without vibration, especially at frequency of 600 Hz and amplitude of 0.75 μm. The material removal rate shows an increase of around 23%. The application of low-frequency vibration has created a more frequent shortest distance between the tool and the workpiece. It also enhances the flushing effect and creates better dielectric circulation between the tool electrode and workpiece. The resultant surface roughness and tool wear rate measured from the machining without vibration are higher than in machining with low-frequency vibration. Thus, the

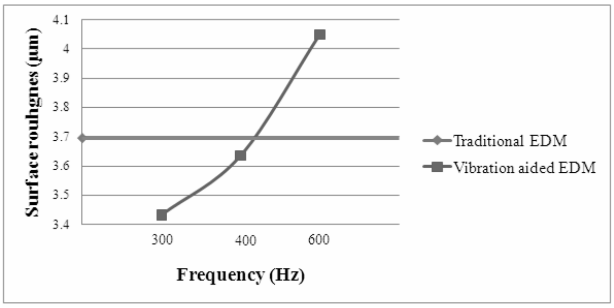

Fig. 4. The effect of low-frequency vibration to the surface roughness at amplitude 0.75 μm.

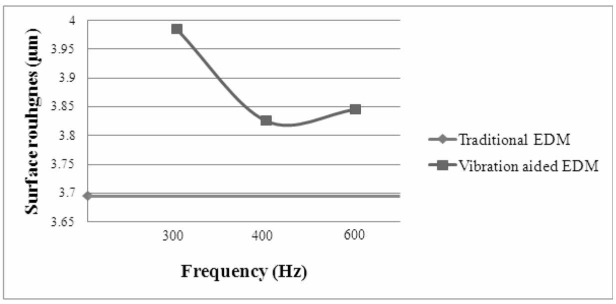

Fig. 5. The effect of low-frequency vibration to the surface roughness at amplitude 1 μm.

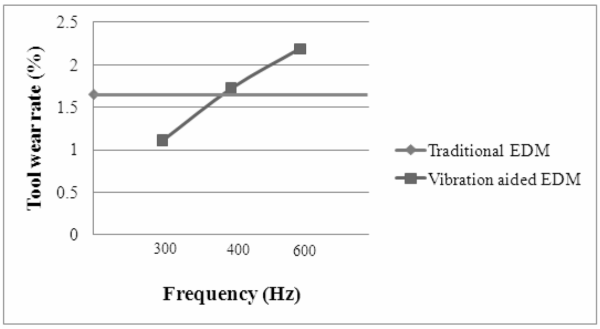

Fig. 6. The effect of low-frequency vibration to the tool wear rate at amplitude 0.75 μm.

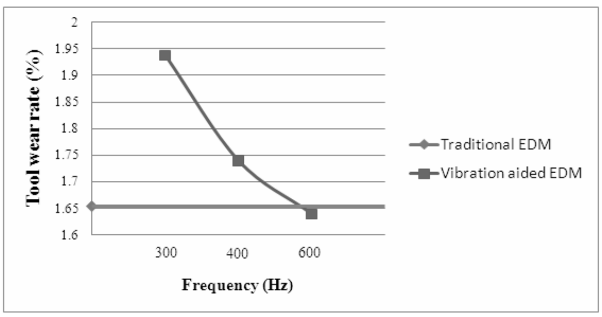

Fig. 7. The effect of low-frequency vibration to the tool wear rate at amplitude 1 μm.

application of low-frequency vibration can be used to increase the material removal rate, and decrease the surface roughness and tool wear rate.

Acknowledgment

The authors are grateful to the ASEAN University Network/Southeast Asia Engineering Education Development Network (AUN/SEED-Net) for supporting this study under Short-term Research Program in Japan.

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Gunawan Setia Prihandana received his Bachelor degree in Mechanical Engineering, Gadjah Mada University, Indonesia. He received master degree and doctoral degree in Engineering Design and Manufacture from University of Malaya, Malaysia. He is currently a researcher in Department of Mechanical and Industrial Engineering, Gadjah Mada University, Indonesia. Dr. Prihandana's research interests include micromachining and Non-Traditional Machining.

Muslim Mahardika received his Bachelor degree in Mechanical Engineering, Gadjah Mada University, Indonesia, Master degree in Engineering Design and Manufacture, University of Malaya, Malaysia and Ph.D degree in Integrated Design Engineering, Keio Unversity, Japan. Currently, he is working for Department of Mechanical and Industrial Engineering, Gadjah Mada University, Indonesia. His research interest includes micro-machining and metrology.