Pulses Model of Electrical Discharge Machining (EDM)

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***Abstract*—This article presents a model of pulses in Electrical Discharge Machining (EDM) system. There are several mathematical models have been successfully developed based on the initial, ignition and discharge phase of current and voltage gap. According to these models, the circuit schematic of transistor pulse power generator has been designed using electrical model in Matlab Simulink software to identify the profile of voltage and current during machining process. Then, the simulation results are compared with experimental results.**

Keywords—Electrical Discharge Machining; Pulse Width Modulation; gap current; gap voltage

I. INTRODUCTION

Electrical Discharge Machining (EDM) is a machining process that enables noncontact drill via thermomechanical effects irrespective of the hardness of the workpiece (see Fig. 1). In EDM process, pulse power generator is required in order to obtain the discharge spark. The efficiency of production is depending on the performance of the pulse power generator. Control servo is used to control the space gap between electrode and workpiece. In creating the spark discharge, a current flow from the electrode through a dielectric fluid due to the gap distance between electrode and workpiece is reduced to a very small clearance approximately 10 to 50 microns [1, 2]. Electrical energy from the spark is converted into heat energy, then builds up the workpiece temperature and melts the area on its surface. The working pulse power generator is an important role in affecting the material removal rate (MRR) and the properties of the machined surface [3, 4]. The filtration system is used to maintain the dielectric fluid and flush out the eroded gap particles. This article presents the pulse phase in the EDM process due to improve in machining parameter. In order to prove the theoretical more clearly is determine by performing the simulation and experimental studies.

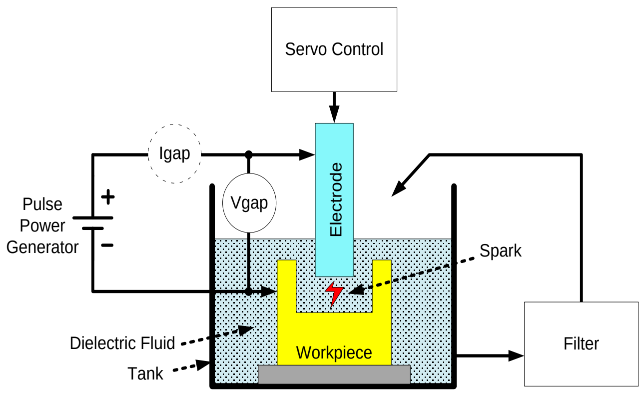

Fig. 1. EDM System

II. EDM Power Generator

Generally, EDM power generator is configured by two important parts known as power supply and pulse generator is shown in Fig. 2[5]. There are several of power supply can be used, such as linear power supply and switching mode power supply (SMPS). Base on the power consumption cost issue, higher material removal rate and good surface finish in EDM parameter, the study is focused on the switching power supply [6]. By using the SMPS topology, the configuration has a high efficiency and high performance [1, 7, 8].

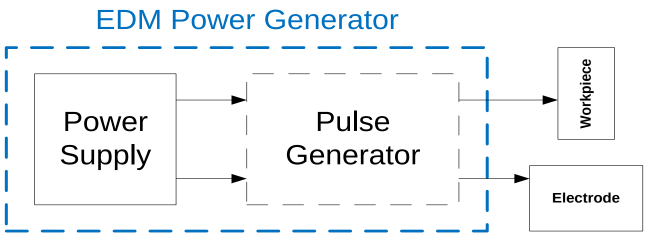

Fig. 2. Block diagram for EDM Power Generator

Pulse generator is divided into two types. There are relaxation (resistance-capacitance) generator and transistor pulse generator. The relaxation circuit type of EDM pulse power generator create pulses through the capacitor charge and discharge behavior. Discharge energy is determined by the used capacitance and by the stray capacitance that exists between electrode and workpiece. The electrical sparks are created from the released charges of capacitor.

The transistor pulse generator is widely used in conventional EDM and provides a higher MRR due to its high discharge energy [9-11]. Moreover, the pulse duration and discharge current can be arbitrarily changed depending on the required machining characteristics. The transistor pulse generator generates a rectangular pulse discharges by controlling the current or voltage source. By changing the duty cycle, pulse width modulation is used to control the transistor states. To ensure a constant processing, the MOSFET transistor is used as a switch to control the output pulse power as shown in Fig. 3.

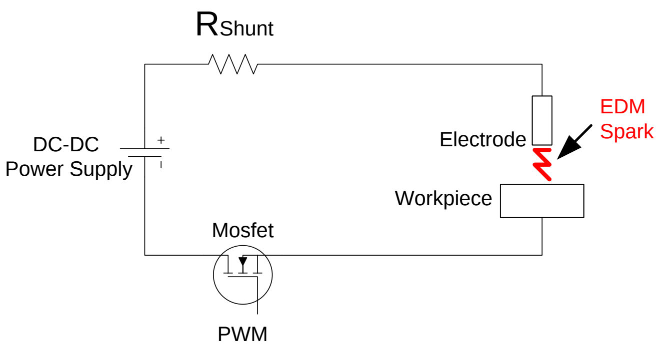

Fig. 3. Transistor type of EDM Pulse Power Generator

III. Modelling EDM System

In this study, a model of EDM pulse power generator was developed to investigate the pulse profile during EDM process. Based on Fig. 3, the schematic circuit of EDM pulse generator has been developed and the mathematical model has been proved by the derived equation. In this schematic design, DC power source as an input source is connected to resistor R_1 (load). Then connected to the gap model between electrode and workpiece which is consisting of R_{ig}, R_{dis} and L_{dis}. To get pulse signal at the output side, it is connected to the MOSFET. Basically there are three phases in the pulse EDM is known as the initial phase, the ignition phase and discharge phase.

A. Initial Phase:

As can been seen from Fig 4, the schematic circuit of EDM pulse generator and the gap model has been designed. In the initial phase of EDM process, the gap is in open circuit state while switch S_1 is off. In this condition, the output voltage is equal to Vgap and current gap is zero. This is occur when the position of the electrode and the workpiece is far or non-discharge.

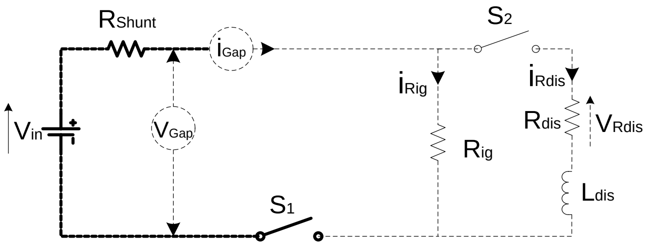

Fig. 4. The circuit in ignition phase condition

By applying Kirchhoff's voltage law. The voltage gap is in open circuit voltage state can be expressed as follows.

$$V_{in} = V_{R_{shunt}} + V_{gap} \quad (1)$$

$$V_{gap} = V_{in} - V_{R_{shunt}} = V_{oc} \quad (2)$$

When the circuit is not formed in a closed-loop network, then no current through in the circuit.

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

B. Ignition Phase:

In the ignition phase, a strong electric field is established between electrode and workpiece. Due to the attractive force of the electric field, there is created an ionization path through the dielectric. During the process, if ignition delay time is too long, this means the circuit is in open circuit and if the ignition delay time is too short, this means the circuit is a short circuit. Both cases are abnormal. It is important keep the ignition delay time to be a constant. From Fig 5, the switch S_1 is turn on and S_2 is turn off. The circuit is formed in a closed loop network. The gap voltage is refers to the voltage through resistor R_{ig} which is become a voltage divider between resistors R_{ig} and R_{shunt}.

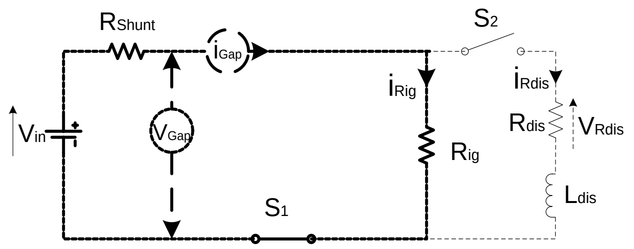

Fig. 5. The circuit in ignition phase condition

Applying Kirchhoff's current law,

$$i_{gap} = i_{R_{ig}} + i_{R_{dis}} \quad (4)$$

When $i_{R_{dis}}$ is zero, current gap during ignition phase can be expressed as follows,

$$i_{gap} = i_{R_{ig}} \quad (5)$$

According to Fig 5, the circuit is formed in a closed-loop network. The gap voltage is the difference between V_{in} and voltage across R_{ig}. By applying Kirchhoff's voltage law, gap voltage can be expressed as follows,

$$V_{in} = V_{R_{shunt}} + V_{gap} \quad (6)$$

$$V_{in} = i_{gap}R_{shunt} + V_{gap} \quad (7)$$

$$V_{gap} = V_{in} - i_{gap}R_{shunt} \quad (8)$$

From Eq. 8, the gap voltage can be express as the voltage divider rule during the ignition phase,

$$V_{gap} = \frac{R_{ig}}{R_{shunt}+R_{ig}} V_{in} \quad (9)$$

C. Discharge Phase:

During the discharge phase, it is initiated by moving the electrode very close to the workpiece. A plasma channel has been form due to ionization of dielectric. Due to the spark gap, voltage drops and current rises abruptly which forms the crater at spot of discharge on the workpiece.

As evident in Fig 6, both of switch S_1 and switch S_2 is turn ON. Switch S_1 has been used due to control the main pulse in pulse generator such duty cycle, time ON and time OFF. Whereas, switch S_2 used to control the transient current and voltage drop during the discharge phase. In order to get current gap i_{gap}, it is obtained by combination between current through resistor R_{ig} and current at $i_{R_{dis}}$.

Refer to the gap model in Fig 6, it consist an inductance L_{dis} connected in series with a resistance R_{dis} and parallel with resistance R_{ig}. The transient time of current and voltage during the discharge phase is determined by the relationship between the inductance L_{dis} and the resistance R_{dis}. The fixed value resistance R_{dis} and larger the inductance L_{dis}, the slower will be the transient time. However, for a fixed value inductance L_{dis}, by increasing the resistance value R_{dis}, fast transient time and therefore the time constant of the circuit becomes shorter. In general, the voltage will drop to about 20V-30V during discharge time [12].

Then, the process will be repeated to the ignition phase which is both switch S_1 and switch S_2 is turn off. All phases will be repeated until the end of the EDM process.

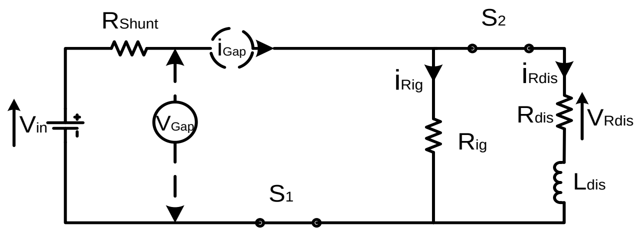

Fig. 6. The circuit in discharge phase condition which is switch (S_1) and switch (S_2) is turn ON

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

$$V_{gap} = i_{R_{dis}}R_{dis} + L_{dis}\frac{di_{R_{dis}}}{dt} \quad (10)$$

$$V_{gap} - i_{R_{dis}}R_{dis} - L_{dis}\frac{di_{R_{dis}}}{dt} = 0 \quad (11)$$

$$V_{gap} - i_{R_{dis}}R_{dis} = L_{dis}\frac{di_{R_{dis}}}{dt} \quad (12)$$

After adjusted,

$$\frac{dt}{L_{dis}} = \frac{di_{R_{dis}}}{V_{gap}-i_{R_{dis}}R_{dis}} \quad (13)$$

Integrating both the equations,

$$\int_0^t \frac{dt}{L_{dis}} = \int_0^i \frac{di_{R_{dis}}}{V_{gap}-i_{R_{dis}}R_{dis}} \quad (14)$$

$$\frac{t}{L_{dis}} = \int_0^i \frac{di_{R_{dis}}}{V_{gap}-i_{R_{dis}}R_{dis}} \quad (15)$$

By using assumption,

$$z = V_{gap} - i_{R_{dis}}R_{dis} \quad (16)$$

$$\frac{dz}{di_{dis}} = -R_{dis} \quad (17)$$

$$di_{R_{dis}} = -\frac{dz}{R_{dis}} \quad (18)$$

So, $-\frac{R_{dis}t}{L_{dis}}$ can be expressed as follows.

$$\frac{t}{L_{dis}} = -\frac{1}{R_{dis}}\int_0^i \frac{dz}{z} \quad (19)$$

$$-\frac{R_{dis}t}{L_{dis}} = \int_0^i \frac{dz}{z} \quad (20)$$

By using integration rule,

$$\ln(z) = \int_0^i \frac{dz}{z} \quad (21)$$

The Eq. (20), can be expressed as follows,

$$-\frac{R_{dis}t}{L_{dis}} = \ln(z)_0^i \tag{22}$$

$$-\frac{R_{dis}t}{L_{dis}} = \ln\left(V_{gap} - i_{R_{dis}} R_{dis}\right)_0^i \tag{23}$$

Applying limits, $-\frac{R_{dis}t}{L_{dis}}$ can be expressed as follows,

$$-\frac{R_{dis}t}{L_{dis}} = \ln\left(V_{gap} - i_{R_{dis}} R_{dis}\right) - \ln\left(V_{gap}\right) \tag{24}$$

$$-\frac{R_{dis}t}{L_{dis}} = \ln\left(\frac{V_{gap} - i_{R_{dis}} R_{dis}}{V_{gap}}\right) \tag{25}$$

Taking antilog on both sides in Eq. (25),

$$e^{-\frac{R_{dis}t}{L_{dis}}} = \frac{V_{gap} - i_{R_{dis}} R_{dis}}{V_{gap}} \tag{26}$$

$$V_{gap} e^{-\frac{R_{dis}t}{L_{dis}}} = V_{gap} - i_{R_{dis}} R_{dis} \tag{27}$$

The current $i_{R_{dis}}$ flow through inductance L_{dis} in series to resistance, R_{dis} can be expressed as follows.

$$i_{R_{dis}} = \frac{V_{gap}}{R_{dis}}\left(1 - e^{-\frac{R_{dis}}{L_{dis}}t}\right) \tag{28}$$

Then, the current gap can be obtained as follows.

$$i_{gap} = i_{R_{ig}} + i_{R_{dis}} \tag{29}$$

In using Eq. (4), the current gap in discharge condition is,

$$i_{gap} = \frac{V_{gap}}{R_{ig}} + \frac{V_{gap}}{R_{dis}}\left(1 - e^{-\frac{R_{dis}}{L_{dis}}t}\right) \tag{30}$$

$$i_{gap} = V_{gap}\left[\frac{1}{R_{ig}}\left(1 - e^{-\frac{R_{dis}}{L_{dis}}t}\right) + \frac{1}{R_{dis}}\right] \tag{31}$$

Using the Kirchhoff law again, V_{in} can be determined by,

$$V_{in} = i_{gap} R_{shunt} + V_{gap} \tag{32}$$

In this phase $V_{gap} = V_{dis}$, the discharge voltage can be represented as below,

$$V_{dis} = V_{in} - i_{gap} R_{shunt} \tag{33}$$

As illustrated in Fig 7, the three phases of EDM pulses has been shown in details. based on the time duration in one period, the initial phase from 0 until t_1, followed by the ignition phase of the t_1 to t_2 and the next phase of the discharge of the t_2 to t_3.

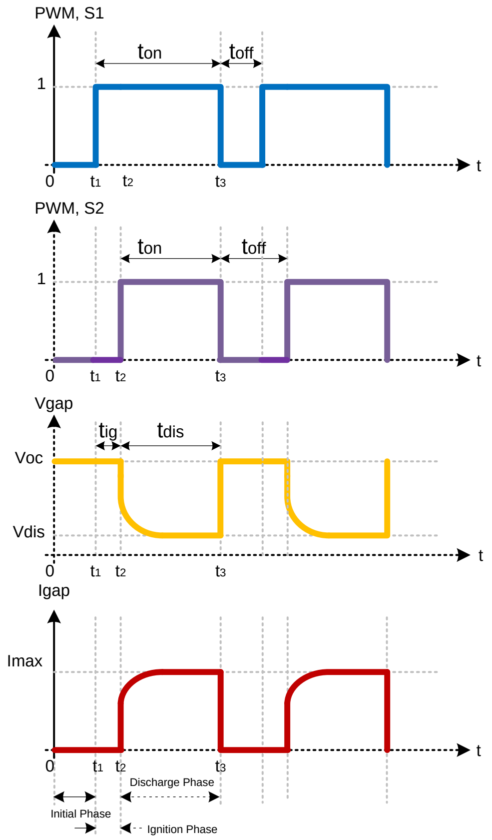

Fig. 7. The profile of EDM pulse which is consists switch (S_1), switch (S_2), gap voltage (Vgap) and current gap (Igap) versus of time

IV. Simulation and Experimental Results

By using the electrical model in Matlab Simulink software, the simulation process has been conducted. As can be seen in Fig. 8, the configuration of the EDM circuit was constructed based on the mathematical model derived. In this simulation, the parameters have been set as the input voltage is 100V, 50 percent duty cycle and 100 microsecond time period. Displayed in Fig. 9(a) shows the results obtained from the simulation design is open circuit voltage, V_{oc}=100V, discharge voltage, V_{dis}=28V and current gap, I_{gap}=2.8A.

In the experimental, transistor type of EDM pulse power generator is used to the design. The following input process parameters are used such as input voltage, V_{in}=100V, load resistance, R_{load}=113Ω and copper material for electrode and workpiece. As can be observed in Fig. 9(b), the output result shows the open circuit voltage, V_{oc}=95V, discharge voltage, V_{dis}=18V and current gap (current through the load resistance), I_{gap}=0.8A. Comparing the simulation and the experimental results, it is evident that these result are in good agreement with the mathematical model derived.

To analyze the completed result, surface finish of the experimental material were viewed under the OMAX

Microscope about 100X magnification as shown in Fig. 10(b) and Fig. 10(c). The result shows the diameter hole is about 1 mm with better surface quality. Usually, a small current gap obtained the better surface finish compare with higher current [13].

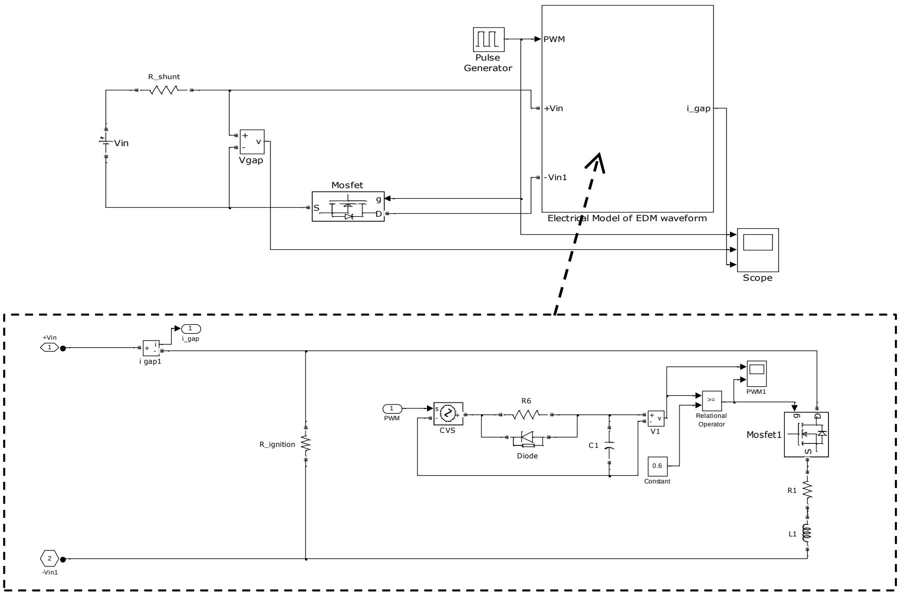

Fig. 8. The electrical model of EDM pulse power generator and the configuration of EDM pulses inside the block diagram

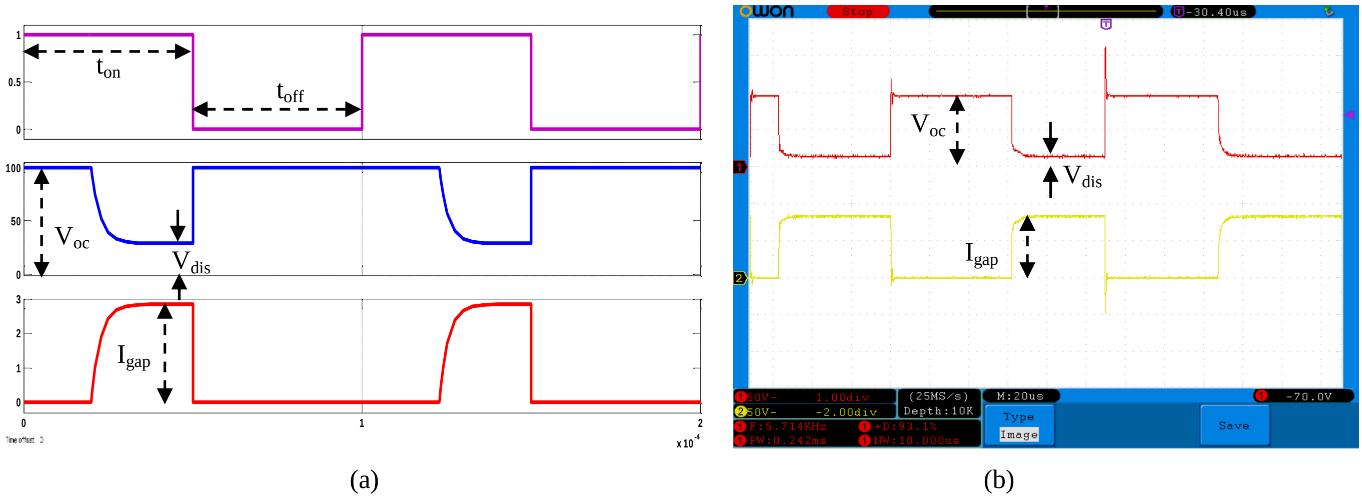

Fig. 9. (a)The simulation results show the pulse width modulation, voltage and current in the gap. (b)The gap waveform displayed from the experiment (Ch1: Gap Voltage, Ch2: Gap Current)

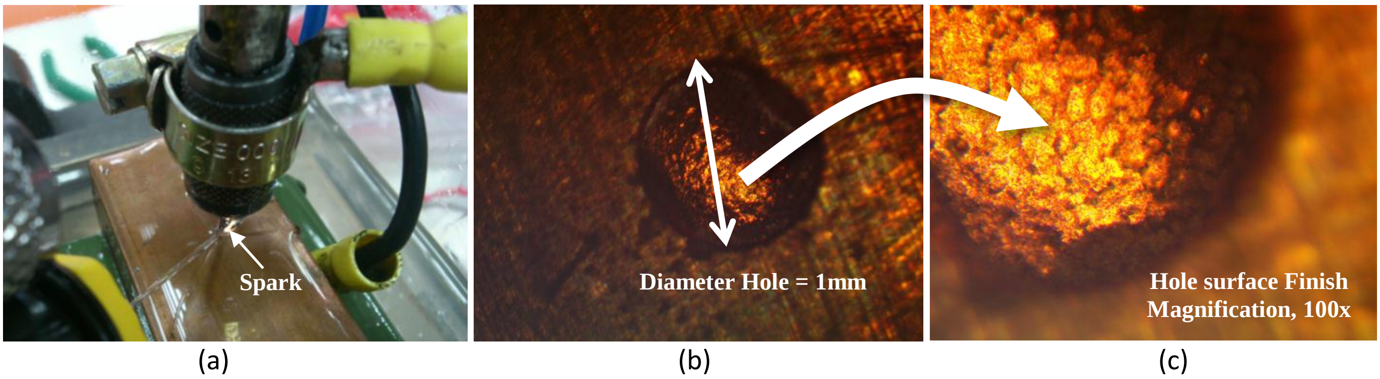

Fig. 10. (a)Spark discharge phase (b)Holes fabricated by the transistor pulse generator (c)Zooming into the hole surface at 100X magnification

CONCLUSIONS

In conclusion, a new mathematical model of EDM pulses has been presented and implemented successfully. Based on current and voltage gap, there are three mathematical models has been developed such as initial, ignition and discharge phase. Referring to the equations described above, Eq. 2 and Eq. 3 can be used in an initial phase conditions while Eq. 5 and Eq. 9 on the ignition phase and Eq. 31 and Eq. 33 for discharge phase. Mathematical model of EDM pulses as the objective of this study has been achieved. The model has been validated by simulation and experimental result. The performance of the simulation design has been tested and give a good result compared with the theoretical pulse shape. Comparing simulation and experimental result, this mathematical model is applicable to other simulation studies relating to the EDM pulses. This is great theoretical and practical importance for EDM process.

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