**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.

**Keywords**

Wire EDM, Tungsten wire, high-speed observation, wire movement, wire deflection, amplitude envelope.

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 et al. (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 and 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 50μm 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 roughness for each experiment by varying wire feed rate and wire tension.

Our previous studies by Okada et al. (2010 and 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.