Module

9

Non conventional Machining

Lesson

39

Electro Discharge Machining

Instructional Objectives

(i) Identify electro-discharge machining (EDM) as a particular type of non-tradition processes
(ii) Describe the basic working principle of EDM process
(iii) Draw schematically the basics of EDM
(iv) Describe spark initiation in EDM
(v) Describe material removal mechanism in EDM
(vi) Draw the basic electrical waveform used in EDM
(vii) Identify the process parameters in EDM
(viii) Describe the characteristics of EDM
(ix) Identify the purpose of dielectric fluid in EDM
(x) List two common dielectric fluid
(xi) Analyse the required properties of EDM tool
(xii) List four common tool material for EDM
(xiii) Develop models for material removal rate in EDM
(xiv) Identify the machining characteristics in EDM
(xv) Analyse the effect of process variables on surface roughness
(xvi) Analyse taper cut and over cut in EDM
(xvii) Identify different modules of EDM system
(xviii) Draw schematic representation of different electrical generators used in EDM
(xix) Analyse working principle of RC type EDM generator

1. Introduction

Electro Discharge Machining (EDM) is an electro-thermal non-traditional machining process, where electrical energy is used to generate electrical spark and material removal mainly occurs due to thermal energy of the spark.

EDM is mainly used to machine difficult-to-machine materials and high strength temperature resistant alloys. EDM can be used to machine difficult geometries in small batches or even on job-shop basis. Work material to be machined by EDM has to be electrically conductive.

2. Process

Fig. 1 shows schematically the basic working principle of EDM process.

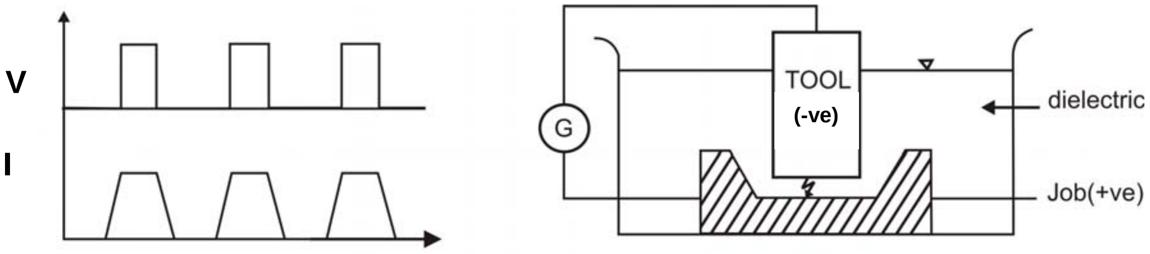


Fig. 1 *Schematic representation of the basic working principle of EDM process.*

In EDM, a potential difference is applied between the tool and workpiece. Both the tool and the work material are to be conductors of electricity. The tool and the work material are immersed in a dielectric medium. Generally kerosene or deionised water is used as the dielectric medium. A gap is maintained between the tool and the workpiece. Depending upon the applied potential difference and the gap between the tool and workpiece, an electric field would be established. Generally the tool is connected to the negative terminal of the generator and the workpiece is connected to positive terminal. As the electric field is established between the tool and the job, the free electrons on the tool are subjected to electrostatic forces. If the work function or the bonding energy of the electrons is less, electrons would be emitted from the tool (assuming it to be connected to the negative terminal). Such emission of electrons are called or termed as cold emission. The “cold emitted” electrons are then accelerated towards the job through the dielectric medium. As they gain velocity and energy, and start moving towards the job, there would be collisions between the electrons and dielectric molecules. Such collision may result in ionisation of the dielectric molecule depending upon the work function or ionisation energy of the dielectric molecule and the energy of the electron. Thus, as the electrons get accelerated, more positive ions and electrons would get generated due to collisions. This cyclic process would increase the concentration of electrons and ions in the dielectric medium between the tool and the job at the spark gap. The concentration would be so high that the matter existing in that channel could be characterised as “plasma”. The electrical resistance of such plasma channel would be very less. Thus all of a sudden, a large number of electrons will flow from the tool to the job and ions from the job to the tool. This is called avalanche motion of electrons. Such movement of electrons and ions can be visually seen as a spark. Thus the electrical energy is dissipated as the thermal energy of the spark.

The high speed electrons then impinge on the job and ions on the tool. The kinetic energy of the electrons and ions on impact with the surface of the job and tool respectively would be converted into thermal energy or heat flux. Such intense localised heat flux leads to extreme instantaneous confined rise in temperature which would be in excess of 10,000^{o}C.

Such localised extreme rise in temperature leads to material removal. Material removal occurs due to instant vapourisation of the material as well as due to melting. The molten metal is not removed completely but only partially.

As the potential difference is withdrawn as shown in Fig. 1, the plasma channel is no longer sustained. As the plasma channel collapse, it generates pressure or shock waves, which evacuates the molten material forming a crater of removed material around the site of the spark.

Thus to summarise, the material removal in EDM mainly occurs due to formation of shock waves as the plasma channel collapse owing to discontinuation of applied potential difference.

Generally the workpiece is made positive and the tool negative. Hence, the electrons strike the job leading to crater formation due to high temperature and melting and material removal. Similarly, the positive ions impinge on the tool leading to tool wear.

In EDM, the generator is used to apply voltage pulses between the tool and the job. A constant voltage is not applied. Only sparking is desired in EDM rather than arcing. Arcing leads to localised material removal at a particular point whereas sparks get distributed all over the tool surface leading to uniformly distributed material removal under the tool.

3. Process Parameters

The process parameters in EDM are mainly related to the waveform characteristics. Fig. 2 shows a general waveform used in EDM.

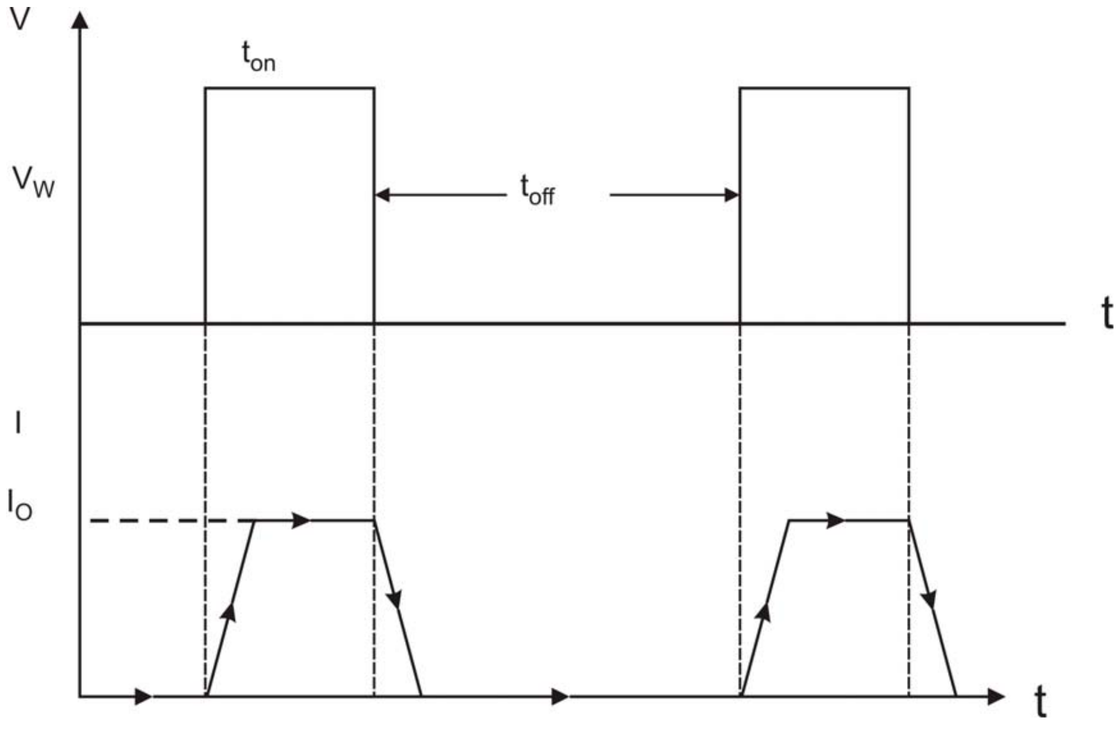


Fig. 2 *Waveform used in EDM*

The waveform is characterised by the

- The open circuit voltage - V_o
- The working voltage - V_w
- The maximum current - I_o
- The pulse on time – the duration for which the voltage pulse is applied - t_{on}
- The pulse off time - t_{off}
- The gap between the workpiece and the tool – spark gap - δ
- The polarity – straight polarity – tool (-ve)
- The dielectric medium
- External flushing through the spark gap.

4. Characteristics of EDM

(a) The process can be used to machine any work material if it is electrically conductive

(b) Material removal depends on mainly thermal properties of the work material rather than its strength, hardness etc

(c) In EDM there is a physical tool and geometry of the tool is the positive impression of the hole or geometric feature machined

(d) The tool has to be electrically conductive as well. The tool wear once again depends on the thermal properties of the tool material

(e) Though the local temperature rise is rather high, still due to very small pulse on time, there is not enough time for the heat to diffuse and thus almost no increase in bulk temperature takes place. Thus the heat affected zone is limited to 2 – 4 μm of the spark crater

(f) However rapid heating and cooling and local high temperature leads to surface hardening which may be desirable in some applications

(g) Though there is a possibility of taper cut and overcut in EDM, they can be controlled and compensated.

5. Dielectric

In EDM, as has been discussed earlier, material removal mainly occurs due to thermal evaporation and melting. As thermal processing is required to be carried out in absence of oxygen so that the process can be controlled and oxidation avoided. Oxidation often leads to poor surface conductivity (electrical) of the workpiece hindering further machining. Hence, dielectric fluid should provide an oxygen free machining environment. Further it should have enough strong dielectric resistance so that it does not breakdown electrically too easily but at the same time ionise when electrons collide with its molecule. Moreover, during sparking it should be thermally resistant as well.

Generally kerosene and deionised water is used as dielectric fluid in EDM. Tap water cannot be used as it ionises too early and thus breakdown due to presence of salts as impurities occur. Dielectric medium is generally flushed around the spark zone. It is also applied through the tool to achieve efficient removal of molten material.

6. Electrode Material

Electrode material should be such that it would not undergo much tool wear when it is impinged by positive ions. Thus the localised temperature rise has to be less by tailoring or properly choosing its properties or even when temperature increases, there would be less melting. Further, the tool should be easily workable as intricate shaped geometric features are machined in EDM. Thus the basic characteristics of electrode materials are:

- High electrical conductivity – electrons are cold emitted more easily and there is less bulk electrical heating
- High thermal conductivity – for the same heat load, the local temperature rise would be less due to faster heat conducted to the bulk of the tool and thus less tool wear
- Higher density – for the same heat load and same tool wear by weight there would be less volume removal or tool wear and thus less dimensional loss or inaccuracy
- High melting point – high melting point leads to less tool wear due to less tool material melting for the same heat load
- Easy manufacturability
- Cost – cheap

The followings are the different electrode materials which are used commonly in the industry:

- Graphite
- Electrolytic oxygen free copper
- Tellurium copper – 99% Cu + 0.5% tellurium
- Brass

7. Modelling of Material Removal and Product Quality

Material removal in EDM mainly occurs due to intense localised heating almost by point heat source for a rather small time frame. Such heating leads to melting and crater formation as shown in Fig. 3.

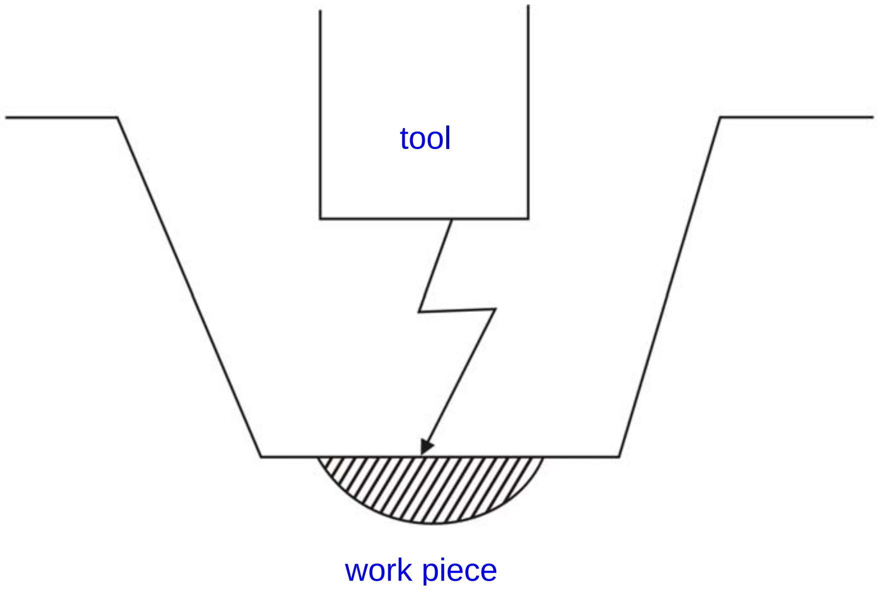


Fig. 3 *Schematic representation of crater formation in EDM process.*

The molten crater can be assumed to be hemispherical in nature with a radius r which forms due to a single pulse or spark. Hence material removal in a single spark can be expressed as

$$\Gamma_s = \frac{2}{3}\pi r^3$$

Now as per Fig. 2, the energy content of a single spark is given as

$$E_s = VIt_{on}$$

A part of this spark energy gets lost in heating the dielectric, and rest is distributed between the impinging electrons and ions. Thus the energy available as heat at the workpiece is given by

$$E_w \quad \alpha \quad E_s$$

$$E_w = kE_s$$

Now it can be logically assumed that material removal in a single spark would be proportional to the spark energy. Thus

$$\Gamma_s \quad \alpha \quad E_s \quad \alpha \quad E_w$$

$$\therefore \quad \Gamma_s = gE_s$$

Now material removal rate is the ratio of material removed in a single spark to cycle time.

Thus

$$MRR = \frac{\Gamma_s}{t_c} = \frac{\Gamma_s}{t_{on} + t_{off}}$$

$$MRR = g\frac{VIt_{on}}{t_{on} + t_{off}} = g\frac{VI}{\left(1 + \frac{t_{off}}{t_{on}}\right)}$$

The model presented above is a very simplified one and linear relationship is not observed in practice. But even then such simplified model captures the complexity of EDM in a very efficient manner. MRR in practice does increase with increase in working voltage, current, pulse on time and decreases with increase in pulse off time. Product quality is a very important characteristic of a manufacturing process along with MRR. The followings are the product quality issues in EDM

- Surface finish
- Overcut
- Tapercut

No two sparks take place side by side. They occur completely randomly so that over time one gets uniform average material removal over the whole tool cross section. But for the sake of simplicity, it is assumed that sparks occur side by side as shown in Fig. 4.

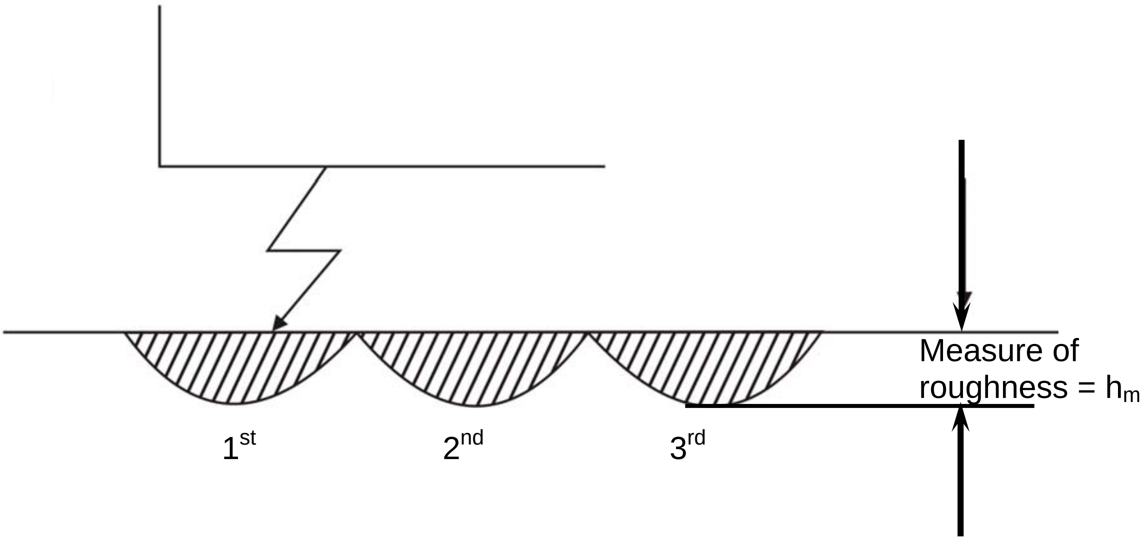


Fig. 4 *Schematic representation of the sparks in EDM process.*

Thus

$$h_m = r \quad \text{and} \qquad \Gamma_s = \frac{2}{3}\pi r^3$$

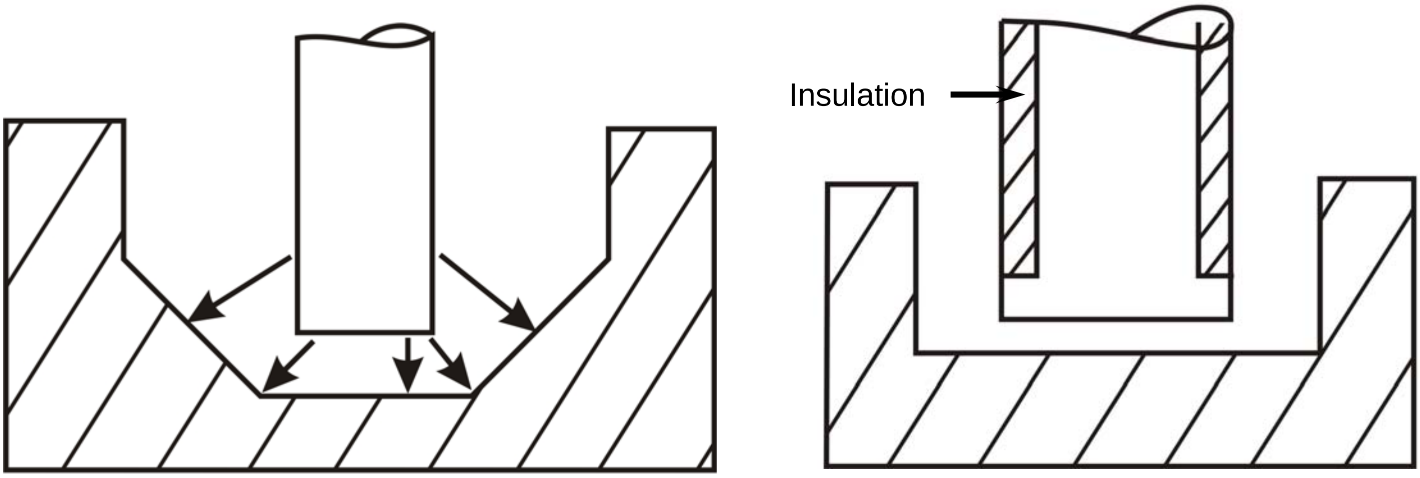
$$\therefore \quad r = h_m = \left(\frac{3}{2}\Gamma_s\right)^{1/3}$$

Now $\quad \Gamma_s = gE_s = gVIt_{on}$

$$\therefore \quad h_m \quad \alpha \quad (\Gamma_s)^{1/3} \quad \alpha \quad \{VIt_{on}\}^{1/3}$$

Thus it may be noted that surface roughness in EDM would increase with increase in spark energy and surface finish can be improved by decreasing working voltage, working current and pulse on time.

In EDM, the spark occurs between the two nearest point on the tool and workpiece. Thus machining may occur on the side surface as well leading to overcut and tapercut as depicted in Fig. 5. Taper cut can be prevented by suitable insulation of the tool. Overcut cannot be prevented as it is inherent to the EDM process. But the tool design can be done in such a way so that same gets compensated.



tapercut and overcut

tapercut prevention

Fig. 5 *Schematic depiction of taper cut and over cut and control of taper cut*

8. Equipment

Fig. 6 shows an EDM machine. EDM machine has the following major modules

- Dielectric reservoir, pump and circulation system
- Power generator and control unit
- Working tank with work holding device
- X-y table accommodating the working table
- The tool holder
- The servo system to feed the tool

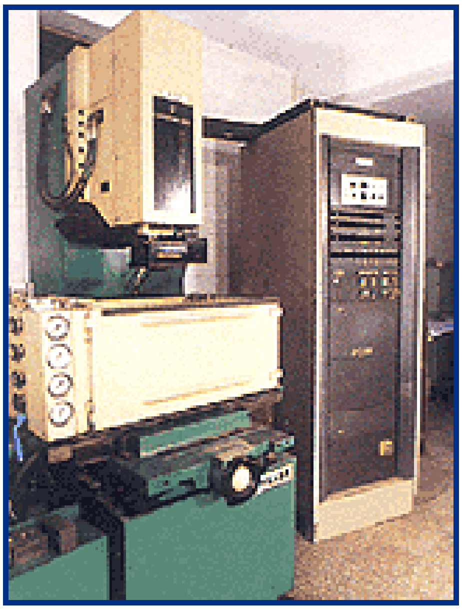


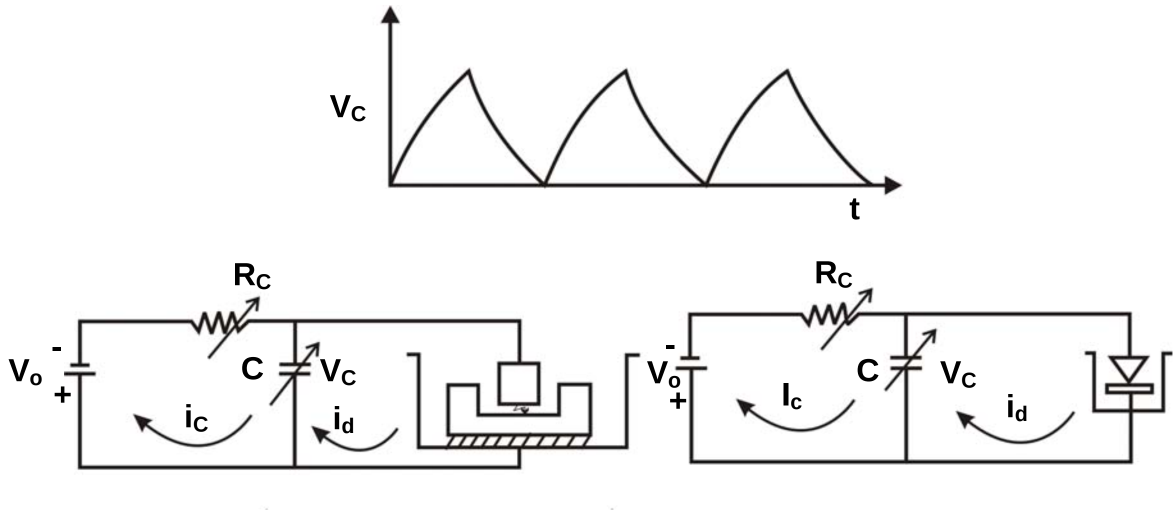
Fig. 6 *Commercial Electro-discharge Machine*

9. Power generator

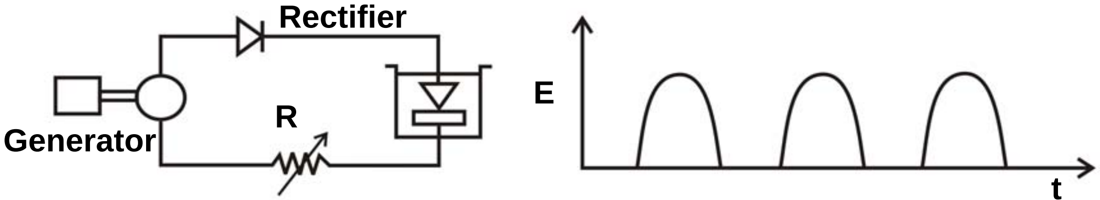
Fig. 2 depicted general nature of voltage pulses used in electro-discharge machining. Different power generators are used in EDM and some are listed below:

- Resistance-capacitance type (RC type) Relaxation generator
- Rotary impulse type generator
- Electronic pulse generator
- Hybrid EDM generator

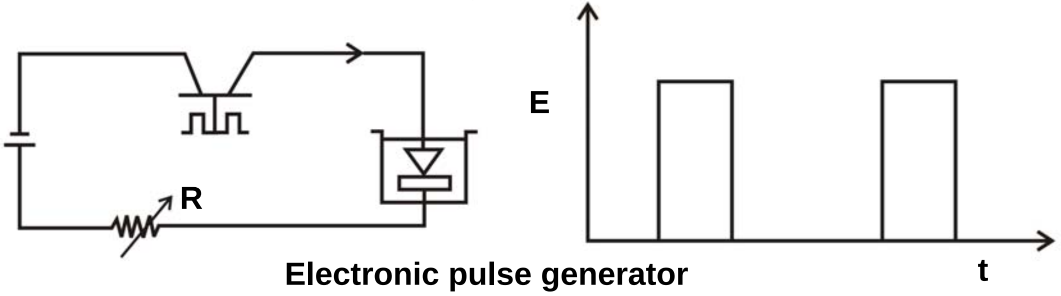
Fig. 7 shows the basic circuit for different type of EDM generators



RC type Relaxation generator



Rotary impulse generator with rectifier



Electronic pulse generator

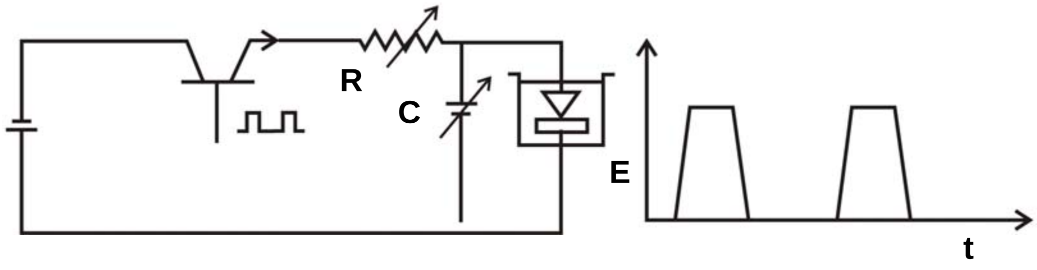


Fig. 7 *Basic circuits for different types of EDM generators.*

10. Analysis of RC type Relaxation EDM Generator

In RC type generator, the capacitor is charged from a DC source. As long as the voltage in the capacitor is not reaching the breakdown voltage of the dielectric medium under the prevailing machining condition, capacitor would continue to charge. Once the breakdown voltage is reached the capacitor would start discharging and a spark would be established between the tool and workpiece leading to machining. Such discharging would continue as long as the spark can be sustained. Once the voltage becomes too low to sustain the spark, the charging of the capacitor would continue. Fig. 8 shows the working of RC type EDM relaxation.

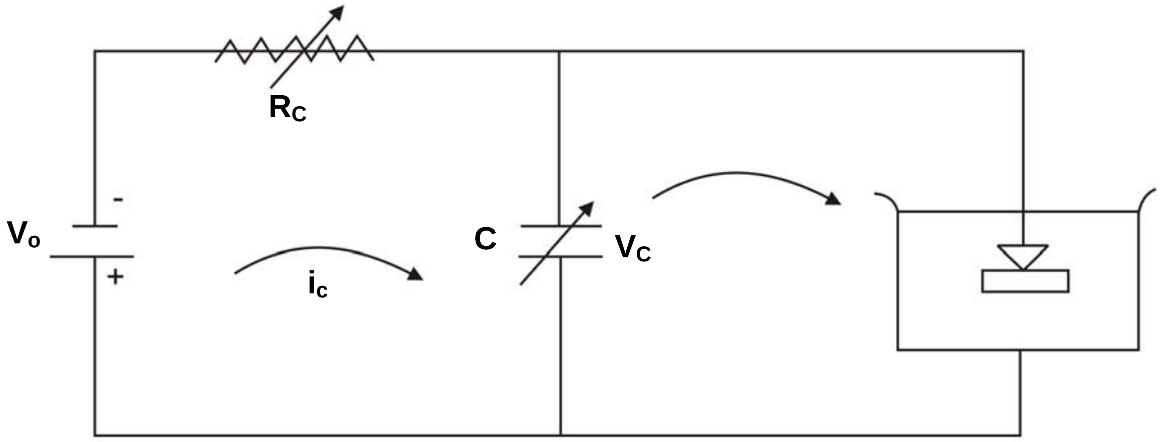


Fig. 8 *Schematic of the working principle of RC type EDM relaxation circuit.*

During charging, at any instant, from circuit theory,

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or $$\frac{dV}{V_o - V_c} = \frac{1}{CR_c}dt$$

At t=0, V_c=0 and t = t_c, V_c=V_c*

$$\therefore \int_0^{V_c*} \frac{dV_c}{V_o - V_c} = \frac{1}{CR_c}\int_0^{t_c} dt$$

$$\Rightarrow -\frac{t_c}{R_c} = \left|\ln(V_o - V_c)\right|_0^{V_c*}$$

$$\therefore V_c * = V_o\left\{1 - e^{-\frac{t_c}{R_cC}}\right\}$$

or $$V_c = V_o\left\{1 - e^{-\frac{t}{R_cC}}\right\}$$

where, I_c = charging current
V_o= open circuit voltage
R_c= charging resistance
C = capacitance
V_c= instantaneous capacitor voltage during charging

Thus at any instant charging current, i_c, can be given as:

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

$$i_c = \frac{V_o e^{-\frac{t}{R_c C}}}{R_c} = i_o . e^{-\frac{t}{R_c C}}$$

During discharging, the electrical load coming from the EDM may be assumed a totally resistive and is characterised by a machine resistance of R_m. then the current passing through the EDM machine is given by

$$i_d = \frac{V_c}{R_m} = -C\frac{dV_c}{dt}$$

where, I_d = discharge current or current flowing through the machine
V_c= instantaneous capacitor voltage during discharging
R_m= machine resistance

The negative sign in front of the derivative of the voltage represents that the V_c is gradually decreasing during discharging.

Now at t = 0 (i.e. at the start of discharging, i.e. initiation of the spark), V_c=V_c* and at t = t_d, V_c=V_d*

$$\int_{V_c^*}^{V_d^*} \frac{dV_c}{V_c} = -\frac{1}{CR_m}\int_0^{t_d} dt$$

$$\therefore \quad -\frac{t_d}{CR_m} = \ln\frac{V_d^*}{V_c^*}$$

$$\therefore \quad V_d^* = \frac{V_c^*}{R_m} . e^{-\frac{t_d}{R_m C}}$$

$\therefore$ The discharging or the machining current I_d is given by

$$i_d = \frac{V_d}{R_m} = \frac{V_c^*}{R_m} . e^{-\frac{t}{R_m C}}$$

Thus the voltage and the current pulses during charging and discharging is given in Fig. 9.

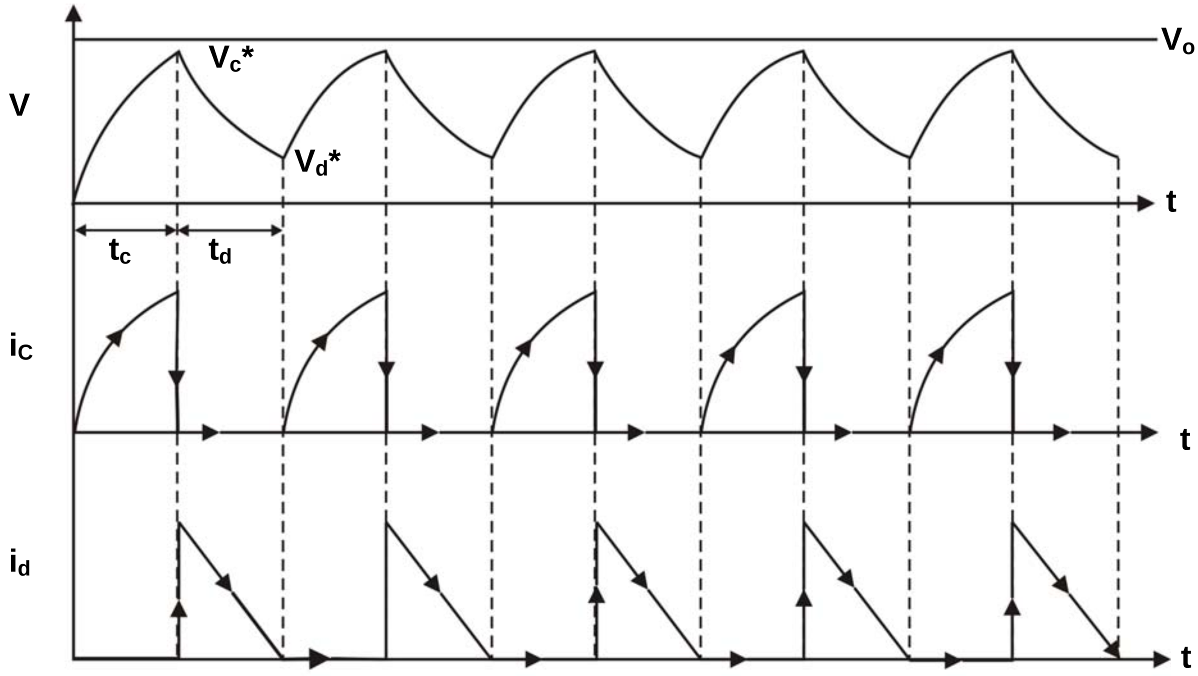

Fig. 9 *Schematic representation of the current pulses during charging and discharging in EDM process.*

For maximum power dissipation in RC type EDM generator $V_c^* = 0.716\ V_o$.
The charging time or idle time or off time, t_c, can be expressed as

$$t_c = -\frac{R_c C}{\ln\left(1 - \frac{V_c^*}{V_c}\right)}$$

The discharging time or machining time or on time can be expressed as

$$t_d = -\frac{R_m C}{\ln\left(\frac{V_d}{V_c^*}\right)^*}$$

∴ Frequency of operation, f

$$f = \frac{1}{t_c + t_d} = \frac{1}{\frac{R_c C}{\ln\left(1 - \frac{V_c^*}{V_c}\right)} + \frac{R_m C}{\ln\left(\frac{V_d}{V_c^*}\right)}}$$

Total energy discharged through spark gap

$$= \int_0^{t_d} i_d^2 R_m dt = \int_0^{t_d} \frac{V_c^{*2}}{R_m^2} R_m e^{-\frac{2t}{R_m C}} dt$$

$$= \frac{V_c^{*2}}{R_m} \int_o^{t_d} e^{-\frac{2t}{R_m C}} dt$$

$$= \frac{V_c^{*2}}{R_m} \cdot \frac{R_m C}{2t} \left| -e^{-\frac{2t}{R_m C}} \right|_0^{t_d}$$

$$= \frac{1}{2} C V_c^{*2} \left\{ 1 - e^{-\frac{2t_d}{R_m C}} \right\}$$

$$\cong \frac{1}{2} C V_c^{*2}$$

Quiz Test

1. Which of the following material cannot be machined by EDM
   (a) steel
   (b) WC
   (c) Titanium
   (d) Glass

2. w(W)hich of the following is used as dielectric medium in EDM
   (a) tap water
   (b) kerosene
   (c) NaCL solution
   (d) KOH solution

3. Tool should not have
   (a) low thermal conductivity
   (b) high machinability
   (c) high melting point
   (d) high specific heat

Problems

1. In a RC type generator, the maximum charging voltage is 80 V and the charging capacitor is 100 μF. Determine spark energy.

2. If in a RC type generator, to get an idle time of 500 μs for open circuit voltage of 100 V and maximum charging voltage of 70 V, determine charging resistance. Assume C = 100 μF.

3. For a RC type generator to get maximum power dissipation during charging $V_c^* = V_o x0.716$. Determine idle time for R_c = 10 Ω and C = 200 μF

4. Determine on time or discharge time if V_o = 100 V and V_d^* = 15 V. Spark energy = 0.5 J. Generator is expected for maximum power during charging. Machine resistance = 0.5 Ω.

Solution to the Quiz Test

1 – (d)
2 – (b)
3 – (a)

Solutions to the Problems

Solution to Prob. 1

$$E_s = \frac{1}{2}CV^2 = \frac{1}{2}x100x10^{-6}x80^2 = 0.32J$$ **answer**

Solution to Prob. 2

$$t_c = -\frac{R_c C}{\ln\left(1 - \frac{V_c{}^*}{V_c}\right)}$$

$$500x10^{-6} = -\frac{R_c x100x10^{-6}}{\ln\left(1 - \frac{70}{100}\right)}$$

$R_C \cong 6\ \Omega$ **Answer**

Solution to Prob. 3

$$t_c = -\frac{R_c C}{\ln\left(1 - \frac{V_c^*}{V_o}\right)} = -\frac{10x200x10^{-6}}{\ln(1 - 0.716)}$$

t_c = 1.58 ms **answer**

Solution to Prob. 4

$$V_c^* = 0.716V_o = 71.6\ V$$

$$E_s = \frac{1}{2}CV^2 = 0.5\ J$$

$$\therefore\quad C = 2x0.5x\frac{1}{(71.6)^2} = 195\ \mu F$$

$$t_d = -\frac{R_m C}{\ln\left(\frac{V_d^*}{V_c^*}\right)} = 62\ \mu F$$ **answer**