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Force feedback feed for electrochemical discharge machining (ECDM) micro-hole drilling

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Abstract
Electrochemical discharge machining (ECDM) has been suggested as an effective micro-hole drilling method for non-conductive materials such as glass and ceramics. Feeding method is one of the most important factors that influence the machining performance in ECDM process. The two traditional feeding methods, i.e. gravity feed and constant velocity feed, suffer from problems including low machining speed, bending of tool electrode and damage on the workpiece etc. In order to tackle these problems, a force feedback feeding method has been proposed. The contact force between the tool electrode and the workpiece is detected in real-time by a pressure sensor and used as the feedback signal to control the motion of Z-axis. A set of experiments using force feedback feeding method have been carried out. Experimental results demonstrate that ECDM with force feedback feeding method accelerates electrolyte refreshing in the machining zone, whereby improving both machining speed and geometric accuracy as compared to traditional methods. Furthermore, the gap between the tool tip and the workpiece is maintained within a small range, and as a result the bending of tool electrode or damage on the workpiece can be avoided.

Keywords— ECDM, Micro-hole drilling, Force feedback feed.

1. Introduction

Electrochemical discharge machining (ECDM) is based on the electrochemical discharge phenomena around the tool electrode. The heat provided by these discharges results in material removal through thermal melting and thermal assisted etching [1]. In order to enhance the process efficiency and machining accuracy, both tool rotation and tool vibration have been applied [2, 3], and a flat sidewall-flat front tool [4] and a spherical end tool [5] were introduced. However, only gravity feed and constant velocity feed for micro-drilling have been investigated. In the gravity feeding mode, the gas film formation at the tool tip is difficult due to the lack of sufficient electrolyte, which results in low machining speed. The constant velocity feeding mode suffers from the bending of tool electrode and damage on the workpiece.

A force feedback feeding method is proposed in this paper. The contact force between the tool electrode and the workpiece is monitored in real-time and used as feedback signal to control the motion of the workpiece. Experiments were conducted to compare the machining performance of this proposed feeding method with other feeding methods.

2. Experimental design

2.1. Experimental setup

The experimental setup mainly consists of two parts as shown in figure 1, a machining head mounted on the Z-axis, and a processing cell filled with electrolyte solution. Different from the traditional ECDM experimental setup, a reversed tool-workpiece configuration was applied: the tool electrode is fixed on the substrate upside down and partly immersed in the electrolyte solution through a small hole on the bottom of the chamber, and the workpiece is mounted on the Z-axis through a pressure sensor. The pressure sensor detects the real-time contact force between the tool electrode and the workpiece and sends it to the control unit of ECDM system. The control unit will correct the motion of Z-axis after receiving the contact force signal.

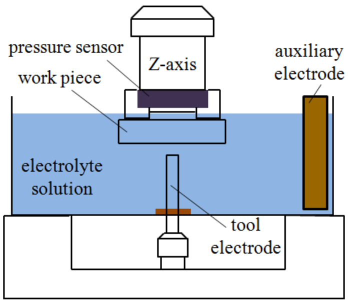

Figure 1. Schematic of ECDM experimental setup for force feedback feeding mechanism.

2.2. The principle of force feedback feeding mechanism

Figure 2 illustrates the scheme of the proposed closed loop force feedback feeding mechanism. A displacement signal is sent to the Z-axis to control its motion when the ECDM hole-drilling process starts. The Z-axis moves forward at a preset constant speed in the beginning, which is similar to the constant velocity feeding mode. As the drilling-hole becomes deeper, insufficient supply of electrolyte in the machining zone leads to a low material removal rate. As a consequence, the gap between the tool tip and the workpiece becomes smaller and smaller. A contact force occurs due to the direct contact between the tool electrode and the workpiece. This contact force is recorded in real-time by the pressure sensor and sent to the control unit. An immediate comparison will be executed. If this contact force F is larger than the preset critical value F_0, a correction displacement signal will be sent to the Z-axis controller to make it retract for a constant distance. Then the

Z-axis moves forward until a new correction displacement signal is received, as shown in Figure 3. In this way, the distance between the tool tip and the workpiece is maintained within a small acceptable range.

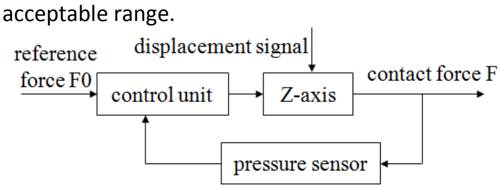

Figure 2. Scheme of the closed loop force feedback feeding mechanism.

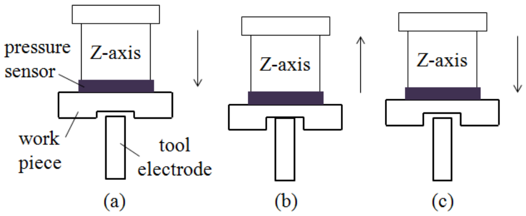

Figure 3. Z-axis retraction in force feedback feeding mechanism.

To investigate the machining performance of the proposed forced feedback feeding mechanism, a set of experiments were conducted. The machining voltage is supplied by a pulse DC power. The tool electrodes are tungsten cylinders with diameter of 500µm. The electrolyte is 6.25mol/L NaOH and the workpieces are soda lime glass microscope slides.

3. Results and discussion

3.1. Effect of feeding method on machining speed

In order to compare the influence of different feeding method on the machining speed, the proposed force feedback feeding method and two traditional feeding methods (the constant velocity feed and the gravity feed) were chosen.

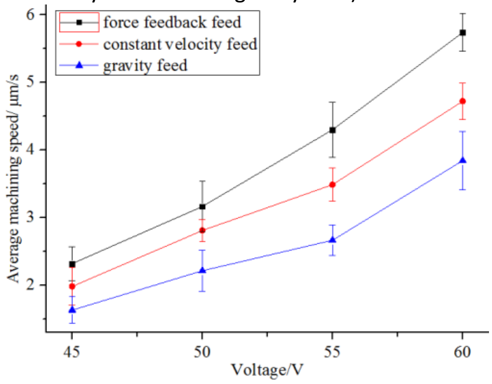

Figure 4. Average machining speed of different feeding methods.

Figure 4. depicts the average machining speed of three different feeding methods within 60s. For each feeding method, four machining voltages were applied. It shows that for each machining voltage, the machining speed of the force feedback feed is the fastest, followed by the constant velocity feed, and the gravity feed is the slowest. From the experimental data, it seems that when using the force feedback feeding method, about a 20% enhancement can be obtained as compared to the constant velocity feeding method, and about 45% as compared to the gravity feeding method. As described in section 2, in the force feedback feeding method, the real-time contact force between the tool electrode and the workpiece is used to control the feed movement of the workpiece to maintain an appropriate gap between the tool tip and the workpiece. This gap allows the electrolyte to flow into and is beneficial to the discharge activity on the tool tip. Furthermore, the workpiece movement accelerates the electrolyte refreshing in the machining hole. Sufficient electrolyte supply in the machining zone results in a higher machining speed. For the constant velocity feeding method, however, it is feasible to maintain a gap between the tool tip and the workpiece in the beginning, but the gap is not controllable and disappears as the hole becomes deeper. Accordingly, the machining speed of this feeding method is slower than the one of the force feedback feeding method. As for the gravity feeding method, there is no gap exists between the tool tip and the workpiece during the whole machining processes, which leads to the slowest machining speed as compared to the other two feeding methods.

3.2. Effect of feeding method on machining geometric accuracy

Figure 5 shows sectional view of the holes machined with different feeding method. A taper angle of 5° is obtained for the force feedback feeding method, while the taper angle increases to 11° and 15° for the constant velocity feeding method the gravity feeding method, respectively. The results show that the hole machined with the force feedback feeding method has the smallest taper angle, while the gravity feeding method results in the worst hole quality with the largest taper angle. This is because that in the force feedback feeding method, the existence of tool-workpiece gap allows more discharge activities to occur on the tool tip instead of on the tool sidewall and this results in a small taper angle. As there is no controllable tool-workpiece gap exists in either the constant velocity feeding method or the gravity feeding method, more discharge activities distribute around the hole entrance and the tool sidewall. Thus, bad quality holes with large taper angle are produced.

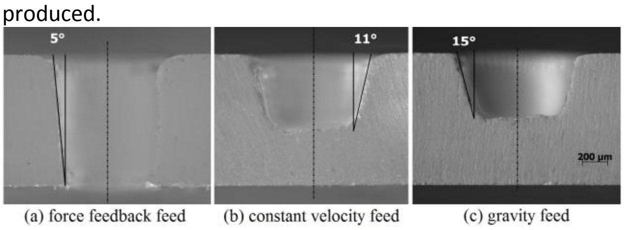

Figure 5. Sectional view of holes machined with different feeding method.

4. Conclusions

In this paper, a force feedback feeding method was proposed, in which the contact force between the tool tip and the workpiece is monitored and used as a real-time feedback signal to control the movement of the workpiece. In this way, the tool-workpiece gap can be maintained within a small range. Experimental investigations show that, in comparison with the constant velocity feeding method and gravity feeding method, the force feedback feeding method improves machining speed by 20% and 45% respectively, and with this method a less tapered hole can be produced.

Acknowledgments

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