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Influence of current impulse on machining characteristics in EDM

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Abstract

Electrical discharge machining (EDM) is a machining process transforming electric energy into thermal energy to remove materials. The current impulse is a very important factor for machining characteristics of EDM. A series of experiments were performed to investigate the influence of current impulse on machining characteristics. The features of current impulse have initial current, current rising slope and impulse pattern. The used patterns of current impulse included rectangular current impulse, trapezoidal current impulse and the 1st order current impulse. The machining characteristics are associated with relative wear ratio (RWR) and material removal rate (MRR). Experimental showed that using trapezoidal current impulse with small initial current or little current rising slope reduced relative wear ratio and material removal rate as well. However, larger relative wear ratio was obtained for workpiece of tungsten carbide when current rising slope was too little. Using the 1st order current impulse with 20 μs current rising time can improve relative wear ratio about 30 % while remain material removal rate the same as rectangular current impulse for tungsten carbide.

Keywords: Trapezoidal current impulse; 1st order current impulse; Material removal rate; Wear ratio

1. Introduction

EDM is one of the most important technologies among non-traditional machining process. It can diminish mechanical stresses, distortions and vibration problems. Material of any hardness can be cut as long as it is conductive. And EDM is easy to generate micro parts without distortion and deformation. However, the electrode wear is relatively obvious, leading to a lack of machining accuracy. EDM process uses electrical discharge spark companying with an extremely high temperature to carry out material removal. It means that EDM is basically an electric-thermal process which transforms electric energy into thermal energy. So the conditions of electric energy supply are an important factor in EDM. The conditions consist of current impulse, voltage, pulse duration, spark gap, and so on. To say it clearly, the current impulse represents an energy function corresponding with time. It determines the energy density into the discharge column of electrode and workpiece. It may be decisive in the wear ratio, metal removal rate, and other machining characteristics.

Over the past few years, not so many studies have been made on the effect of current impulse. Taniguchi et al. [1] developed the theoretical model to obtain appropriate current impulse with the smallest wear ratio and largest MRR for EDM. De Bruyn [2, 3] noted that the wear ratio was greatly improved by using the trapezoidal current impulse instead of the rectangular one. Feeney and Crookall [4] used the trapezoid current impulse with positive and negative slopes in EDM. They pointed out that electrode wear would be reduced much and the MRR would also be decreased when the value of initial current is the half

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of the peak current. Wang [5] found noted that the wear ratio with the triangle current impulse was improved about 30% than the one with the trapezoidal one, while the MRR with the triangle one was less than 10%. However they still have not solved the problem to reduce wear ratio also companying with reducing material removal rate.

This paper is intended as an investigation about the influence of different current impulse on EDM machining characteristics. We utilized trapezoid pattern of current impulse to discuss the influence of initial currents (I_0) and current rising slope (m_{cr}) on relative wear ratio (RWR) and material removal rate (MRR). Besides trapezoid current impulse (TCI), rectangular current impulse (RCI) and a current impulse of nonlinear rising slope were also investigated. SKD steel and tungsten carbide were used as work-pieces to compare the difference of machining characteristics in EDM.

2. Experimental

2.1 The programmable current impulse system

In the beginning, we developed a programmable current impulse system to generate different current impulse. The schematic of the programmable current impulse system is shown in Fig. 1. It was consisted of one electric voltage (V) and 16 parallel circuits of resistance (R) connecting to switch. Every pulse duration, at least, uses 63 sequences of short period (t) and the total pulse duration (Ton) was fixed at 80 μs. The discharge current I(t) is changeable and is determined by $m(t)\frac{V}{R}$, while m(t) is the number of switching on. If the relationship of I(t) was satisfied for specified current impulse, various patterns of

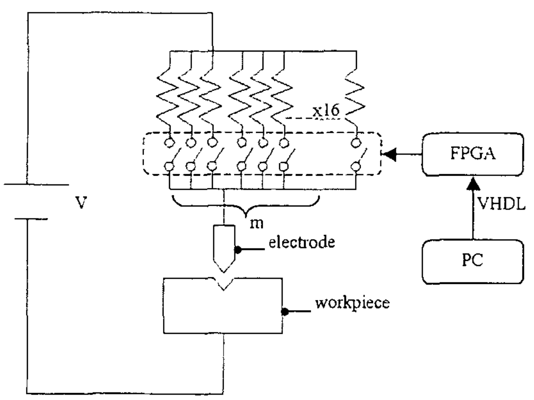


Fig. 1. Schematic of programming current impulse system.

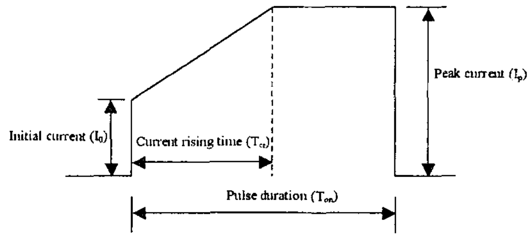


Fig. 2. Features of trapezoidal current impulse.

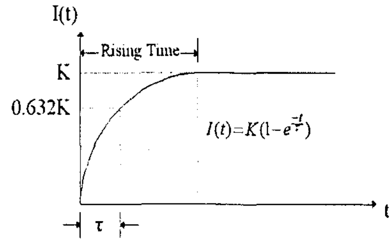
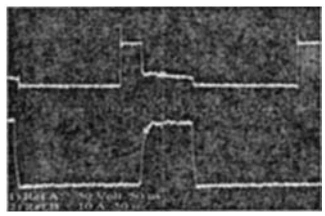
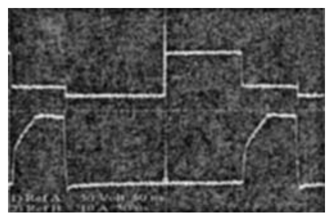


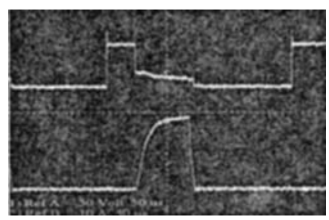
Fig. 3. The 1st order system.



rectangular current impulse (RCI)



trapezoidal current impulse (TCI)



1st order current impulse (1stCI)

Fig. 4. The practical patterns of current impulse from an oscilloscope.

current impulse are available. For the rectangular current impulse, I(t) is kept at peak current during whole period. When the increment of I(t) is constant until reaching peak current, we can obtain the trape-

Table 1. Machining parameters.

Working parameters	Working condition
Open voltage	100 V
Peak current (I_p)	26 A
Pulse duration (T_{on})	80 μs
Off time (T_{off})	160 μs
Machining depth	2 mm (Tungsten carbide) and 4 mm (SKD11)
Electrode	ϕ6 mm electrolytic coppers (anode)
Current pulse pattern	Rectangular, trapezoidal and 1st order
Initial current (I_o)	3.25 A, 6.5 A, 13 A and 16.25 A
Current rising slope (m_{cr})	0.3, 0.6 and 1.5
Current rising time (T_{cr})	4 μs ,15 μs ,22 μs , 38 μs ,52 μs , 68 μs ,

zoidal current impulse. Fig. 3 shows the features of trapezoidal current impulse. The 1st order current impulse presents the mathematics function $I(t) = K(1-e^{-t/\tau})$ shown as in Fig. 3. Fig. 4 shows the practical patterns of the generated current impulse from an oscilloscope.

2.2 Experimental conditions

The commercial EDM was used in this study. The electrolytic copper electrode of 6 mm diameter was used as the anode. Workpieces as tungsten carbide and SKD11 were connected to the cathode. The dielectric was EDM oil (IDEMITSU 2028). The peak current (I_p) was fixed at 26 A for all experiments. The relative wear ratio (RWR) was the weight ratio of electrode wear to workpiece removal. The machining parameters are listed in Table 1.

3. Experimental results and discussion

3.1 SKD11 – a cold die steel

3.1.1 The influence of the current rising slope and initial current

In this section, the influences of the initial current (I_o) and current rising slope (m_{cr}) on MRR and wear ratio are discussed by using the trapezoid. The I_o was changed with 3.25 A, 6.5 A, 13 A, and16.25 A. The m_{cr} was varied from 0.3 to 1.5.

The relation between m_{cr} and MRR of SKD11 for different I_o is shown in Fig. 5. The MRR increased with the increase of the I_o when using the same m_{cr}. Besides, the MRR increased with the increase of the

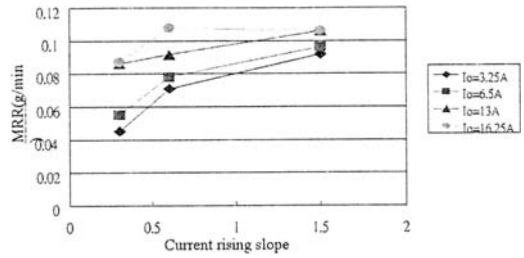


Fig. 5. The relation between current rising slope (m_{cr}) and MRR of SKD11.

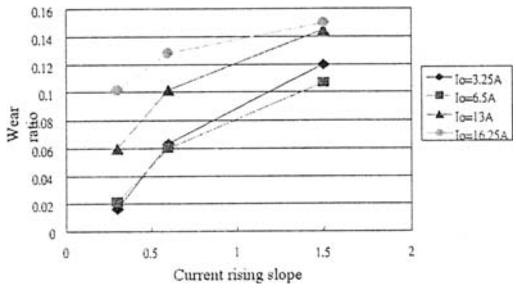


Fig. 6. The relation between Current rising slope (m_{cr}) and wear ratio of SKD11.

m_{cr} for the same I_o. And the increasing trend of MRR was similar when the I_o was 3.25 A and 6.5 A. The MRR was saturated when m_{cr} was larger than 0.6 for the curve of I_o 16.25 A.

The relation between m_{cr} and wear ratio was shown in Fig. 6. The wear ratio increased with the increase of I_o when the same current slope was used. And it also increased with the increase of m_{cr} for the same initial current.

3.1.2 The influence of the pulse pattern

In this section, the same I_o but different rising patterns such as the trapezoidal current impulse (TCI) and the 1st order current impulse (1st CI) were used to examine their machining characteristics. The rectangular current impulse (RCI) is also pointed because of the largest MRR and largest RWR among all current patterns.

Fig. 7 showed the relation between MRR and the current rising time for different pulse pattern. When the 1st CI and TCI were used, the MRR decreased with the increase of the current rising time. Besides, the MRR of the 1st CI was larger than the one of TCI.

The relation between current rising time (t_{cr}) and wear ratio for different impulse patterns is shown in Fig. 8. Whenever t_{cr} was, the wear ratio of RCI was the largest among all current impulses. The wear ratio

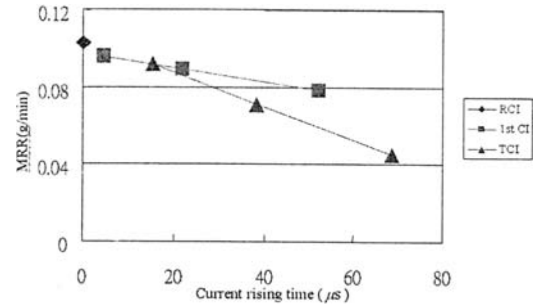


Fig.7. The MRR of SKD11 with different current impulse.

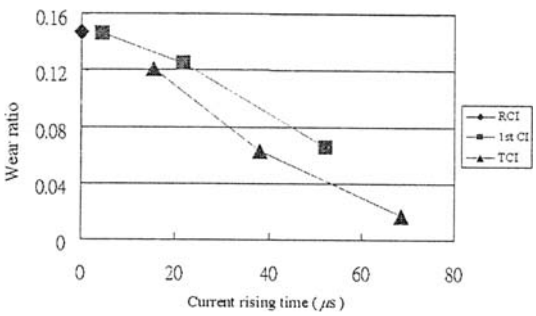


Fig. 8. The wear ratio of SKD11 with different current impulse.

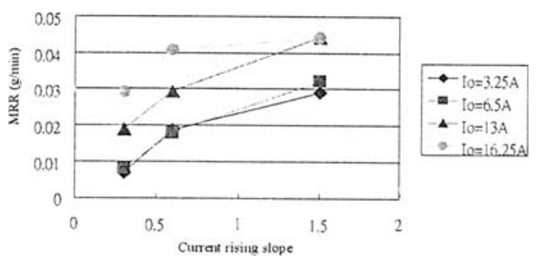


Fig. 9. The relation between current rising slope (m_{cr}) and MRR with tungsten carbide.

decreased with increase of t_{cr}. Relative wear ratio of the 1st CI was larger than the one of TCI.

3.2 Tungsten carbide with high melting point material

3.2.1 The influence of the current rising time and initial current

The relation between m_{cr} and MRR for different I_o is shown in Fig. 9. The MRR increased with the increase of m_{cr}. The increasing trend of MRR was similar when Io was 3.25 A and 6.5 A. It did not increase anymore when m_{cr} was larger than 0.6 for the curve of I_o =16.25 A.

The relation between the m_{cr} and the wear ratio for different initial currents is shown in Fig. 10. Except

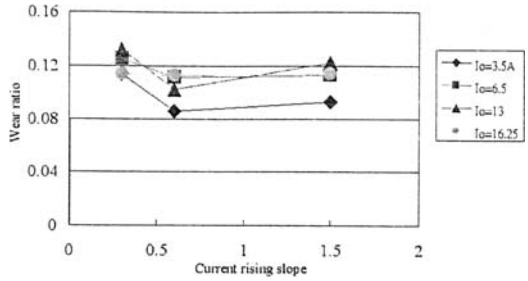


Fig. 10. The relation between current rising slope and wear ratio with tungsten carbide.

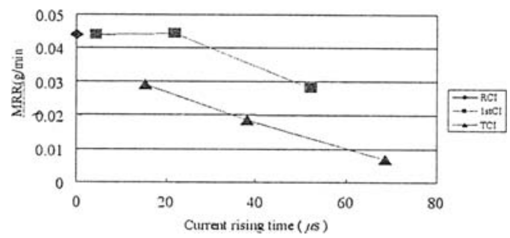


Fig. 11. The MRR of tungsten carbide with different current impulse.

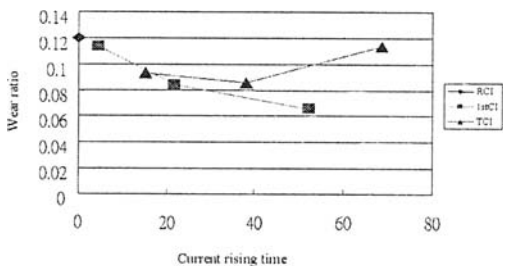


Fig. 12. The MRR of tungsten carbide with different current impulse.

for Io=16.25 A, the smallest wear ratio appeared when the m_{cr} was 0.6 for each curve of I_o. The wear ratio was not affected because Io was near to peak current (for I_o 16.25 A). It decreased with the increase of the m_{cr} when m_{cr} was smaller than 0.6.The wear ratio increased with the increase of the m_{cr}, which was larger than 0.6. The reason of larger wear variation at small m_{cr} was relative to less energy density for the high melting point material. Energy density was too less to heat material normally, leading to more probability of discharge arc and lower MRR. The arc usually caused large wear of electrode. Oppositely, the wear ratio was increased to high melting point material, and less m_{cr} will cause larger wear ratio.

3.2.2 The influence of the pulse pattern

Fig. 11 shows the relation between the T_{cr} and

MRR for different patterns of current impulses. MRR was the largest among the pulse patterns when the RCI was used. MRR decreased with the increase of T_{cr} for the TCI. However, the MRR remains constant when the current rising time was less than 20 μs for the 1^{st}CI, and then MRR decreased with the increase of the T_{cr}.

The relation between the current rising time and the wear ratio for different pulse patterns is shown in Fig. 12. The wear ratio decreased with the increase of the t_{cr} for the 1^{st} order CI. When t_{cr} was less than 40 μs for TCI, the wear ratio decreased with the increase of t_{cr} and there was the smallest value of wear ratio at 40 μs. When the current rising time was more than 40 μs, the wear ratio increased with increase the current rising time. The reason of larger wear at small m_{cr} was due to less energy density relatively for the high melting point material. Energy density was too less to heat high melting point material normally, leading to more probability of discharge arc and lower MRR. The arc usually caused large wear of electrode. Oppositely the wear ratio was increased to high melting point material and less m_{cr} will cause larger wear ratio.

4. Conclusion

In this study, the programmable digital circuit system has been developed and machining characteristics of different current impulses were investigated. Using the rectangular current impulse (RCI) always results in the largest MRR and the largest RWR because of the maximum initial current (Io) and the shortest current rising time (T_{cr}). To use trapezoidal current impulse (TCI) with small initial current or long current rising time can reduce RWR but its MRR also becomes low. Small initial current and long current rising time give little energy density, resulting in small metal removal rate and wear ratio. However, too small initial current and long current rising time leads to more discharge arc. That is why RWR of the current rising slope 0.3 is larger than one of the current rising slope 0.6 for tungsten carbide of the high melting point. In this study, we found the 1^{st} order current impulse (1^{st} CI), a proposed non-trapezoidal pulse form, can improve wear ratio and had the same MRR as RCI for the tungsten carbide. The wear ratio using the 1^{st}CI with Tcr = 20 μs was less 30 % than the one by using the RCI while its MRR was the same. It is useful to utilize non-trapezoidal pulse form of large Io instead of trapezoid current impulse for EDM of high melting point material such as multicrystal diamond, tungsten carbide and so on.

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