Electrolysis Free Micro EDM in Water Using Electrostatic Induction Feeding Method*

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Abstract
This paper describes the machining characteristics of electrolysis-free micro EDM in water using the electrostatic induction feeding method. With the electrostatic induction feeding method, if deionized water is used for the working liquid, electrolysis can be prevented because bipolar voltage is applied to the working gap. Results of micro-holes drilling showed that the material removal rate with deionized water is higher than that with oil, and the oversize of holes machined in deionized water is smaller. Moreover, micro-holes could be drilled successfully even in a tap water with the oversize of several micrometers using this method.

Key words: Micro EDM, Electrostatic Induction Feeding, Electrolysis, Deionized Water

1. Introduction
Electrical discharge machining (EDM) is one of the most useful methods for micro-machining (1). In conventional micro EDM, relaxation type pulse generators shown in Fig. 1 (a) are generally used because short pulse duration with low discharge energy can easily be obtained. With this pulse generator however, when water is used as the dielectric liquid, since mono-polar high voltage is applied to the working gap to ignite the discharge, leak current easily flows through the working gap. As a result, machining accuracy drops due to electrolytic dissolution of the workpiece, although use of water is profitable for higher material removal rate (2).

With the electrostatic induction feeding method (3) shown in Fig. 1 (b) which has been developed by the authors to decrease discharge energy in micro EDM, since the pulse power supply is coupled to the working gap by capacitance, the leak current is interrupted. Moreover, because the voltage applied to the working gap is bipolar, the average gap voltage is zero. In addition, given that electrolysis-free machining can be realized by alternating gap voltage (4),...
in this research, electrolysis free micro EDM in water was conducted using the electrostatic induction feeding method, and its machining characteristics were compared with those of the conventional relaxation pulse generator.

2. Principle of electrostatic induction feeding EDM

Figure 2 shows the principle of the new pulse generator using electrostatic induction feeding. A pulse power supply is coupled with the working gap by capacitance $C_1$. $C_2$ is the capacitance of the working gap between the tool electrode and workpiece. A bipolar pulse voltage is applied with a constant pulse duration. In this example, $C_1$ is assumed to be equal to $C_2$, and the electric charges are shown with + and -. When the voltage of the pulse power supply becomes $E$, both $C_1$ and $C_2$ are charged (i). In the working gap, the tool electrode and workpiece are charged positive and negative respectively, creating a high electric field. Accordingly, discharge occurs (ii). During discharge, electrons are conducted from the workpiece to the tool electrode. The discharge duration is very short, ranging from several ns to several tens of ns, depending on the capacitance of $C_1$. Subsequently, the discharge energy per pulse is kept constant regardless of the frequency of the pulse power supply. After the discharge, there is no current flowing through the circuit and the working gap voltage is kept constant at a low voltage equal to the discharge voltage. Hence, discharge does not occur until the latter half cycle of the pulse where the voltage of the pulse power supply becomes -$E$ (iii).

Since the tool electrode accepts electrons during the previous discharge, the tool electrode is charged negative, and contrarily the workpiece is charged positive. Consequently, discharge occurs with the polarity opposite to that in the previous one (iv), and electrons are conducted from the tool electrode to the workpiece. After discharge, like the previous discharge, the working gap voltage does not increase until the next cycle. In this way, the initial cycle of the pulse power supply ends, followed by the repetition of the steady cycle from (i') to (iv). Figures 2 (ii) and 2 (iv) show that discharge is bipolar with this method.

Fig. 2 Principle of electrostatic induction feeding method
3. Comparison of electrolytic corrosion

With the conventional relaxation pulse generator, when deionized water is used as the working liquid, current continues to leak through the working gap during the discharge delay time until discharge is ignited, resulting in serious electrolytic corrosion and dissolution. In contrast, with the electrostatic induction feeding method, since the pulse power supply is coupled to the working gap by capacitance, the leak current is interrupted. Moreover, since the working gap voltage is bipolar, electrolysis hardly occurs. Thus, the extent of electrolytic dissolution was compared between the relaxation pulse generator and the electrostatic induction feeding method at a gap width with which discharge is difficult to occur.

3.1 Experimental method

A rod tool electrode was placed opposed to a plate workpiece at a fixed gap width of 5μm. The tool electrode was a tungsten rod 57μm in diameter prepared by the wire electro-discharge grinding (WEDG) method (5). The workpiece was a stainless steel (SUS304) plate. Using the relaxation pulse generator and electrostatic induction feeding method, voltage was applied for 30 seconds to the working gap filled with deionized water of 1MΩ cm in resistivity. Conditions of applying voltage to the gap for the relaxation pulse generator and electrostatic induction feeding method are shown in Tables 1 and 2, respectively. Since discharge does not occur in both generators due to the large gap width, the leak current flowed continuously in the case of the relaxation pulse generator. With the electrostatic induction feeding method, the total amplitude of the pulse power supply was set at 100V to obtain the open gap voltage of about 40V to 50V, equivalent to that of the relaxation pulse generator.

3.2 Experimental results

Figure 3 shows photos of the workpiece surface and cross-sectional shapes along the dotted lines for the relaxation pulse generator. The cross sections show that the portion of the workpiece under the tool electrode was removed by electrolytic dissolution. The removed volume was larger with higher power supply voltage. Figure 4 shows the results for the electrostatic induction feeding method. Electrolytic dissolution is negligible compared to that with the relaxation pulse generator.
4. Machining characteristics in deionized water and oil

Using the electrostatic induction feeding method, micro-holes were drilled in deionized water and oil to compare the following machining characteristics of these two dielectric liquids: machining speed, oversize of machined micro-hole, and tool wear ratio.

4.1 Experimental method

Micro-holes were drilled in a stainless steel (SUS304) plate with a thickness of 50μm under the machining conditions shown in Table 3, using a tungsten rod about 50μm in diameter as the tool electrode. The dielectric liquid was deionized water or EDM oil. The resistivity of deionized water was kept at 1MΩcm using an ion exchanger. The workpiece was immersed in the dielectric liquid which was not circulated, but still in the work tub. During machining, the Z-axis was fed at a constant speed, but it was retracted when short circuiting occurred. Short circuiting was detected based on the measured working gap voltage. Figure 5 shows the working gap voltage measurement system for the feed control of Z-axis. The working gap voltage was measured using a differential amplifier. Since discharge was bipolar in this pulse generator, the working gap voltage measured was first

Fig. 3 Workpiece surface and cross-sectional shape using relaxation pulse generator (tool electrode diameter: 57μm)

Fig. 4 Workpiece surface and cross-sectional shape using electrostatic induction feeding method (tool electrode diameter: 57μm)

Fig. 5 Working gap voltage measurement system for feed control of Z-axis
transduced to an absolute value. Then it was smoothed to obtain the average working gap voltage, which was input to the feed controller of the Z-axis. In the experiment, the set feed speed of the Z-axis was changed from 3 μm/s to 60 μm/s in order to change the discharge frequency. With the electrostatic induction feeding method, non-contact electric feeding allows the tool electrode to be rotated at high speeds up to tens of thousands rpm. Since high speed tool electrode rotation is effective for lowering the temperature on the electrode surface, machining speed can be improved, and tool wear ratio can be lowered. In the fundamental experiments of this study, the tool electrode was not rotated at high speed using a non-contact feeding capacitance. Instead power was fed to the tool electrode by the contact method using a mica capacitor as the feeding capacitance \( C_1 \), which was connected to the rotating tool electrode using a brush. Accordingly, the tool electrode was rotated at 3000 rpm which was the highest rotation speed achievable using the brush.

4.2 Experimental results

Figure 6 shows waveforms of the working gap voltage and discharge current during machining. Decrease in the open voltage within one pulse duration of 0.5 μs was caused by the leak currents through both the dielectric liquid in the gap and the gap voltage measurement circuit for the feed control of the Z-axis. Since the resistivity of deionized water was lower than that of oil, the decrease in the open voltage within one pulse duration was quicker in deionized water than in oil. However, it can be seen in Fig. 6 that the discharge current waveforms were more or less the same between the two dielectric liquids. By expanding the discharge current waveform in the time domain, the discharge duration were found to be about 20 ns with both dielectric liquids.

Figure 7 shows the comparison of micro-holes machined in both dielectric liquids. There is no significant difference in the appearance of the holes, indicating that electrolysis

| Table 3 Machining conditions of electrostatic induction feeding method. |
|---------------------------------|---------|---------|
| Pulse power supply              | Total amplitude [V] | 140      |
|                                 | Frequency [Hz]      | 1M       |
|                                 | Duty factor [%]     | 50       |
| Feeding capacitance \( C_1 \) [pF] | Deionized water (1MΩ cm, EDM oil) |
| Dielectric                      |                      |
| Tool electrode rotation [rpm]    | 3000               |
| Tool electrode                  | Tungsten (diameter: 50 μm) |
| Workpiece                       | SUS304 (thickness: 50 μm) |
| Tool electrode                  |                      |
| Workpiece                       |                      |
| Set feed speed [μm/s]            | 3 - 60              |

Fig. 6 Working gap voltage and discharge current waveforms of electrostatic induction feeding method

(a) EDM oil

(b) Deionized water
was negligible even in deionized water.

Figure 8 shows the relationship between the material removal rate and set feed speed with the two dielectric liquids. The material removal rate was obtained by dividing the measured removal volume by the machining time. In both dielectric liquids, the material removal rate initially increased with increasing set feed speed due to the increase in discharge frequency. After the peak however, further increase in the set feed speed led to decrease in the material removal rate because short circuiting occurred and the Z-axis was retracted frequently. With oil, the material removal rate started decreasing at the set feed speed of 8μm/s earlier than with deionized water. As a result, the maximum material removal rate with oil was about 15000μm³/s. On the other hand, with deionized water, short circuits hardly occurred even at higher feed speeds. Consequently, the maximum material removal rate with deionized water was about 45000μm³/s, three times higher than that with oil.

Figure 9 shows the relation between the oversize of machined micro-holes and set feed speed. The oversize was defined as half of the difference between the diameter of the inlet of machined micro-hole and the tool electrode diameter. As shown in Fig. 9, micro-holes with smaller oversize could be obtained with deionized water. This is because the higher material removal rate resulted in shorter machining time, decreasing the probability of discharge ignited on the side surface of the tool electrode.

Figure 10 shows the relation between the tool wear ratio and set feed speed. The tool wear ratio was obtained by dividing the volume of tool wear with the removal volume of the workpiece. Under the same feed speed, the tool wear ratio was higher in deionized water than in oil. This is probably because the
tool electrode was dissolved due to electrolysis during the interval when the polarity of the tool electrode was positive in deionized water.

5. Micro-hole drilling using tap water

Since the electrostatic induction feeding method can prevent the electrolysis, micro-holes were drilled using tap water. Although tap water is most inexpensive and readily available, it is normally inappropriate as a working liquid because of its low resistivity of 10kΩ cm or less.

5.1 Experimental method

With the relaxation pulse generator and electrostatic induction feeding method, micro-holes were drilled in a stainless steel (SUS304) plate with a thickness of 30μm using a tungsten rod 30μm in diameter as the tool electrode prepared by the WEDG method. Machining conditions used in the relaxation pulse generator and electrostatic induction feeding method are shown in Tables 4 and 5, respectively. The feed speed of the Z-axis was set at 20μm/s.

5.2 Experimental results

Figure 11 shows a micro-hole machined in tap water using the relaxation pulse generator. The oversize was significantly large: 20μm or more due to the electrolytic dissolution. Figure 12 shows a micro-hole machined in tap water using the electrostatic induction feeding method. Figure 13 shows waveforms of the working gap voltage and discharge current during machining in tap water. Because the resistivity of tap water was lower than that of the deionized water used in the previous section, the current easily leaked through the working gap, resulting in reduced open voltage within one pulse duration quicker than Fig. 6 (b) in deionized water. Nevertheless, with the electrostatic induction feeding method, the side gap of the
machined micro-hole was 1.5 μm or less, significantly smaller than that of the relaxation pulse generator.

6. Conclusions

With the electrostatic induction feeding method, since bipolar voltage is applied to the working gap, electrolysis is insignificant compared to the conventional relaxation pulse generator. Machining results of micro-holes showed that the material removal rate with deionized water 1 MΩ cm in resistivity was higher than that with oil. Since the machining time could be shortened, the number of discharge ignited on the side surface of the tool electrode was smaller in deionized water, resulting in smaller oversize. Even with tap water 10 kΩ cm or less in resistivity, the oversize was several micrometers, more or less the same as oil.

References