Gaussian Energy Distribution of a RC-Circuit Based Single Discharge Pulse in Micro-EDM

Vishwa Bhanu, P. Sudhakar Rao

***Abstract*: Owing to the non-isoenergetic nature of discharge pulses in resistance-capacitance (RC) based micro-EDM (µEDM), the volume of micro-crater generated by each pulse varies significantly. This fact has driven the researchers in this work to propose an electrothermal principle-based analytical model to approximate dimensional (diameter and depth) accuracies of such micro-craters. An investigation has been done to robustly apprehend the nature of energy distribution during single discharge micromachining in µEDM. The study gradually substantiates the theoretical nature of energy distribution during a single discharge. The predicted nature of energy distribution helps in comprehending the volume removed from the workpiece, energy loss, and machining efficiency.**

***Index Terms*: Data Acquisition, MATLAB, µEDM, RC Circuit, and Single Discharge.**

I. INTRODUCTION

Humankind could have never thought of scaling the potential of the first discharged spark ever witnessed. Nevertheless, we march to accomplish the robustness of the quintessential lightning. In notable words of Michael Faraday, the phenomenon is described as "the beautiful flash of light attending the discharge of common electricity."

The µ-EDM system consists of a proposed relaxation circuit (known as RC circuit) in which electrode and workpiece, both are electrically conductive and are immersed in a dielectric bath, as shown in Fig. 1. In this process, the metal is removed using electric spark erosion, and it is a controlled metal removal process [1]. For the removal of material from the electrically conductive workpiece, the workpiece and the tool electrode are immersed in a liquid dielectric, and rapid recurring sparks are generated using a discharge pulse generator [2]. The workpiece is connected to the anode (+ve) terminal, and since at anode lesser material erosion occurs the electrode is connected to the cathode (-ve) terminal. Once a voltage is applied to the tool the suspended free ions and electrons in the dielectric fluid concentrate between the electrode and workpiece under the force of electric field and ionization, and as a breakdown of dielectric occurs a bridge for current to flow through the dielectric to the workpiece is generated for a short period. Then the electrically intensive arc or spark is produced, creating sufficient heat to melt a part of the workpiece and some of the tool material.

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*****Correspondence Author(s)
Vishwa Bhanu, Department of Mechanical Engineering, NITTTR, Chandigarh Email: vishwa811anu@gmail.com
Dr. P. Sudhakar Rao, Assistant Professor, Department of Mechanical Engineering, NITTTR, Chandigarh. Email: psrao_mech@yahoo.co.in

The high population of electrons and ions among the tool and workpiece forms a plasma channel [3]. Due to the less electrical resistance of the plasma channel, a vast amount of electrons advances from tool to workpiece and ions from workpiece to tool [3]. In the temperature range of around (10,000 ºC – 12000 ºC), material removal takes place due to the melting or vaporization of the workpiece [4]. The occurrence of plasma channel raises the temperature, and the instantaneous vaporization of metallic particles causes the material removal. Due to the flushing action in the dielectric fluid after the spark, the melted particles are removed partly. Eventually, the plasma channel diminishes when the potential difference decreases. The breakdown of the plasma channel initiates pressure force or shock wave. These pressure forces and shock waves clear the molten metal using flushing method and removing the material under the region of spark. The gap conditions between tool and workpiece govern the frequency and energy content of a spark

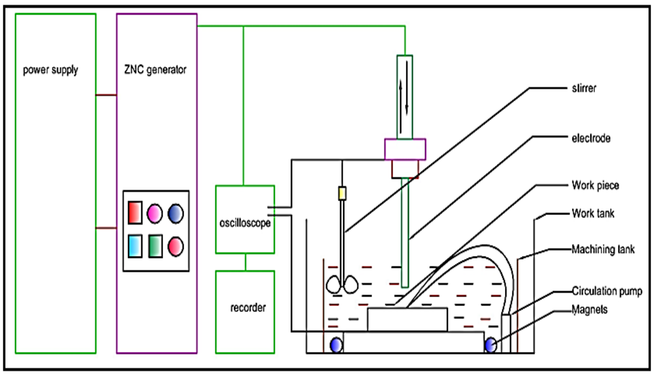

Fig. 1 Schematic diagram of basic EDM process

II. RC CIRCUIT

There are various electrical circuits available in order to have dc voltage in the form of pulses across the tool and workpiece gap in µ-EDM. These electrical circuits vary from one another based on operating parameters, but in all of them, a capacitor is used for storing the electrical charge and discharging across the gap. Depending upon the applications and requirements, the different electrical circuits such as in µ-EDM can be used. An RC circuit is the oldest and most widely used circuit in EDM. It is still used very productively in the industrial environment. The principle setup of an RC circuit comprises of a direct current source in combination with resistance and a capacitor. A typical EDM machine can have several resistances and capacitors in various combinations, but the basic working principle remains the same.

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Fig. 2 shows a simple RC circuit. The DC voltage source (V_o) is used to charge a variable capacitor (C) via a variable resistance (R). The virtual output waveforms are depicted in Fig. 3.

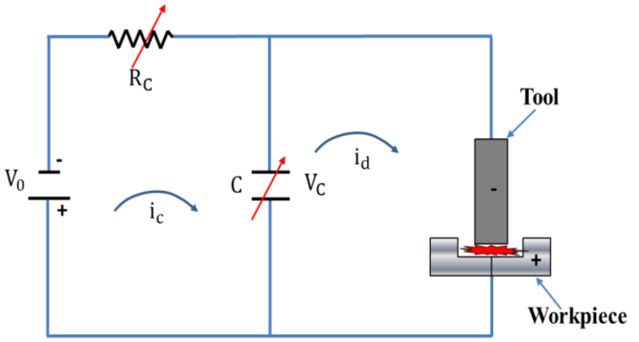

Fig. 2 Schematics diagram of the RC circuit

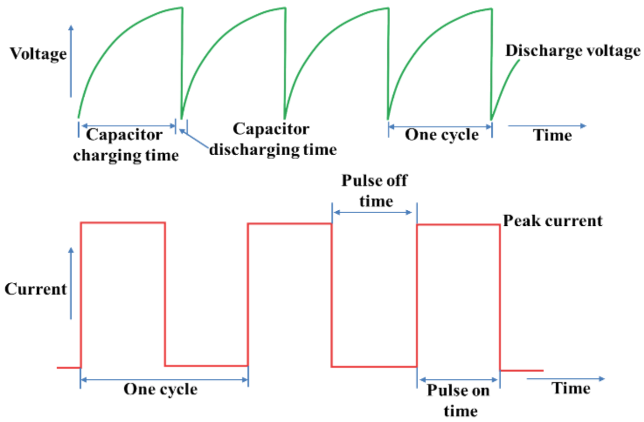

Fig. 3 Ideal voltage and current waveforms for the RC circuit

When a potential difference (V_o) is applied, charging current (i_c) flows, and the capacitor gets charged gradually to a value (V_c). The gap voltage [5], i.e., the voltage across the capacitor during charging is given by (1)

$$V_c = V_o\left(1 - e^{-t/R_cC}\right)V_c = V_o\left(1 - e^{-t/R_cC}\right)$$
(1)

and charging current is given by (2)

$$i_c = \frac{V_o - V_c}{R_c} i_c = \frac{V_o - V_c}{R_c}$$
(2)

Here R_c is charging resistance and C is capacitance, and ‘t’ denotes the instantaneous time when V_o is applied.

Also, the voltage $V_d V_d$ across the capacitor during discharging is given by (3)

$$V_d = V_0\ (e^{-t/R_cC})V_d = V_0\ (e^{-t/R_cC})$$
(3)

and discharging current (i_d) is given by (4)

$$i_d = \frac{V_o}{R_c} \cdot e^{-t/R_cC} i_d = \frac{V_o}{R_c} \cdot e^{-t/R_cC}$$
(4)

The time taken for a capacitor to get charged is known as the charging time. During this time, as there is no spark generation between tool and workpiece; hence, no machining takes place. Therefore, this time is also described as pulse off time [6]. The time taken for the capacitor to get discharged is known as discharging time. During discharging the current flows in the EDM machine through the spark gap and this time is named as pulse ON time $(T_{ON})(T_{ON})$. The discharging time is generally less (only 10%) than the charging time. The duration in which complete charging and discharging of capacitor take place is known as one cycle.

III. DATA ACQUISITION

A data acquisition setup connected to resistance-capacitor (RC) pulse generator type µ-EDM (Model: Mikrotools DT-110) is used to acquire voltage and current characteristics during a single discharge. The pulse generator parameters were set on a fixed supply voltage of 100 V. For keeping the ideal experimental conditions delay time of 50 µs was given. Furthermore, ON time of 100 µs, and OFF time of 100 µs were fixed for ideal machining conditions. The setup comprises of a differential type voltage sensor (Model: YOKOGAWA 701938) and a hall-effect sensor-based current clamp (Model: FLUKE i30, Everett). The voltage sensor captures voltage waveforms between the discharge gap with the bandwidth of 200 MHz, and the current sensor probe works in a sensitivity of 100 mV/a, with a current sensing range of 5 mA to 30 A DC. The current probe works within a maximum voltage operating limit of 300 V. The importance of the current clamp is to capture the current pulses for estimating the discharge energy in real-time. Both sensors are connected to a µ-EDM and are inter-connected with a National Instruments (NI) based Data Acquisition (DAQ) system. The DAQ system uses a digitizer card (NI 5122) as a NI based module to receive and process the signals from both the sensors in real-time with a sample rate of 100 MS.

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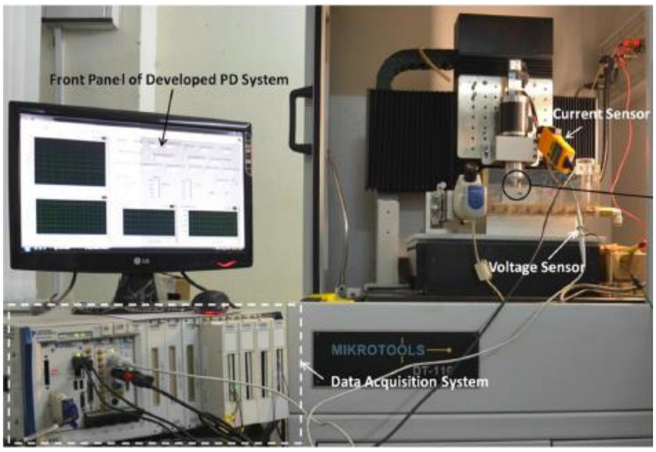

Fig. 4 Experimental setup detailed with voltage, current sensors, and DAQ system [7]The setup of the DAQ system is represented in Fig. 4.

The specification and requirements for the controller of the DAQ system are a 2 GHz processor operating system and an onboard mounted RAM of 4 GB or more up to 8 GB.

These specifications are necessary to process the signals acquired from the sensors. A program pre-written in LabVIEW (Make: NI, 2018) library helps in processing and discriminating the pulses. LabVIEW is a commercial virtual instrumentation software, and it has inbuilt libraries for converting the signals stored into a readable text file format. The data can be stored either in an excel sheet format or a text file format.

IV. DISCHARGE ENERGY PLOT

Using the data obtained from the DAQ system, different plots are plotted to study the nature of the discharge. The data stored in excel sheets are imported to MATLAB. A code is executed to plot and arrange the voltage waveform in the form of a virtual single discharge pulse. Fig. 5 depicts that after a delay time when the capacitor was in a charged state, a sudden discharge occurs, and the charging of the capacitor begins respectively.

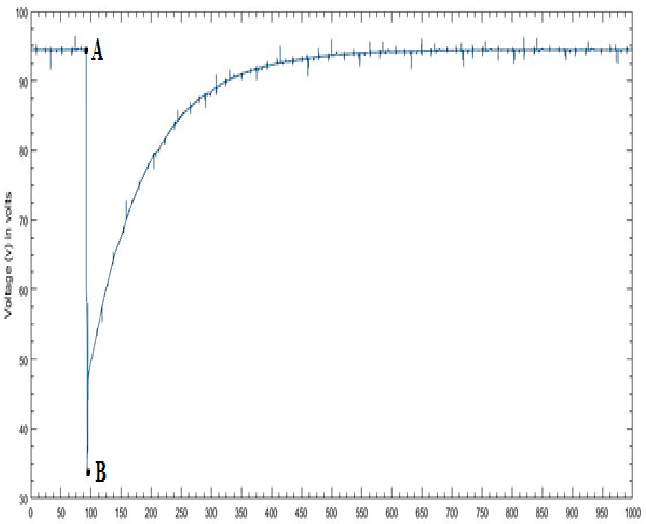

Fig. 5 Voltage (V) vs. Time (μ-sec) plot for a single discharge

Since the machining occurs only during the voltage discharge through an RC circuit, the primary focus is on the voltage drop in the plot, which is represented by AB coordinated. The data points along AB represents the voltage discharge with time; the discharge is an immediate process that occurs within the fraction of a micro-second hence data points obtained for voltage discharge are lesser than the data points obtained for the consecutive charging process which takes time to charge the capacitor. The discharge portion is cropped and again plotted conforming a linear drop as shown in first (I) plot of Fig. 6. However, there is an inevitable noise which magnifies on a larger scale axis. Also, for the corresponding data points along AB in real-time, the current discharge data points are imported into MATLAB and are plotted against time, as shown in the second (II) plot of Fig. 6. The current rises and falls during the voltage discharges, but it lacks sharp peek and fall due to the presence of noise and lesser sensitivity of the current sensor. Now, to obtain the power (P) [5], i.e.

$$P = V_d \cdot i_d P = V_d \cdot i_d$$

(5)

The corresponding discharge voltage data points are multiplied to the current data points and are plotted, as shown in the third (III) plot of Fig. 6. Moreover, to obtain energy, we multiply the power obtained by a change in time ($\Delta t \Delta t$). Here, the sampling rate was 100 MS, so the change in time is taken to be 0.1. As discharge energy (E) [7] is given by (6):

$$E = \sum_0^{T_{ON}/\Delta t} V_d \cdot i_d \cdot \Delta t E = \sum_0^{T_{ON}/\Delta t} V_d \cdot i_d \cdot \Delta t$$

(6)

The energy plot shown in the fourth (IV) plot of the Fig. 6 is given a curve Gaussian curve fitting for better visualization of the nature of energy discharge.

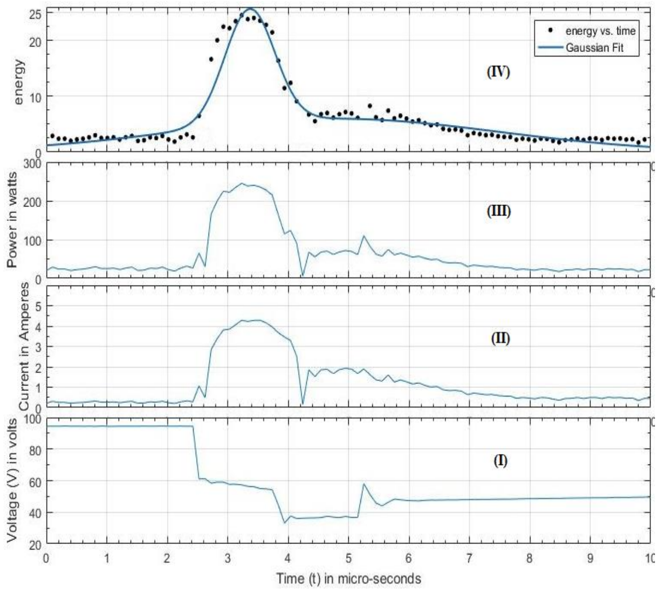

Fig. 6 Voltage (V), Current (A), Power (W), and Energy (J) distribution plots against Time (μ-sec)

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The Gaussian model represented above in Fig. 6 have a curve fit normalized by a mean of 5 and a standard deviation of 2.909. The Goodness of fit is represented in the following Table I.

Table- I: Goodness of Gaussian curve fit

SSE	R-square	Adjusted R-square	RMSE
72.24	0.9857	0.9853	0.6102

V. RESULTS AND DISCUSSION

A non-contact type optical profilometer test provided the profile of the crater in a single discharge. The craters profile is compared with the obtained Gaussian plot to observe the effect and material removal from the workpiece by the single discharge. Fig. 7 shows the 3D image of crater and Fig. 8 depicts the crater profile the depth both obtained from the profilometer.

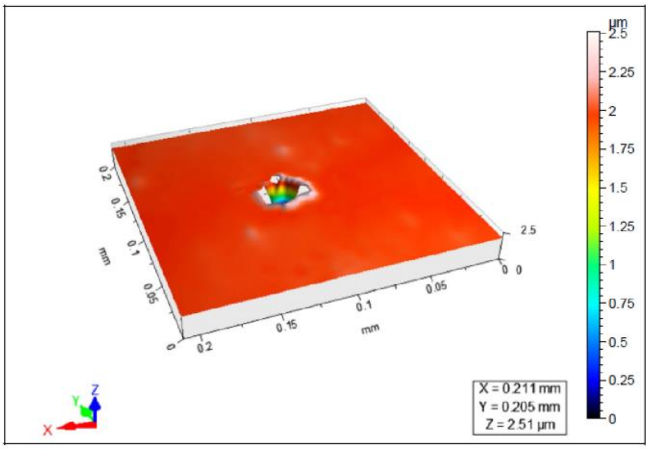

Fig. 7 3-D visualization of crater under profilometer (non-contact type)

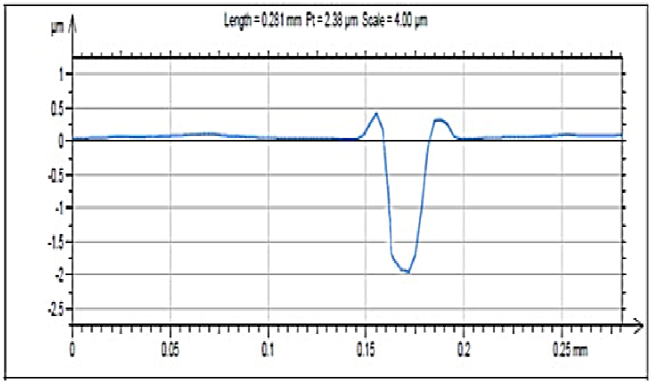

Fig. 8 Depth and profile plot obtained on profilometer (non-contact type)

To consider the distribution of energy generated during spark over the crater, the fourth (IV) plot in Fig. 6 is flipped vertically, and the crater's profile in Fig. 8 are superimposed with the help of Photoshop tools as shown in Fig. 9. The shaded part is the crater, and it is evident that profiles are similar but not congruent because the energy is lost to the surroundings as heat during machining.

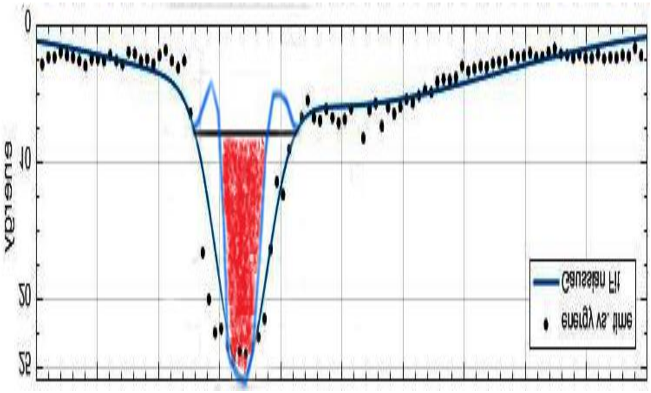

Fig 9. Superimposed visualization of crater profile and energy distribution plot

The dielectric, debris present in the dielectric, and workpiece all act as resistance and absorbs heat, contributing to energy loss. Also, the material and dielectric properties affect the size and profile of the crater obtained, i.e., material removal from the surface. The Gaussian energy distribution explains the morphology of crater created and aids in a better understanding of material removal from the surface.

VI. CONCLUSIONS

The crucial conclusions of the experimental and analyzed study carried out to investigate the distribution of energy for voltage discharge during a single discharge in RC based μμ EDM is that the energy distribution profile obtained is found to be Gaussian in nature and energy loss occur due to heat dissipation in surroundings. The relation between discharge voltage and output energy is complex and can be optimized using a controlled RC circuit. This nature can be further explored to prepare a robust model of spark mechanism in μ μEDM that will give more control over the material removal rate and higher machining finish. Energy distribution being Gaussian in nature is responsible for the Gaussian nature profile of the crater formed in a single pulse discharge, the energy distribution being maximum at the center.

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AUTHORS PROFILE

Vishwa Bhanu completed Bachelors degree from Dehradun Institute of Technology, Dehradun in Mechanical Engineering. Presently, pursuing M.E. at NITTTR in Manufacturing Technology. Key areas of research interests include advanced micro-machining, magnetic levitation, and energy conservation.

Dr. P. Sudhakar Rao Assistant Professor in Mechanical Engineering Department, NITTTR, Chandigarh. He completed his Ph.D. from IIT Roorkee. Key areas of research interests include Manufacturing Technology, Engineering Design, Non-Conventional Machining, CAD/CAM/CIM, Engineering Materials, and RPT/RE.

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