Increasing Removal Efficiency of Electrical Discharge Machining using LC Pulse Generator

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This paper aims to increase the removal efficiency of electrical discharge machining by superimposing a high peak and short pulse current to a conventional rectangular discharge current pulse. To obtain the discharge current pulse with high peak and short duration, a high electric current is supplied to a circuit involving an inductance. When the circuit is switched off, a high electromotive force is induced, which causes a dielectric breakdown in the interelectrode gap. Since the induced electromotive force increases significantly to generate a discharge current which is the same as the inductance current before the breakdown, the rising speed of the discharge current is higher than conventional discharge current pulses. The optimal timing of superimposition was investigated, and it was found that the material removal rate was maximized when the timing of superimposition was at the end of the rectangular pulse.

NOMENCLATURE

U_{in} = voltage of power source of LC pulse generator
L = inductance of LC pulse generator
C = capacitance of LC pulse generator
f = switching frequency

1. Introduction

Electrical discharge machining (EDM) is capable of machining electrically conductive materials regardless of hardness with high accuracy. However, the material removal rate of EDM is significantly low compared to cutting processes. The reason is considered that the removal efficiency which is defined as the ratio of removal volume to the total volume of material melted during discharge is only several % [1]. Most of the melted material is resolidified in the discharge crater, generating a brittle layer loaded with a tensile stress causing micro cracks. Hence, increasing the removal efficiency is a challenge to improve the material removal rate and to reduce the heat affected zone on the finished surface.

From a thermo-hydraulic analysis of melt pool dynamics in discharge craters, Li and Yang [2] found that the dominant driving force of removal in EDM is the recoil force, which is a kinetic reaction force due to material evaporation. Ishikawa and Kunieda [3] tried to increase the removal efficiency by optimizing the pulse shape of the discharge current. Under the same discharge energy per pulse, a right-angled triangular pulse with ramp up shape resulted in higher removal efficiency compared to right-angled triangular pulse with ramp down shape or conventional rectangular pulse. This is because the melted material is supposed to be removed all at once when the current peaks at the end of discharge.

Hence, in this study, a shock impulse which has a negligibly small energy but has a high peak current was superimposed to a conventional rectangular pulse to obtain high removal efficiency. The shock impulse was generated by the LC pulse generator which was newly developed by Jiang and Kunieda [4] to obtain high material removal rate in micro EDM.

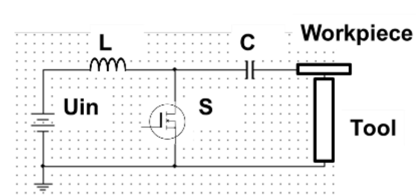
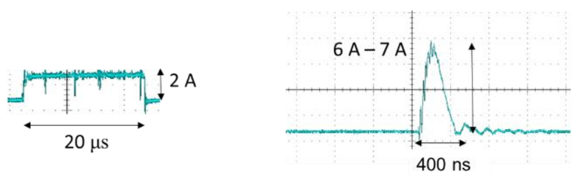


Fig. 1 LC pulse generator

2. Rectangular pulse superimposed with shock impulse

2.1 LC pulse generator

Fig. 1 shows the principle of the LC pulse generator [4]. Energy starts being stored in the inductance L when the switch S is on. Voltage of the power supply U_{in} may be small, for example, only 12 V in the present work. The inductance current increases with time t until S is switched-off. When S is switched-off, electromotive force is induced in L to keep the same current. Thereby a discharge is ignited in the gap between the tool electrode and workpiece. Due to the high electromotive force, the rising speed of the discharge current is significantly high, while the discharge duration is short. If the switching frequency of S is f, the discharge current is $U_{in}/2fL$. C is the capacitor used to prevent leak current flowing through the inter-electrode gap after discharge ignition.



(a) Conventional rectangular pulse

(b) Right-angled triangular short pulse generated by LC pulse generator

Fig. 2 Conventional rectangular pulse and triangular short pulse generated by LC pulse generator

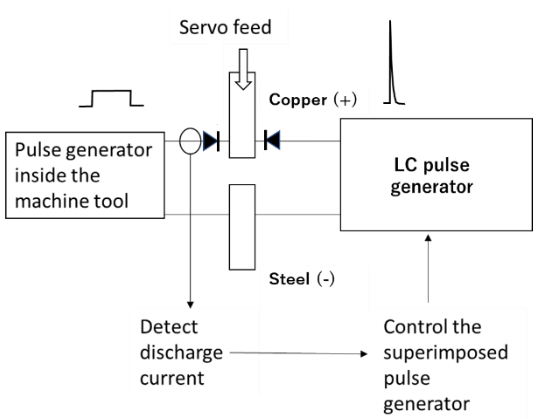


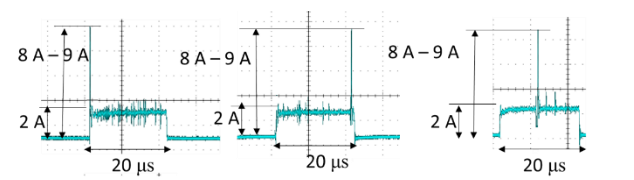
Fig. 3 Method to superimpose shock impulse on conventional rectangular pulse

Table 1 Machining conditions

Power source voltage of LC pulse generator U_{in}	12 V
Inductance L	250 µH
Off-time of switch S	1 µs
Anode	Copper ϕ 5 mm
Cathode	Steel ϕ 5 mm
Machining time	45 min

2.2 Superimposition of shock impulse

To increase the removal efficiency of the conventional rectangular discharge current pulse shown in Fig. 2(a), the impulse shown in Fig. 2(b) was superimposed using the method shown in Fig. 3. The rectangular pulse was generated by the transistor pulse generator installed on the sinking EDM machine (Sodick C32). Detecting a dielectric breakdown using a current sensor, the shock impulse generated by the LC pulse generator was superimposed at either one of the three timings: at the moment of dielectric breakdown (Fig. 4(a)), at the end of discharge (Fig. 4(b)), and at the middle of discharge duration (Fig. 4(c)).



(a) Superimposed at dielectric breakdown

(b) Superimposed at end of discharge

(c) Superimposed at middle of discharge duration

Fig. 4 Different timings of superimposition of shock impulse on conventional rectangular pulse

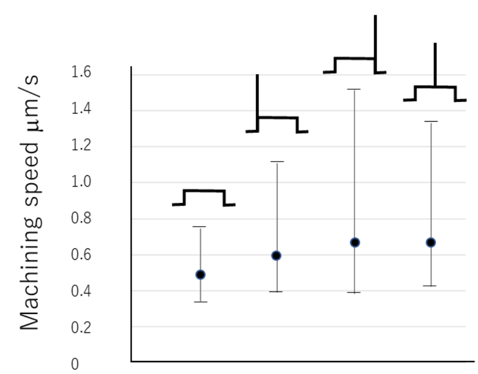


Fig. 5 Comparison of machining speed between rectangular pulses superimposed with shock impulse and conventional rectangular pulse

3. Machining experiments

3.1 Experimental method

Influence of the shock impulse on material removal rate was investigated. As shown in Fig. 3, a carbon steel rod of 5 mm in diameter was used as cathode and machined using a copper rod of the same diameter under the conditions shown in Table 1.

3.2 Experimental results

During machining, the feed distance per one minute was measured to obtain the machining speed. The measurement was repeated 45 times during 45 minutes machining for the conventional rectangular pulse and superimposed pulses shown in Fig. 4. The results are shown in Fig. 5. The solid dots indicate the average machining speed. The machining speed was increased when the shock impulse was superimposed. The machining speed was highest when the shock impulse was superimposed at the end of discharge duration. The machining speed was increased by 39% compared to the conventional pulse, although the discharge energy of the shock pulse is only 3 % of that of the rectangular pulse. The effect of the shock pulse is small when the shock pulse is superimposed earlier. These results indicate that the melted material was removed from the crater with the help of the shock pulse superimposed at the end of discharge. Thus, it was found that the removal efficiency can be increased by superimposing the shock pulse at the end of discharge.

4. Conclusions

To increase the removal efficiency of EDM, a shock impulse was superimposed to the rectangular discharge current pulse which is normally used. Since the melted material in the discharge crater can be removed efficiently by the short pulse with high peak current at the end of discharge, the removal efficiency can be increased. The short pulse was generated by the LC pulse generator. Although the discharge energy of the short pulse was only 3 % of the rectangular pulse, the material removal rate increased by 39 % compared to the conventional rectangular pulse.

ACKNOWLEDGEMENT

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