A review on short pulse generator used for micro electric discharge machining

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ABSTRACT

Micro-EDM is a promising noncontact micro machining process; where the precisely controlled electric spark occurred between the tiny electrodes and erodes the material from electrically conductive work piece. Application of this Micro EDM is rapidly growing in manufacturing of metal products irrespective of its hardness having geometric features in range of micrometer to nanometer scale. In order to ensure the material removal in the order of few cubic micrometers it is desirable to use a low energy, shorter pulsed discharges at very high frequency. In this study, the detailed literature review related to low energy and short pulsed power circuits to use in Micro-EDM process conditions has been carried out. The advantages and issues of obtaining such high frequency short pulsed low energy discharge have been critically studied to set the future directions for further investigation.

1. Introduction

Electric discharge machining (EDM) is among the earliest non-conventional manufacturing process which was first invented in 1940 in USSR [1] widely used in tool rooms after 1968. It is a noncontact micro machining process; where the precisely controlled electric spark occurred between the tiny electrodes, used to erode the material from electrically conductive work piece [1-13]. A pulse generator provides the discharge energy, and a CNC (Computer Numeric Control) motion controller ensures the advancement of the tool to maintain the desired spark gap [15]. Moreover, the motion controller is responsible for retracting the electrode, whenever the short circuit happens. According to global market forecast for electrical discharge machines to be worth some $8.5 billion in the near future [16]. Application of the Micro-Nano scale EDM is rapidly growing in manufacturing of metal products having geometric features in the range of micrometer to nanometer scale due to its machining capability on any kind of conductive materials irrespective of their hardness [16–20]. It is capable of machining semi conductive materials also [20–22]. In addition to that, it is a burr-free process which can produce a good surface finish with desirable accuracy and repeatability [1]. Since it is a non contact machining process there are no issues of vibration error, mechanical stress or residual stress [24]. This machining has its wide applicability to produce micro-dies, molds [25], micro probes, different type of fuel nozzles surgical tools, ultra-fashioned jewelerry, finishing parts for aerospace and automotive industries [25-27]. It is also very useful to generate complex 3D features [28] with high aspect ratio [29]. Micro-EDM is one of the most efficient machining process for the extremely hard materials like tungsten carbide (WC) [30] [31] Titanium alloy (Ti-Al06)[32], Inconel alloy [33] and so on.

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Since EDM is a electro thermal machining process, the power circuit plays a pivotal role in machining conditions such as crater size, material removal rate (MRR), tool wear rate (TWR) [34]. The power circuit to generate ultra high frequency signal with required frequency as well as with least energy is one of the most important key aspect in Micro nano scale EDM. In conventional EDM a high voltage as well as high

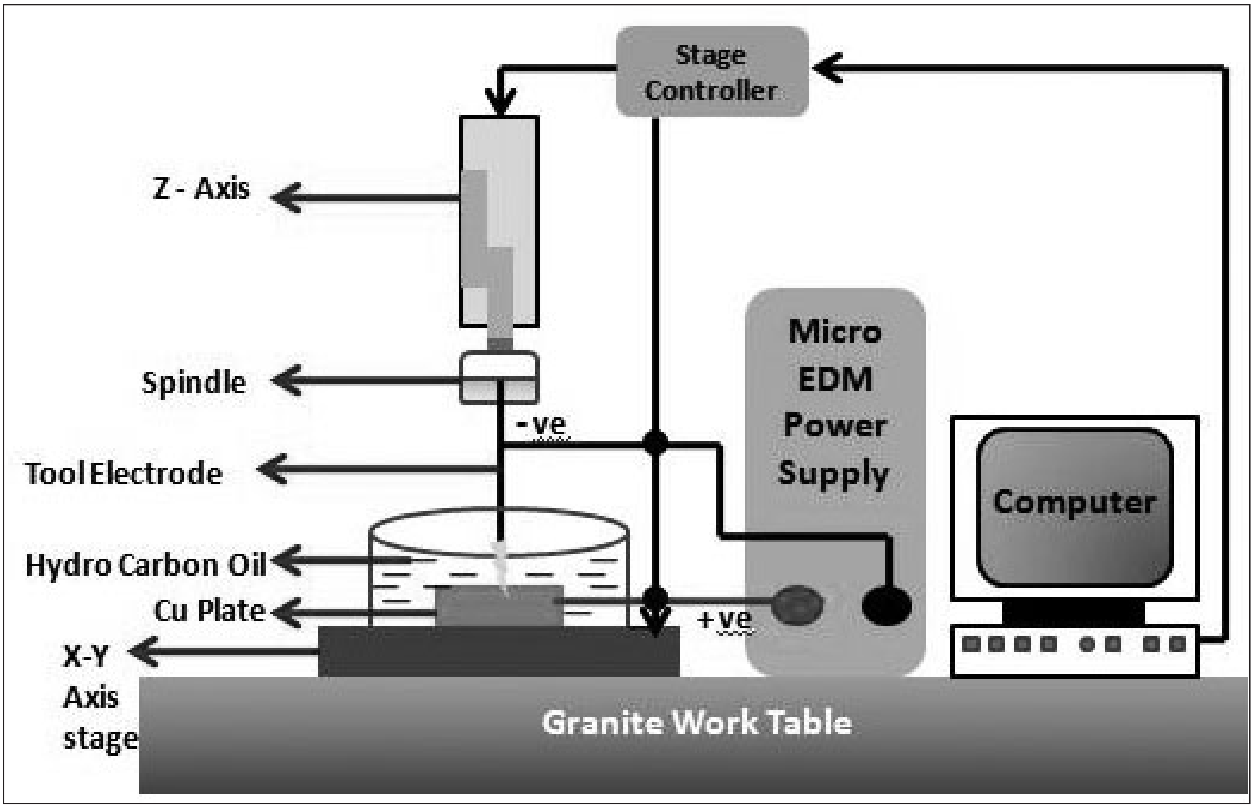

Fig. 1. Micro EDM setup.

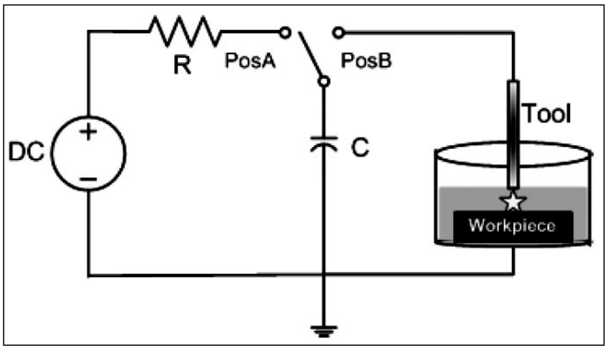

Fig. 2. Schematic of RC single pulse generator for Micro EDM.

current is required as the machining feature size is large. However to maintain small feature size in the order of few microns is a great challenge and it is only possible when discharge energy is very low (~150µJ). A schematic diagram of Micro EDM setup is shown in figure 1, in which the Micro EDM power supply is basically a high frequency pulse generator.

However, the review presented in this study primarily focused on the different type of high frequency pulsed power circuit used in Micro EDM. Several researches had been carried out by researchers. Power circuits used in EDM are mainly of two type RC relaxation circuit and transistor type pulse generation circuit. Other than these methods some more advanced methods are also critically reviewed in this study. A comparative study of different methods is represented in tabular form.

2. Different Type of Pulsed Power Circuit

2.1 RC relaxation circuit for micro-nano EDM

RC relaxation circuit is the most commonly used circuit for conventional EDM [35]. In most of the conventional EDM an RC charging-discharging circuit is used to generate the spark between the electrodes. In Micro EDM also same concept of using RC circuit continues at the beginning of micro EDM era [36]. Y.S. Wong et al. reported the use of RC circuit in Micro EDM for single spark generation [37] RC circuit is a very simple circuit to generate high frequency pulses for required frequency used for Micro EDM circuit. The circuit diagram for the same is shown below in figure 2.

It is a very normal resistive capacitive circuit where the capacitor is being charged through resistor and charging, discharging of capacitor is controlled by using Pos A and Pos B switch. When the switch is connected to Pos A the capacitor begins to charge and as per its time constant

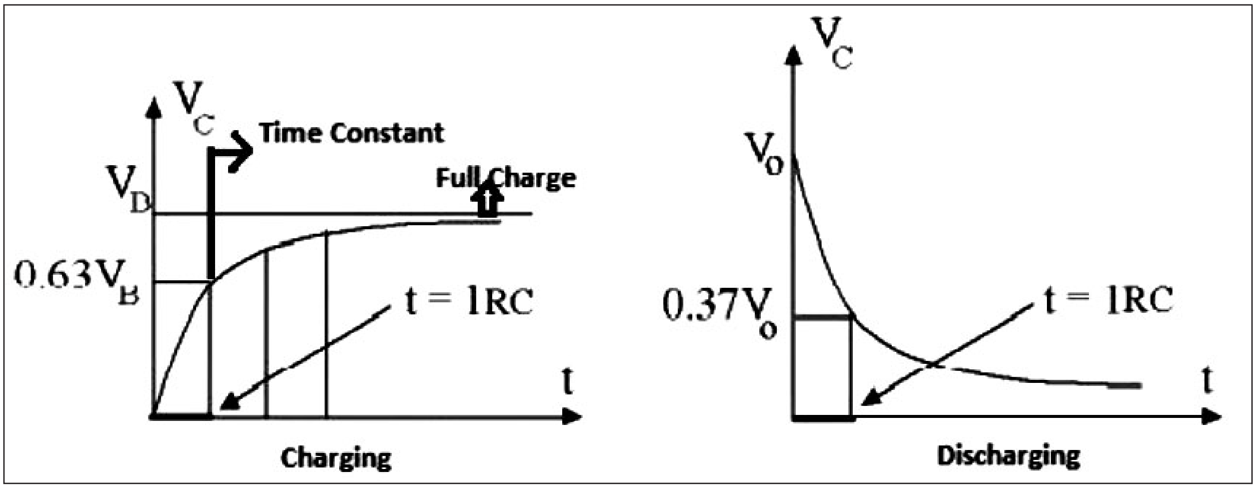

Fig. 3. Charging discharging phenomena of capacitor.

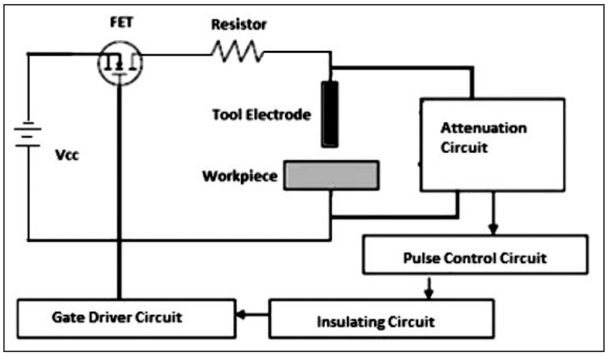

Fig. 4. Schematic diagram of transistor type iso pulse generator [39].

reaches to full value i.e. upto supply voltage. Time constant is the required time to charge the capacitor up to 63.2% of its full value and it is determined by the product of R and C. After that when the charging is completed, the switch would be connected to Pos B and now the circuit is ready to discharge with required spark gap between working tool and workpiece electrodes. Thus the charging discharging is done according to switching and micro craters are formed through single discharge. The charging time of capacitor can be varied by using variable resistor. The charging and discharging phenomena is shown below in figure 3.

2.2 Transistor type iso pulse generator

Masuzawa and Fujino [38] were the first researcher who actually applied the transistor type pulse generator in micro scale EDM and they also claimed the successful generation of discharge pulse of 220 ns which was applied for comparatively coarse machining. Hara et al. [39] and Nakazawa et al. [40] investigated the development and performance of the transistor type pulse generator for micro - EDM. This group of researchers reported that the transistor should be periodically switched on and off during a period of 1000ns with a constant pulse width of 100ns to get the semi finishng. [40]. Guangmin et al. [41] developed a transistor-type pulse train generator capable of generating 90-ns pulse on-time

Transistor type iso pulse generator is basically a combination of some small circuits. It consists of a FET, voltage attenuator, pulse control circuit, insulating circuit, gate driver circuit along with a constant supply voltage. Unlike RC relaxation circuit there is no capacitor for charging or discharging. The main purpose of using these circuits is discussed below.

Voltage attenuator attenuates the gap voltage between the two electrodes at the time of discharge takes place. As the output of this attenuator circuit is fed into pulse control circuit which can only be operated in low voltage, the voltage attenuation is required. Pulse control circuit is an IC based circuit which can control the pulse on time, discharge duration etc. Next the insulating circuit placed between the pulse control circuit and gate driver, acts as an insulator between the digital circuit and gate driver. It isolates the digital circuit (pulse control circuit) from rest of the circuit, so that the high discharge current can't flow into the digital circuit and destroy it. Gate driver circuit is used to supply sufficient voltage to the gate of the FET which is mainly used as a switch between supply voltage and both electrodes. Figure 4 reveal the schematic diagram of the transistor type iso pulse generator.

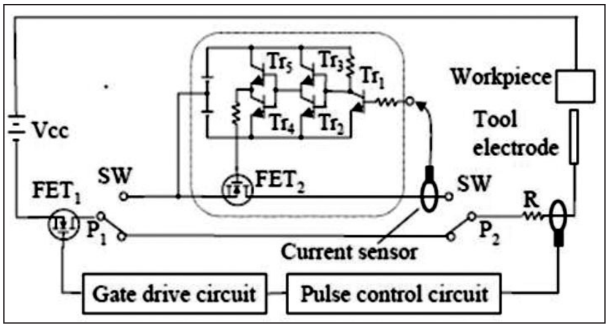

Fig. 5. Schematic diagram of advanced transistor type iso pulse generator [43].

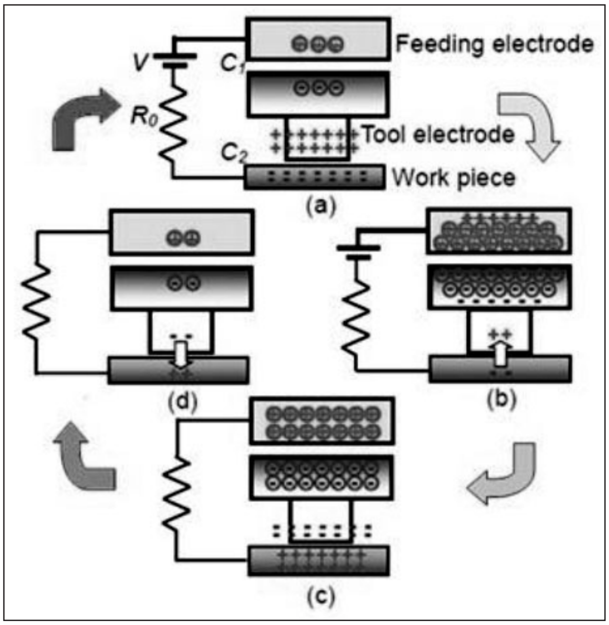

Fig. 6. Capacity coupled pulse generator [44].

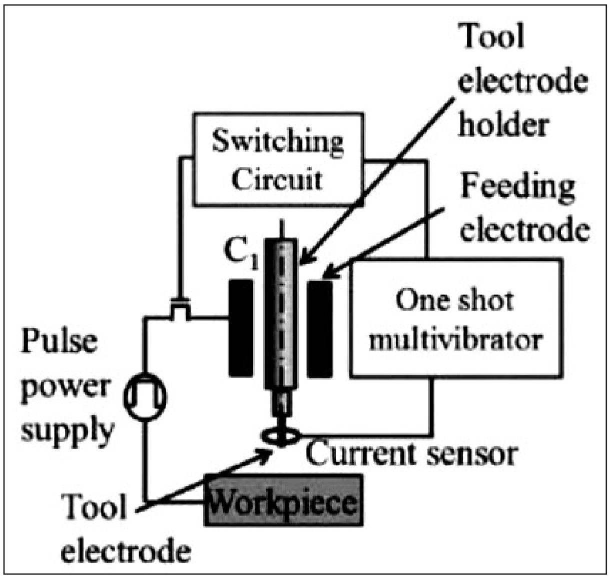

Fig. 7. Electrostatic induction feeding by controlled pulse train method [46].

2.3. Advanced transistor type iso pulse generator

The basic principle of advanced transistor type iso pulse generator and Transistor type iso pulse generator is almost same and it was discussed by Han et al. [42] and [43]. As numerous numbers of elements are used in transistor type pulse generator circuit for detecting the discharging signal, it requires much time to send the feedback to the switching circuit. Since the required discharging time is very much small for better surface finish, ideally the feedback circuit should be very compact to shorten the delay time while discharging. Han et al. (2003) had presented a detailed study on transistor type pulse generator used in Micro EDM and proposed this advanced transistor type iso pulse generator and reported the pulse duration reduction about 30 ns which is perfect for fine finishing by micro-EDM machining [43].

It is an improvised version of previous circuit which is described in sec 2.2. Here a current sensor is used instead of using a gap voltage detection unit. Since it is an ultra fast process, the current sensor of frequency response up to 2 GHz is used. As the outcome of the current sensor is less than 5V, the output can be directly fed into pulse control circuit and thus no voltage attenuation is required. When only semi finishing is required, the P1 & P2 is connected and operation goes on as discussed before but the dotted supplementary circuit is included at the time of fine finishing. Since voltage attenuator circuit and insulator circuit is removed and only very few high frequency elements are used, the lingering time for response problem is solved. The schematic diagram of whole circuit is revealed in figure 5.

2.4. Electrostatic induction feeding method

Kunieda et al. discussed about this concept of capacity coupled pulse generator [44]. The feeding electrode, tool electrode, and work piece are coupled by capacitors in series. From the fig 5 C1 is the capacitance between the feeding electrode and tool electrode, and C2 is the capacitance between tool electrode and work piece. Here C1 is assumed to be much larger than C2. A pulsed voltage V is applied between the feeding electrode and workpiece electrode.

When the pulsed voltage V is applied, the capacitance C1 and C2 are charged. In the working gap, the work piece and tool electrode

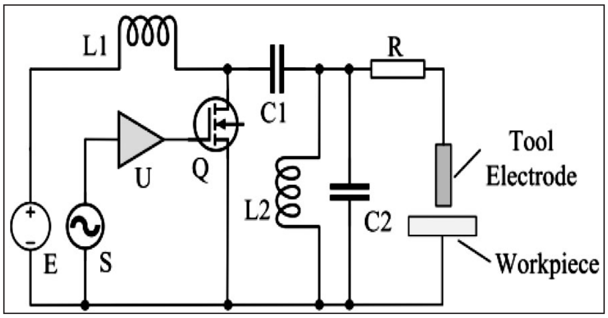

Fig. 8. Circuit diagram of very high frequency (VHF) pulsed power supply [47].

are charged negative and positive respectively and creates a high electric field. Accordingly, discharge occurs and electrons are conducted from the work piece to the tool electrode. Since discharge duration is significantly short, not longer than several tens of nanoseconds, dielectric breakdown strength of the working gap is recovered immediately. After the constant pulse duration, the voltage of the pulse generator becomes 0. In order to balance the voltage of the feeding gap with the voltage of the working gap, as shown in Figure 6, the feeding electrode, tool electrode, and work piece are coupled by capacitors in series.

2.5 Electrostatic induction feeding by controlled pulse train method

Yahagi et al. first introduced the concept of using the pulse train method in electrostatic induction feeding method [45]. Abbas et al. improvised the method of electrostatic induction feeding by introducing the controlled the pulse train [46]. It is a modified version of capacity coupled pulse generator for improving the discharge energy. In the previous study it was discussed that capacity coupled pulse generator is suitable for nano EDM as it is capable to generate minimum surface roughness 0.23µm. In this study a new circuit had been developed where pulse train duration remained constant to control the discharge intensity for getting the same material removal.

The circuit includes a one shot multi-vibrator, a switching circuit to control the machining efficiency. In this method a very high frequency voltage is applied between the two electrodes. A current sensor is used to sense the starting time of the ignition. Once the discharge ignites, the current sensor senses in terms of the value of current, and then sends the signal to the one shot multi-vibrator. The multi-vibrator initiates the discharge pulse and allows it to continue the controlled pulse train. Pulse train is nothing but a group of discharges occurred in a preset time at the same location. At the end of preset time a signal is sent to the switching circuit to stop supplying the pulse and initiate the pulse interval time. In this pulse interval duration the dielectric strength restored and again the power supply is switched on and the whole process repeats iteratively. Therefore the higher discharge energy forms larger crater dimension. According to the authors, since the controlled pulse duration is used the crater dimension can also be controlled.

2.6 Very High Frequency (VHF) resonant micro-EDM pulse generator

Wang et al. proposed the method of using very high frequency (VHF) pulse generator for the operation micro EDM [47] In their study a VHF resonant discharge pulse generator with maximum 90MHz frequency and high voltage was designed to achieve very low discharge energy and a large gap of discharge between tool and workpiece. It is an inductive capacitive circuit.

The schematic diagram of the electronic circuit using the VHF generator is shown in Fig. 8. S, the source of the signal is controlled by a microcontroller to generate a very high frequency excitation signal of sine wave which can be varied in the range of 30 to 300 MHz. A power amplifier U is used to amplify the source signal. The amplified signal is then fed to the gate of the MOSFET Q to drive it. The coupling capacitor C1 is used to filter the DC signal, and C2 and L2 is used to generate a resonant amplification. A DC power supply is used to operate the entire circuit system. L1 is a high-frequency inductor, which is applied to isolate the AC signal source from DC power source and ground. For a specific value of L2 and C2, the resonance frequency fr occurs, which minimizes the impedance.

2.7 Pulse forming line

In the paper "A Review of Short Pulse Generator Technology" the concept of Pulse forming Line (PFL) was described [48]. PFL is a very essential sub system of a pulsed power supply. It is a very important element of a pulsed power system to generate the pulse with a very fast rise time as well as desired pulse width. Generally the impedance of high voltage generator is high. On the contrary the loads of pulsed power devices offer comparatively lower impedances,

Table 1
Comparative study of different pulsed power supply.

Sl No.	Method	Key features	Limitations
1.	RC relaxation circuit	• RC charging discharging circuit to generate high frequency pulses.	• Capacitor requires comparatively more time. • High discharge frequency cannot be obtained. • No provision to control over the pulse interval as well as pulse duration. • There is no control over the voltage in pulse discharge. • Uniform crater cannot be achieved.
2.	Transistor Type iso Pulse Generator	• It consists of a FET, voltage attenuation circuit, pulse control circuit, insulating circuit, gate driver circuit along with a constant supply voltage. • It achieved upto 100ns pulse width.	• Quite complicated circuit • Numerous number of electrical elements between electrode and switching circuit • Take more time to give feedback to switching when the discharge occurs • Uniform crater cannot be achieved.
3.	Advanced transistor type iso pulse generator	• It is an advanced version of previous circuit. • A current sensor is incorporated to detect the time of discharge. • It achieved less than 100ns pulse width.	• Quite complicated circuit • Number of electrical elements between electrode and switching circuit is more.
4.	Electrostatic induction feeding method	• It consists of feeding electrode, tool electrode, and work piece are coupled by capacitor in series • It doesn't have any stray capacitance	• It has no control over the pulse frequency. • Low energy spark generator but not good for ultra high frequency pulse generation. • Polarity of the tool and workpiece electrodes are changed alternatively, consequently the material would be removed from both the electrodes. • TWR increases significantly.
5.	Electrostatic induction feeding by controlled pulse train method	• Introduces controlled pulse train with electrostatic induction feeding. • Includes a one shot multi vibrator and a switching circuit. • Suitable for low surface roughness i.e. good surface finish.	• It also requires high amplitude of voltage. • Though the tool wear rate (TWR) is less compared to conventional electrostatic induction feeding method, the TWR is significantly high for applying the alternating current.
6.	VHF resonant micro-EDM pulse generator	• In this method maximum 90 MHz frequency can be produced. • As small as 6nJ energy can be produced. • Suitable for ultra smooth surface finishing (Ra min=42nm)	• Requires a very high voltage. • Couldn't get enough time to recover the dielectric strength. • Polarity of the tool and workpiece electrodes are changed alternatively, consequently the material would be removed from both the electrodes. • TWR increases significantly
7.	Pulse Forming Line	• PFL is used to match the impedance between source and load to get the maximum power.	• It is generally operated on a very high voltage. • High voltage is not required for Micro nano edm.

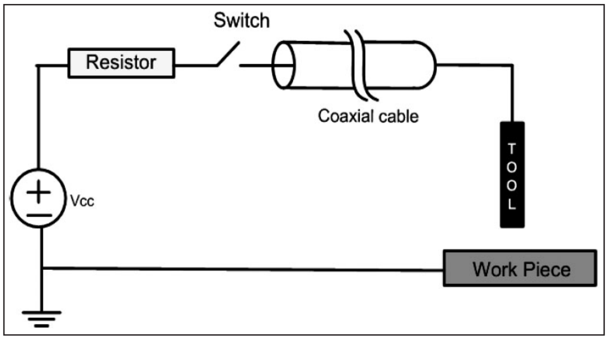

Fig. 9. Schematic of pulse forming line.

In order to match the impedance between source and load PFL is used in intermediate stages. A very important feature of the PFL is that it takes few microseconds to charge and discharges only within a few hundreds of nano seconds through the loads. It has its wide applicability for impedance matching between the load impedance and source impedance to deliver the maximum power. The schematic of the power supply is shown in figure 9.

3. Summary of Literature Review

Summary of Literature Review Shown on Table 1.

4. Conclusion

This study extensively reviews the different type of pulsed power supplies which are capable of generating high frequency and specially used in Micro EDM. All the circuits discussed over here show many advantages as well as carry some limitations. The comparative study of all the power supply has been discussed elaborately. Moreover, the gaps in literature and research work are also discussed. As all the electrical parameters such as peak current, discharge voltage, pulse frequency, duty ratio depend on the applied power supply, it plays a pivotal role in the machining performance such as material removal rate (MRR), tool wear ratio (TWR), overcut etc. of Micro EDM. This agile and extensive review will help the researcher immensely to mitigate the limitations of different methods and focus on the advantageous factors.

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