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Study on the movement of wire electrode during fine wire electrical discharge machining process

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ABSTRACT

Wire movements and vibrations are one of the most important phenomena of wire electrical discharge machining (EDM) process. Unstable wire electrode behavior and large wire vibration amplitude during the process cause wire breakage, low shape accuracy and large machined surface roughness. In this study, direct observation using high-speed camera investigated the movements of tungsten wire electrode during fine wire EDM process. The results showed that the vibration amplitude and frequency depended mainly on the wire tension, and the amplitude direction. The amplitude in the direction parallel to the machining direction was a little larger than that in the perpendicular one. In addition, the backward deflection of wire could be confirmed even in fine wire EDM. Also, the wire vibration mode was analyzed, and it could be varied with the machining position of the thin workpiece, which possibly led to smaller wire amplitude. Furthermore the amplitude envelope of wire electrode during the process was clarified.

1. Introduction

The miniaturization of mechanical and electronic components with complex shapes is a great challenge in manufacturing applications which demands for high precision machining processes. Wire electrical discharge machining (WEDM) is one of the most extended non-conventional machining processes used to produce complex shapes and profiles. It is a thermoelectric process in which workpiece material is eroded by a series of discrete sparks between the workpiece and a traveling wire electrode immersed in a liquid dielectric medium. These electrical discharges melt and vaporize minute amount of the workpeice material, which is then ejected and flushed away by the dielectric (El-Hofy, 2005).

In wire electrical discharge machining (EDM) process, the movements, orientations and vibrations of wire electrode are one of the most important phenomena affecting the machining process. However, the control is difficult because of the complex behavior of the wire during cutting caused by bubble expansion, electrostatic force and electromagnetic force. Unstable wire electrode behavior and large wire vibration amplitude during the process cause wire breakage, low shape accuracy and large machined surface roughness. The reduction of wire electrode vibration and deflection is very important in order to attain high shape accuracy and high efficient machining.

In the case of normal-scale wire EDM using wire electrode with the diameter of sub-millimeter, the wire vibration model during the process is regarded as superposition of mainly 1st order mode string vibration and plural higher order ones (Yamada et al., 1997 and Han et al., 2002). Nishikawa and Kunieda (2009) developed in-process measurement of the wire electrode behavior using a sensor. They concluded that the surface shape predicted from the wire behavior coincided well with the surface shape measured after machining. Iwata et al. (1995, 1996) simulated wire EDM in order to show the effect of wire vibration on shape accuracy. Furthermore, a model of material removal mechanism in wire EDM considering the wire vibration was proposed (Yamada et al., 2006). However, the wire movements in fine wire EDM using a thin wire with the diameter less than about 50 μm for cutting relatively thin workpiece had not yet been clarified sufficiently. Klocke et al. (2013) analyzed of sinking EDM electrode deflection measurements for the manufacturing of high aspect ratio cavities. They show the results of dynamic lateral deflection of high aspect ratio macro sinking EDM slit-formed graphite electrodes. A highly precise laser-interferometer was used to measure electrode vibration during a continuous sinking EDM process. Meena et al. (2013) studied the effect of wire feed rate and wire tension during machining of Pr–Al–SiC–MMCs by WEDM. They investigated cutting speed, width of cut, spark gap, metal removal rate, surface roughness, peak

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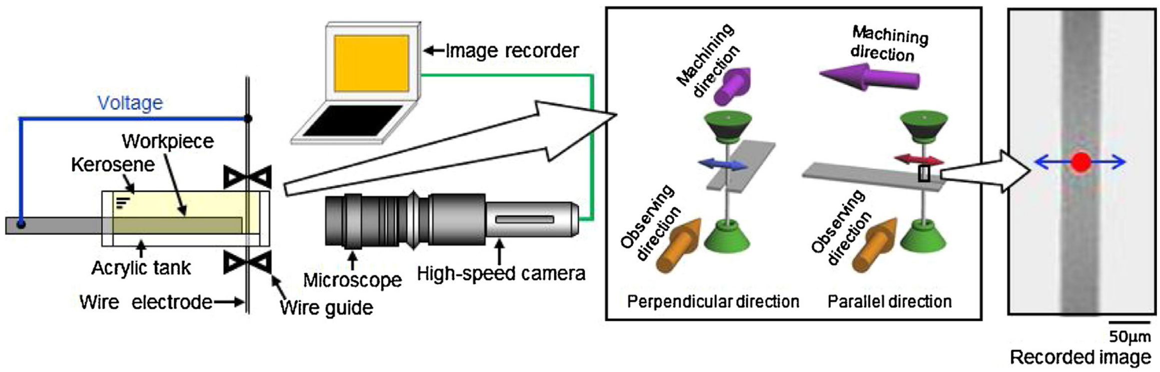

Fig. 1. High-speed observation system for fine wire EDM.

roughness for each experiment by varying wire feed rate and wire tension.

Our previous studies by Okada et al. (2010, 2013) reported the wire movements during the 1st-cut conditions fine wire EDM for thin workpiece. Direct microscopic observation using a high-speed video camera was studied and analyzed. A high-speed observation model consisting of a running tungsten wire electrode, a thin workpiece and an acrylic small tank was built. In addition, the wire movements were observed from the rear of wire by the high-speed video camera.

In this study, the vibration amplitude and frequency of tungsten wire electrode during fine wire EDM were investigated and the effects of electrical discharge conditions and wire conditions were discussed. In addition, the amplitude of wire vibrations in the directions both parallel and perpendicular to the machining direction were compared by observing the wire movements from the rear and the side of the wire. Furthermore, the vibration mode of wire movements was investigated by frequency analyses, and the influence of machining position of the thin workpiece on the wire vibration mode was discussed for reducing the wire vibration amplitude. Also, the amplitude envelope of wire electrode during the process was investigated.

2. Experimental work

In wire electrical discharge machining process, the gap between the electrode and workpiece is very small, it is only several tens of micrometers and emerged in the oil. Moreover, the view of the gap was obstructed by the electrode and workpiece, making the observation of the wire movements difficult. The current study establishes a high-speed observation system using transparent material such as acrylic small tank to observe the wire movements in the gap (machining area) during fine wire EDM process as shown in Fig. 1.

The experimental studies were performed on CNC EDM high precision wire cut machine. The machine maker is SODICK, Japan and its model is AP 200 L. A kerosene type working fluid was used. The absolute viscosity of the dielectric Kerosene is 0.00164 Pa s. The workpiece material was SKD11 in JIS specifications which used widely as a metal mold of 1.0 mm in thickness. Also, Tungsten wire of 50.0 μm in diameter was used in this work. Table 1 lists wire EDM operating conditions. A series of wire EDM experiments with varying wire tension values and distance between guides were carried out. Kerf width was measured by using NIKON high optical microscope under magnification of 100 times. The measurement were made three times at three different positions along the kerf width and the average value was calculated.

The wire movements during the process were observed from the rear and the side of wire by the high-speed video camera. The digital high-speed video camera system (KEYENCE VW-6000) was used for recording images for the wire running. The recording conditions are listed in Table 2. The observation area is 1.0 mm above the top edge of workpiece, and the view size is 0.4 × 0.2 mm. The recording speed was set mainly to 8000 frame per second (fps), but 24,000 fps for detailed investigation of wire vibration mode. Nyquist–Shannon sampling theorem is a principle that engineers follow in the digitization of analog signals. For analog-to-digital conversion to result in a faithful reproduction of the signal, slices, called *samples*, of the analog waveform must be taken frequently. The number of samples per second is called the sampling rate or sampling frequency. According to the Nyquist–Shannon sampling theorem, the sampling rate must be at least $2f_{max}$, or twice the highest analog frequency component. In this work, the range of frequency is from 0 to 12 kHz. i.e., the frequency ranges from 0 to 12,000 Hz. Thus, the f_{max} = 12,000 Hz and so, the sampling rate is equal 24,000 according to Nyquist–Shannon sampling theorem. The sampling rate of the used high speed camera is equal 24,000 fps.

Basically, electrical discharge machines maker recommended 1st cut conditions for steel of 1.0 mm in thickness with tungsten wire of 50.0 μm in diameter was applied. The wire vibration during the process was analyzed with the motion analysis program (DITECT DIPP Motion Pro). In order to emphasize the edge of wire during the recording, back lighting method was used. The wire edges of each recorded frame in the movie were automatically detected, and the temporal horizontal displacements of wire were tracked by the image analysis program. Then, the amplitude and the frequency of wire vibration were evaluated. In this study, the

Table 1
Wire EDM operating conditions.

Working condition	Description
Pulse duration (t_e)	1.0 μs
Pulse interval (t_o)	9.0 μs
Discharge current (i_e)	20 A
Servo voltage (S_v)	90 V
Wire tension (W_t)	0.5–4.0 N
Wire running speed (W_s)	7.0 m/min
Flow rate (F_r)	6.0 L/min
Distance between guides (L_g)	31 mm, 46 mm

Table 2
Recording conditions.

Parameter	Description
Recording speed	8,000, 24,000 fps
Shutter speed	1/40,000 s
Recording time	2.0 s
View size	0.4 × 0.2 mm