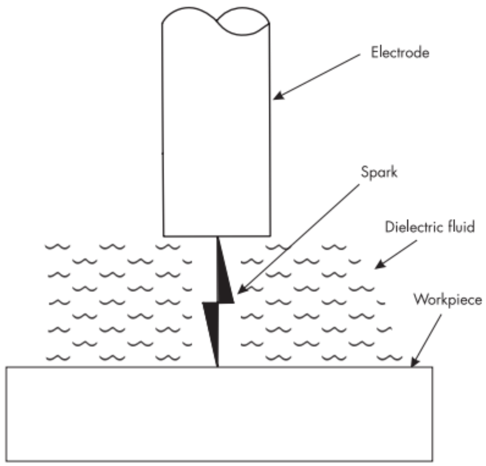
Electrical Discharge Machining

ME688: Advanced Machining Processes
Instructor: R K Mittal

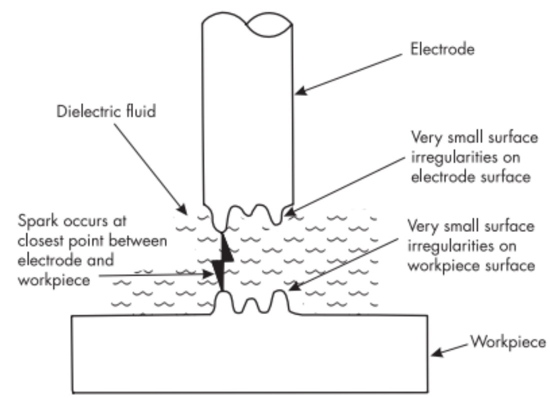
Introduction

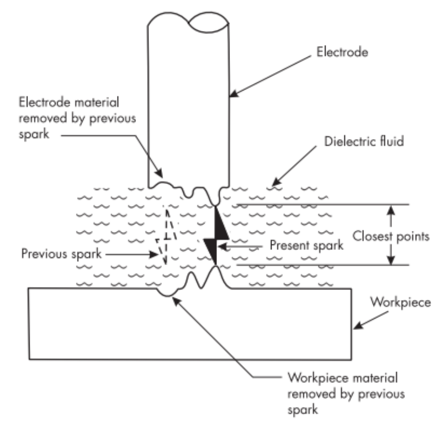
- Process for machining of electrically conductive materials
- Material removal by precisely controlled sparks that occur between an electrode and a workpiece in the presence of a dielectric fluid
- The electrode may be considered the cutting tool
- The electrode does not make physical contact with the workpiece for material removal
- Since the electrode does not contact the workpiece, EDM has no tool force
- The electrode must always be spaced away from the workpiece by the distance required for sparking, known as the sparking gap



Introduction

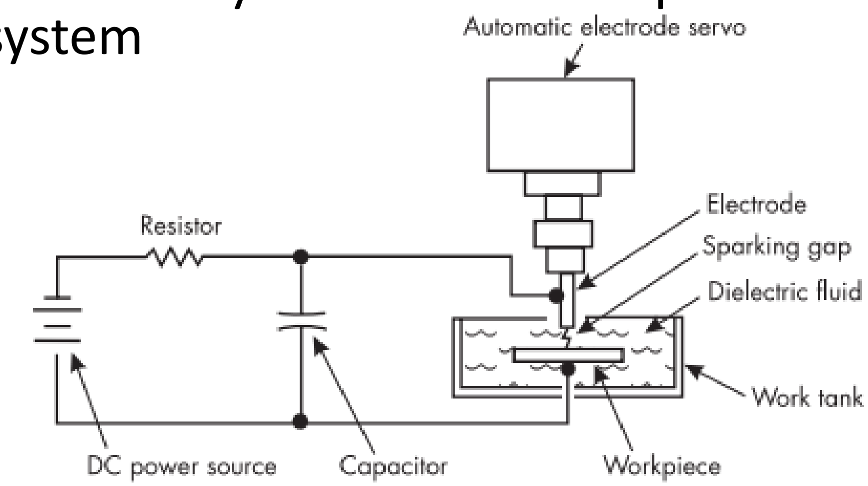
- As gap is reduced, the current intensity becomes greater than the strength of the dielectric causing it to break
- This phenomenon is the same as the breakdown of a capacitor
- This allows current to flow between the two electrodes. As a result, material is removed from both the electrodes
- Once the current flow stops, new liquid dielectric is usually conveyed into the electrode zone enabling the solid particles (debris) to be carried away
- Adding new liquid dielectric in the electrode volume is commonly referred to as flushing
- Also, after a current flow, a difference of potential between the two electrodes is restored to what it was before the breakdown, so that a new liquid dielectric breakdown can occur





Development of EDM

- In 1770, English Physicist Joseph Priestley studied the erosive effect of electrical discharges
- EDM process was developed almost simultaneously in the USA and the USSR at the beginning of World War II
- In 1943, the Lazarenkos developed a spark-machining process with an electrical circuit that used many of the same components as the automobile ignition system



Lazarenko resistor-capacitor (R-C) EDM machine

Development of EDM

- At the same time Stark, Harding, and Beaver work became the basis for the vacuum-tube EDM machine and an electronic-circuit servo system that automatically provided the proper electrode-to-workpiece spacing for sparking, without the electrode contacting the workpiece
- The vacuum tube made it possible to increase spark frequency from 60 times per second to thousands of sparks per second
- In 1952, the manufacturer Charmilles created the first machine using the spark machining process and was presented for the first time at the European Machine Tool Exhibition in 1955

Lazarenko resistor-capacitor (R-C) EDM machine

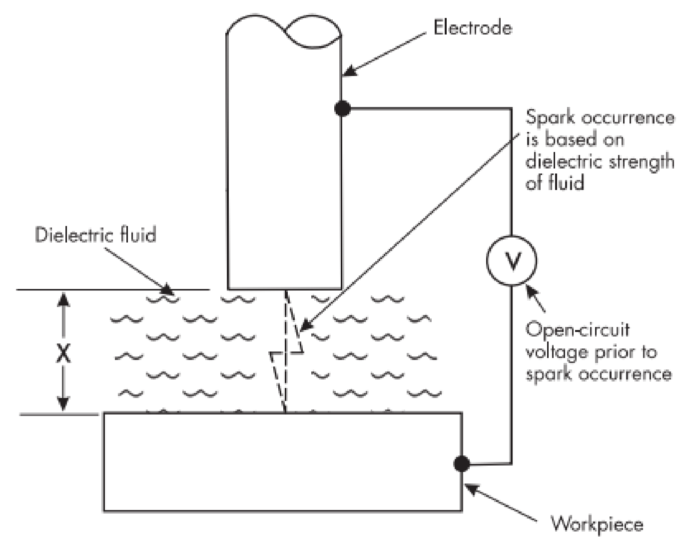
Development of EDM

- In 1967, a numerical controlled wire-cut EDM machine produced in the USSR was displayed at a machine exposition in Montreal, Quebec, Canada
- Seibu developed the first CNC wire EDM machine in 1972 and the first system was manufactured in Japan
- Recently, the machining speed has gone up by 20 times
- This has decreased machining costs by at least 30 percent and improved the surface finish by a factor of 1.5

Lazarenko resistor-capacitor (R-C) EDM machine

Mechanism of Material Removal

- The removal of material is based upon the electrodischarge erosion (EDE) effect of electric sparks occurring between two electrodes that are separated by a dielectric liquid
- Material removal takes place as a result of the generation of extremely high temperatures generated by the high-intensity discharges that melt and evaporate the two electrodes.



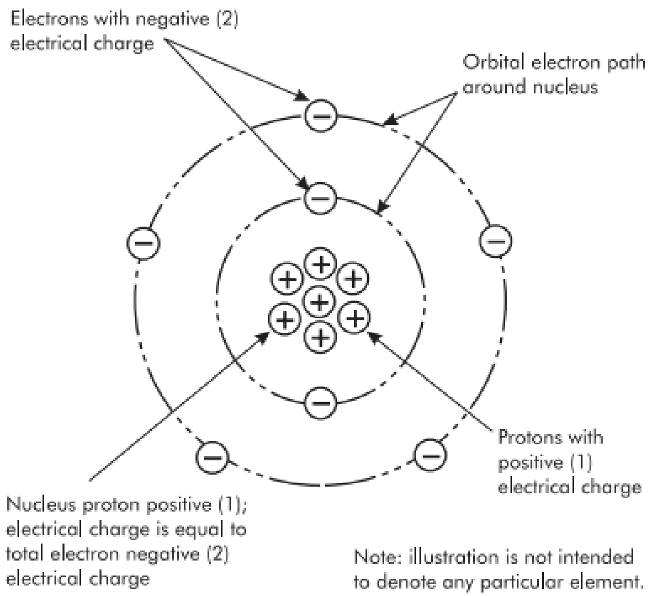
Mechanism of Material Removal

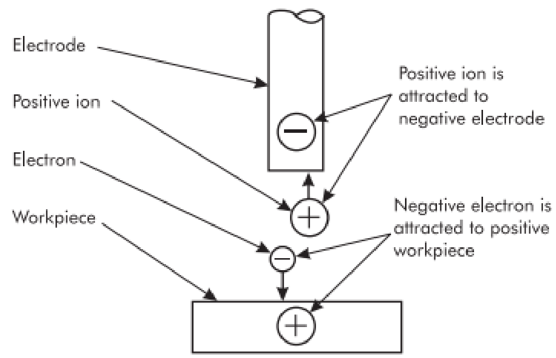
Ionization

- When electrode comes closer to workpiece, the dielectric fluid ionizes and changes from an electrical insulator into an electrical conductor
- Electricity flows between the electrode and the workpiece through the ionized dielectric fluid
- After ionization of the dielectric fluid, electricity continues to flow through the fluid until spark energy is OFF
- Once OFF, the dielectric fluid deionizes and the fluid, again, becomes an electrical insulator.
- This process of dielectric-fluid ionization and deionization occurs for each spark
- While EDM machining is in progress, dielectric-fluid ionization and deionization takes place thousands of times each second

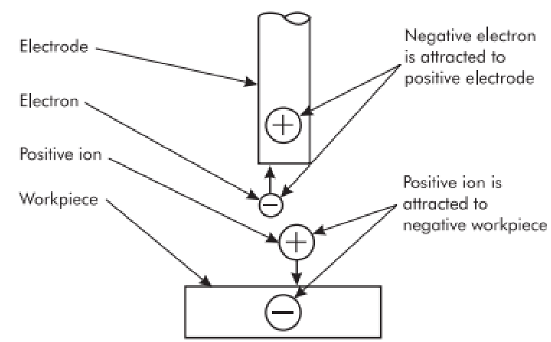
Mechanism of Material Removal

Ionization





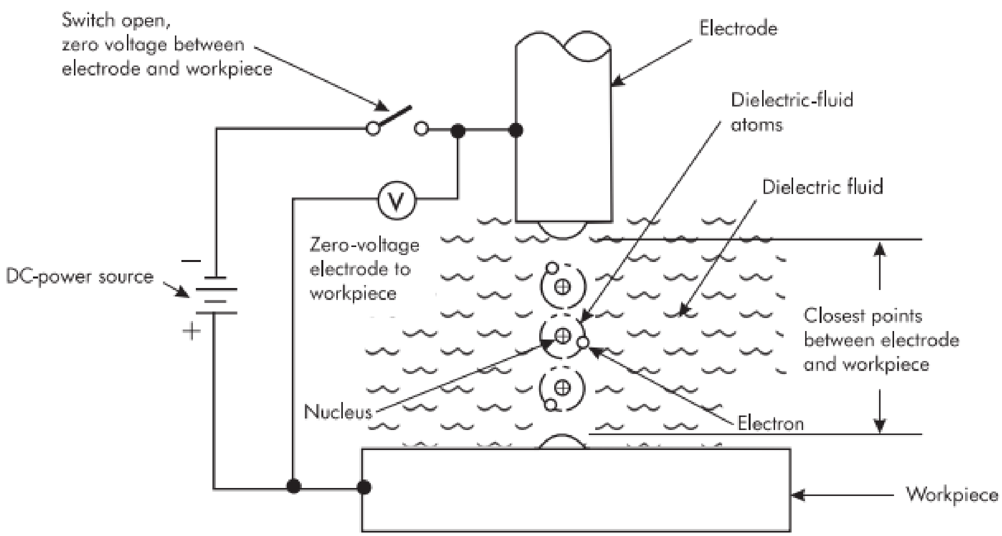
A. Negative electrode polarity



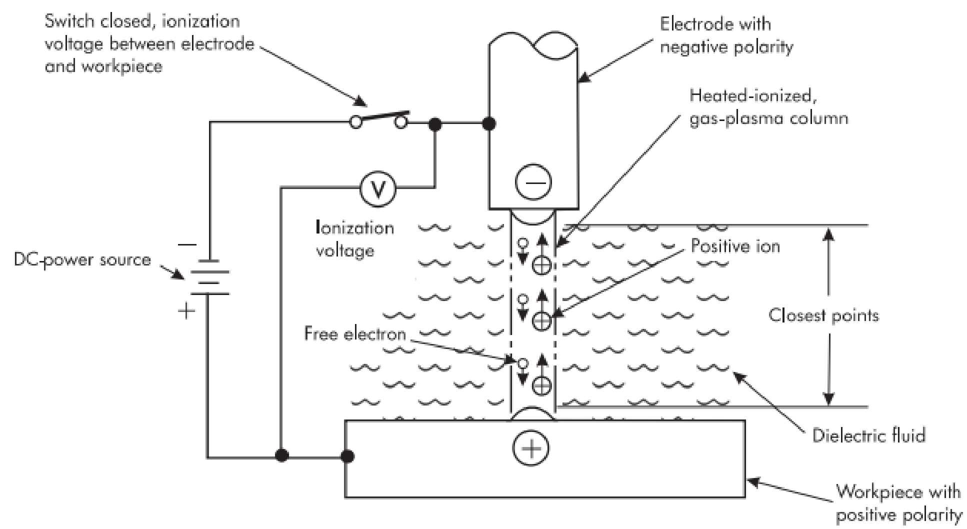
B. Positive electrode polarity

Mechanism of Material Removal

Ionization



No voltage



With voltage

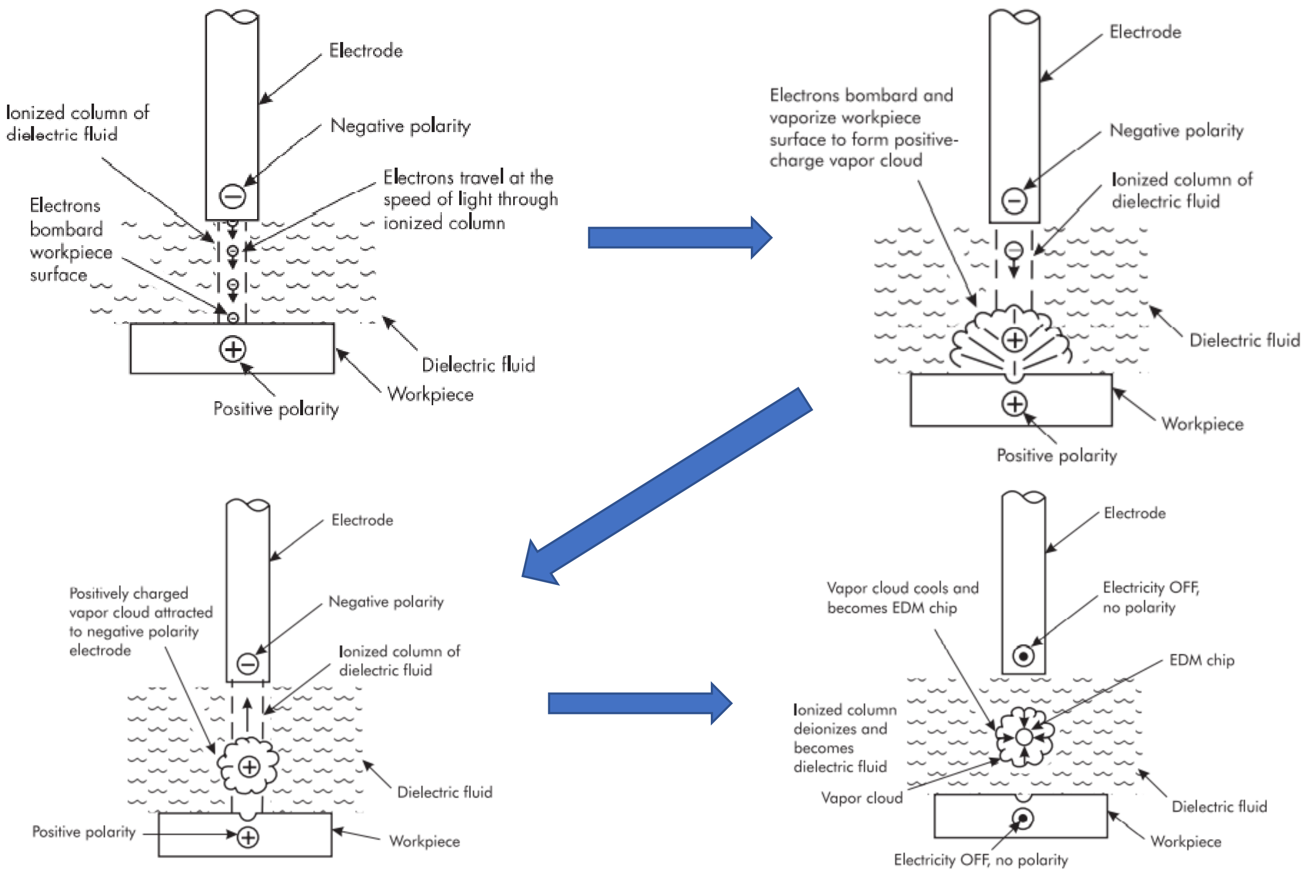
Mechanism of Material Removal

- The EDM process removes material by thermal energy, an indicator that heat is involved
- The temperature at the spark is actually high enough to vaporize the material
- Thermal energy is provided by electricity flowing between the electrode and workpiece in the form of a spark
- Amperes are used to denote the amount of electricity used in the machining process

Mechanism of Material Removal

- As electrons bombard the workpiece, releasing their energy in the form of heat, this vaporizes the workpiece surface into a cloud
- Since the workpiece has positive polarity, the vapor cloud is also positively charged
- This positively charged vapor cloud is attracted to the negatively charged electrode
- During the time that the vapor cloud is in transit toward the electrode, the spark electricity is turned OFF
- This eliminates the vapor cloud's electrical attraction to the electrode
- The dielectric fluid deionizes, and the vapor cloud is cooled to form an EDM chip

Mechanism of Material Removal

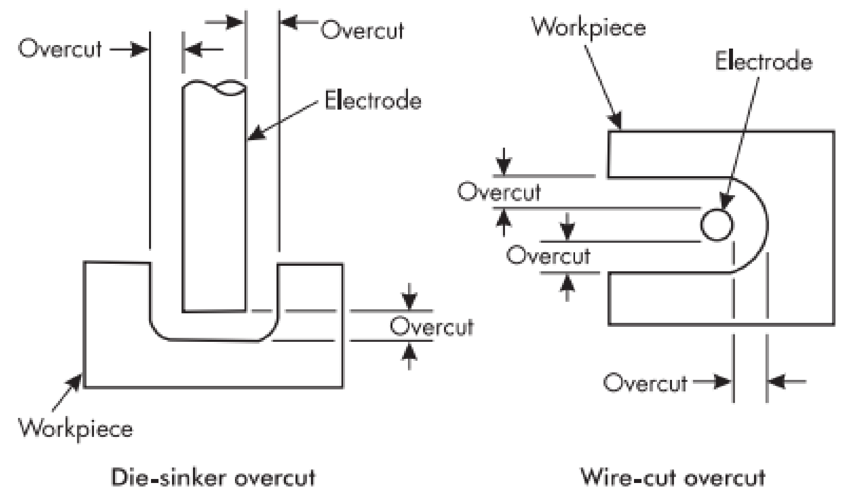


Mechanism of Material Removal

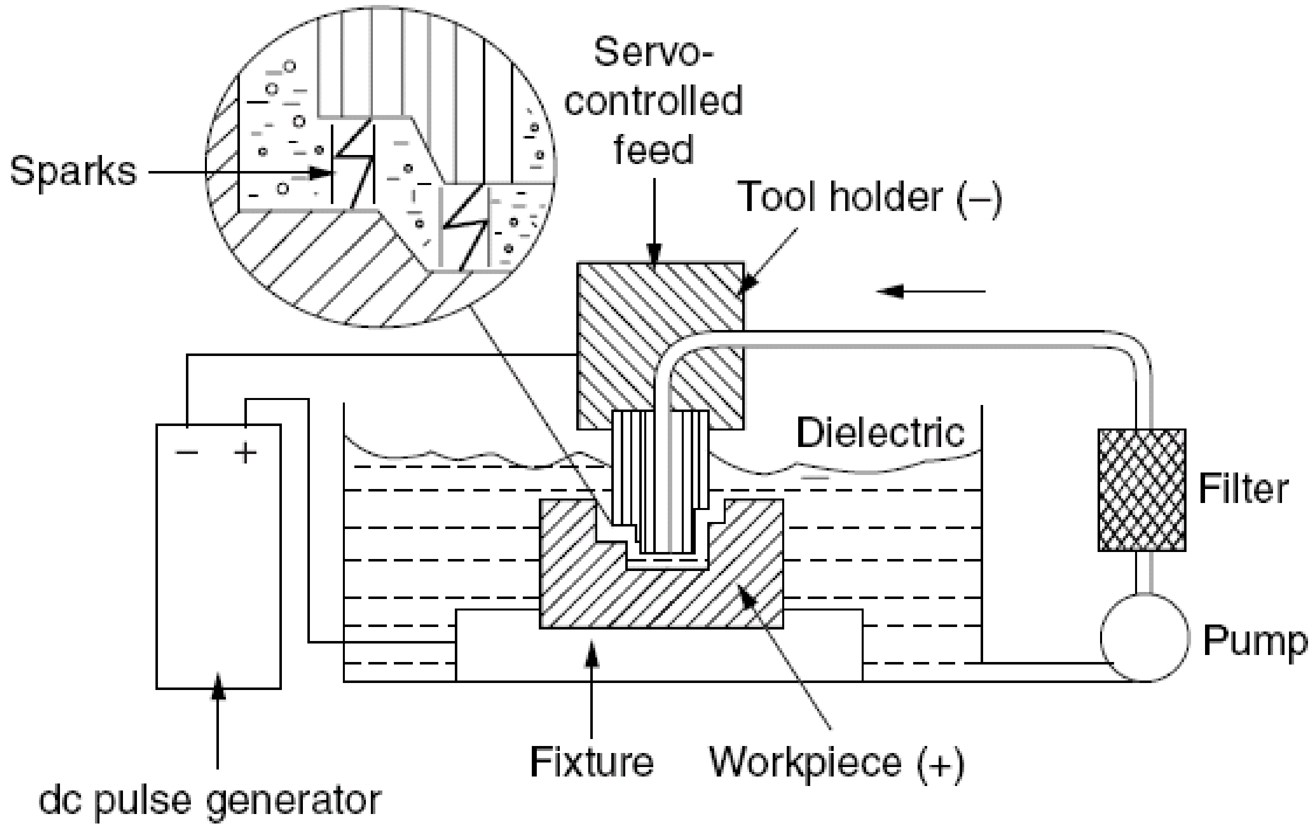
- Negative electrons bombard the positive workpiece surface and positive ions bombard the negative electrode surface
- This bombardment causes the surface materials of both the electrode and workpiece to be vaporized with each spark
- The weight of a positive ion, consisting of the atom nucleus and remaining electrons, is thousands of times greater than the weight of an electron
- Since the positive ion has such a heavy weight, it accelerates much slower than the electron
- Fewer positive ions than electrons arrive at the bombardment surface during sparking, which is why electrons are considered the primary source of energy for EDM material removal

Overcut in EDM

- Overcut is the gap distance between the electrode and the workpiece's machined surface produced by sparking
- Sparking overcut accurately follows the electrode shape without regard to size, shape, or number of electrodes in use
- The overcut produced from a male-shaped electrode having sharp corners produces a corner radius in the machined workpiece



EDM System


Sparks
Servo-
controlled
feed
Tool holder (–)
Dielectric
Filter
Pump
−
+
dc pulse generator
Fixture
Workpiece (+)

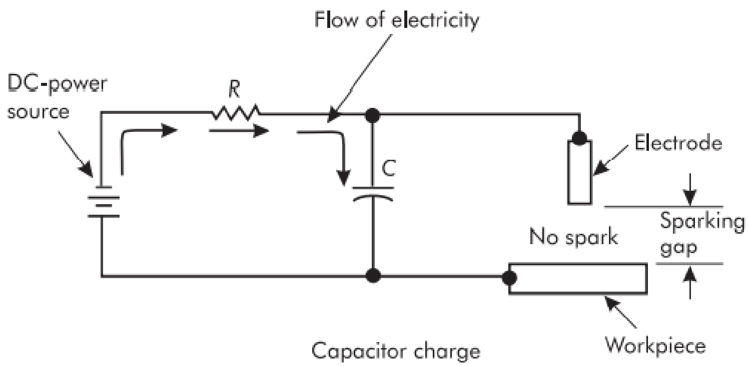
Power Supply System

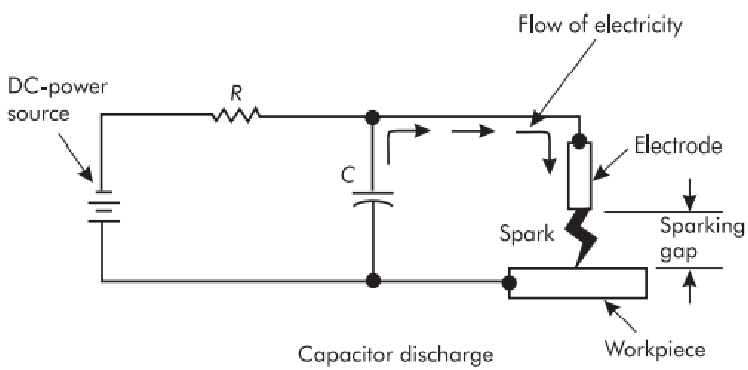
- Two types of EDM-power supplies:
  - resistor-capacitor power supply
  - Transistor controlled pulse-power supply
- The sparks produced by the resistor-capacitor (R-C) and the pulse-power supply are quite different and depend on waveform

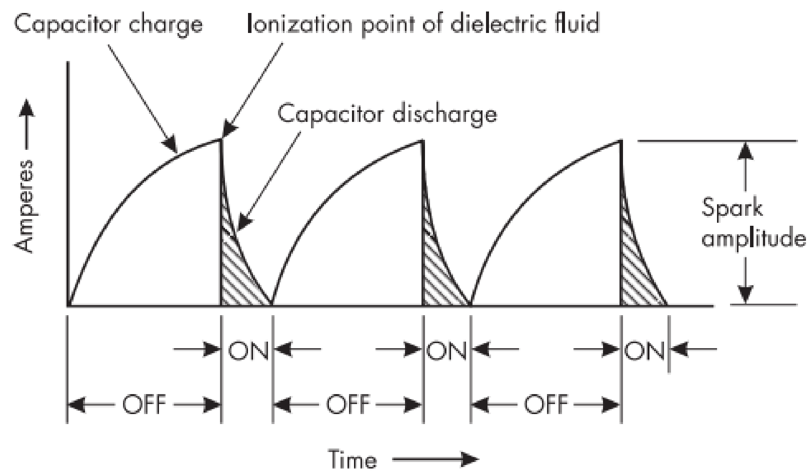
Resistor-Capacitor (R-C) -Type EDM-Power Supply

- The main parameters to choose from at setup time are the resistance(s) of the resistor(s) and the capacitance(s) of the capacitor(s)
- In an ideal condition, these quantities would affect the maximum current delivered in a discharge
- Current delivery in a discharge is associated with the charge accumulated on the capacitors at a certain moment
- Little control is expected over the time of discharge, which is likely to depend on the actual spark-gap conditions
- Advantage: RC circuit generator can allow the use of short discharge time more easily than the pulse-controlled generator
- Also, the open circuit voltage (i.e. voltage between electrodes when dielectric is not broken) can be identified as steady state voltage of the RC circuit

Resistor-Capacitor (R-C) -Type EDM-Power Supply



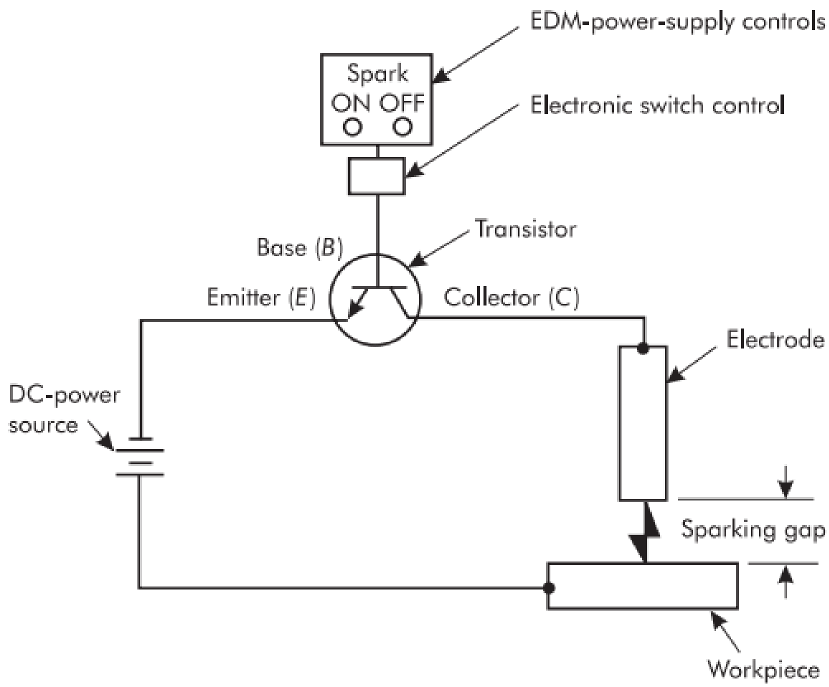


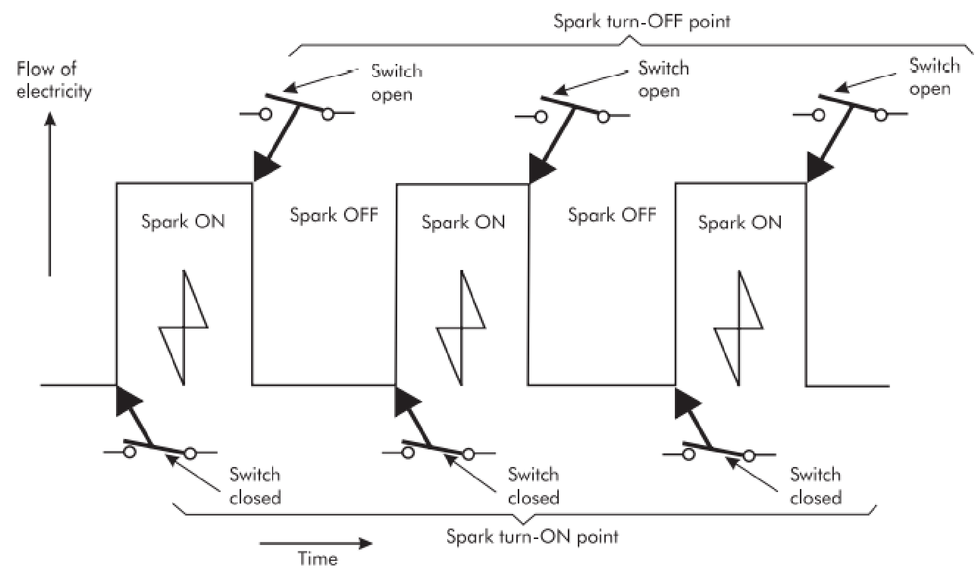


Pulse-Power Supply System

- In generators based on transistor control, the user is usually able to deliver a train of voltage pulses to the electrodes
- Each pulse can be controlled in shape, for instance, quasi-rectangular
- In particular, the time between two consecutive pulses and the duration of each pulse can be set
- The amplitude of each pulse constitutes the open circuit voltage
- Thus, maximum duration of discharge is equal to duration of a voltage pulse
- Maximum current during a discharge that the generator delivers can also be controlled

PULSE-POWER-SUPPLY WAVEFORM





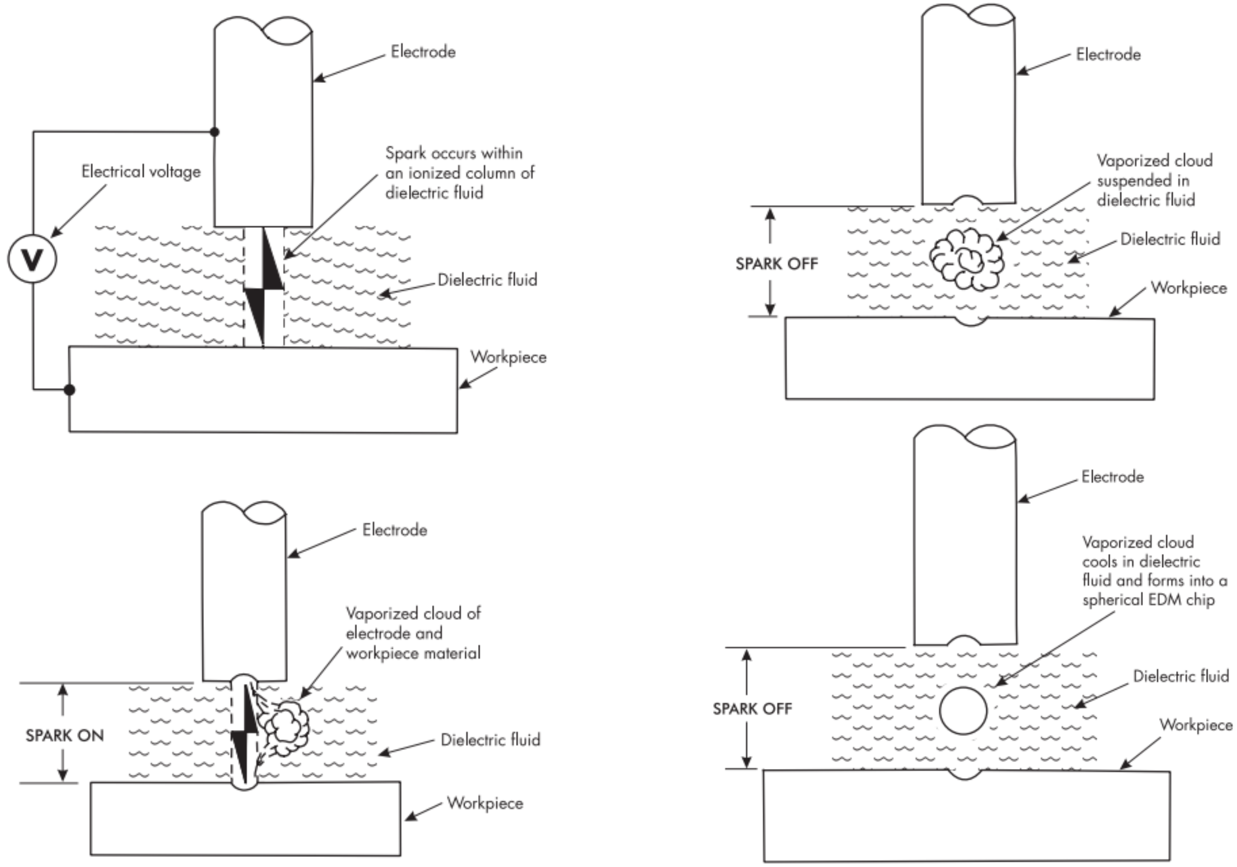
Dielectric Fluid

- A dielectric material is required to maintain the sparking gap between the electrode and workpiece
- This dielectric material is normally a fluid
- Die-sinker type EDM machines usually use hydrocarbon oil, while wire-cut EDM machines normally use deionized water
- The main characteristic of dielectric fluid is that it is an electrical insulator until enough electrical voltage is applied to cause it to change into an electrical conductor
- The dielectric fluids used for EDM machining are able to remain electrical insulators except at the closest points between the electrode and the workpiece
- At these points, sparking voltage causes the dielectric fluid to change from an insulator to a conductor and the spark occurs

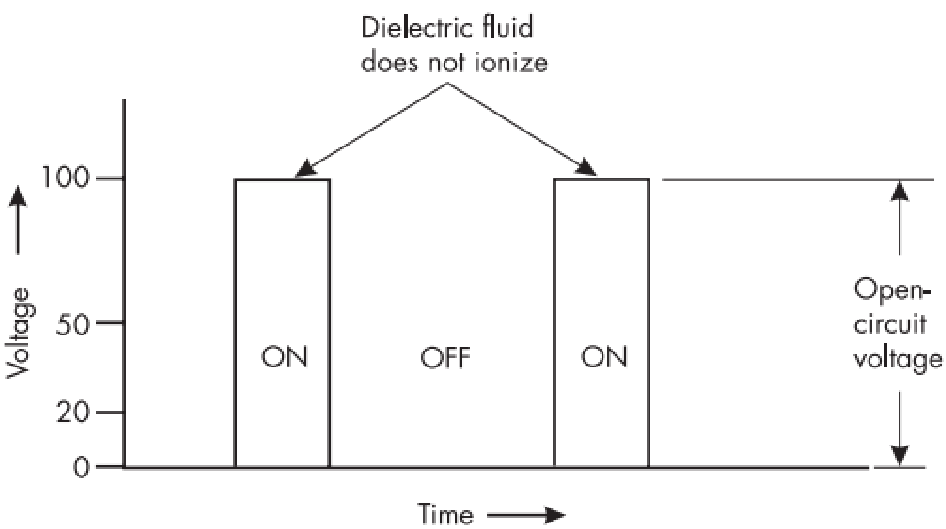
Dielectric Fluid

- The time at which the fluid changes into an electrical conductor is known as the ionization point
- When the spark is turned off, the dielectric fluid deionizes and the fluid returns to being an electrical insulator
- This change of the dielectric fluid from an insulator to a conductor, and then back to an insulator, happens for each spark
- Dielectric fluid used in EDM machines provides important functions in the EDM process. These are:
  - controlling the sparking-gap spacing between the electrode and workpiece
  - cooling the heated material to form the EDM chip
  - removing EDM chips from the sparking area

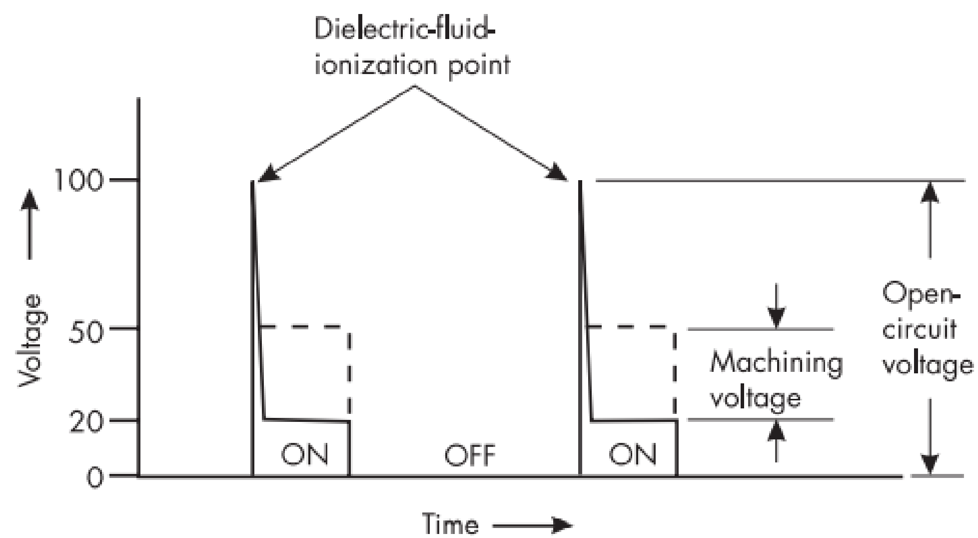
Dielectric Fluid



Voltage and Amperes

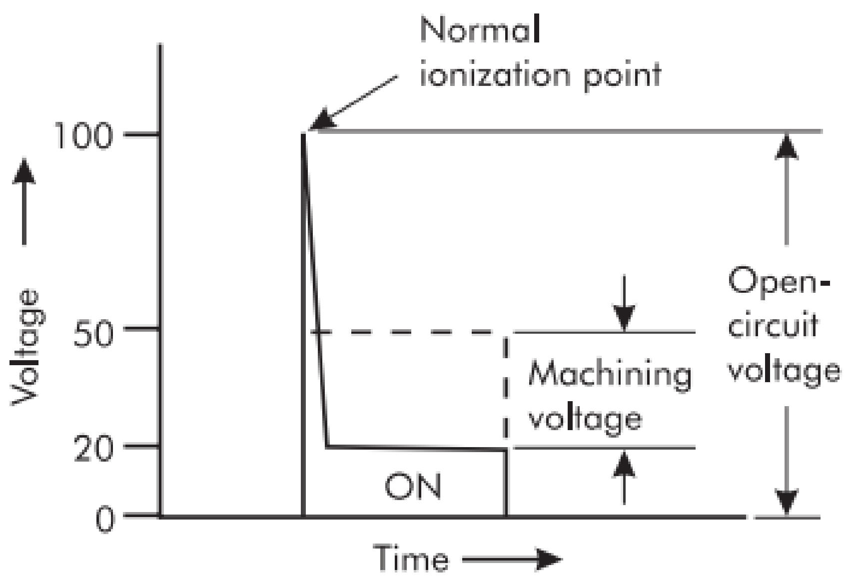


A. Sparking-gap voltage *without* dielectric-fluid ionization

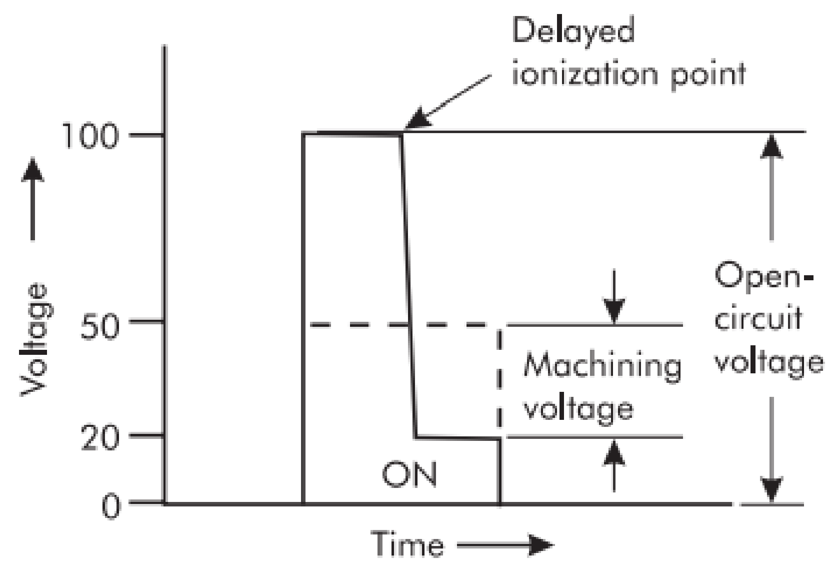


B. Sparking-gap voltage *with* dielectric-fluid ionization

Voltage and Amperes

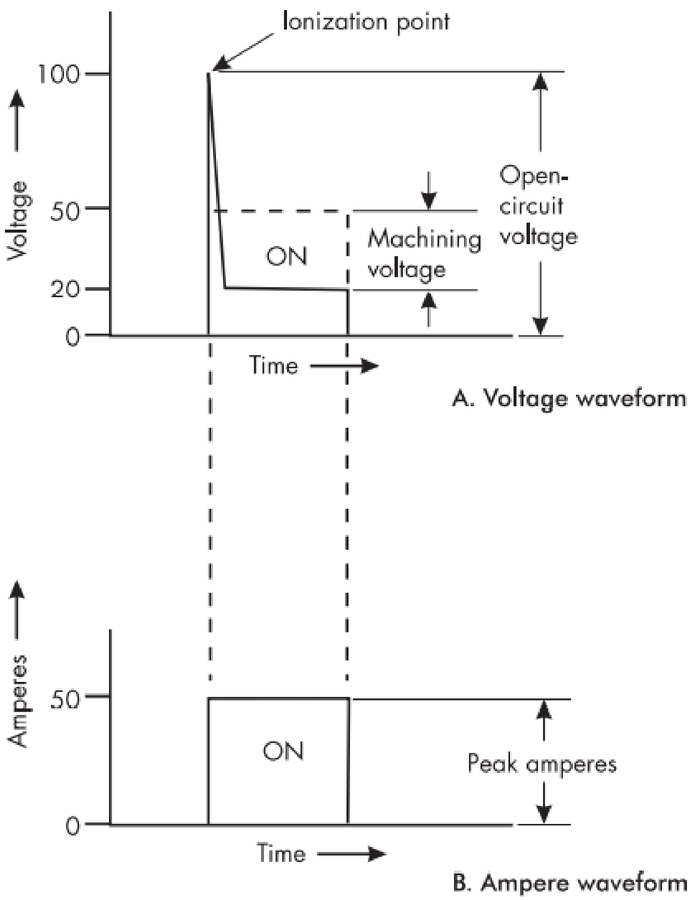


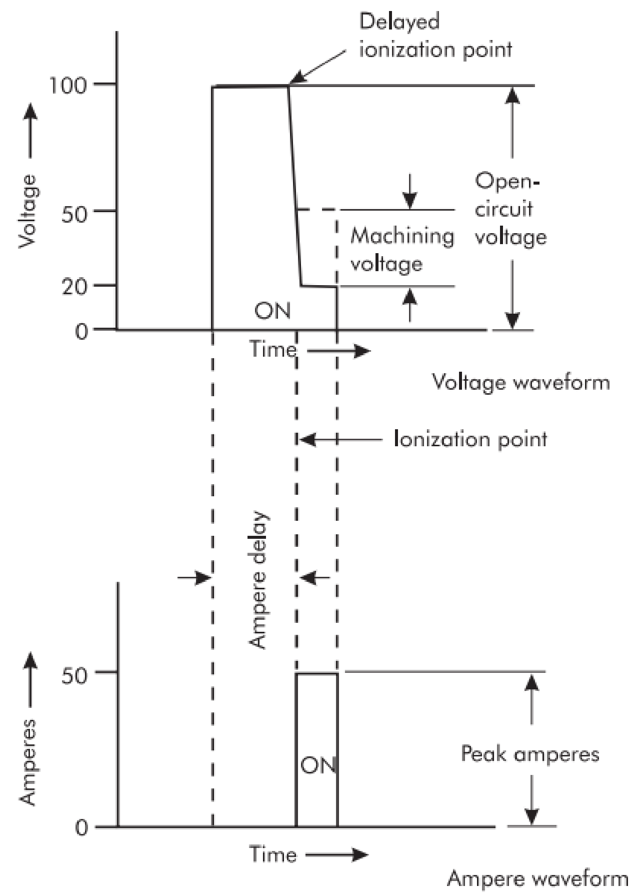
A. Normal dielectric-fluid ionization



B. Delayed dielectric-fluid ionization

Voltage and Amperes





Analysis of R-C Circuits

- Charging voltage and charging current:

The charging current (i_{ct}) flowing in charging circuit at time ‘t’ is given by

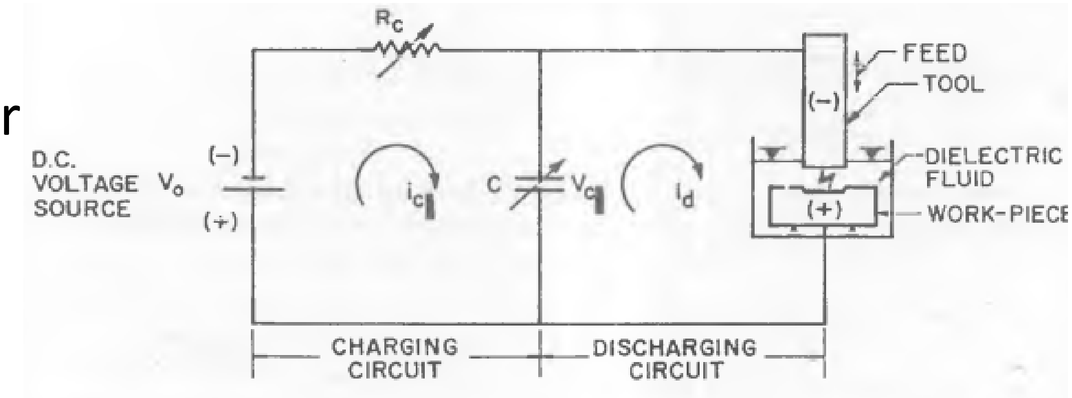
$$i_{ct} = \frac{V_0 - V_{ct}}{R_c} = C\frac{dV_{ct}}{dt}$$

V_0 = supply voltage

V_{ct} = Charged voltage of capacitor

R_c = Charging resistance

C= Capacitance



Analysis of R-C Circuits

$$i_{ct} = \frac{V_0 - V_{ct}}{R_c} = C\frac{dV_{ct}}{dt}$$

Integrating both sides;

$$\ln(V_0 - V_{ct}) = -\frac{t}{R_c C} + K$$

At t=0, $V_{ct} = 0$; $\mathrm{K} = \ln(V_0)$

$$V_{ct} = V_0\left(1 - e^{-\frac{t}{R_c C}}\right)$$

$$i_{ct} = \frac{V_0}{R_c}\left(e^{-\frac{t}{R_c C}}\right)$$

Where $R_c C$ is called time constant 'τ'

Power Delivered to the Discharging Circuit

The energy delivered to the discharging circuit at any time t is given by:

$$dE_n = \; i_{ct} V_{ct} dt = \frac{V_0}{R_c} \left(e^{-\frac{t}{\tau}}\right) V_0 \left(1 - e^{-\frac{t}{\tau}}\right) dt$$

Integrating both sides;

$$E_n = \frac{V_0^2}{R_c} \left[-\tau e^{-\frac{t}{\tau}} + \frac{\tau}{2} e^{-2\frac{t}{\tau}} \right] + K'$$

At t=0, $E_n = 0; K' = \frac{V_0^2}{R_c} \frac{\tau}{2}$

$$E_n = \frac{V_0^2 \tau}{R_c} \left[\frac{1}{2} - e^{-\frac{t}{\tau}} + \frac{1}{2} e^{-2\frac{t}{\tau}} \right]$$

Power Delivered to the Discharging Circuit

Suppose the energy E_n is delivered to the discharging circuit for time τ_c (= t) then the average power delivered (P_{avg}) is given by :

$$P_{avg} = \frac{E_n}{\tau_c} = \frac{V_0^2}{R_c x}\left[\frac{1}{2} - e^{-x} + \frac{1}{2}e^{-2x}\right]$$

Where $x = \frac{\tau_c}{\tau}$

The condition for the maximum power to be delivered to the discharging circuit is given by

$$\frac{dP_{avg}}{dx} = 0$$

$$x = 1.26 \quad V_{ct} \approx 0.72V_0$$

Current in the Discharging Circuit

The current (i_d) flowing in discharging circuit at time 't' is given by

$$i_d = \frac{V_{ct}}{R_s} = -C\,\frac{dV_{ct}}{dt}$$

V_{ct} = Charged voltage of capacitor; R_s = Sparking resistance

C= Capacitance

After integration;

$$\ln(V_{ct}) = -\frac{t}{R_s C} + K''$$

At t=0, $V_{ct} = V_{c0}$; $K'' = \ln(V_{c0})$

$$V_{ct} = V_{c0} e^{-\frac{t}{R_s C}}; \quad i_d = \frac{V_{c0}}{R_s}\left(e^{-\frac{t}{R_s C}}\right)$$

Energy dissipated across the sparking gap is given by $W_d = \frac{1}{2} C V_b^2$ calculate ??

Material Removal rate in RC Circuit

Charged voltage of capacitor $V_{ct} = V_0\left(1 - e^{-\frac{t}{R_c C}}\right)$

$$t_c = R_c C \ln\left(\frac{1}{1 - V_{ct}/V_0}\right)$$

Frequency of charging (f_c) is given by: $f_c = \frac{1}{t_c + t_d} \approx \frac{1}{t_c}$ (why??)

$$f_c = \frac{1}{R_c C}\left[\frac{1}{\ln\left(\frac{1}{1 - V_{ct}/V_0}\right)}\right]$$

Material Removal rate in RC Circuit

Material removal rate should be proportional to the total energy delivered in the sparking per second:

$$MRR \propto \frac{1}{2} C V_b^2 f_c$$

$$MRR = K_1 C V_b^2 \, \frac{1}{R_c C} \left[\frac{1}{\ln\left(\frac{1}{1 - V_{ct}/V_0}\right)} \right]$$

$$MRR \propto \frac{1}{R_c}$$

Surface Finish

- In EDM, each spark results in approximately spherical crater formation on the surface of the workpiece
- Hence, the center line average (H) value of surface finish will be a function of crater depth (h) and frequency of sparking (f_c)

$$H \propto \frac{h}{f_c}$$

- The volume of the material removed ($\propto h^3$) per discharge will be proportional to the energy delivered during sparking ($= CV_b^2/2$). Hence, $h^3 \propto CV_b^2$

$$h \propto C^{1/3}V_b^{2/3}$$

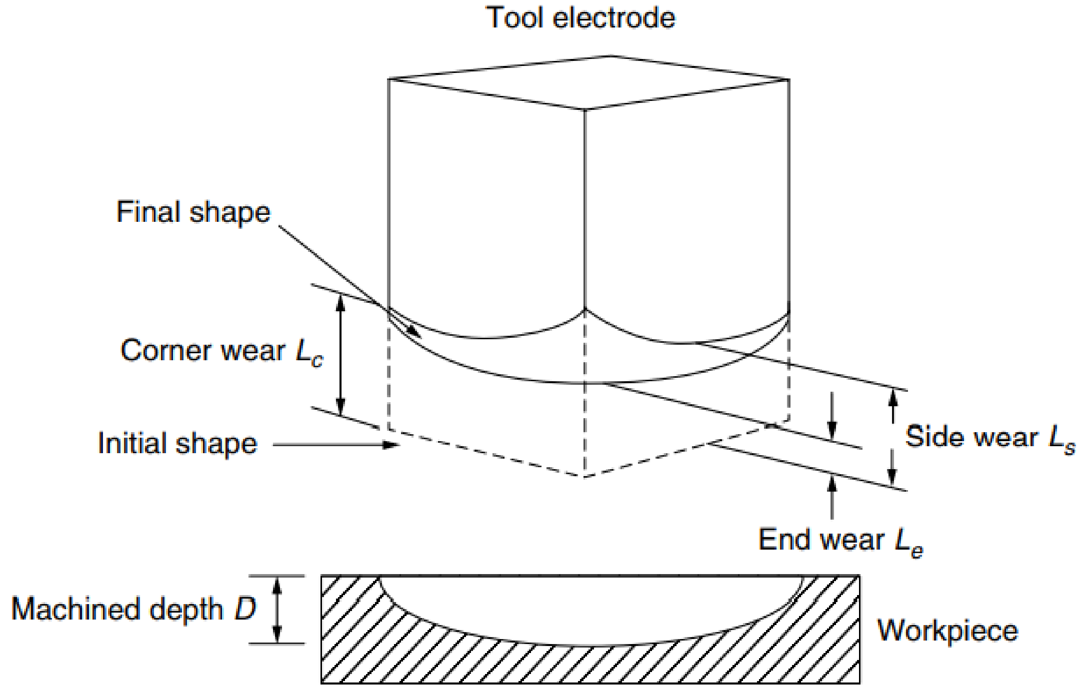
$$H \propto \frac{C^{1/3}V_b^{2/3}}{f_c}$$

Electrode Material

- Electrode materials must be electrically conductive
- Electrode should also have features such as:
  - a high melting point
  - low wear rate
  - an ability to be easily machined
  - a low cost
- Electrode Material:
  - Brass, Copper (highly stable and relatively low wear rate)
  - Copper tungsten (low wear rate, expensive, and cannot be easily shaped)
  - Graphite (easily machinable, low wear rate, and high conductivity)
  - Copper graphite
  - Zinc Alloys
  - Carbon

Electrode Wear

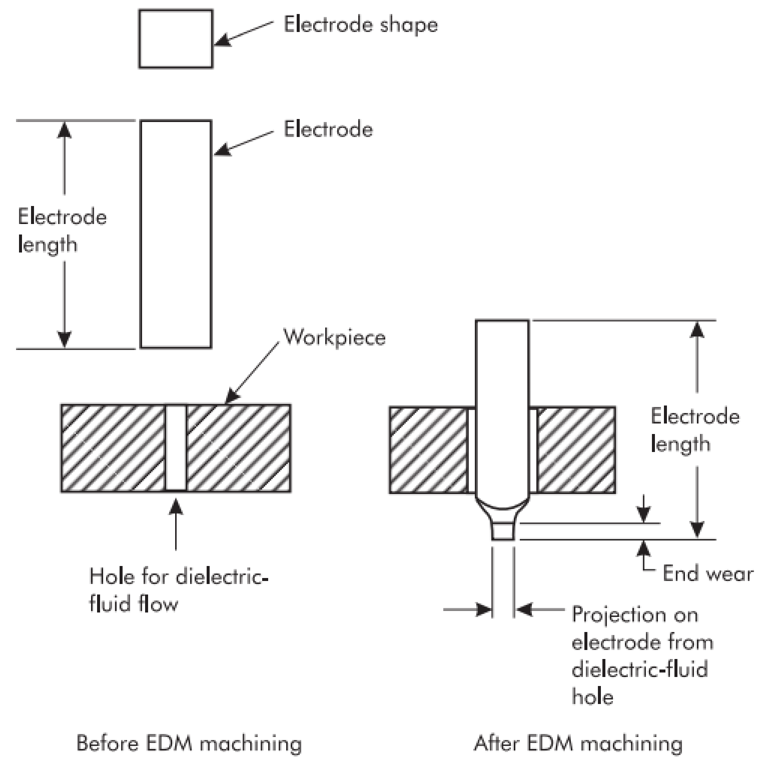
- Electrode wear is specified in one of four ways
  - Corner wear
  - End wear
  - Side wear
  - Volumetric wear



Electrode Wear

End wear:

- Difference between the original electrode length and the electrode length after machining.
- The electrode's end wear is noted by measuring the cylindrical extension of the electrode material that has passed through the pre-drilled hole.
- End wear = Starting Length – Final Length
- End wear ratio = depth of cut / end wear



Electrode Wear

Corner wear:

- Difference between the original electrode length and the point on the electrode corner that still retains the original corner shape.
- Corner wear is the standard for determining the length of the electrode or the number of electrodes required to complete the workpiece shape in die-sinking operations.
- Corner Wear = Apparent Corner Wear + End Wear
- Corner wear ratio = depth of cut / corner wear

Electrode Wear

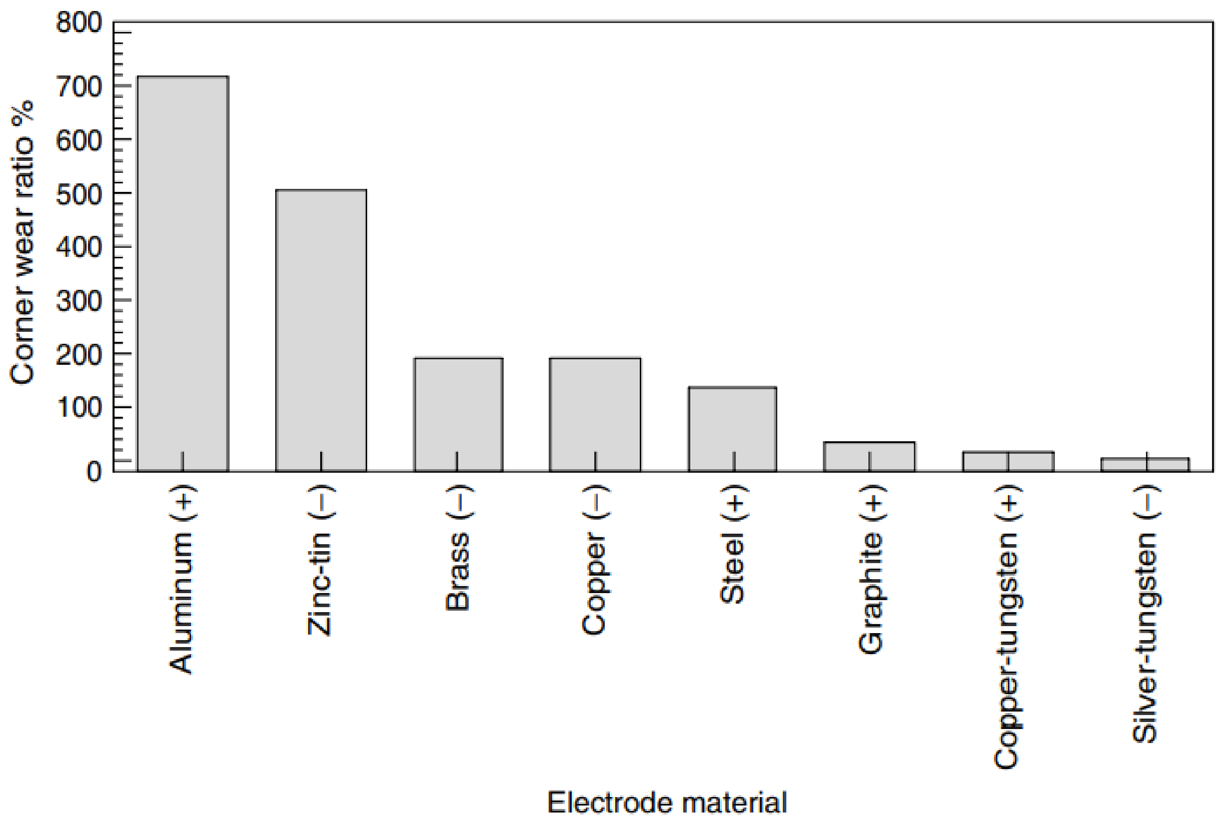
Volumetric wear:

- Comparison of the electrode’s total volume prior to EDM, to the electrode’s volume upon completion of machining.
- Volumetric wear is used to compare the volume of electrode consumed to the volume of workpiece machined.
- Volumetric wear ratio = volume of workpiece removed/volume of electrode loss

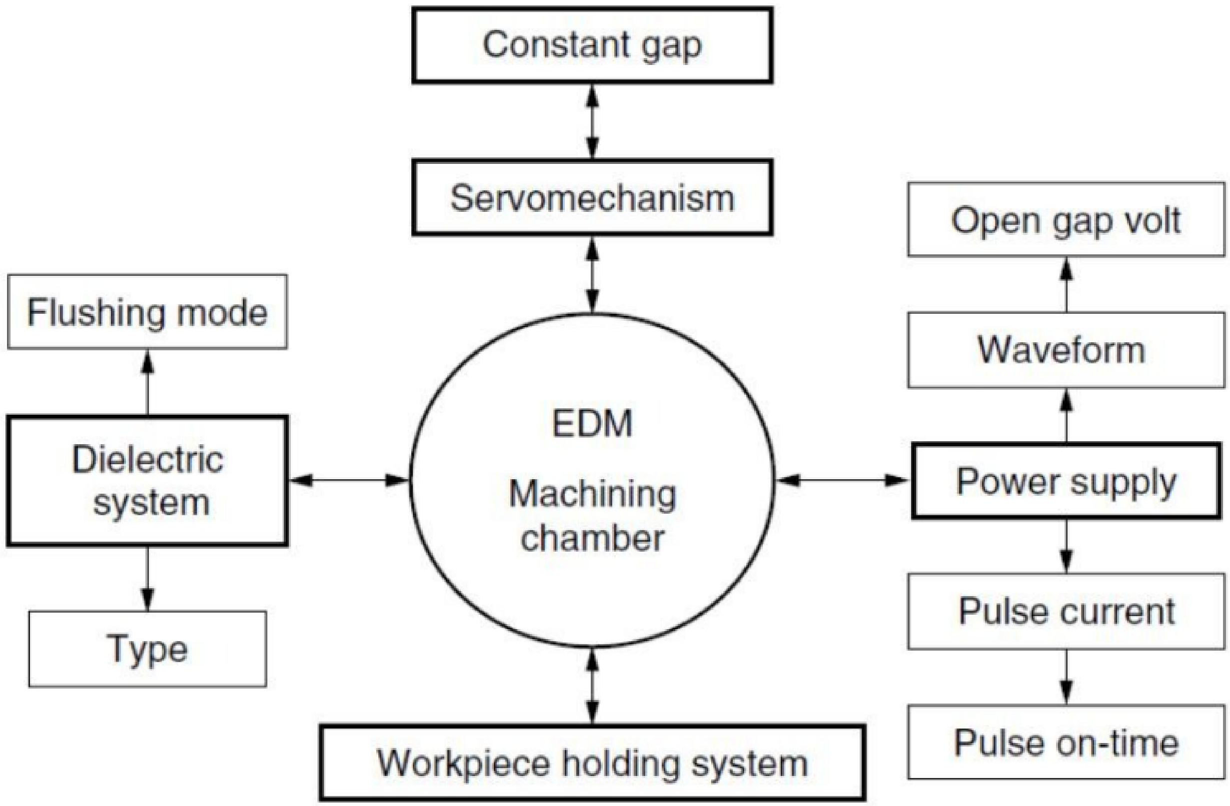
Side wear:

- Comparison between the original electrode length and the side surface of the electrode that shows the full electrode shape after the machining operation is complete.
- Side wear is the wear used as a reference on circular electrodes, since corner wear is not a consideration
- Side wear ratio = depth of cut / side wear

Electrode Wear



Components


Constant gap
Servomechanism
Flushing mode
Dielectric system
Type
EDM
Machining chamber
Open gap volt
Waveform
Power supply
Pulse current
Pulse on-time
Workpiece holding system

Advantage

- Complex shapes that would otherwise be difficult to produce with conventional cutting tools
- Extremely hard material to very close tolerances
- Very small work pieces where conventional cutting tools may damage the part from excess cutting tool pressure
- There is no direct contact between tool and work piece Therefore, delicate sections and weak materials can be machined without any distortion
- A good surface finish can be obtained

Disadvantage

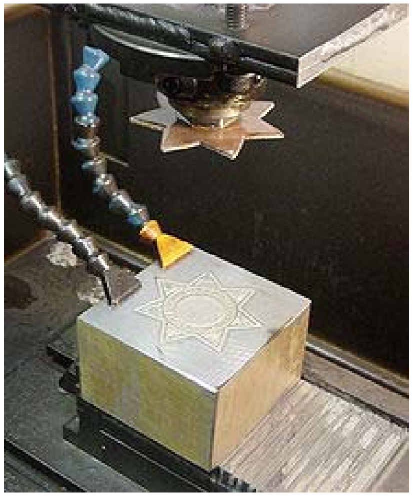
- The slow rate of material removal
- For economic production, the surface finish specified should not be too fine
- The additional time and cost used for creating electrodes for ram/sinker EDM
- Reproducing sharp corners on the workpiece is difficult due to electrode wear
- Specific power consumption is very high
- Power consumption is high
- "Overcut" is formed
- Excessive tool wear occurs during machining
- Electrically non-conductive materials can be machined only with specific set-up of the process

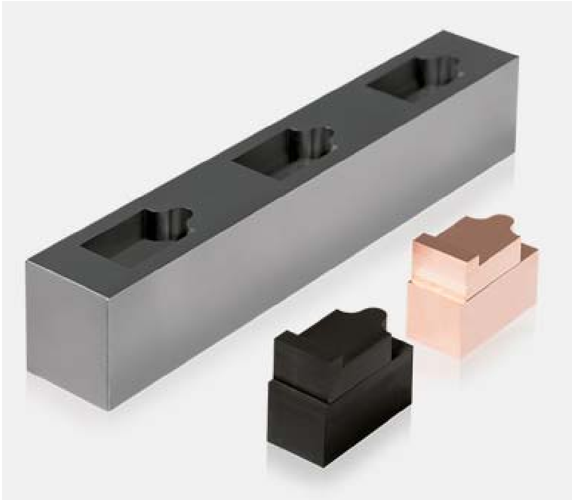
Applications

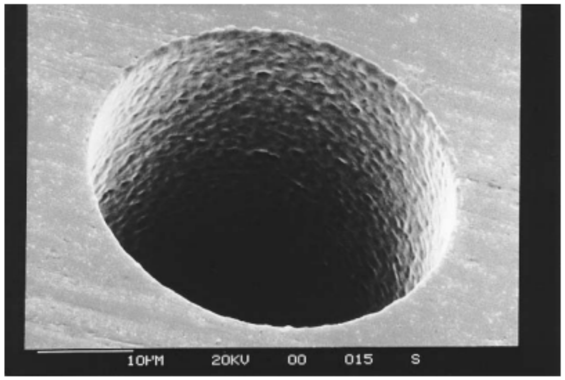
- Drilling of micro-holes, thread cutting, helical profile milling, rotary forming, and curved hole drilling
- Delicate work piece like copper parts can be produced by EDM
- Can be applied to all electrically conducting metals and alloys irrespective of their melting points, hardness, toughness, or brittleness
- Other applications: deep, small-dia holes using tungsten wire as tool, narrow slots, cooling holes in super alloy turbine blades, and various intricate shapes
- EDM can be economically employed for extremely hardened work piece
- Since there is no mechanical stress present (no physical contact), fragile and slender workpieces can be machined without distortion
- Hard and corrosion resistant surfaces, essentially needed for die making, can be developed

Applications

- Drilling
- Sawing
- Machining of Die and molds
- Texturing







[EDM Video link0]

[EDM Video link1]

[EDM video link2]

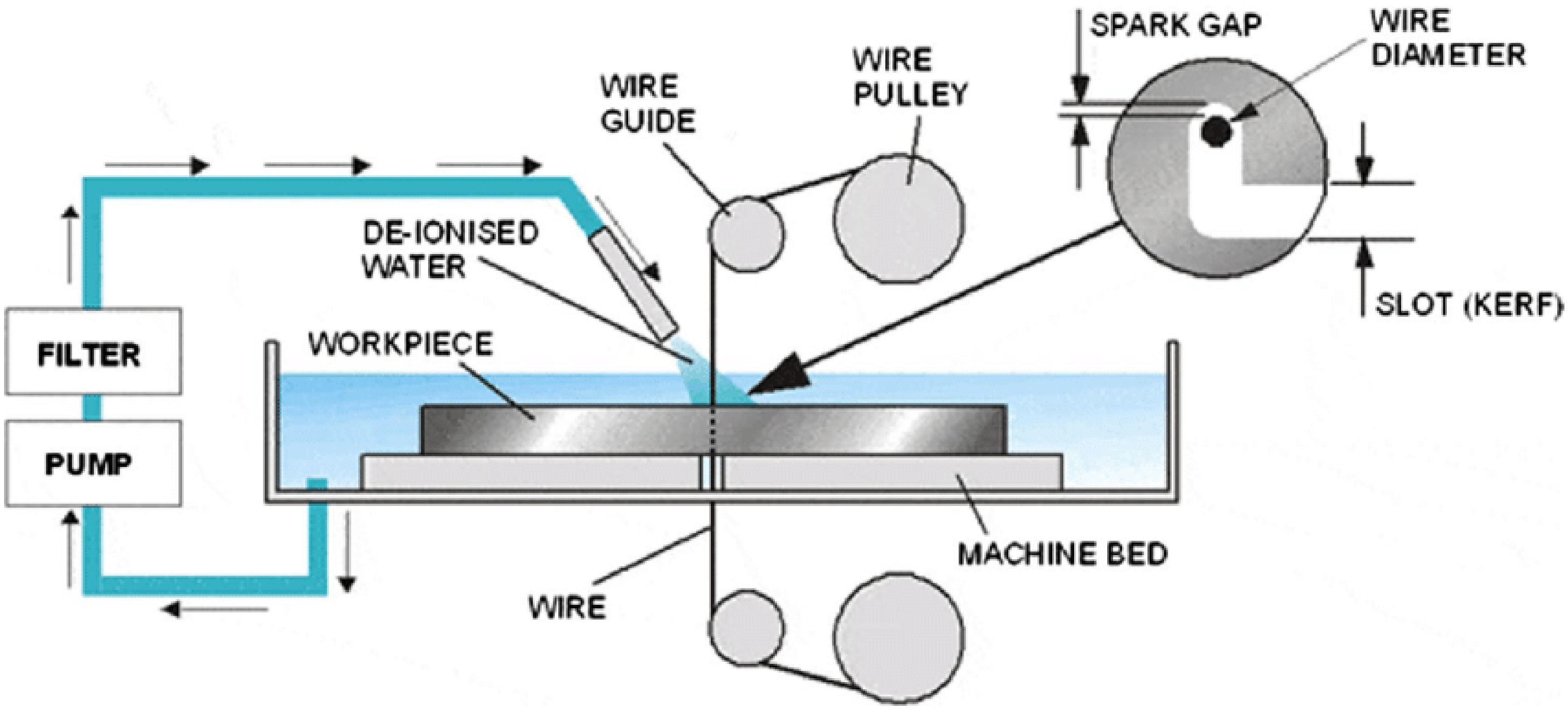
Wire EDM

- The wire electrical discharge machining (WEDM) is applied electrothermal machining processes
- The material removal from the workpiece occurs due to non-stationary electrical discharges developed between the traveling wire tool electrode and the workpiece
- Essential Aspects of the WEDM Processes:
  - use of a traveling wire electrode vertically positioned and supported in the machining zone
  - As a working fluid, deionized water is usually preferred
  - Wire and workpiece should electrically conductive

Wire EDM

- In wire electric discharge machining (wire EDM), a wire (about 0.05-0.30 mm diameter) is used as an electrode and deionized water as dielectric
- A nozzle is employed to inject the dielectirc in the machining area in wire EDM
- Electrodes (wire and workpiece) are connected to a pulsed DC supply
- Heat generated due to sparking results in the melting of workpiece and wire material, and sometimes part of the material may even vaporize like in conventional EDM
- A constant gap between tool (wire) and workpiece is maintained with the help of a computer controlled, positioning system
- This system is used to cut through complicated contours specially in difficult-to-machine materials
- This process gives a high degree of accuracy and a good surface finish

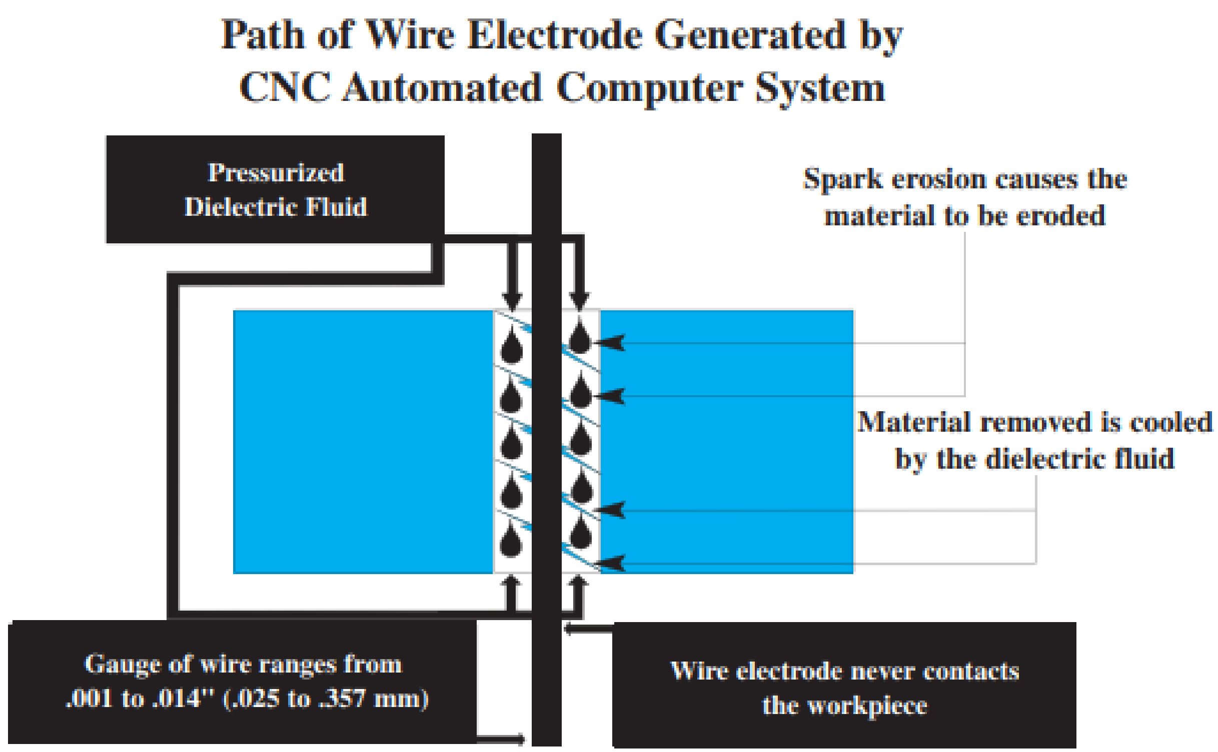
Wire EDM System



Wire EDM

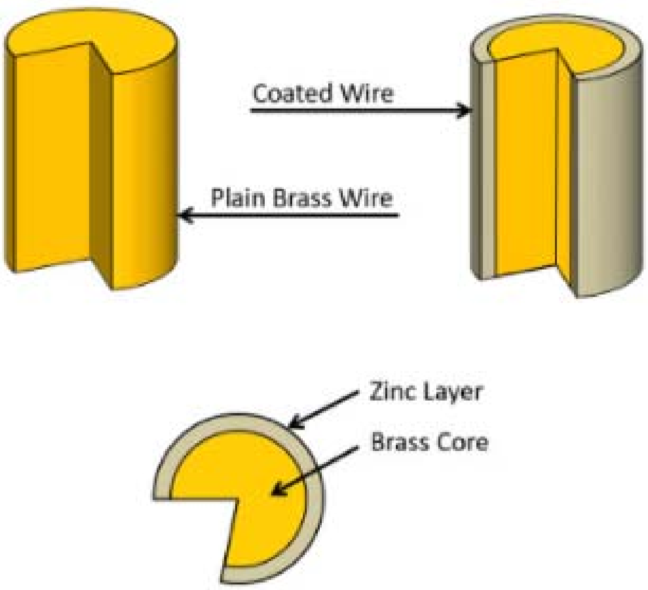
- Wire material:
  - Brass
  - Zinc
  - Molybdenum
  - Tungsten

- Wire constantly fed into the gap



Stratified Wire

- Stratified wires have a wire core coated with one or more layer of different material
- Usually consists of an alloy with low vaporization temperature, plated to a higher tensile strength core
- Special coating to enhance cutting speeds and surface quality
- The special outer coating helps to preserve the inner core of the wire.

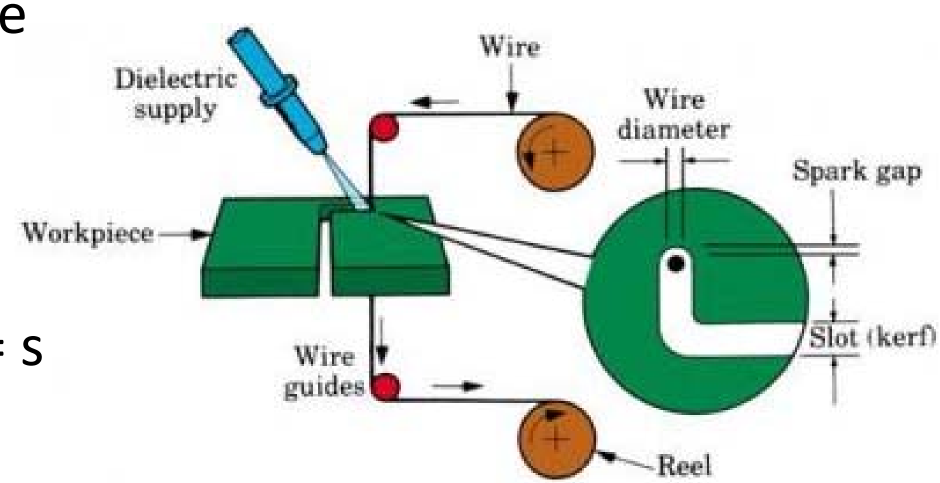


Stratified Wire

- The outer layer vaporizes more quickly than the inner core due to the higher zinc content, protecting the integrity of the inner core and minimizing wire breaks
- It is through this protection that additional electrical power can be applied to improve machining speeds without seeing an increase in wire breaks when compared to standard brass wire
- Operational profit can be increased when using coated wire
- Less wire will be consumed per part

MRR

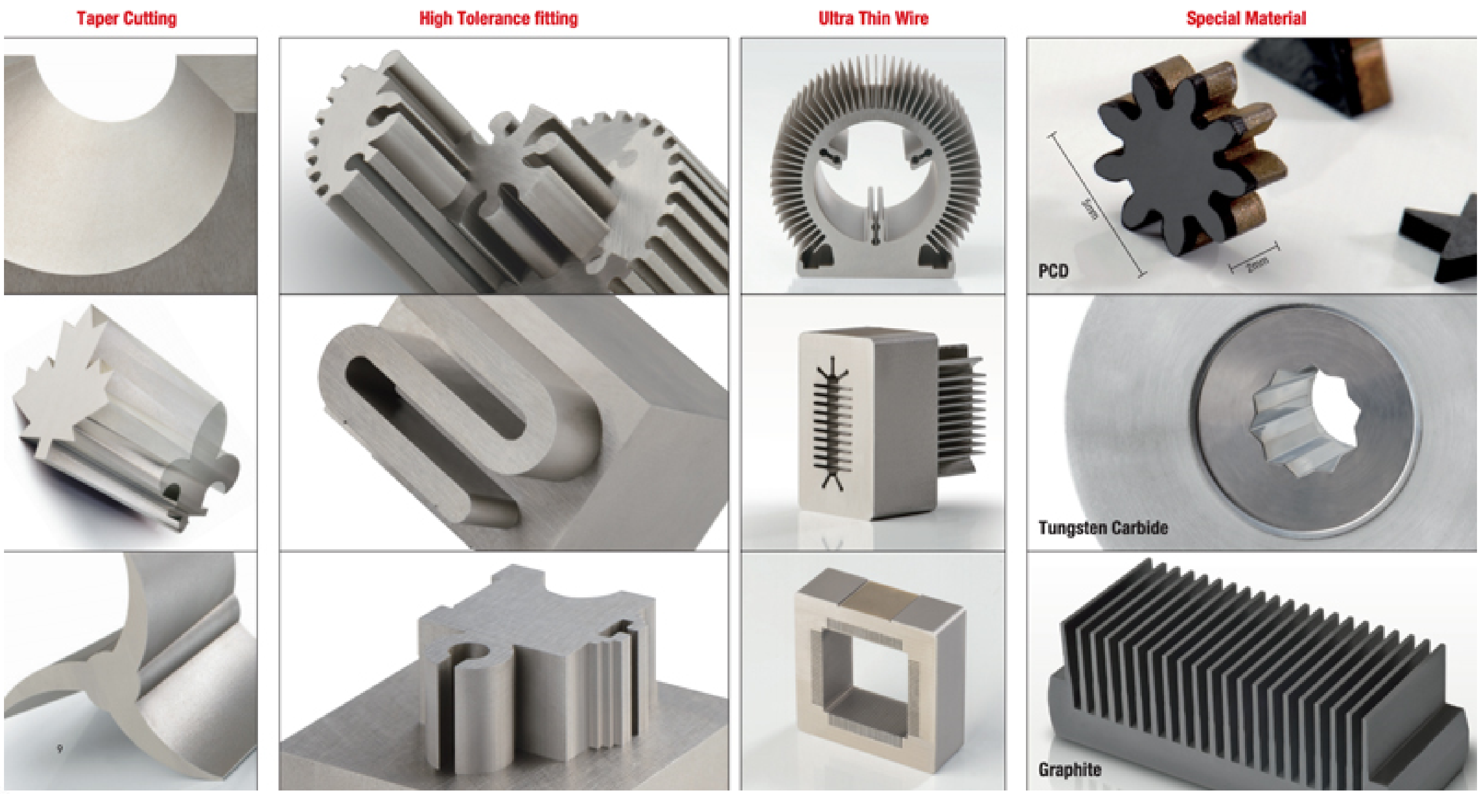
- Feed rate of wire into the workpiece = V
- Workpiece thickness or height =h
- Wire diameter = d
- Gap between wire and workpiece = s



Slot width = w = d+(2*s)

MRR=V*h*w

Applications

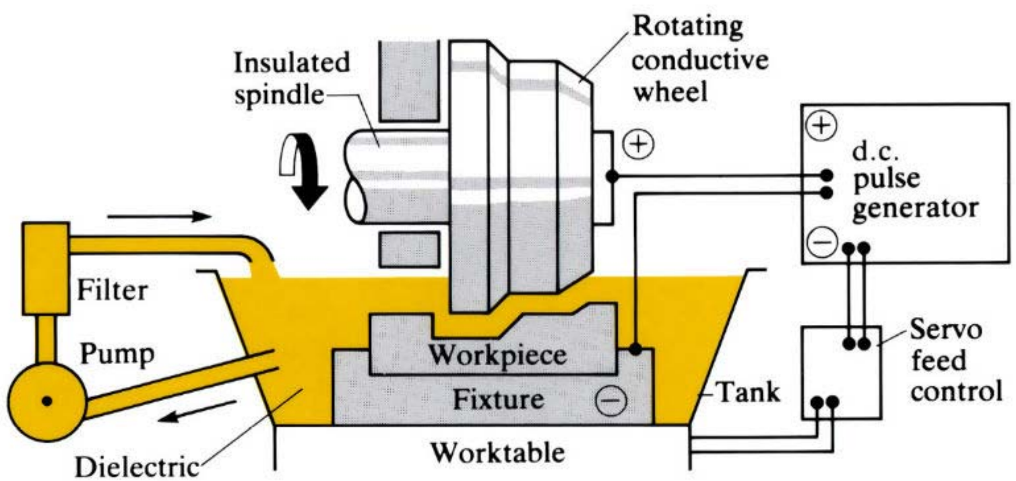


[Wire EDM Gear Wheel]

[Wire EDM Video 1]

Electric Discharge Grinding

- Electric discharge grinding (EDG) is the process which works on the same principle as EDM
- A rotating wheel, made of electrically conductive material (usually graphite), is used as a tool
- A part of the grinding wheel (cathode) and workpiece (anode) both are immersed in the dielectric, and are connected to pulsed DC supply



Electric Discharge Grinding

- The rotating motion of the wheel ensures the effective flow of dielectric in the IEG, and hence flushing of the gap with dielectric can be eliminated
- Mechanism of material removal is exactly same as in EDM except that rotary motion of the tool (i.e. wheel) helps in effective ejection of the molten material
- Contrary to conventional grinding, there is no direct physical contact (except during short circuit, if so) between the tool and the workpiece, hence, fragile and thin sectioned specimens can be easily machined
- EDG is considered to be economical compared to the conventional diamond grinding
- During EDG, the material removal takes place due to melting and/or vaporization but not by mechanical action like shearing

Electric Discharge Grinding

- An alternative to ultrasonic machining (USM) and electrochemical machining (ECM)
- Common tool materials are graphite, copper, Cu/graphite, brass, steel, W and Cu/W
- Tools should be designed to allow a good flow of dielectric and venting of any gases produced during machining
- In some cases, the tool and/or workpiece are vibrated to improve the flushing action of the dielectric

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