

Current Pulse Generated by Spark of Electrical Discharge Machining (EDM)

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Abstract. Electrical Discharge Machining (EDM) is a process that uses electrical discharges to erode electrically conductive material where the electrode and workpiece do not touch. Spark between electrode and workpiece in the EDM process produced magnetic fields. The magnetic fields is found to have an effect on debris circulation in the gap of EDM, so it can decrease the abnormal electrical discharge. An electric current has an effect on the magnetic field produced. EDM uses the RC-generator configuration, so it is able to produce greater currents. This paper presents the calculation current pulse generated by spark of EDM. This calculation can be used to predict peak currents from EDM pulses. Predict peak current is used to find out the maximum magnetic field and determine the maximum current rating of a component. Pulse current calculation can use the equation that has been stated.

1. Introduction

Electrical Discharge Machining (EDM) is known as spark erosion machining that uses electrical discharges to erode electrically conductive material and does not touch directly between the electrode and workpiece [1]. In general, EDM system consists of power generator, spark gap control, flushing and workpiece positioning system [2,3]. EDM power supply consists of 2 types, RC-Generator and pulse power generator.

RC-Generator is based on resistor and capacitor. Relaxation generator or RC-Generator is based on the energy storage capacitor to be charged, and then the capacitor discharge when the voltage difference between two electrodes of spark gap exceeds the breakdown threshold [4].

The spark process causes the material surface to melt and evaporate, this eroded material and residue is called debris. The debris from workpiece and electrode in EDM process would be accumulated in the gap. The magnetic fields can improve debris circulation in the gap, so it can decrease the abnormal electrical discharge [5,6]. Abnormal electric discharges are arcs, open circuit and short circuit. A magnetic field is generated by an electric current where EDM uses the RC-generator configuration, so it is able to produce greater currents.

Some magnetic field and current pulse research on EDM describes the effect of material removal rate (MMR), electrode wear rate (EWR) and surface roughness [7-9]. The effect of magnetic fields to electronics is explained by Xianguo, X., et al [10] and some results [11,12]. This paper presents the



calculation current pulse generated by spark of EDM. Calculation peak current is used to find out the maximum magnetic field and determine the maximum current rating of a component.

2. Hardware System

2.1. Schematic Diagram of EDM

EDM design power supply uses type RC Generator. Figure 1 shows the Relaxation Generator or RC generator circuit consists of a power supply, resistor (R1), capacitor (C), resistor (R2) as a internal resistance, inductor (L), Rs as a current sensor and spark gap.

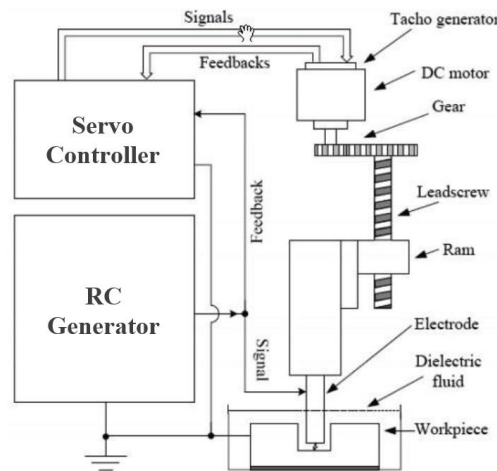


Figure 1. Schematic of EDM

A EDM uses 3 kV and 1 μ F film capacitor. A film capacitor has low Equivalent Series Inductance (ESL) and low Equivalent Series Resistance (ESR), so it is suitable to generate high pulse power. The values of R1 50 k Ω and C 1 μ F with tolerance 20% produce a period of 300 ms. Magnetic field is generated by a coil with the value 11 μ H. the maximum current in the coil is up to 1000 A. The internal resistance (R2) in the film capacitor, resistance of coil and resistance of cables is about 4 Ω with tolerance 20%.

2.2. Generation of High DC Voltage

EDM uses a Multilevel Boost Converter as a high voltage DC power supply [13]. Multilevel boost converter schematic is shown in Figure 2.

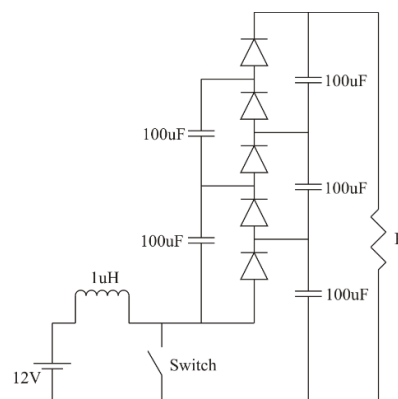


Figure 2. Schematic of Multilevel Boost Converter

The DC voltage transfer function of the Multilevel boost converter is shown in Equation 1, assuming in an ideal state.

$$V_{output} = N \times \frac{1}{1-D} V_{input} \quad (1)$$

Where N is a number of levels Multilevel Boost Converter. The duty cycle (D) is the time ratio between switch on and total period.

2.2.1 Current Calculation

The calculation of current in the Multilevel boost converter circuit is used in the Equation 2 [14].

$$I = \frac{N^2 \times V_{IN} \times D}{(1-D)^2 \times R_C} \quad (2)$$

2.2.2 MOSFET

SiHG14N50D power MOSFET is switching component for Multilevel Boost Converter. It has Drain-Source Voltage (V_{DS}) 500V, Continuous Drain Current (I_D) 14A and Maximum Power Dissipation (P_D) 208W.

2.2.3 Diode

MUR1560 diode has ultrafast 35 and 60 ns recovery time with high repetitive reverse voltage 600 V and high rectified forward current (IF) 15 A.

2.2.4 Inductor

The multilevel boost converter operates in the Continuous Conduction Mode (CCM) with the Equation 3 [17].

$$L = \frac{5 \times (1-D)^2 \times D \times R}{N^2 \times f} \quad (3)$$

2.2.5 Capacitor

The capacitor of multilevel boost converter is used to filter of output voltage. The minimum capacitance that results in voltage ripple can be written as Equation 4 [15].

$$C_{min} = \frac{d \times V_o}{V_r \times R \times f} \quad (4)$$

2.3. Current Pulse Measurement

The current pulse of EDM uses a shunt resistor (R_s) for changing the current into voltage and using an oscilloscope to analyze the current pulse as shown in Figure 3.

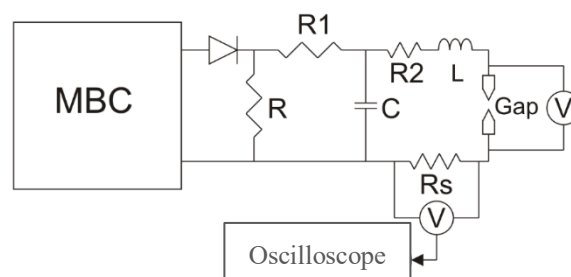


Figure 3. Measurement current pulse

3. Results and Discussions

The results of measurement at coil current and the induced voltage are shown in Table 1. A Capacitor film has an initial voltage at 500 V and 1000 V with a rating of 3kV 1 μ F. Variation in the measurement of the distance between coil and target coil is 1 cm, 4 cm, 8 cm and 12 cm.

Table 1. Coil current and induced voltage of target coil for low and high voltage of capacitor

Voltage of Capacitor	Coil Current	Induced Voltage	
500 V			
1000 V			

The pulse current on capacitor with initial 500 V is about 104 A and the pulse current on capacitor with initial 1000 V is about 227 A. According to Table 1, the current and the distance will affects the induced voltage.

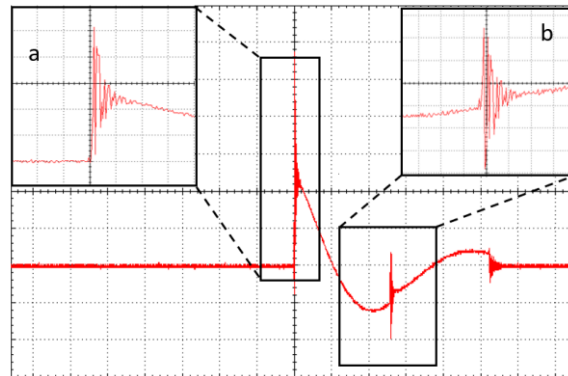


Figure 4. Noise switching wave at induced voltage at voltage capacitor 1000 V

Figure 4 shows current waves is in a form of a sine wave with damped factor depending on the RLC circuits [16]. Noise at target coil in figure 4 point a is caused by the change of electric current abruptly and flowing through parasites components. Similar to figure 4 point b with the addition of negative current and voltage value.

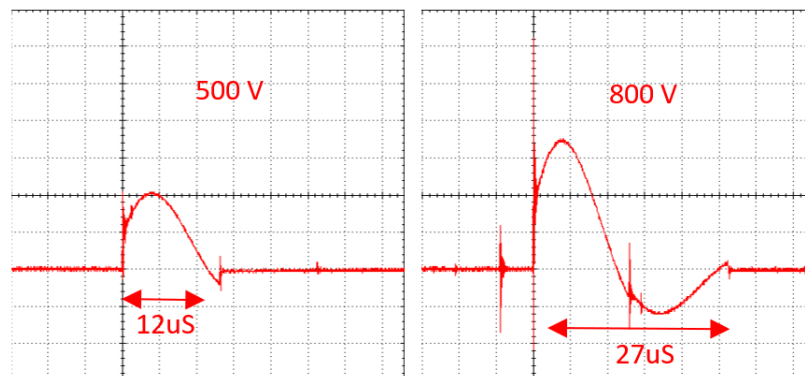


Figure 5. Comparison of wavelengths of capacitor voltage 500 V and 800 V

Figure 5 shows comparison of wavelengths between experiment with voltage of capacitor 500 V and 800 V. The current wavelength at 500 V is 12 μs and 800 V is 27 μs . The 500 V capacitor voltage has half wave, while 800 V capacitor voltage resulted full wave. This is because the voltage after half wave is smaller than the air breakdown voltage. The ionization density when discharge at the first half wave and second half wave have different values. It is larger since the ionization recoverytime is faster than the half wave.

The equivalent circuit shown in Figure 1 is calculated to estimate the pulse current of coil loop. The pulse current produced is in a form of a damping factor sine wave depending on the components. According to [17], the dumping factor has 3 options:

1. If $R^2 > 4L/C$, the Overdamping pulse means there are two real roots.
2. If $R^2 = 4L/C$, the Critical Damping means that the two roots are equal.
3. If $R^2 < 4L/C$, the Under Damping means there are two complex roots.

In this case, the current pulse are under damping sine wave because $R^2 < 4L/C$. This gives the equation roots with values:

$$i(t) = e^{-\lambda t}(A \cos \omega t + B \sin \omega t) \quad (5)$$

Following the current pulse, then the equation becomes,

$$i(t) = e^{-\lambda t}(B \sin \omega t) \tag{6}$$

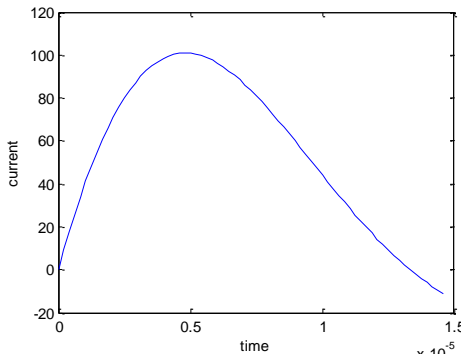
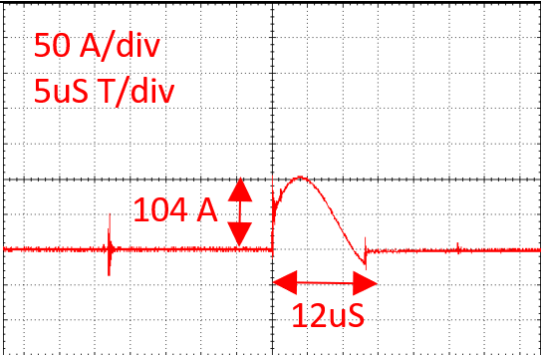
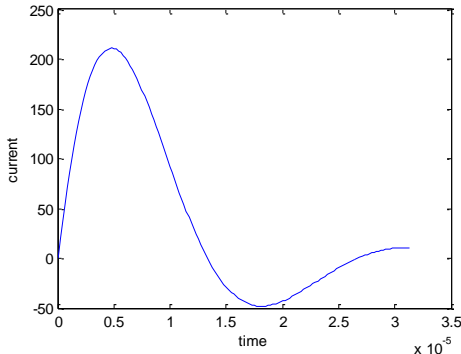
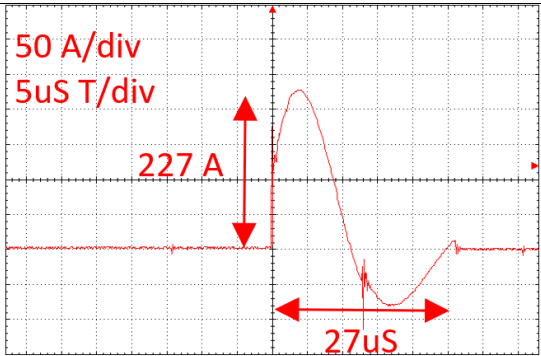
Where, $\lambda = \frac{R}{2L}$ and $\omega = \frac{1}{\sqrt{LC}}$, so the value of $\lambda = 111111.11$ and $\omega = 235702.26$. In order to eliminate the value B, t is assumed the capacitor to be fully charged with capacitance about 1 μF and voltage 1000V, 800V and 500V.

$$v(t) \times C = \int i(t) = \int e^{-\lambda t}(B \sin \omega t) \tag{7}$$

$$v(t) \times C = \frac{e^{-\lambda t}}{\lambda^2 + \omega^2} (\lambda \sin \omega t - \omega \cos \omega t) B \tag{8}$$

So, the value of B is 397.465 when $t=0$ and voltage is about 1000 V. The value of B is 190.092 when voltage 500V. The Table 2 presents a comparison of pulse currents of coil loop between calculations and experiments. The calculation results are obtained from Equation 6 and simulate it with MATLAB.

Table 2. Pulse current comparison

Voltage of Capacitor	Calculation	Experiment
500 V		
1000 V		

The voltage of capacitor is 500 V, the maximum voltage calculated is 101 A at 4.8 μs and the maximum voltage of experiment is 104 A at 4.2 μs . The voltage of capacitor is 1000 V, the maximum voltage calculated is 211 A at 4.8 μs and the maximum voltage of experiment is 227 A at 4.2 μs . The results of calculations and experiments have little difference due to the tolerance value of each component and effect of the parasite components.

4. Conclusion

The results of current calculations and experiments have little difference due to the tolerance value of each component and effect of the parasite components. In addition, the calculations have shown graphs that are similar to the results of the experiment. This calculation can be used to predict peak currents from EDM pulses. Predict peak current is used to find out the maximum magnetic field and determine the maximum current rating of a component. Pulse current calculation can use the equation that has been stated.

Acknowledgments

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