Electric Discharge Machining

by

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Scheme of Presentation

- Process mechanism of EDM
- Types of EDM and EDM Operations
- Dielectric Fluids
- Flushing Techniques
- Process Parameters
- Pulses in EDM
- Power supply for EDM
- Simple theoretical model for MRR and Surface roughness
- EDM Applications

History pf EDM

- B. R. Lazarenko and N. I. Lazarenko → investigated ways of preventing the erosion of tungsten electrical contacts due to sparking way back in 1943 .

- Finding → Erosion could be more precisely controlled if the electrodes were immersed in a dielectric fluid → This eventually led them to invent an EDM machine.

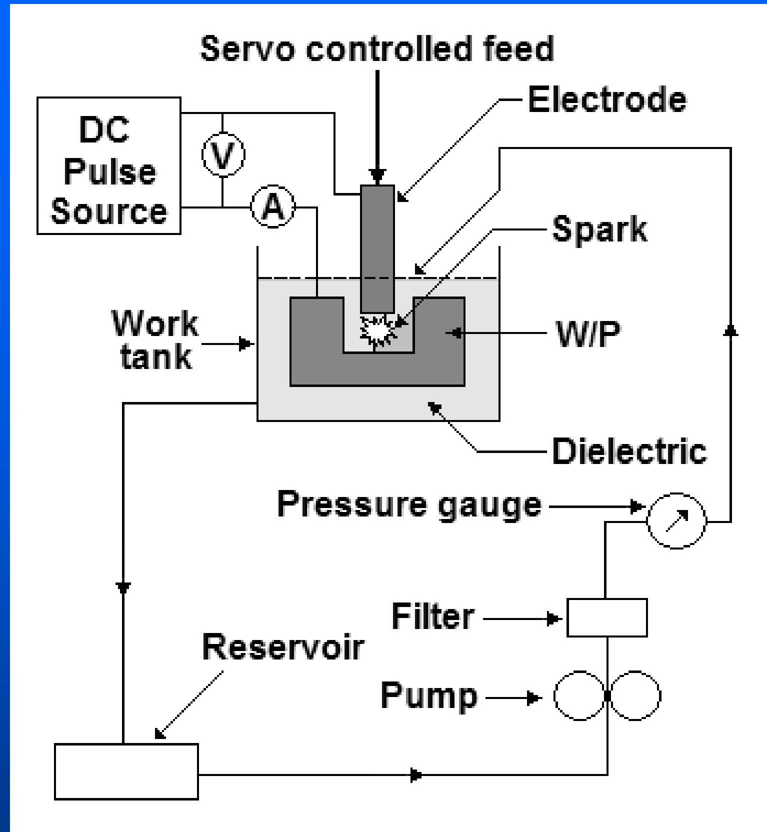
- *[Ref: Electric Spark Method for the Machining of Metals, B. R. Lazarenko, N. I. Lazarenko, H. Brutcher Technical Translations, 1950]*

Electrical Breakdown

Rapid reduction in the resistance of an electrical insulator that can lead to a spark jumping around or through the insulator.

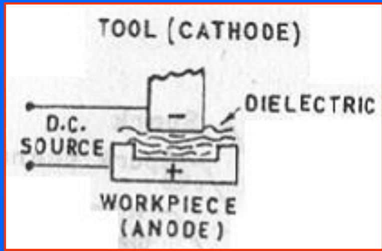
Dielectric breakdown is the failure of an insulating material to prevent the flow of current under an applied electrical stress. The **breakdown voltage** is the voltage at which the failure occurs, and the material is no longer electrically insulating.

Scheme of EDM



Potential difference between the two electrodes → A series of sparks → Intense heat → Melts and evaporates the materials

Dielectric fluid

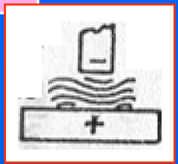


Charging voltage is applied

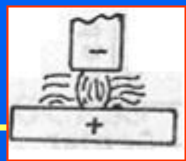
A critical voltage is reached

Critical voltage establishes an ionised column

Builds avalanche of electrons



A high density current flows



Spark is initiated

Rapid rise of temperature

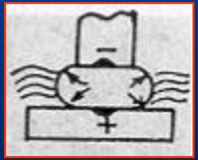
Transfers heat to cathode and anode

Melts and vaporises surfaces of –ve and +ve electrode

Dielectric is decomposed

Inertia of adjacent dielectric creates high pressure

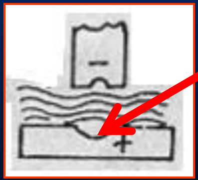
Stoppage of pulse results in an implosive a blast



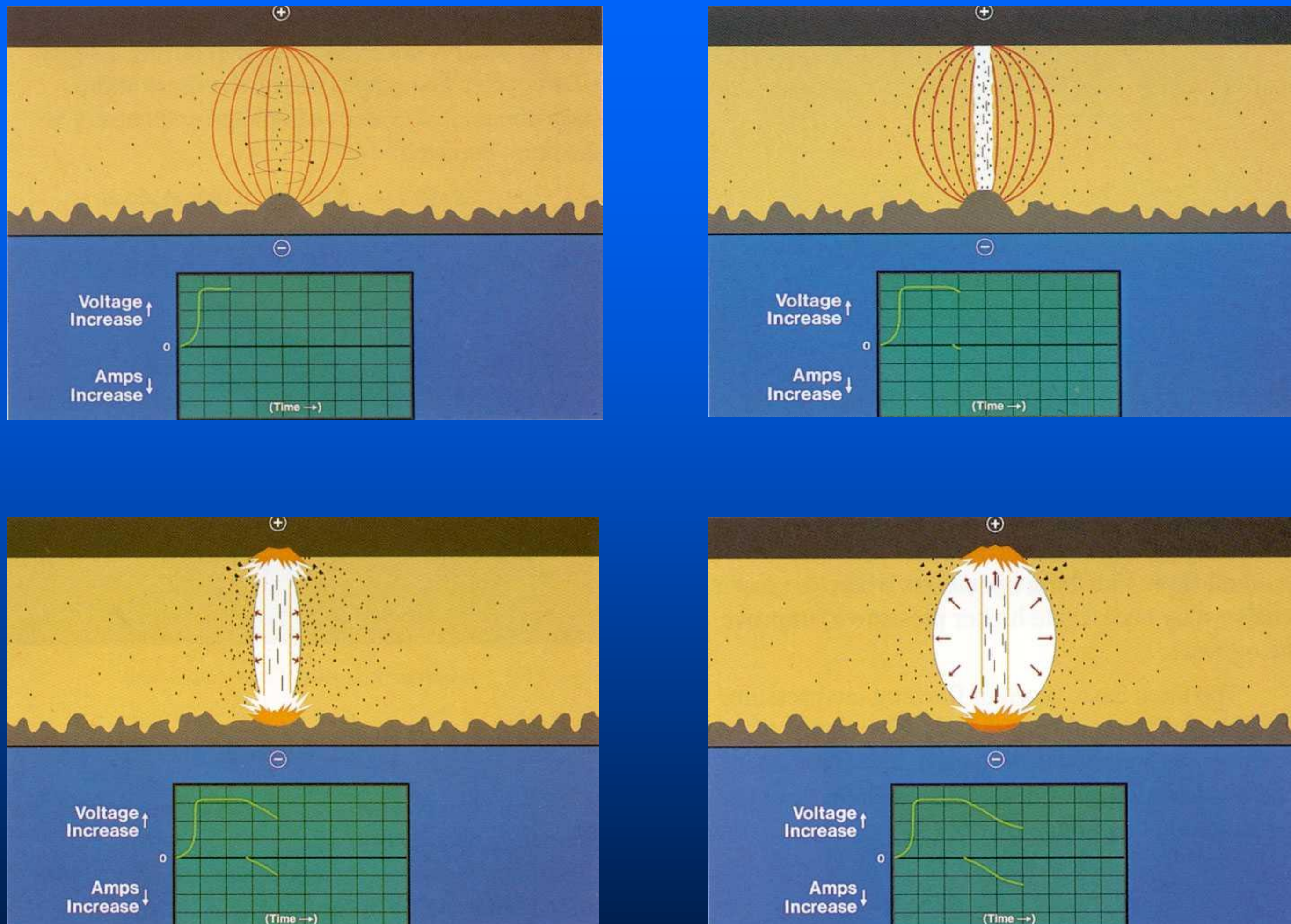
Removes molten debris of anode and cathode

Leaves a crater behind

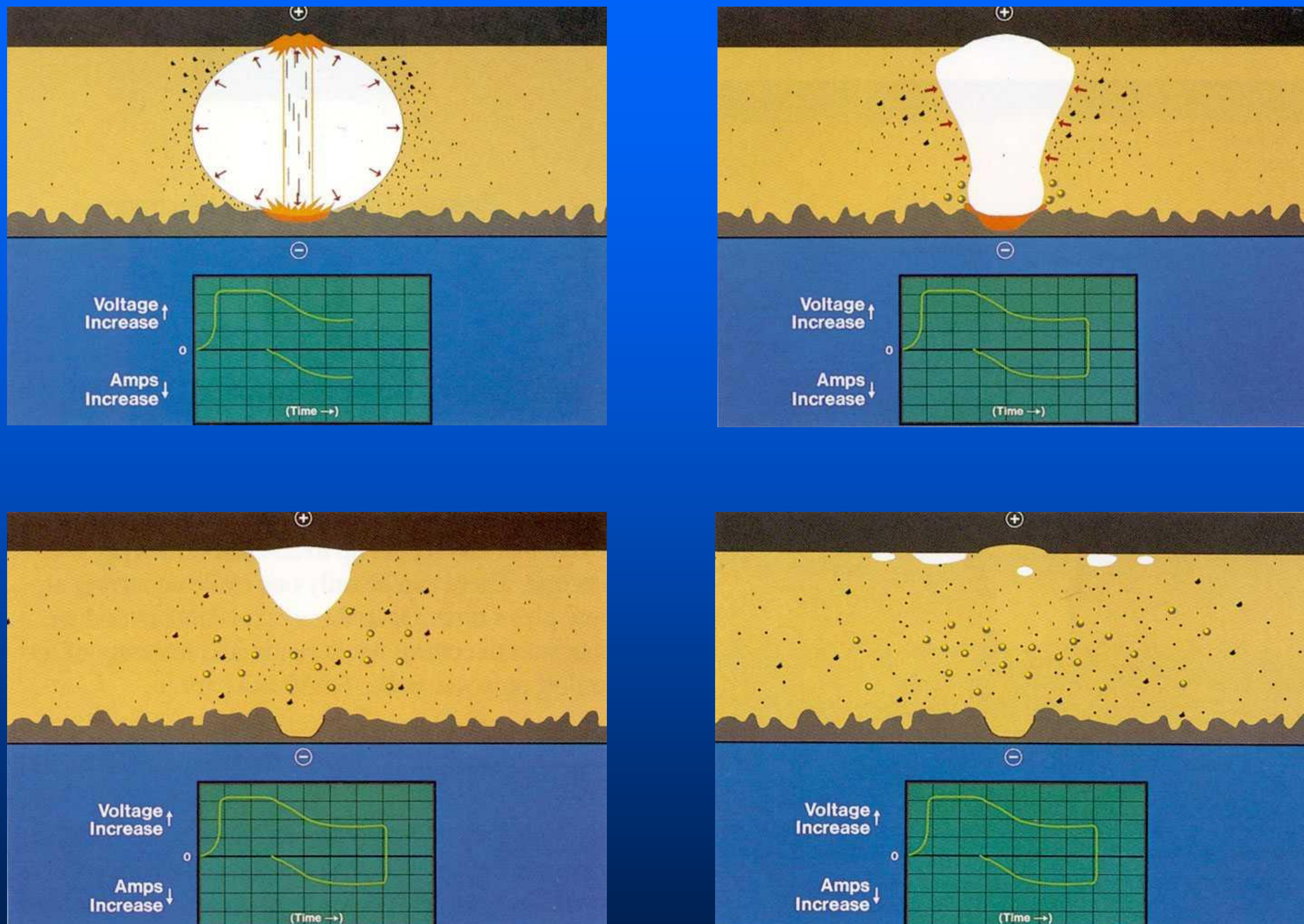
Crater



Material Removal Mechanism in EDM



Material Removal Mechanism in EDM

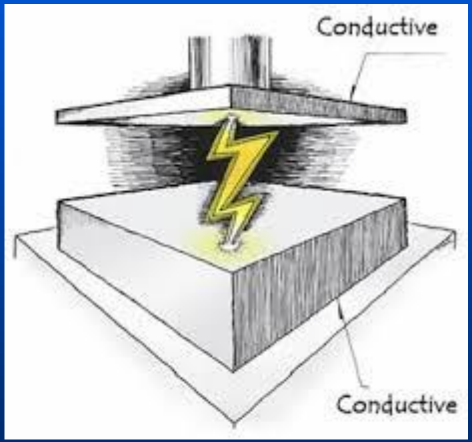


Need → control the spark energy to employ for machining

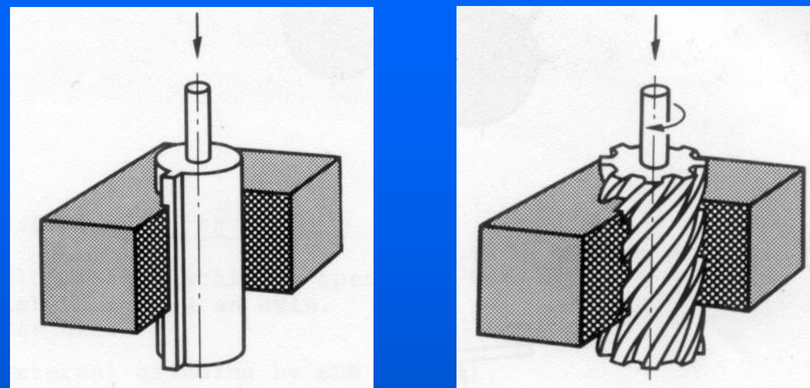
Sparking frequency → many thousands per second

Final shape of the job → a result of thousands of craters each one superimposed over the other and it is inverse shape of that of the tool.

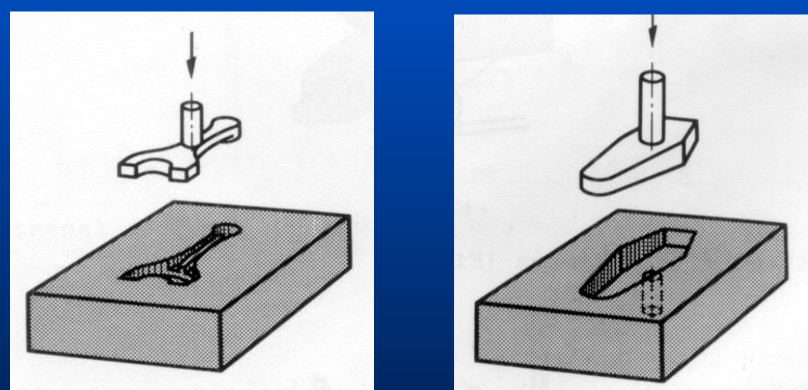
Type of EDM-ing Operations



Sinking by EDM

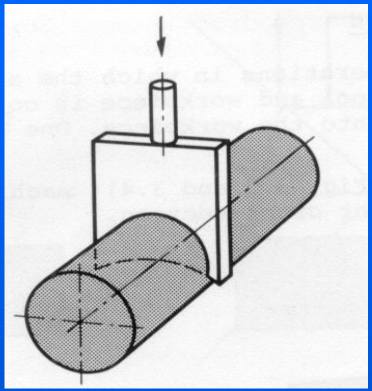


Machining through holes

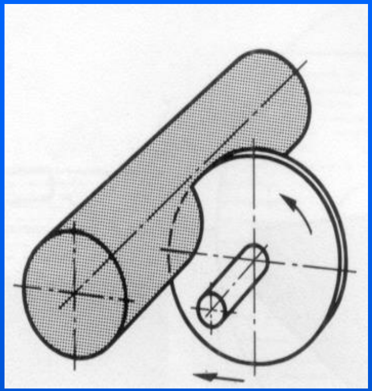


Three dimensional die-sinking

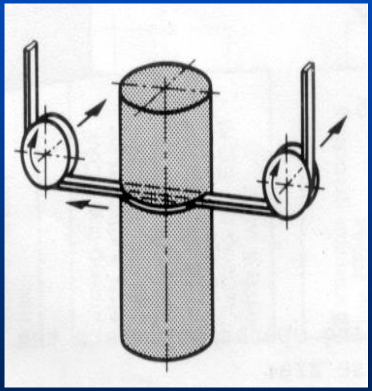
Cutting by EDM



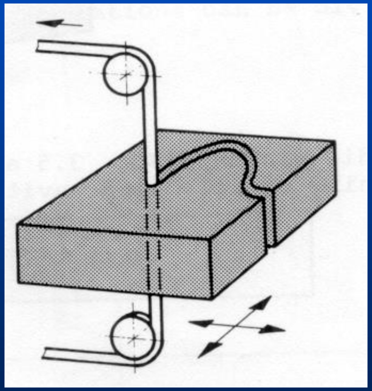
Cutting with a blade



Cutting with a rotating disc

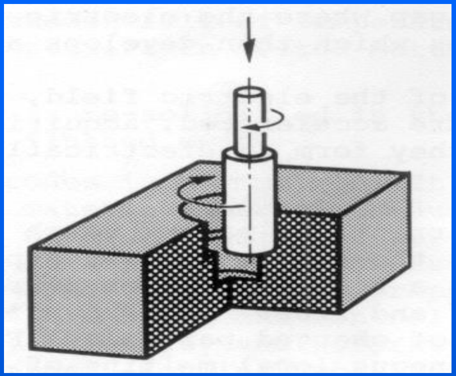


Cutting with a ribbon

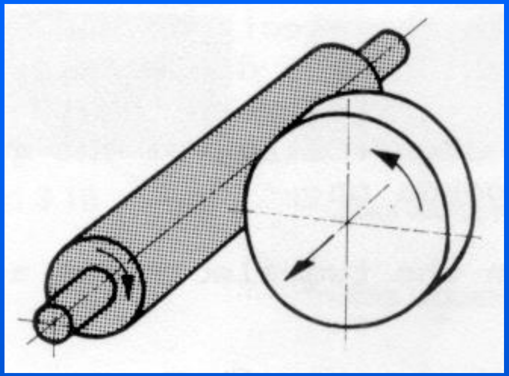


Cutting with a wire

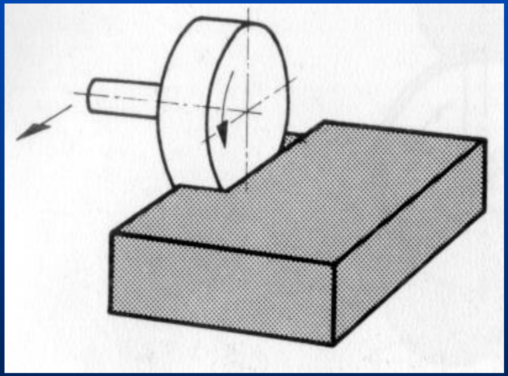
Grinding by EDM



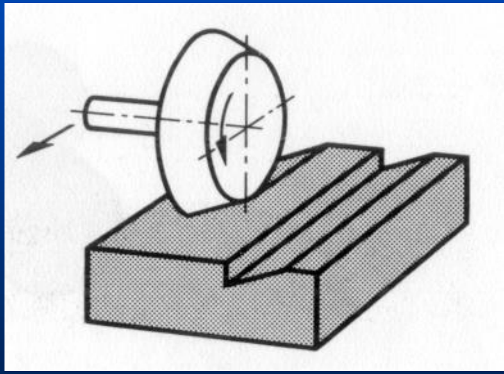
Internal grinding



External grinding

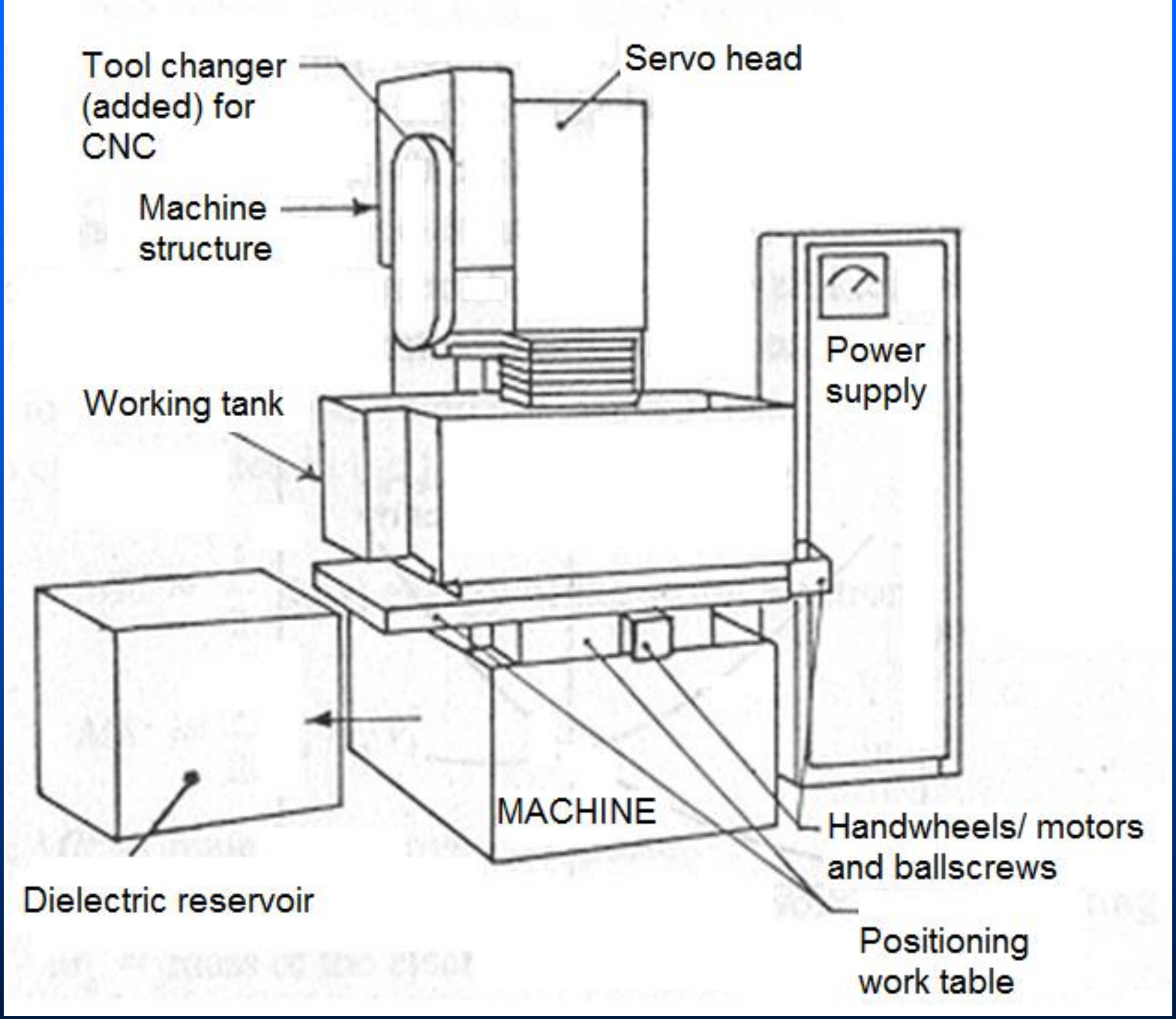


Surface grinding

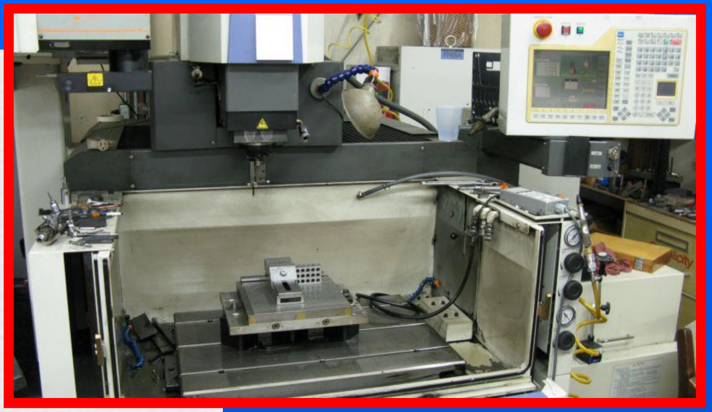


Profile grinding

EDM Die-Sinking Machine



EDM Die-Sinking Machine

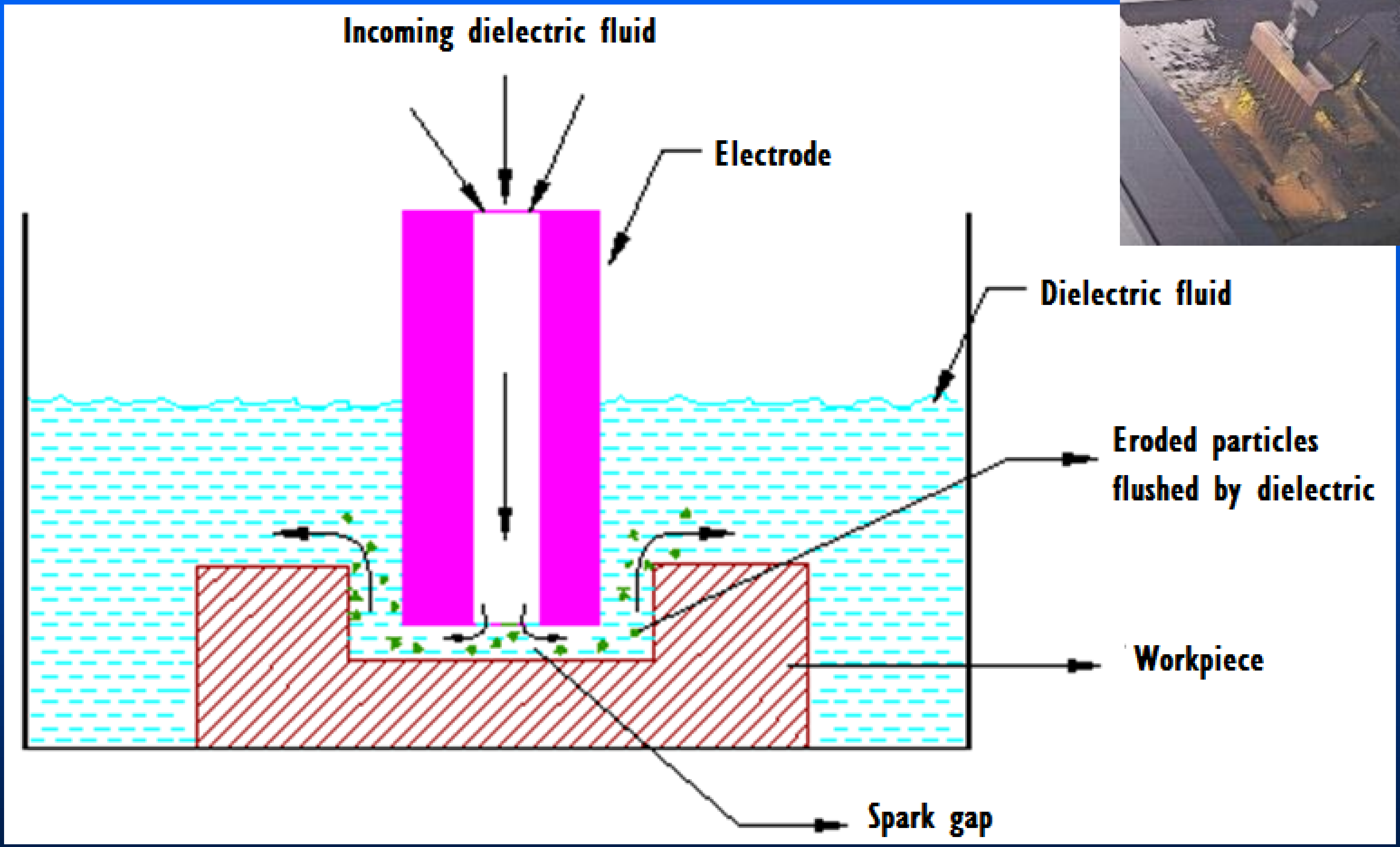


EDM Machine Elements

Elements of EDM

- → Dielectric system
- → Servo system
- → Electrodes: work piece and tool
- → Power supply

Dielectric Fluid in EDM



Main functions of dielectric Fluid in EDM

- To provide insulation in the gap between the electrode and the workpiece below threshold voltage.
- Stabilize the spark process by ionizing and deionizing the spark channel at fixed frequencies.
- Concentrate the spark channel.
- To flush the eroded particles, produced during machining, from the discharge gap.
- To cool the section that was heated by the discharge machining.

Ideal Characteristics Dielectric Fluid

- Good electrical discharge efficiency ← enables quick ionisation & deionisation
- Low viscosity ← enables easy flow in narrow gap
- High flash point ← reduces fire hazard
- Good thermal & oxidation stability ← less degradtion
- Minimum odor ← environment friendly
- Low cost

Commonly used Dielectric Fluids in EDM

- Transformer oil
- Paraffin oil
- Lubricating oil
- Kerosene oil
- Deionized water → good ionizing and deionizing capability/ high MRR, high TWR, corrosive, good coolant → used in WEDM

Flash points for common liquids

- Gasoline 4.5º C
- Ethanol 12.5º C
- Kerosene 49º C
- Diesel 62º C
- Vegetable Oil 327º C

The flash point for commonly used EDM dielectric oils ranges from 71º C to 124º C.

Dielectric System

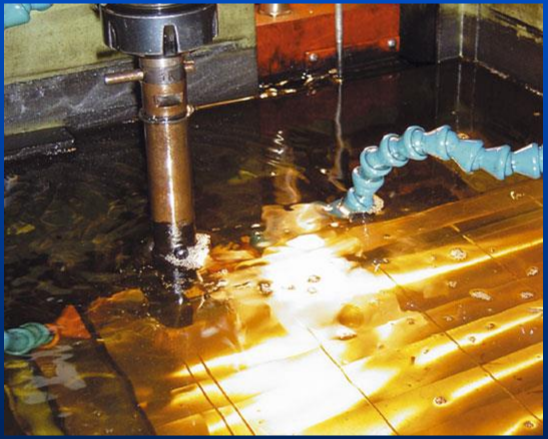
Dielectric system

- → Dielectric fluid
- → Reservoir
- → Filters
- → Pump
- → Delivery devices

Need for Flushing in EDM

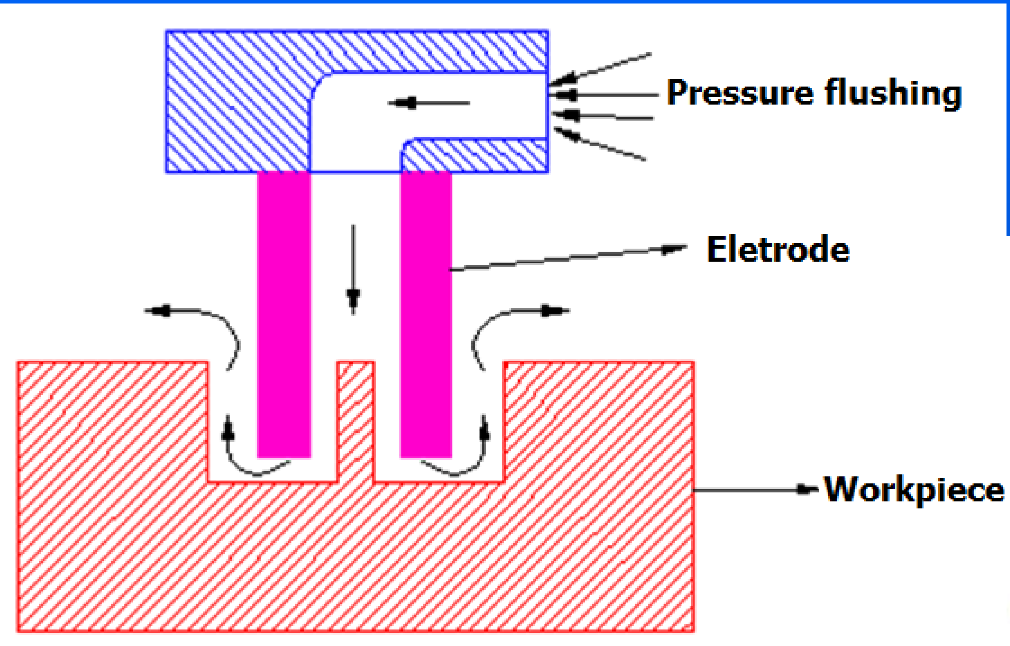
- Inadequate flushing → result in arcing, decreased electrode life, and increased production time.
- The fluid should have the ability to flow through the spark gap, removing debris, chips, and particles eroded by the EDM process. ← low viscosity

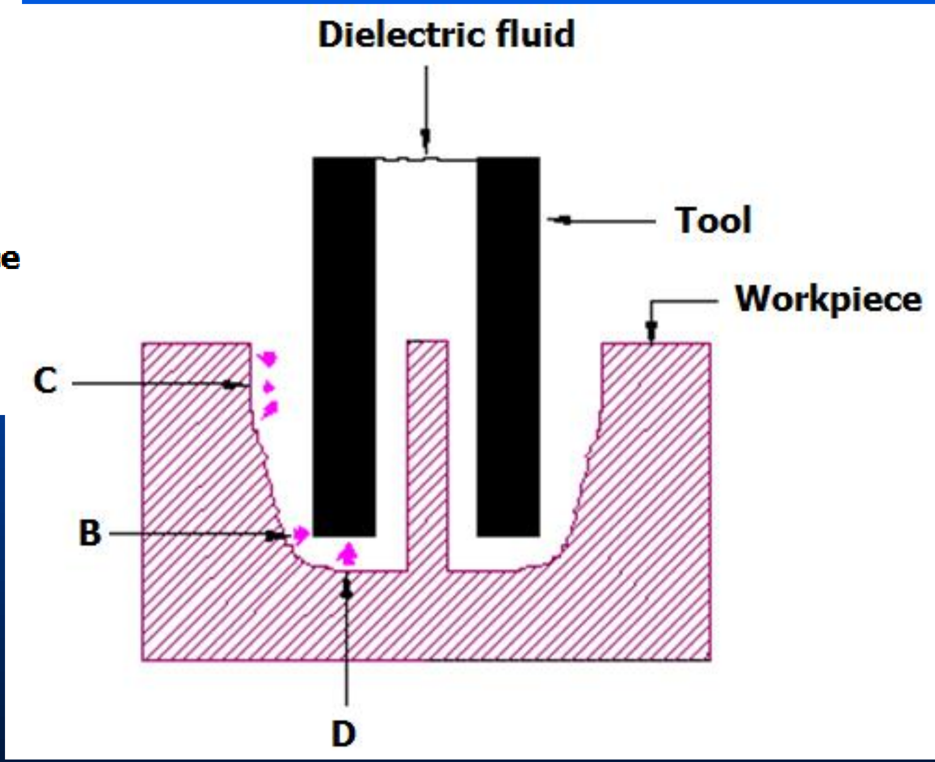
Flushing Techniques



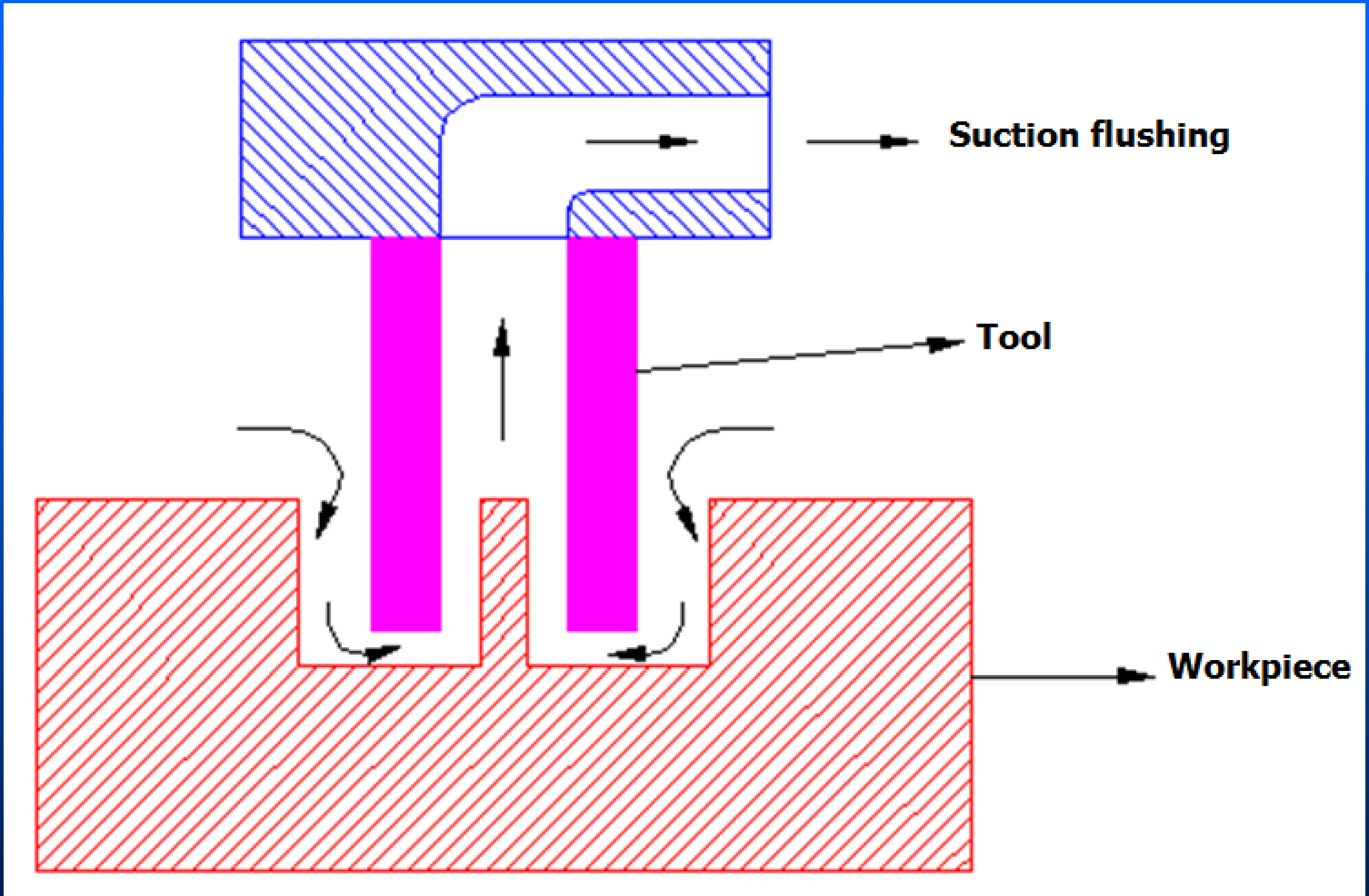
- Normal flushing
- Reverse flushing
- Jet flushing
- Immersion flushing
- Intermittent opening up the gap by lifting tool

Normal Flushing

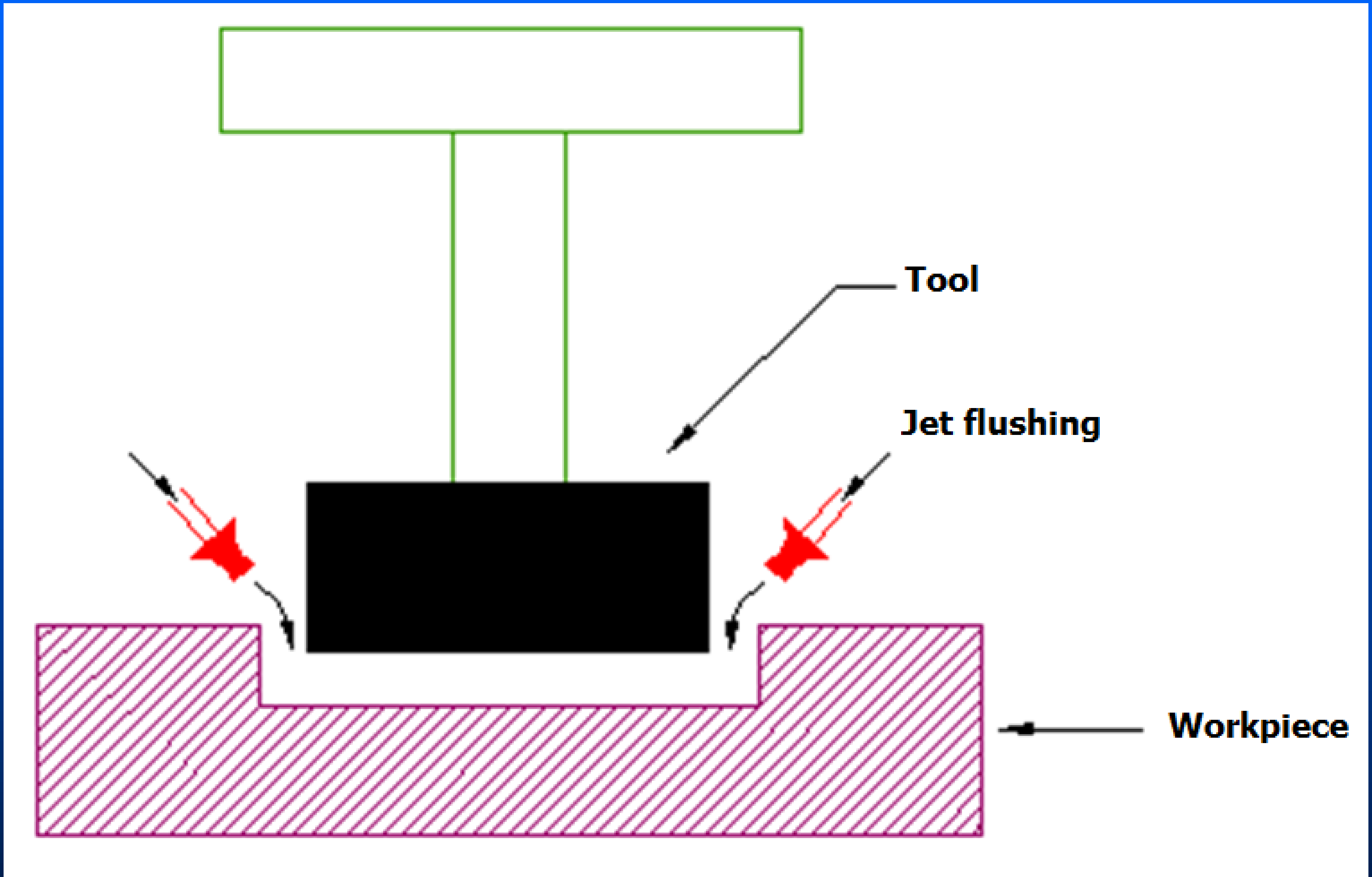




Reverse Flushing



Jet Flushing



Tool Materials for EDM

Copper electrode

Bass electrode

Copper-tungsten electrode

Silver-tungsten electrode

Tungsten electrode

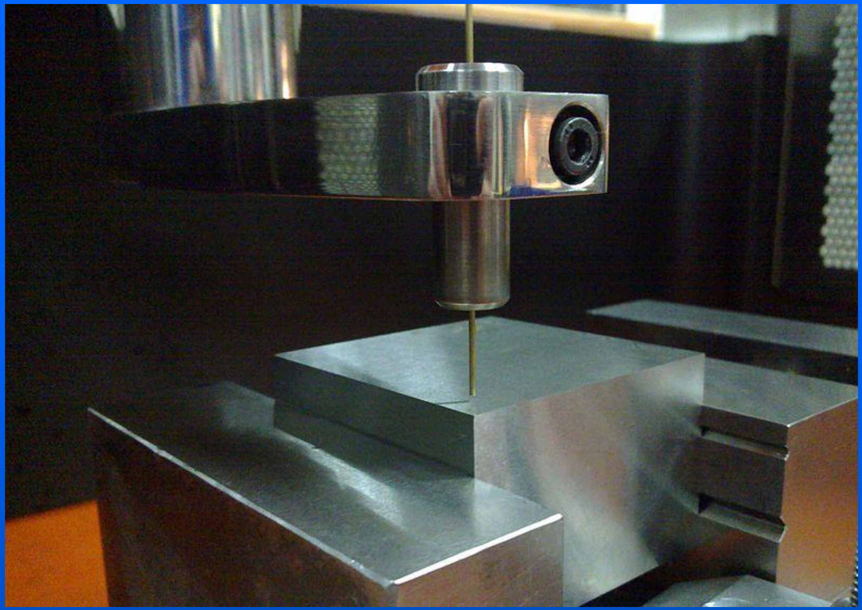
Graphite electrode

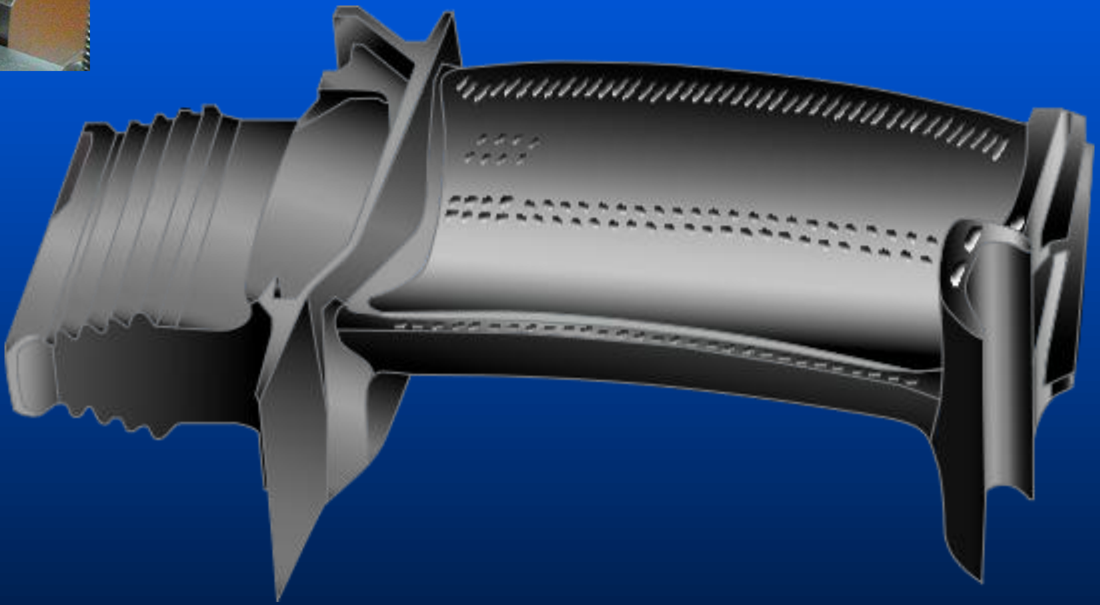
Copper impregnated graphite

Eletroformed electrode

Selection of Tool Materials for EDM

Material	Wear Ratio	MRR	Fabrication	Cost	Application
Copper	Low	High in roughing	Easy	Moderate	All metals
Brass	High	High on finish range	Easy	Low	All metals
Tungsten	Lowest	Low	Difficult	High	Only where small holes are to be drilled
W-Cu alloys	Low	Low	Difficult	High	High accuracy job
Copper-Graphite	Low	High	Very delicate, Difficult	Material	All metals
Zn-based alloy	High	High in roughing	Easily die-casted	Low	All metals





Small Hole Drilling on Turbine Blade

Tool Wear

- Compensation for reduced length ← tool wear
- Electrode refeeding → brings tool to a reference point

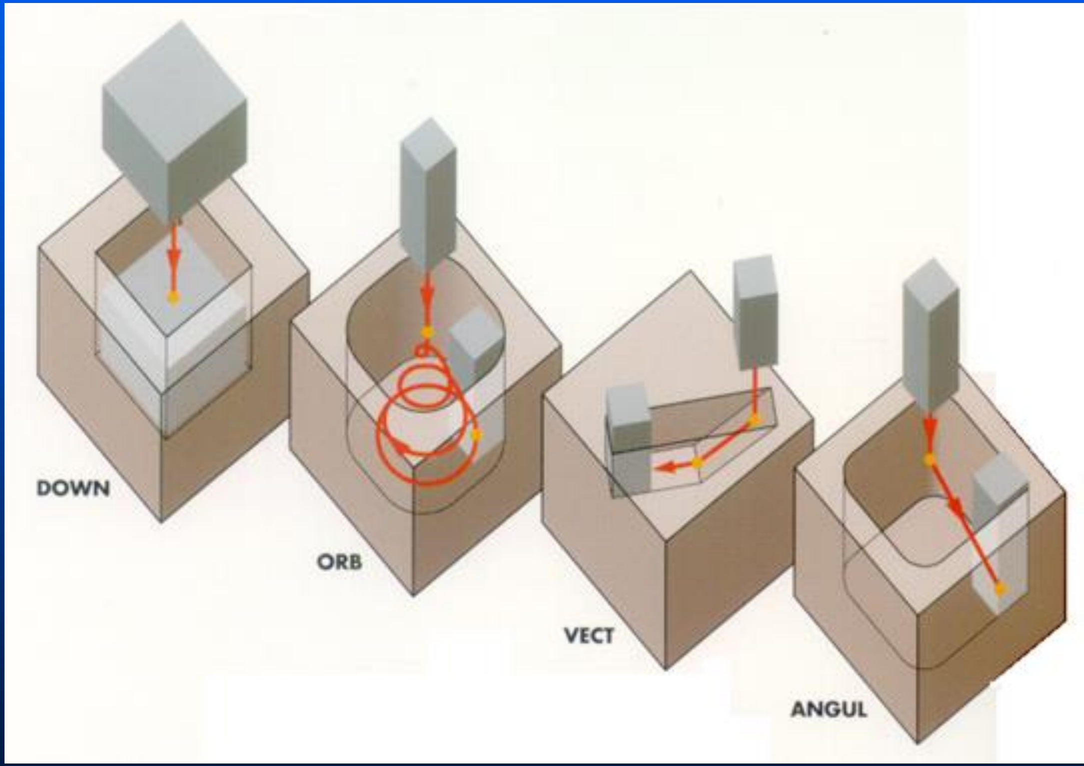
Automatic Tool Changer

- Many tools mounted on a magazine – called one at a time by CNC program
- Reduces tool-changing time
- CNC-EDM more popular

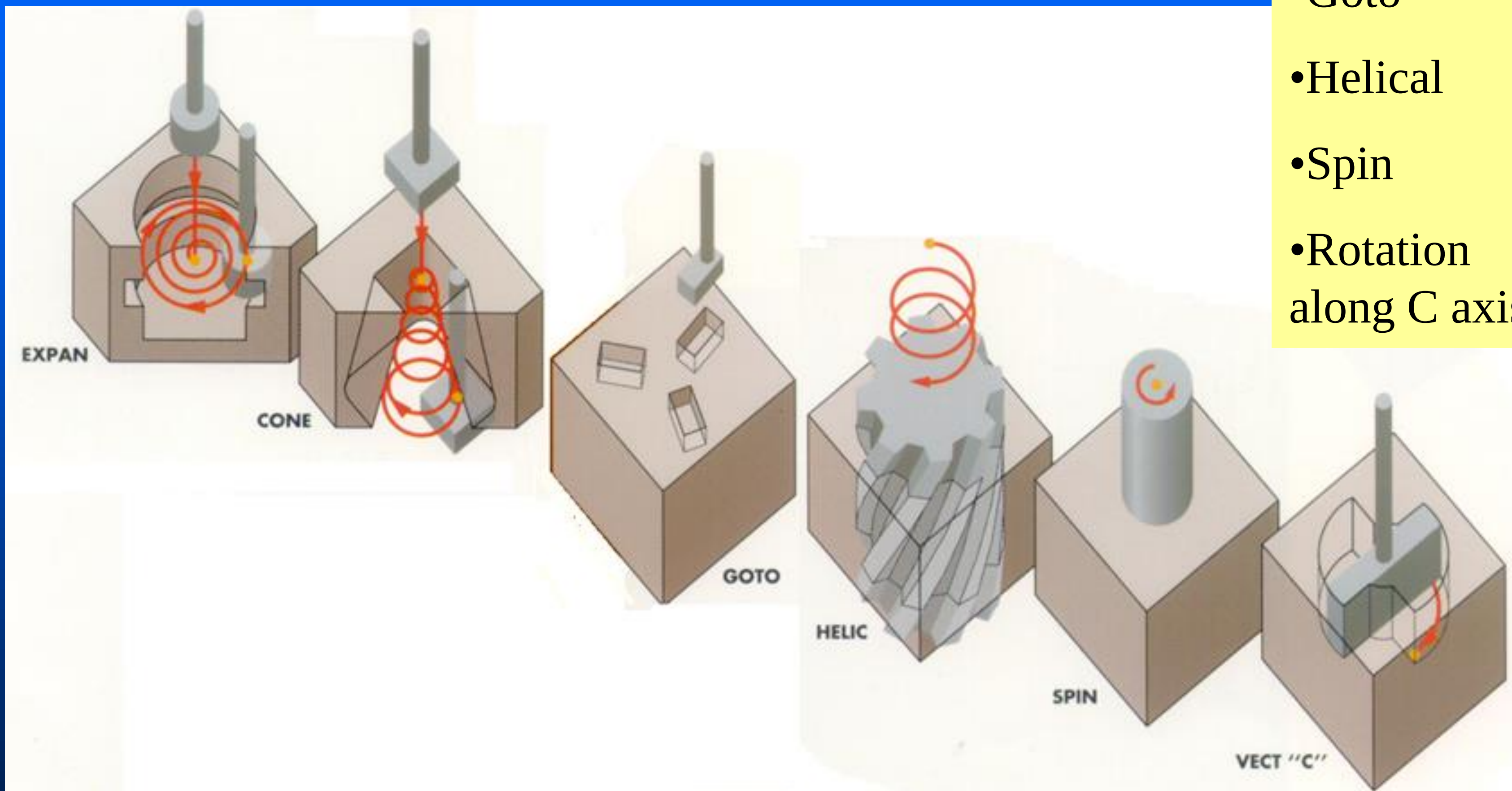
EDM Operations

- EDM equipped with CNC
- Better removal of debris and ease of machining in attaining complex form

- •Downwards
- •Orbital
- •Vectorial
- •Angular



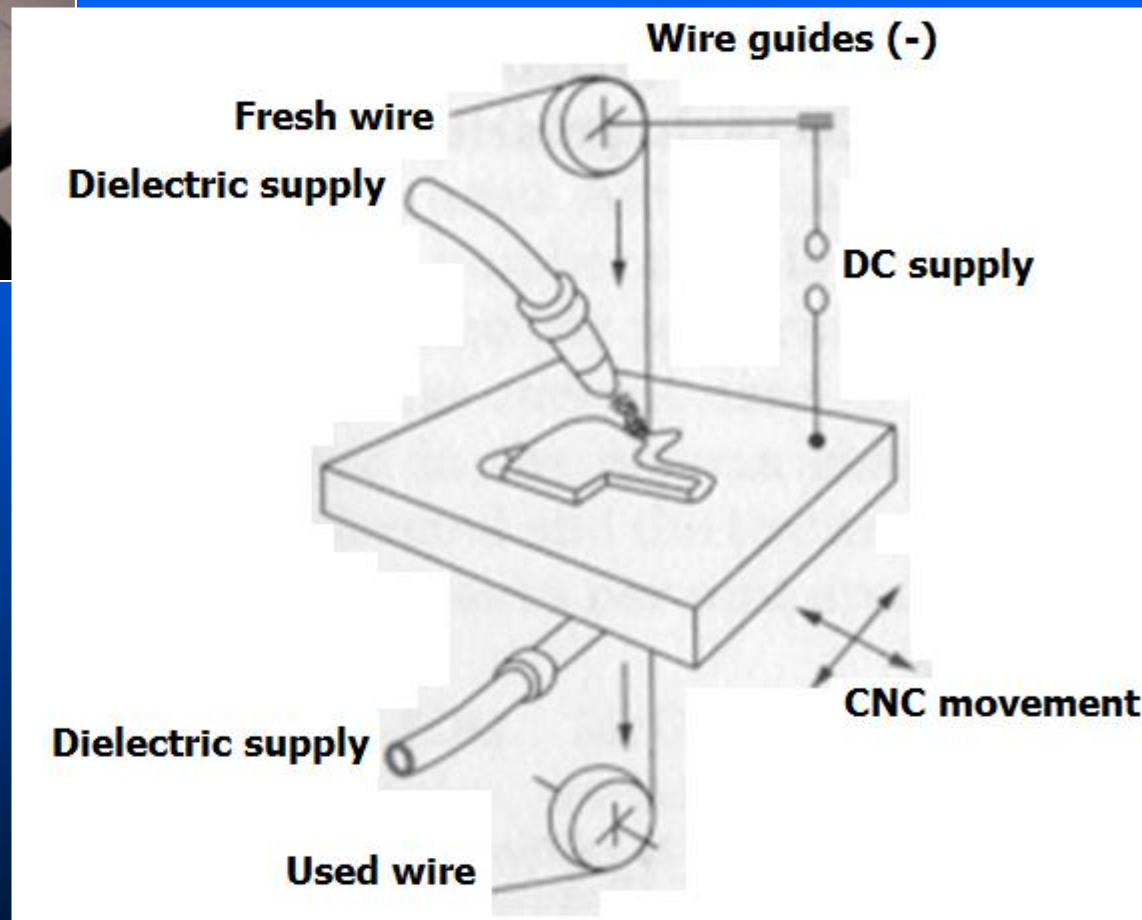
EDM Operations



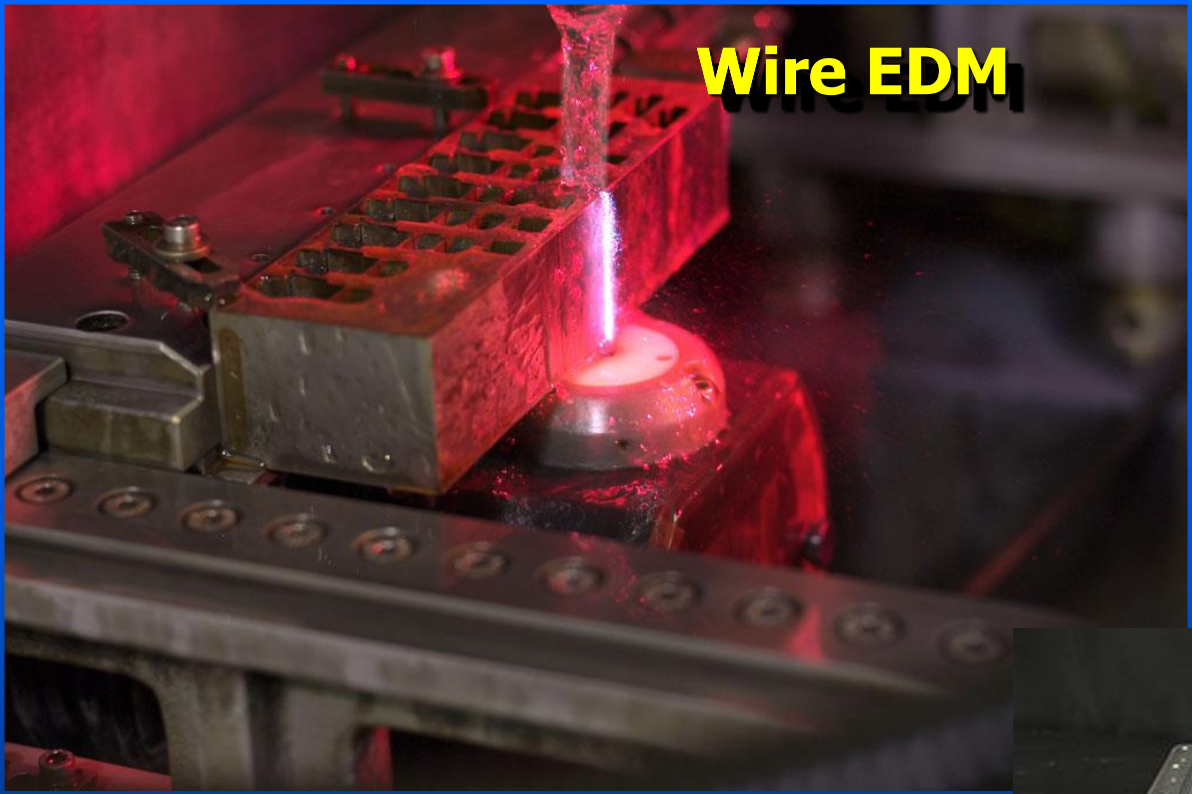
- Expanding
- Conical
- Goto
- Helical
- Spin
- Rotation along C axis

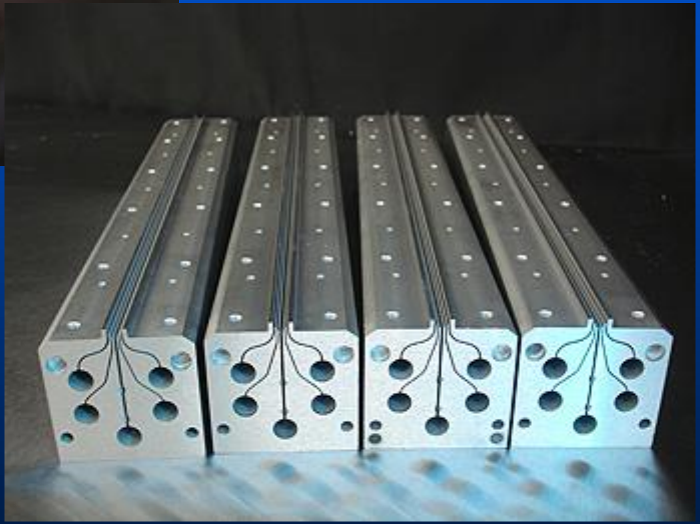
Wire EDM

Edm wire
Edm wire

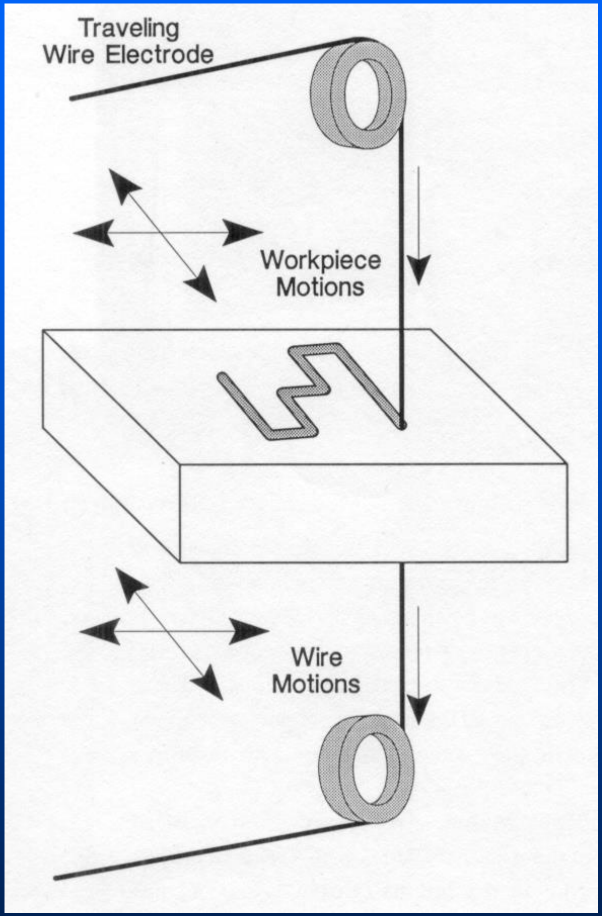


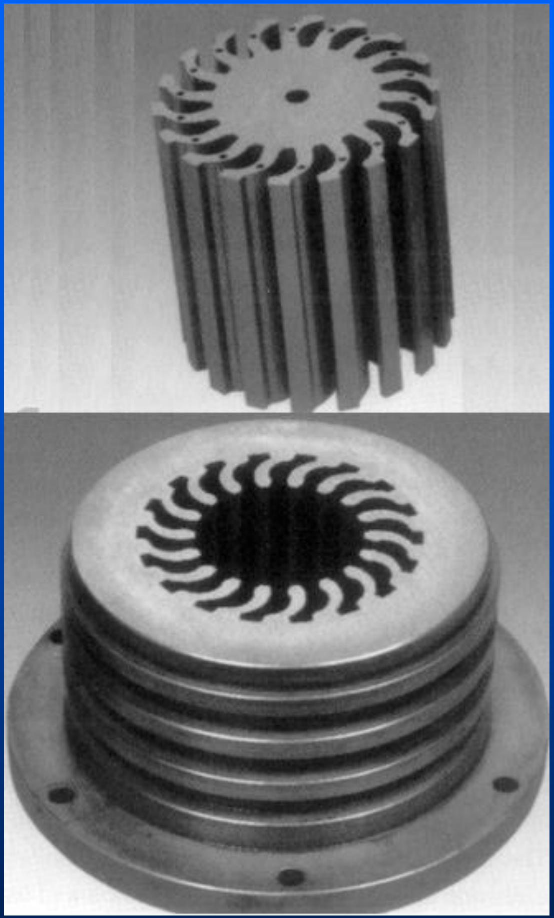
Wire guides (-)
Fresh wire
Dielectric supply
DC supply
CNC movement
Dielectric supply
Used wire


Wire EDM



Wire EDM

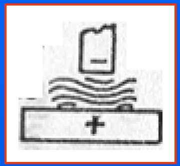


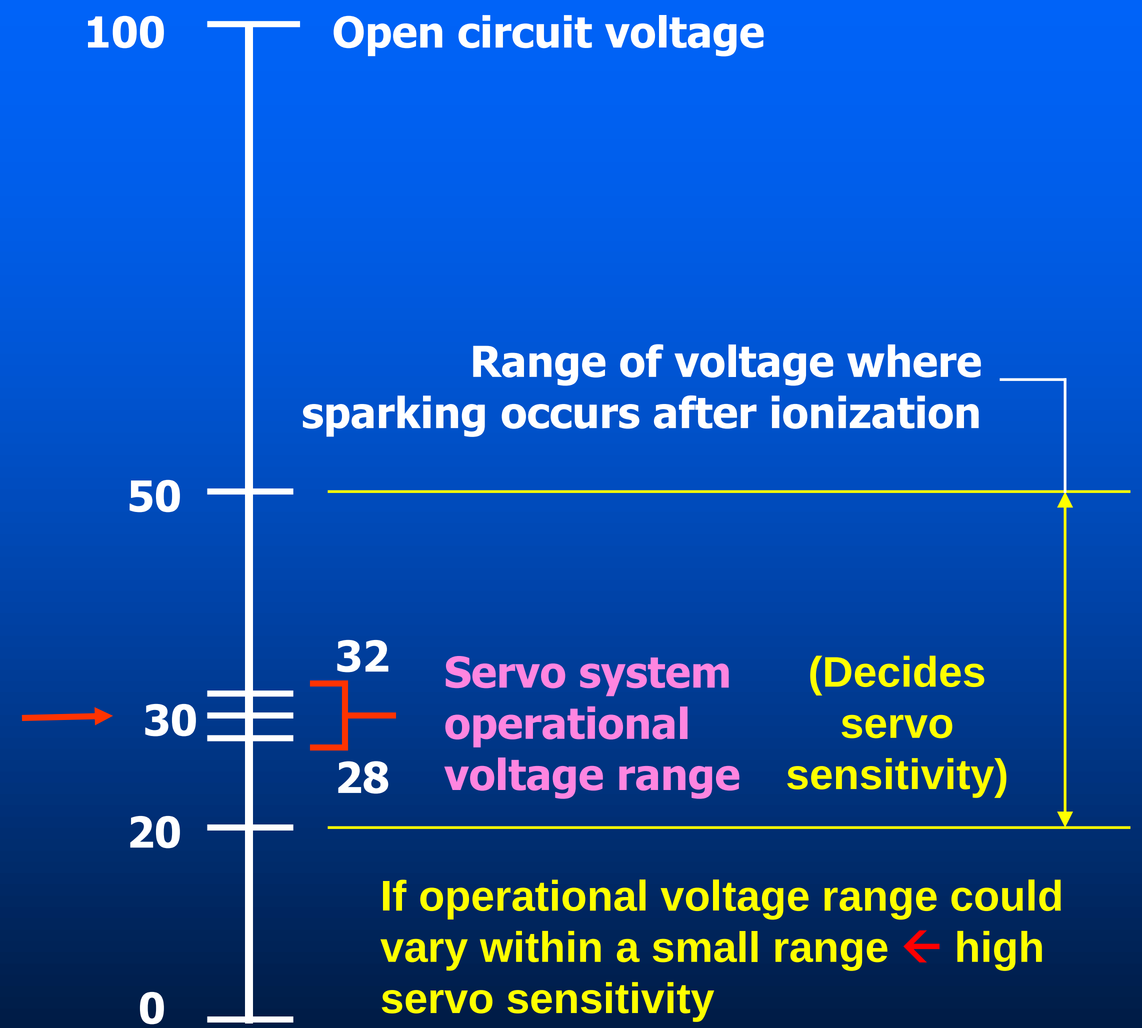


Servo system in EDM

- To maintain pre-determined gap between the electrodes
- Gap bridged by electrically conductive materials → signal to servo system → reverse direction
- Reciprocates towards work piece until dielectric flushes gap
- If flushing is inefficient → very long cycle time

Servo Operation Based on Machining and Reference Voltage





If operational voltage range could vary within a small range ← high servo sensitivity

Pulses in EDM

- Performance measures such as MRR, tool wear, and surface finish for the same energy depend on the shape of the current pulses.

- Depending upon the situation in the gap which separates both electrodes, principally four different electrical pulses may be distinguished:

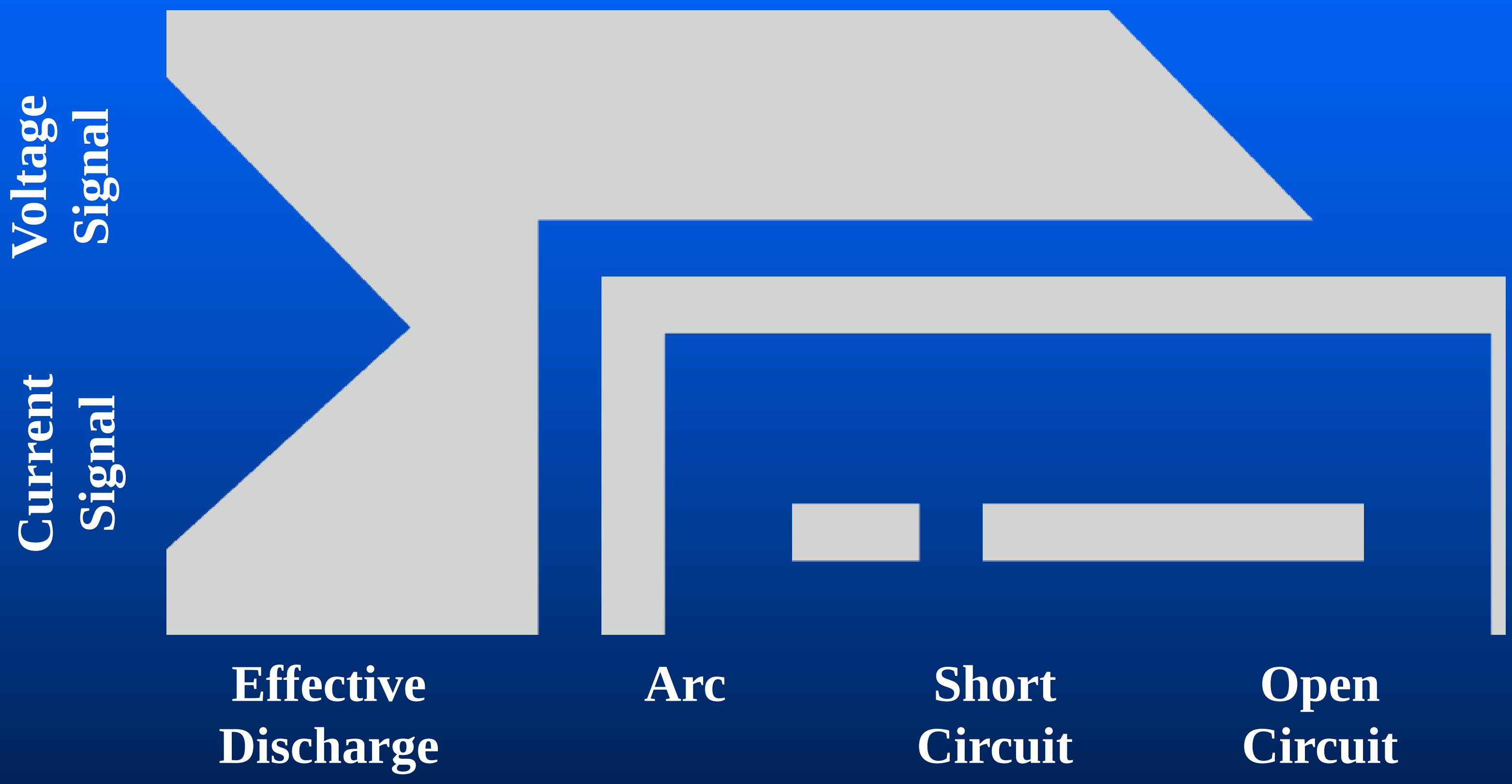
a) Open circuit or open voltage

b) Effective discharges or real Sparks

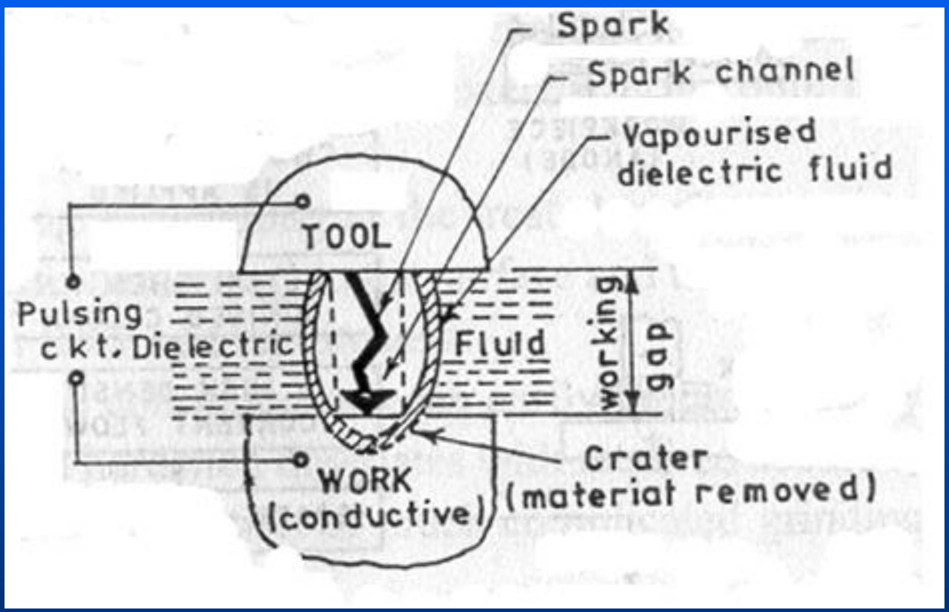
c) Arcs and

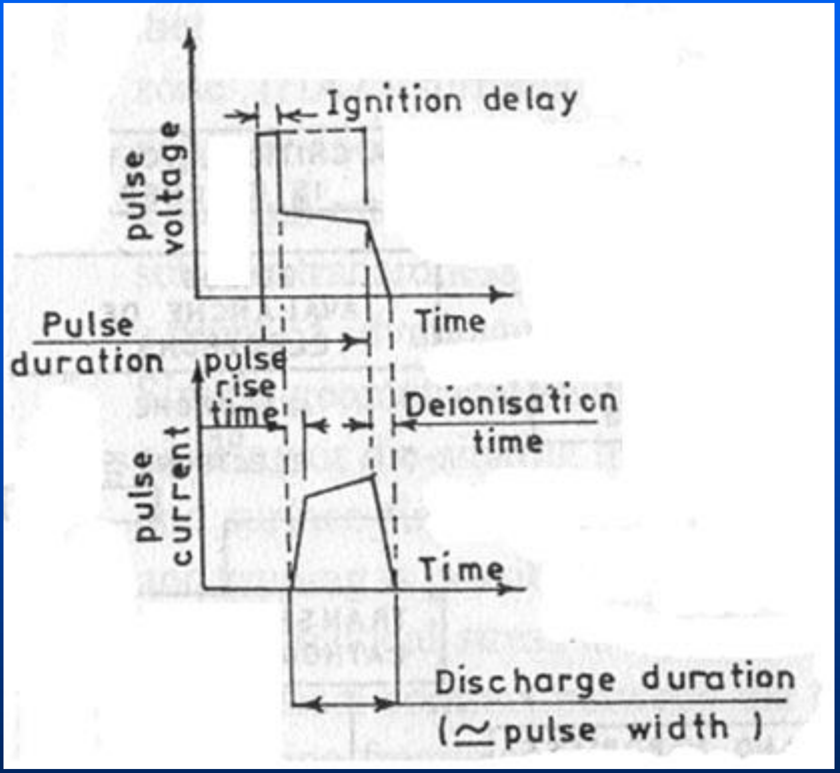
d) Short circuits

Pulses in EDM



Puse Waveform for Effective Discharge



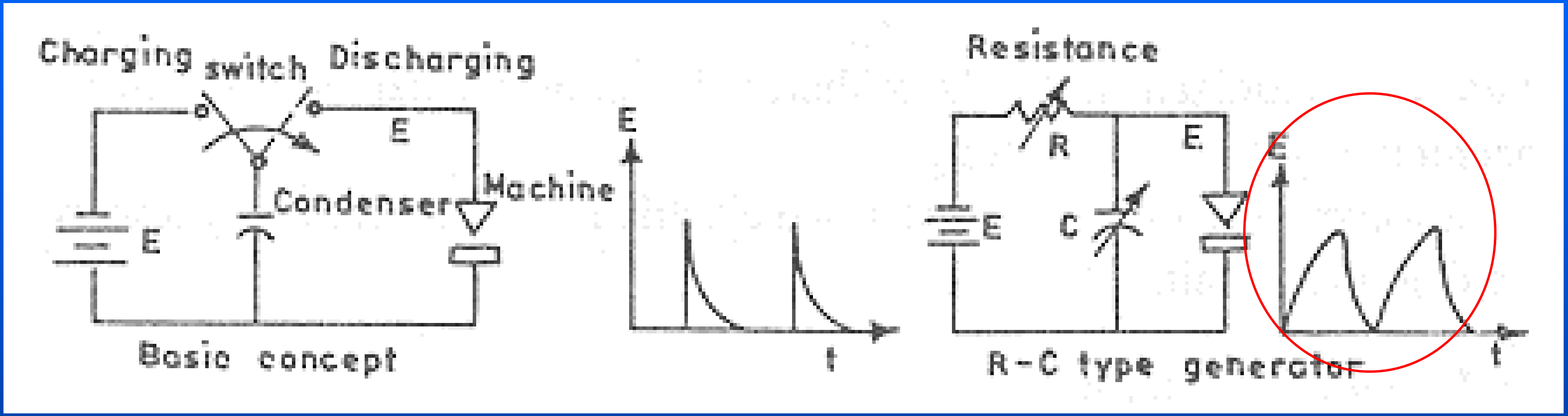


Pulse Generators

Controlled pulse generator governs shape and frequency of pulsing. It enables

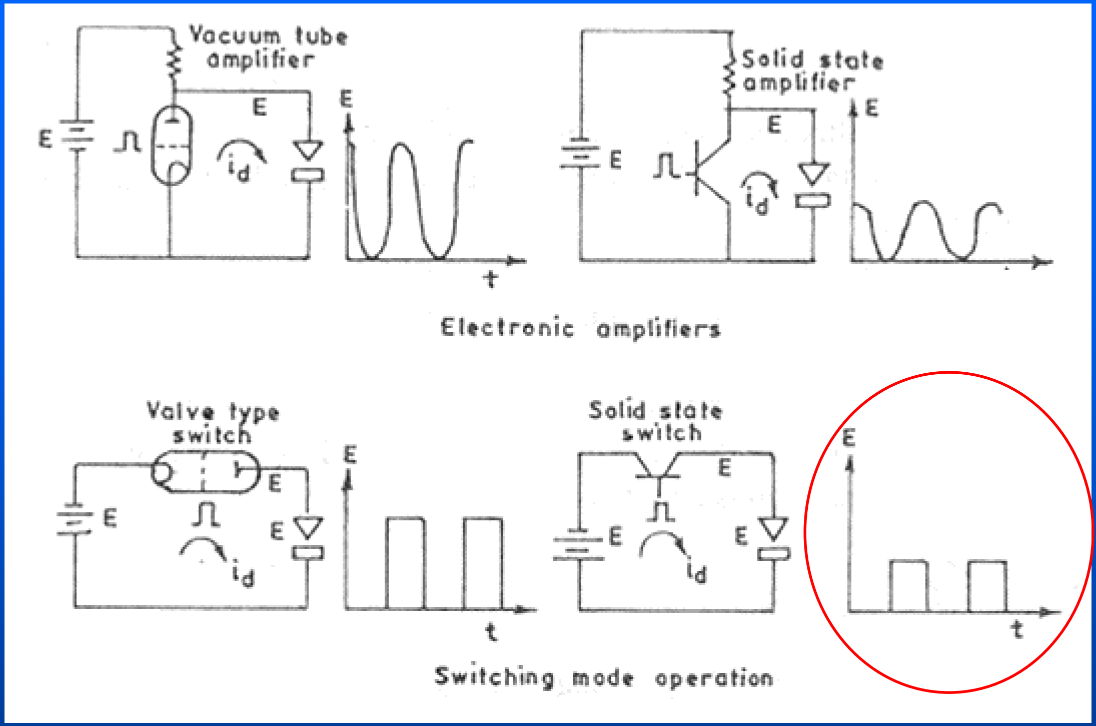
→ rough machining (high energy and low frequency), or
→ finish machining (low energy and high frequency)

Pulse Generators



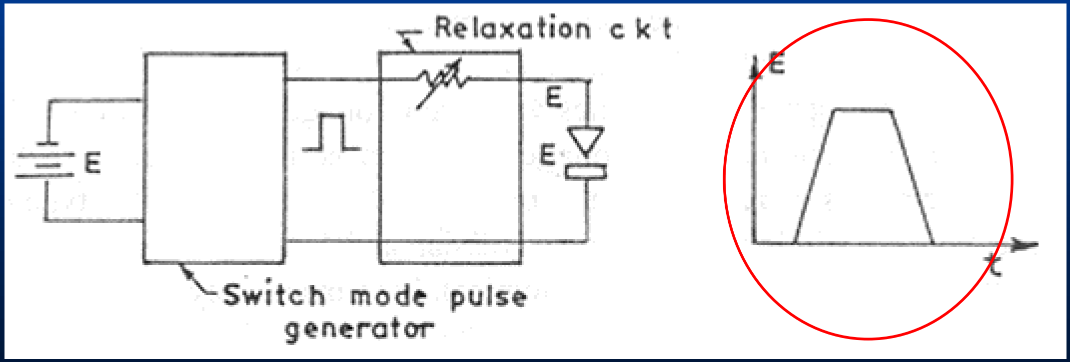
Relaxation generator or RC generator

Pulse Generators

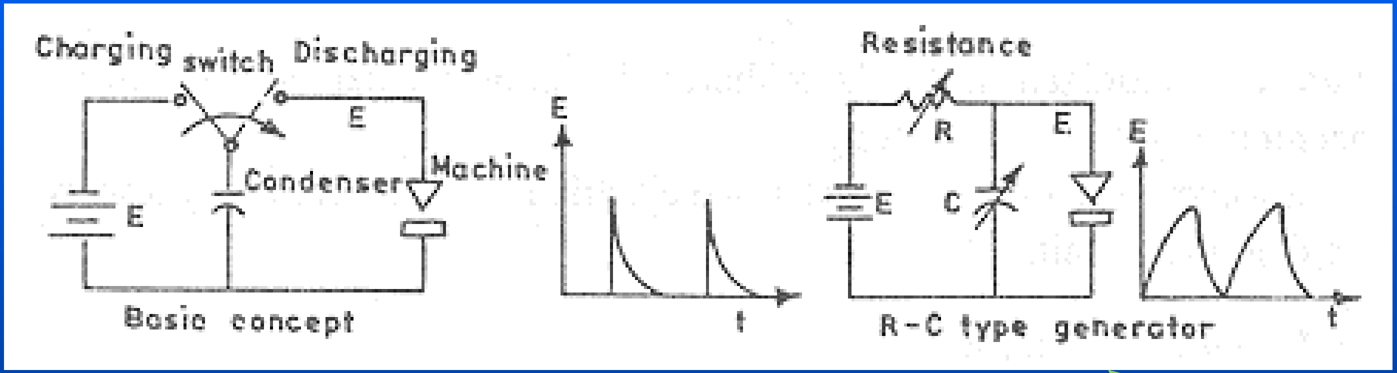


Electronic Pulse Generator

Hybrid Pulse Generator
(Electronic + Relaxation)



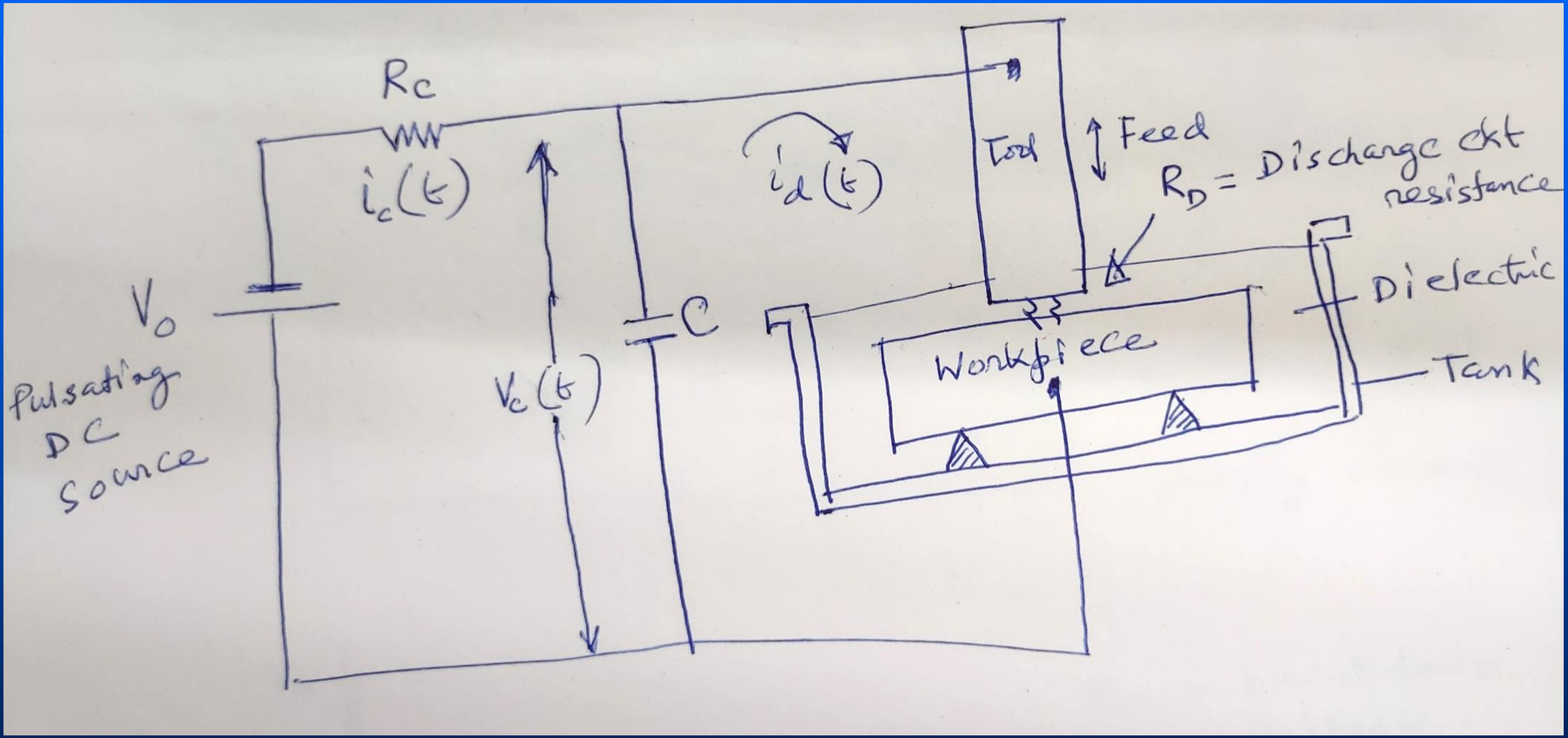
Relaxation Generator



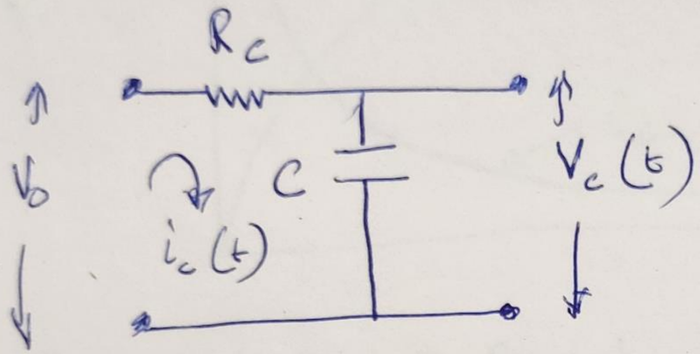
Charging portion

Discharging portion

Relaxation Generator



Charging portion of a Relaxation Generator



$$i_c(t) = \frac{V_0 - V_c(t)}{R_c} = C\frac{dV_c}{dt}$$

$$\frac{dV_c}{V_0 - V_c} = \frac{1}{C.R_c}\,dt$$

At $t = 0$, $V_c = 0$ and at $t = t_c$, $V_c = V_c$

$$\int_0^{V_c} \frac{dV_c}{V_0 - V_c} = \frac{1}{C.R_c}\int_0^{t_c} dt$$

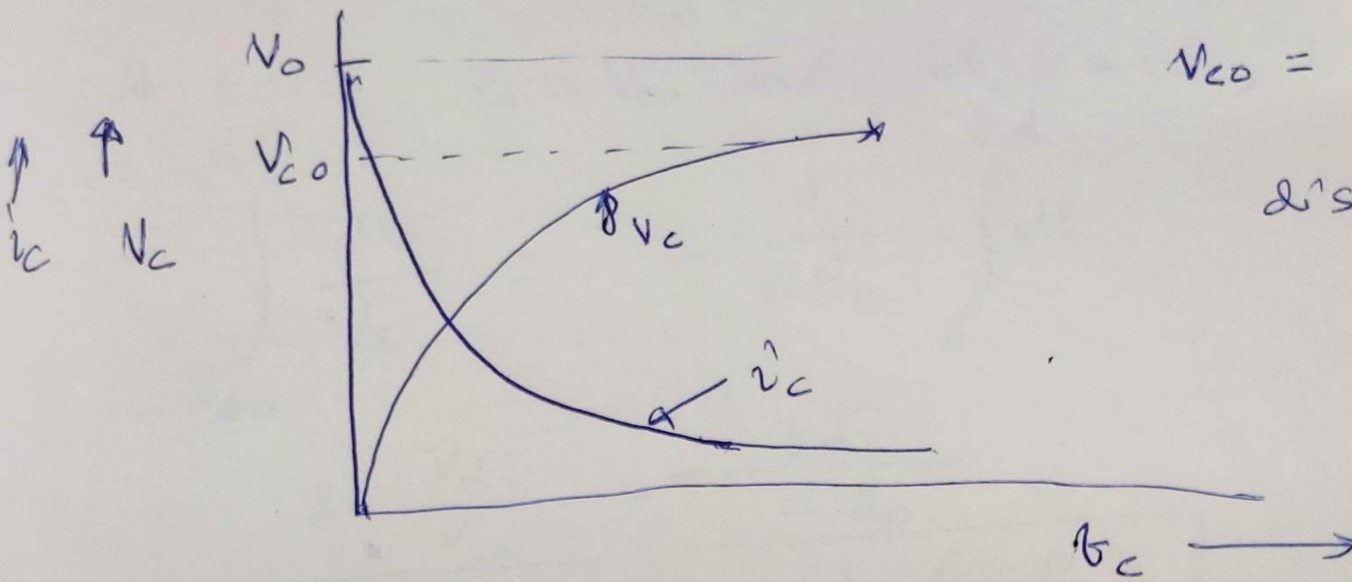
$$\Rightarrow \ln\left(\frac{V_0 - V_c}{V_0}\right) = -\frac{1}{C.R_c}\,t_c$$

$$\boxed{V_c = V_0\left[1 - e^{-(t_c/C.R_c)}\right]}$$ → exponential rise of charging voltage with time

Now, $$i_c = \frac{V_0 - V_c}{R_c} = \frac{V_0 - V_0\left[1 - e^{-(t_c/CR_c)}\right]}{R_c}$$

$$\therefore \boxed{i_c = \frac{V_0}{R_c} e^{-(t_c/C.R_c)}}$$ → exponential decay of charging current

V_{co} = breakdown voltage
↓
discharge takes place



The factor $C.R_c$ is defined as the 'time constant' of the circuit.
It is equal to the time taken by the condenser to reach 0.638 times the charging voltage.

For $t_c = C.R_c$

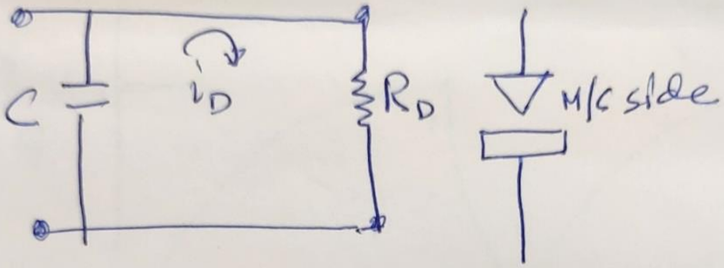
$$V_c = V_0\left[1 - e^{-(C.R_c/(C.R_c))}\right]$$

$$= V_0(1 - 0.372)$$

$$= 0.638\, V_0$$

=

Discharging portion of a Relaxation Generator



R_D = total resistance of the discharge portion

= Lead resistance + spark gap resistance

$$i_d = \frac{V_d}{R_D} = -C\frac{dV_d}{dt}$$

$$\frac{dV_d}{V_d} = -\frac{1}{C.R_D}\,dt$$

At $t=0$, $V_d = V_{co}$ and at $t = t_d$, $V_d = V_d$

$$\int_{V_{co}}^{V_d} \frac{dV_d}{V_d} = -\frac{1}{CR_D}\int_0^{t_d} dt$$

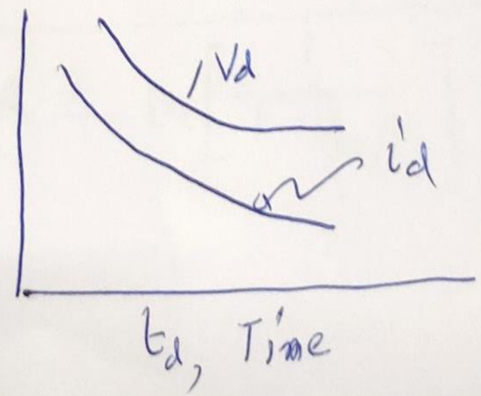
$$\ln\frac{V_d}{V_{co}} = -\frac{t_d}{C.R_D}$$

$$\boxed{V_d = V_{co}\, e^{-(t_d/C.R_D)}}$$

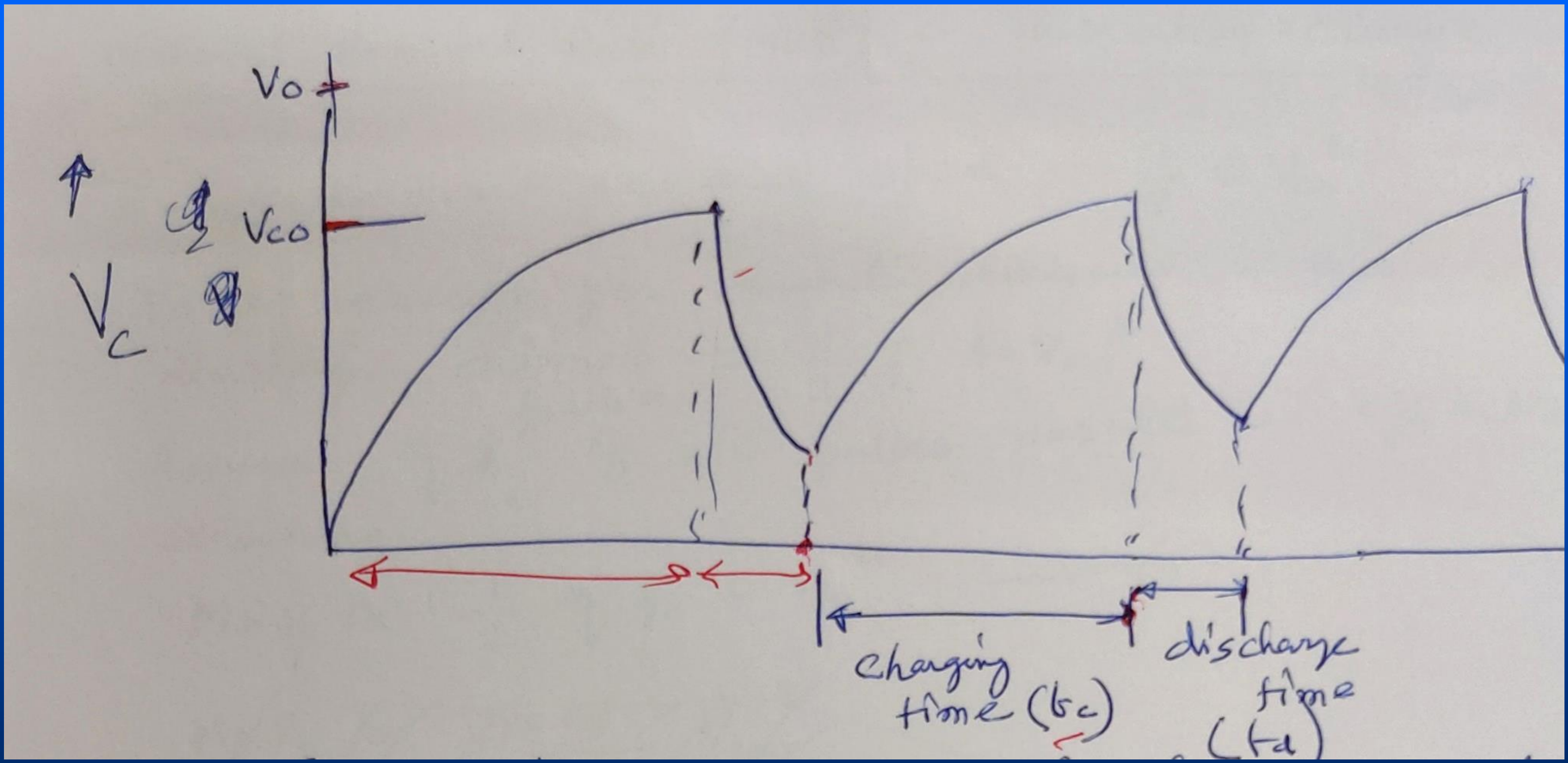
$$\therefore \quad \boxed{i_d = \frac{V_d}{R_D} = \frac{V_{c0}}{R_D} e^{-(t_d / (C \cdot R_D))}}$$

↑ discharge current

↑ Voltage



Pulse Shape of a Relaxation Generator



Saw-tooth curve ← in actual operation of a RC-generator

Frequency of operation

Charging time

$$t_c = C \cdot R_c \ln\left[\frac{1}{1-\frac{V_{co}}{V_o}}\right]$$

Discharge time

$$t_d = R_D \cdot C \ln\left[\frac{V_d}{V_{co}}\right]$$

Frequency

$$f = \frac{1}{t_c + t_d}$$

$$= \frac{1}{R_c \cdot C \ln\left[\frac{1}{1-V_{co}/V_o}\right] + R_D C \cdot \ln\left[V_d/V_{co}\right]}$$

If, $t_c \gg t_d$

$$f \approx \frac{1}{t_c}$$

Material Removal Rate in a Relaxation Generator

Energy delivered in each spark

$$= \frac{1}{2} C\, V_{co}{}^{2}$$

Total energyper second delivered

$$= \frac{1}{2} f_c\, C\, V_{co}{}^{2}$$

Assume η fraction of all pulses results in effective discharge.

$$\mathrm{MRR} \propto \frac{1}{2} \eta\, f_c\, C\, V_{co}{}^{2} \qquad \ldots\ldots..(1)$$

Frequency of charging when $t_c \gg t_d$

$$f_c = \frac{1}{t_c} = \frac{1}{R_c\, C}\ \frac{1}{\ln\left(1 - {V_{co}}/{V_o}\right)} \qquad \ldots\ldots\ldots..(2)$$

$$\text{Let } K_f = \frac{1}{\ln\left(1 - V_{co}/V_o\right)} = f_c\, C\, R_c$$

$$\text{So,} \qquad MRR \propto \frac{1}{2}\eta\, \frac{K_f}{R_c}\, V_{co}^{\,2}$$

From equations (1)and (2),

$$\boxed{MRR = \frac{K_1\,\eta}{2\,R_c} V_{co}^{\,2} \left[\frac{1}{\ln\left(1 - V_{co}/V_o\right)}\right]}$$

Where K_1 is the constant of proportionality

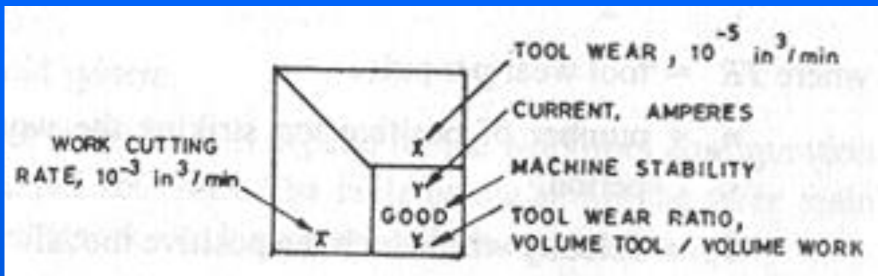
Process Parameters of EDM

- Peak current setting
- Gap voltage
- Capacitance
- Pulse on time
- Pulse off time
- Duty factor
- Polarity

Process Variables

- Increase in current or spark voltage → increased MRR, higher surface roughness
- Low Inter-electrode Gap → low MRR, high surface finish, better accuracy
- Increase in spark frequency → improved surface finish ← as energy is shared by more number of sparks → decreased crater size
- Decreased pulse duration → low MRR, better surface finish, low electrode wear

Effect of Polarity

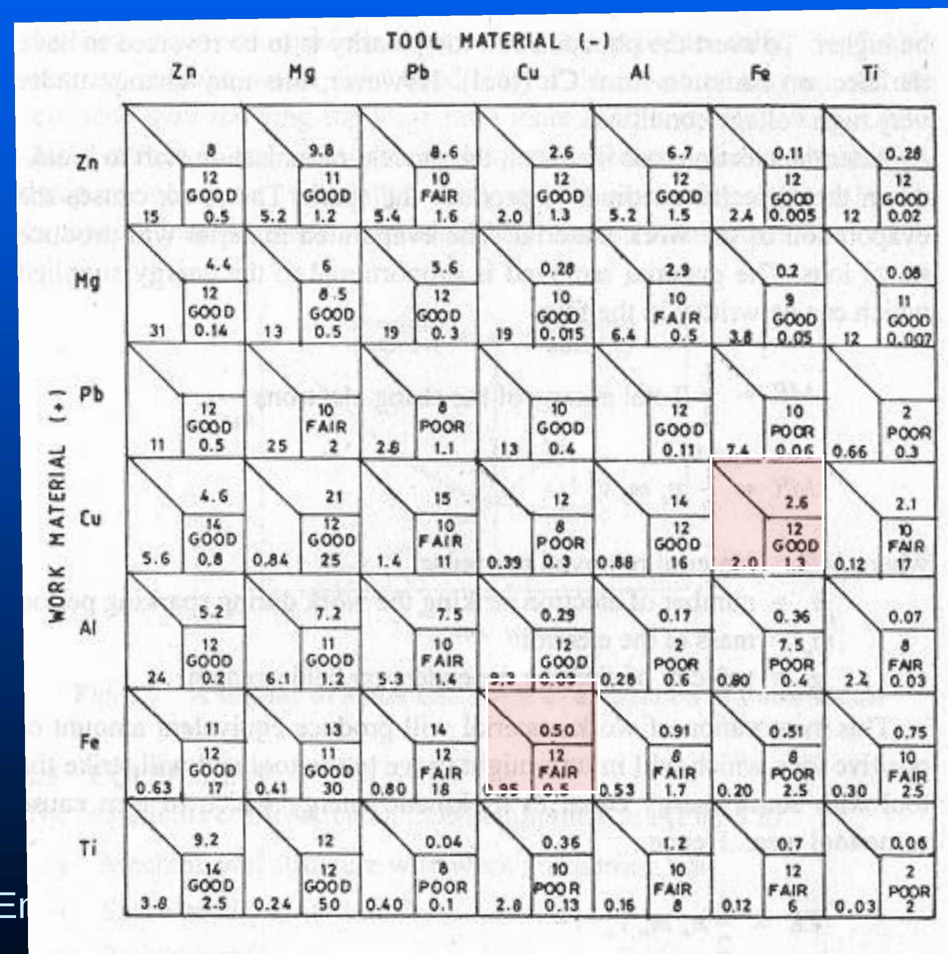


For machining ferrous material with copper tool, what polarity should be given to the work piece and why?

Choosing iron "negative and cooper tool "positive" gives a stronger discharge than vice versa.

Iron atom can give away electrons more easily…

Electro-discharge machining characteristics of various electrode-material combinations

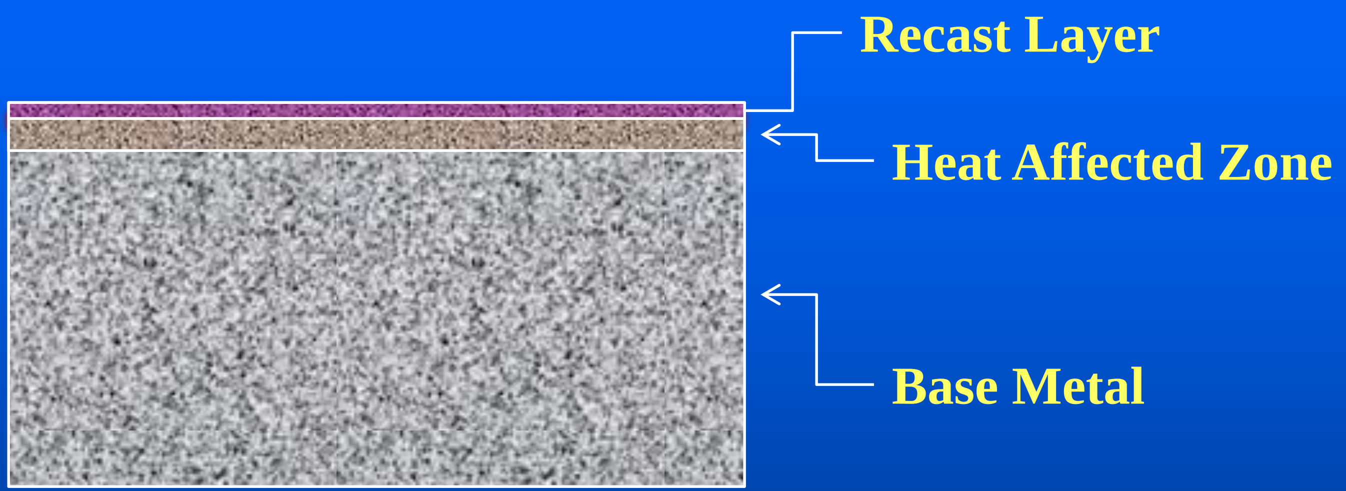


TOOL MATERIAL (-)

WORK MATERIAL (+)	Zn	Mg	Pb	Cu	Al	Fe	Ti
Zn	8 · 12 GOOD 0.5 · 15	9.8 · 11 GOOD 1.2 · 5.2	8.6 · 10 FAIR 1.6 · 5.4	2.6 · 12 GOOD 1.3 · 2.0	6.7 · 12 GOOD 1.5 · 5.2	0.11 · 12 GOOD 0.005 · 2.4	0.28 · 12 GOOD 0.02 · 12
Mg	4.4 · 12 GOOD 0.14 · 31	6 · 8.5 GOOD 0.5 · 13	5.6 · 12 GOOD 0.3 · 19	0.28 · 10 GOOD 0.015 · 19	2.9 · 10 FAIR 0.5 · 6.4	0.2 · 9 GOOD 0.05 · 3.8	0.08 · 11 GOOD 0.007 · 12
Pb	12 GOOD 0.5 · 11	10 FAIR 2 · 25	8 POOR 1.1 · 2.8	10 GOOD 0.4 · 13	12 GOOD 0.11	10 POOR 0.06 · 7.4	2 POOR 0.3 · 0.66
Cu	4.6 · 14 GOOD 0.8 · 5.6	21 · 12 GOOD 25 · 0.84	15 · 10 FAIR 11 · 1.4	12 · 8 POOR 0.3 · 0.39	14 · 12 GOOD 16 · 0.88	2.6 · 12 GOOD 1.3 · 2.0	2.1 · 10 FAIR 17 · 0.12
Al	5.2 · 12 GOOD 0.2 · 24	7.2 · 11 GOOD 1.2 · 6.1	7.5 · 10 FAIR 1.4 · 5.3	0.29 · 12 GOOD 0.03 · 9.3	0.17 · 2 POOR 0.6 · 0.28	0.36 · 7.5 POOR 0.4 · 0.80	0.07 · 8 FAIR 0.03 · 2.2
Fe	11 · 12 GOOD 17 · 0.63	13 · 11 GOOD 30 · 0.41	14 · 12 FAIR 18 · 0.80	0.50 · 12 FAIR 0.5 · 0.95	0.91 · 8 FAIR 1.7 · 0.53	0.51 · 8 POOR 2.5 · 0.20	0.75 · 10 FAIR 2.5 · 0.30
Ti	9.2 · 14 GOOD 2.5 · 3.8	12 · 12 GOOD 50 · 0.24	0.04 · 8 POOR 0.1 · 0.40	0.36 · 10 POOR 0.13 · 2.8	1.2 · 10 FAIR 8 · 0.16	0.7 · 12 FAIR 6 · 0.12	0.06 · 2 POOR 2 · 0.03

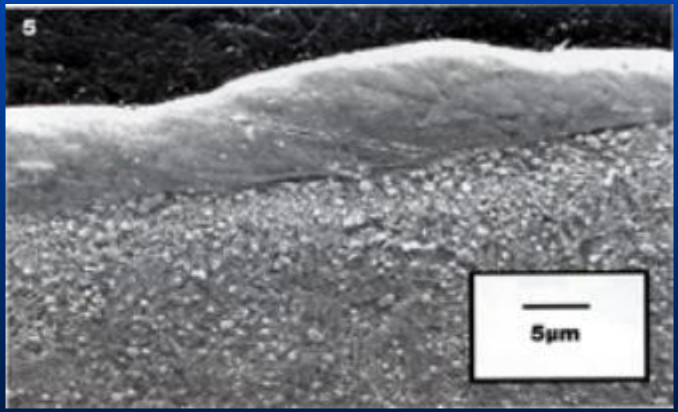
Surface Integrity in EDM

Surface topography nad subsurface metallurgy

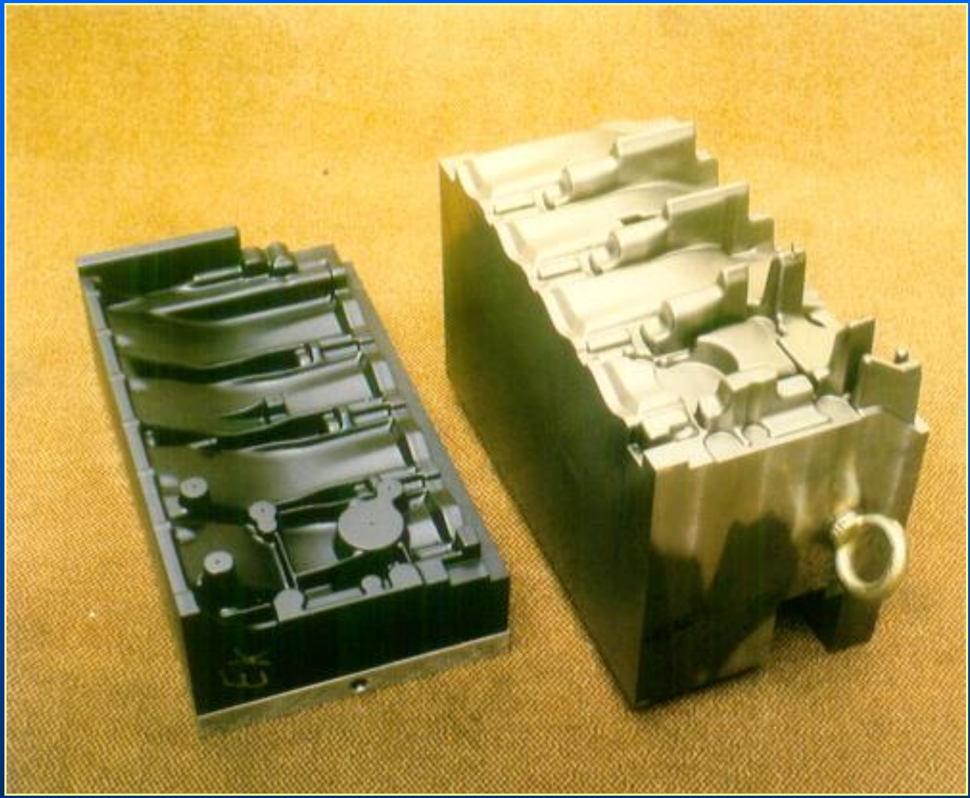


Recast Layer

- Molten metal not flushed away, resolidified on workpiece
- hardened due to fast cooling, hardness (6o HRC),
- thin : 2.5 – 50 micron
- may contain micro-cracks
- should be removed



EDM Applications



Part of mould for casting a crankcase

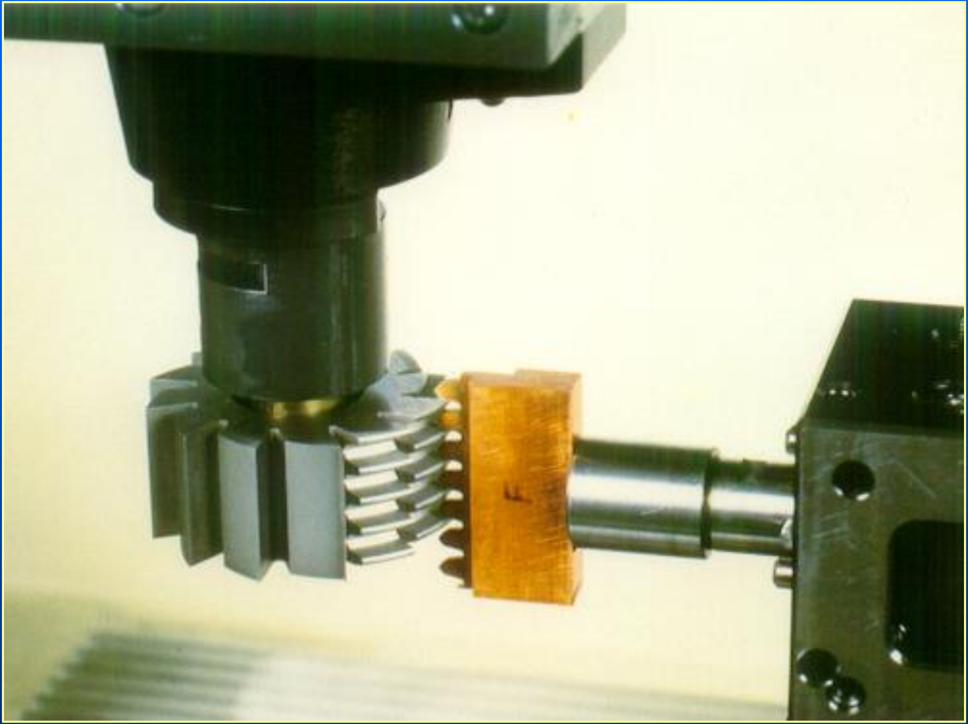
Material : Steel

Dimensions : 200 x 150 mm

Electrode : One graphite electrode for rouging and finishing

Machining time : 30 hours

EDM Applications



Machining of gear wheel cutter

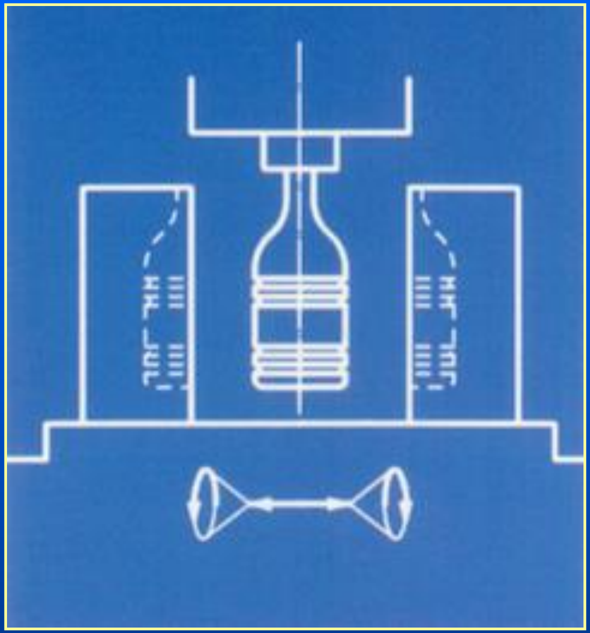
Material : Hardened Steel

Surface finish : 5 micron

Electrode : Copper electrode,
one for rouging, one
for finishing

Machining time : 3 hours 30 min

EDM Applications



Material : Steel

Preliminary Machining : Boring a 50 mm diameter hole

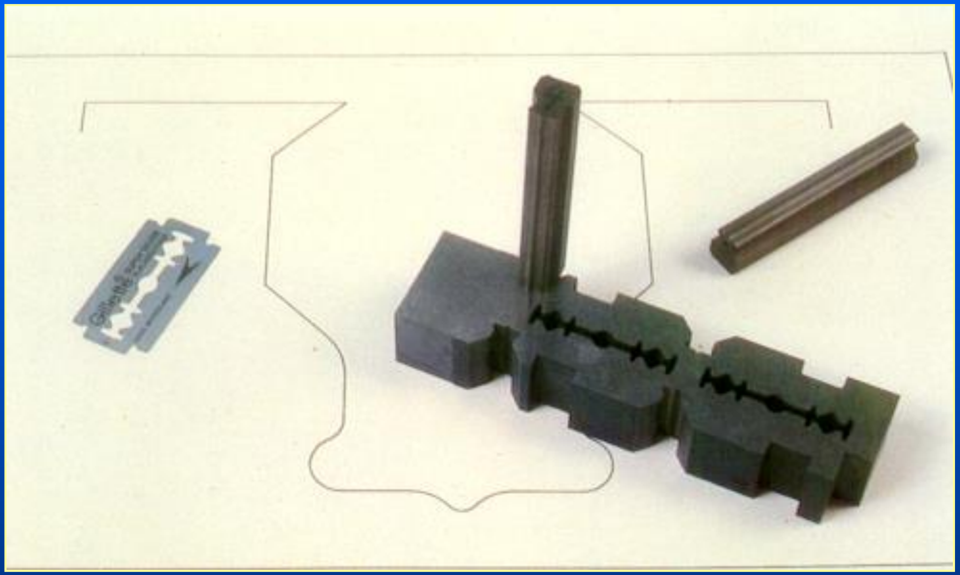
Electrode: Two graphite electrodes. One for rouging and one for finishing

Surface finish : 1.3 micron R_a

Machining time : 50 hours

Mould for a bottle (1 ½ litres)

EDM Applications



Punch and die set for cutting razor blades

Material :
Die in carbide 63 mm, Punch in carbide 20 mm

Geometric tolerance : 2 μm

Surface finish : 1.1 micron R_a

Relief angle :
Die 4 minutes, Punch 1 minute

Machining time :
Die:15 hours, Punch: 3.5 hours

EDM Applications

Material : Hardened Steel

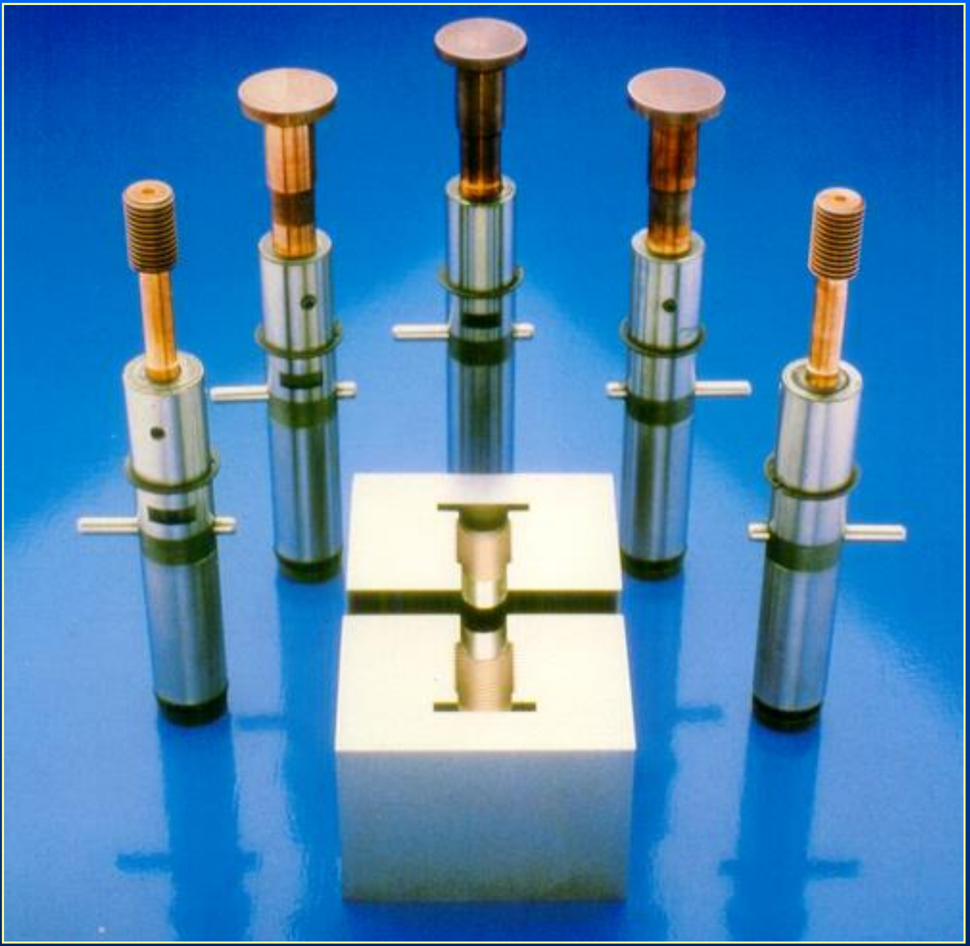
Electrode : Copper

Surface Finish: 0.14 μm (polished)

Machining time: 1 hour 30 min

Machining of engraving of knurling wheel

EDM Applications



Material : Steel

Precision : 0.01mm

Electrode : Copper

Surface Finish: 0.4 mm R_a

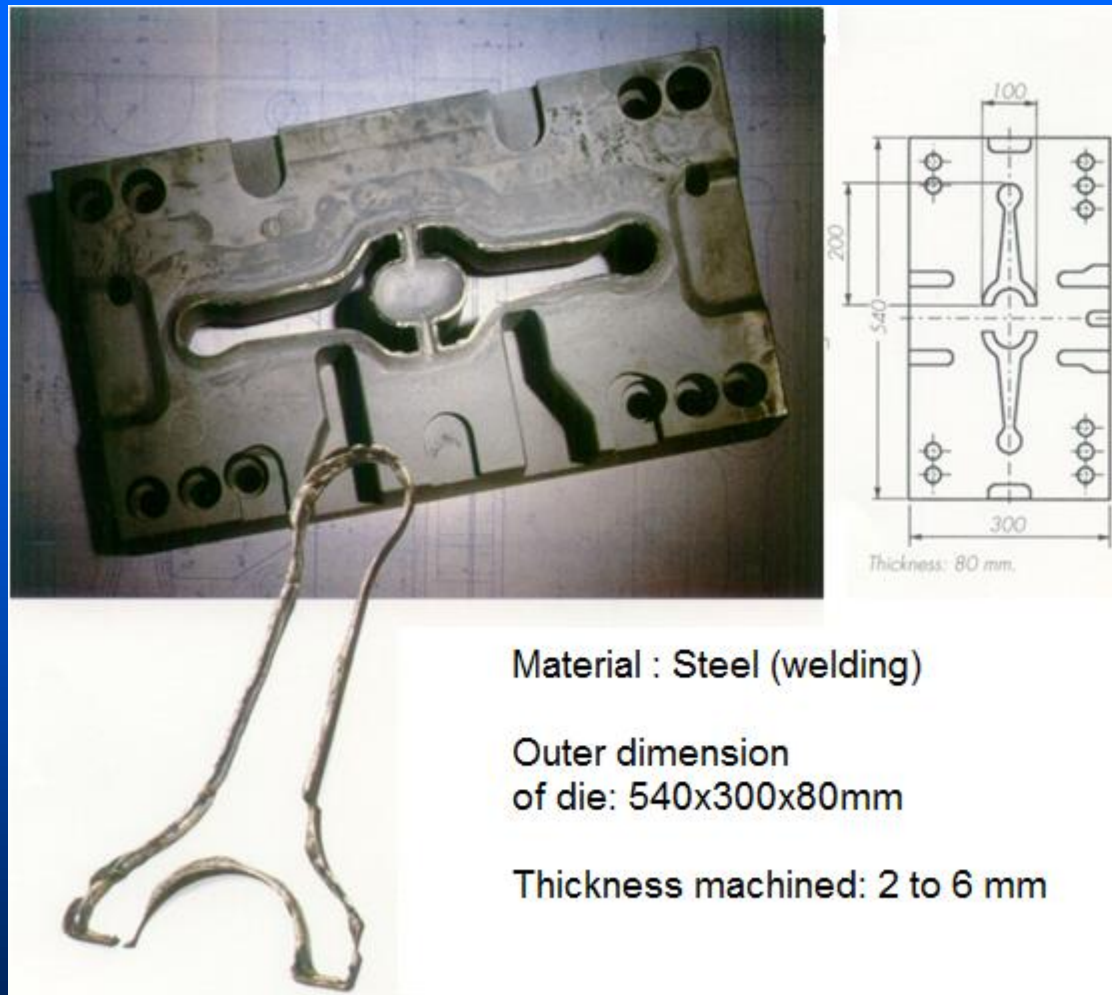
Machining time: 9 hours

Two cavity mould with very fine surface finish

EDM Applications

Parts of dies for the forging of universal joints (automotive industry)

EDM Applications



Cutting of a connecting rod trimming die built up by welding

Thank You