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Mathematical Model of Electrical Discharge Machining Pulse Profile

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ABSTRACT

Electrical Discharge Machining (EDM) is a non-conventional manufacturing process where the removal of the unwanted materials is performed without a direct contact between the electrode and workpiece. This paper reports the mathematical model of EDM pulses that focuses on open circuit and normal discharge of circuit condition. The model is based on the equivalent electrical model of voltage and current control where the normal discharge model employs ignition delay of 4µs, 10µs and 16µs. By applying Kirchhoff's voltage law, the voltage gap of an open circuit can be expressed according to a closed-loop network with zero current flow. As a result, the developed mathematical model capables to represent the pulse profile in EDM machining process.

1. Introduction

With the advancement of technology in the field of space research, missile and nuclear industry, there is an increased demand for very complicated and precise component[1, 2]. The need for micro-features, components, and products is rapidly increasing in diverse industries such as electronics, medical and aviation[3]. Electrical Discharge Machining (EDM) is one of the most accurate non-conventional manufacturing processes used for cutting or creating intricate shapes in very hard or difficult-to-cut with electrically conducting materials[4–6]. EDM is a process of electric conductive material removal that filled with dielectric fluid between an electrode and a workpiece by using an accurately controlled electrical discharge (spark) through a small gap (approximately 10 to 50 microns) [7–9]. In EDM, the two electrodes that called electrode and workpiece are separated by the dielectric fluid[4,9]. The electrode and workpiece are connected to a DC power supply [10,11]. The sparks occur for a short duration which is between 0.1 to 2000 µs[12,13]. This process is repeated until the material is removed. In this paper, the model of pulse profile represents the open circuit, normal discharge, arc and short circuit during the machining process. Figure 1 shows the pulse profile during the machining process.

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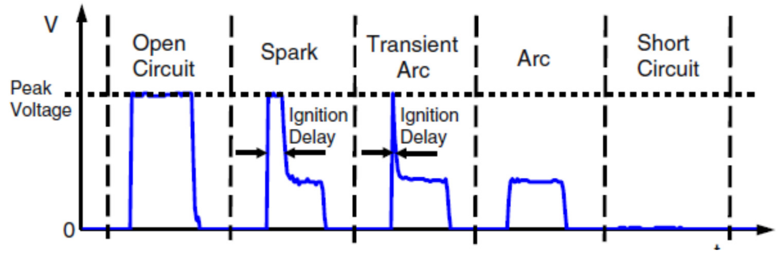

Fig. 1. Pulse Profile of EDM [5]

2. Mathematical Model of EDM Pulse Profile

The model of pulse power generator has been divided into 4 phase which are initial phase, ignition phase, discharge phase and ejection phase. A MOSFET has been used as a switch to control the output as to ensure a constant processing during the model of machining process. The electrical pulse generator model of the pulse profile of EDM is illustrated in Figure 2. Four MOSFETs have been used to characterise all condition of the pulse profile. The parameter of the pulse profile has been engaged from the voltage gap and current gap.

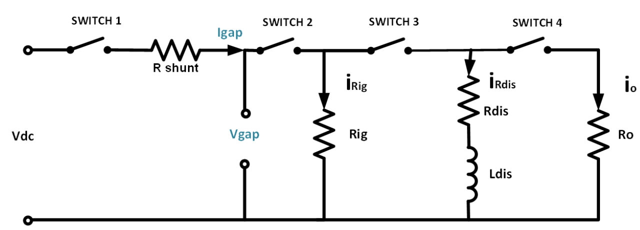

Fig. 2. Equivalent Circuit Pulse Generator Model

Pulse generator model consists of open circuit model and normal discharge model that include normal discharge1 model for ignition delay 4µs, normal discharge2 model for ignition delay 10µs and normal discharge3 for ignition delay 16µs, arc model and short circuit model. However, this paper focuses on the open circuit and normal discharge model.

2.1 Open Circuit Pulse Profile Model

The initial phase of EDM machining process is open circuit pulse profile. Figure 3 shows equivalent circuit for initial phase condition. In this condition only switch 1 turn ON, else switch OFF.

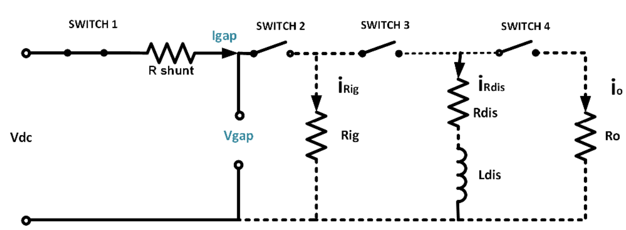

Fig. 3. Equivalent circuit initial phase condition

By applying Kirchhoff's voltage law, the voltage gap is an open circuit and can be expressed as follows

$$v_{in} = v_{Rshunt} + v_{gap} \quad (1)$$

$$v_{gap} = v_{in} - v_{Rshunt} = v_{opencircuit} \quad (2)$$

When the circuit is not in a closed-loop network, current is zero.

$$i_{gap} = \frac{v_{gap}}{R_{shunt}+R_{ig}} = 0 \quad (3)$$

2.2 Normal Discharge Pulse Profile Model

The normal discharge pulse profile consists of 4 phases during the process which are initial phase, ignition phase, discharge phase and ejection phase. The initial phase is similar as explain in subsection 2.1. Figure 4 shows an equivalent circuit of the second phase in normal discharge pulse profile which is ignition phase condition. In this phase both switch 1 and switch 2 is turned ON else switch 3 and switch 4 are turned OFF. The circuit is formed in a closed loop network. The gap voltage is referring to the voltage through resistor R_{ig} which becomes a voltage divider between resistors R_{ig} and R_{shunt}.

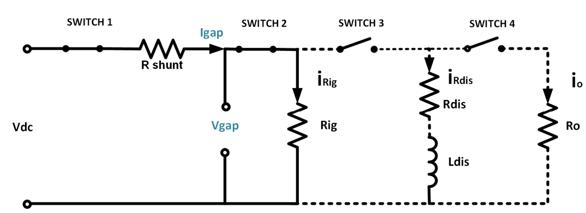

Fig. 4. Equivalent circuit ignition phase condition

Applying Kirchhoff's current law,

$$i_{gap} = i_{Rig} + i_{Rdis} + i_o \quad (4)$$

When i_{Rdis} and i_o become zero due to open circuit on switch 3 and switch 4, current gap during ignition phase can be expressed as follows,

$$i_{gap} = i_{Rig} \quad (5)$$

According to Figure 4, the circuit is formed in a closed-loop network. The gap voltage is the difference between V_{in} and voltage across R_{ig}. The gap voltage can be expressed as follows,

$$v_{in} = v_{Rshunt} + v_{gap} \quad (6)$$

$$v_{gap} = v_{in} - i_{gap}R_{shunt} \quad (7)$$

From Equation 7, the gap voltage can be express as the voltage divider rule during the ignition phase,

$$v_{gap} = \frac{R_{ig}}{R_{ig}+R_{shunt}} V_{in} \quad (8)$$

Figure 5 shows an equivalent circuit of the third phase in normal discharge pulse profile which is discharge phase condition. In this phase, switch 1, switch 2 and switch 3 are turned ON. Switch 1 has been used to control the main pulse in pulse generator such duty cycle, time ON and time OFF and period. Switch 2 and Switch 3 are used to control the transient current and voltage drop during the discharge phase. The ignition delay has been controlled during this state. The current gap is obtained by a combination of the current through resistor R_{ig} and current through R_{dis}.

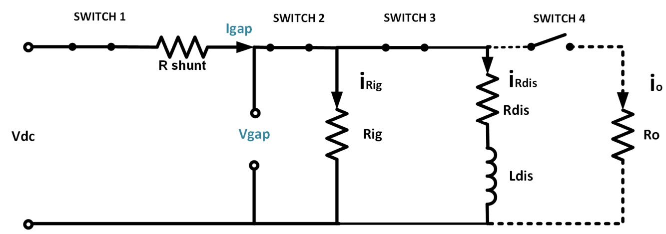

Fig. 5. Equivalent circuit discharge phase condition

In the mathematical model, the gap voltage can be derived as follows.

$$v_{gap} = i_{Rdis}R_{dis} + L\frac{di_{dis}}{dt} \quad (9)$$

$$i_{gap} = i_{Rig} + i_{Rdis} \quad (10)$$

$$L\frac{di_{dis}}{dt} = v_{gap} - i_{Rdis}R_{dis} \quad (11)$$

$$\frac{di_{dis}}{dt} = \frac{v_{gap} - i_{Rdis}R_{dis}}{L} \quad (12)$$

$$\frac{dt}{L} = \frac{di_{dis}}{v_{gap} - i_{Rdis}R_{dis}} \quad (13)$$

Integrate both sides;

$$\int_0^t \frac{dt}{L} = \int_0^{i_{dis}} \frac{di_{dis}}{v_{gap} - i_{Rdis}R_{dis}} \quad (14)$$

$$\frac{-R_{dis}t}{L} = \frac{ln[v_{gap} - i_{Rdis}R_{dis}]}{ln(v_{gap})} \quad (15)$$

Taking antilog on both sides;

$$e^{\frac{-R_{dis}t}{L}} = \frac{v_{gap} - i_{Rdis}R_{dis}}{v_{gap}} \quad (16)$$

$$i_{Rdis}R_{dis} = v_{gap} - v_{gap}e^{\frac{-R_{dis}t}{L}} \quad (17)$$

$$i_{Rdis} = \frac{v_{gap} - v_{gap}e^{\frac{-R_{dis}t}{L}}}{R_{dis}} \quad (18)$$

From equation (10), the current gap in discharge condition is given by,

$$i_{gap} = v_{gap}\left[\frac{1}{R_{dis}}\left(1 - e^{\frac{-R_{dis}t}{L}}\right) + \frac{1}{R_{ig}}\right] \quad (19)$$

where,

$$v_{gap} = v_{in} - i_{gap}R_{shunt} \tag{20}$$

3. Conclusion

A mathematical model of the pulse power generator has been developed based on the equivalent electrical model. The model capable to represent the pulse profile in EDM machining process using the equivalent electrical model of voltage and current control. By applying Kirchhoff's voltage law, the voltage gap of an open circuit can be expressed according to a closed-loop network with zero current flow. Similar procedures can be imposed to arc model and short circuit model.

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