Advanced Manufacturing Processes (AMPs)

Electrical Discharge Machining (EDM)

by
Dr. Sunil Pathak
Faculty of Engineering Technology
sunilpathak@ump.edu.my

Chapter Description

- Aims
  - To provide and insight on Electrical Discharge Machining Process
  - To provide details on fundamental and advances in EDM Process
  - Advantages and Limitations of EDM is also Presented

- Expected Outcomes
  - Learner will be able to know about the Fundamentals of EDM
  - Learner will be able to identify role of EDM in todays sceneries

- Other related Information
  - Student must have some basic idea of conventional manufacturing and machining
  - Student must have some fundamentals on materials

- References
  - ……..
  - ……..
  - ……..

Electro Discharge Machining (EDM)

PROCESS HISTORY

Universiti Malaysia PAHANG
Engineering • Technology • Creativity

- EDM is a precision **material removal** process using an accurately controlled **electrical discharge** (spark) to erode an electrically **conductive** material.
- **Metal Erosion** by **Spark Discharges** was *First* Observed by **Sir Joseph Priestley in 1768**
- **Spark Discharges** were Used Increasingly for **Disintegration of Various Materials to Remove Broken Taps, Drills, and Reamers** and to **Produce Colloidal Solution.**

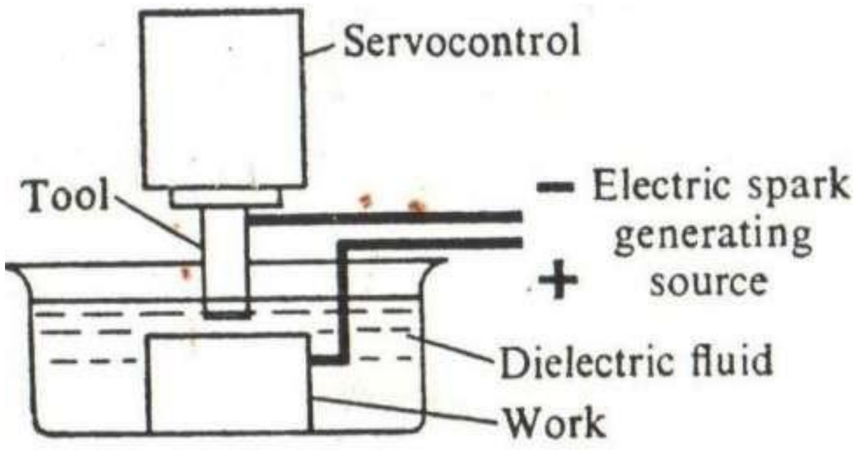
1700 – EDM phenomenon was first noticed and conceptualized
1881 – Meritens used arcs for welding
1948 - Two Russians **B.R. and N.I. Lazarenko** first applied the principle to a machine for material removal
1970 – Start of big growth in use of EDM. Annual growth was about 30 %.

Background

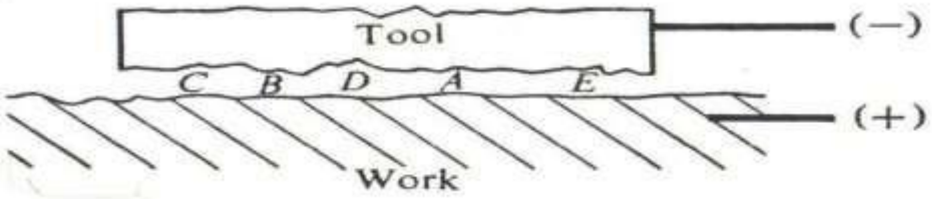
- When **two electrodes** are **subjected** to **electrical sparking** (discharging), the electrode will **experience erosion/wear**
- If two electrodes are of same material, **greater erosion** occurs on **positive** electrode.
- In a **spark plug**, for example, the **erosion needs to be minimized**.
- In **machining**, researchers seek to **maximize material removal rate** (MRR)
- For maximum MRR with minimum tool wear, **work** is made **positive**, **tool** is made **negative**.

Process Principle

- **A thermal energy based process in which an electrically Conducting Material** is Removed by **Controlled Erosion** Through a **Series of Sparks**
- Tool (negatively charged electrode) and workpiece (positively charged) are immersed in a bath of **dielectric** fluid (depth of 50 mm over work surface is maintained to eliminate fire risk).
- Dielectric fluid is **circulated** under pressure through a pump, usually through hole/s in tool.
- Spark **gap** of about 0.025 to 0.05 mm (0.0125 to 0.125 mm) is maintained by servomotor.
- The tool is mounted on chuck attached to machine spindle. The spindle **vertical feed** is controlled by servomotor through a reduction gearbox.
- Tool and workpiece are connected to a DC relaxation circuit fed either from a DC generator or rectifier.



Basic scheme of electric discharge machining.



Details of electrode surface characteristics.

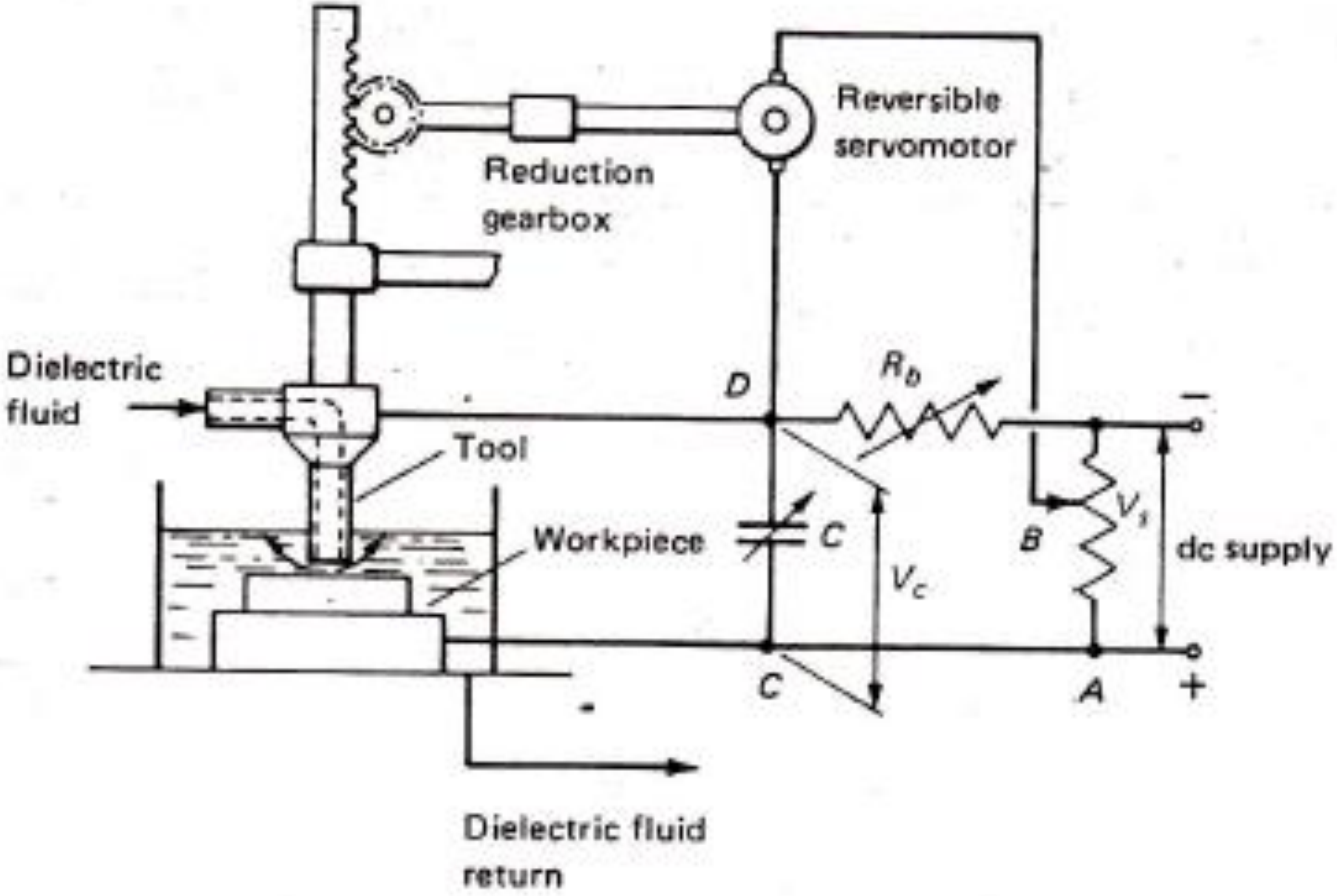
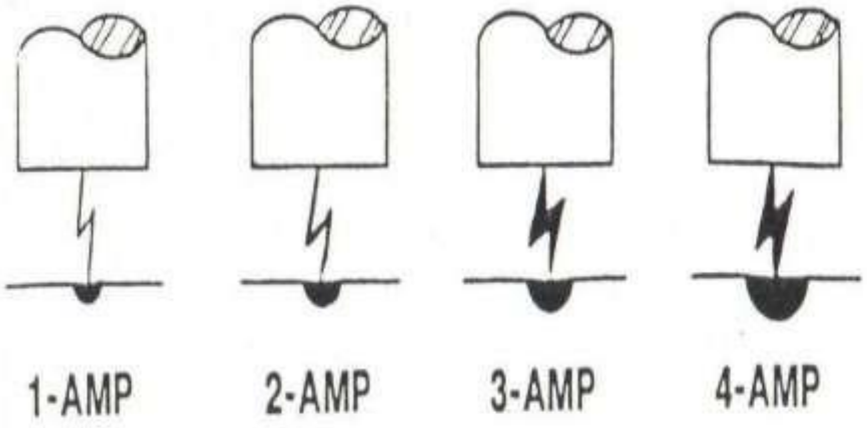


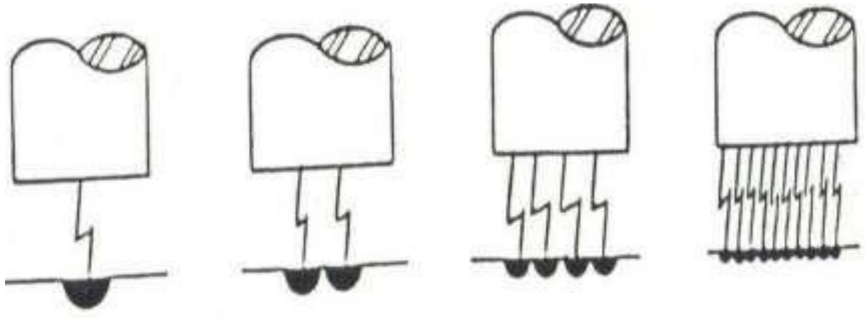
FIG. 1 Electrical-discharge machining.

SUMMARY of EDM CHARACTERISTICS

Parameter	Details
Dielectric	Hydrocarbon (Petroleum) Oils Kerosene Deionized Water
Dielectric Flow Pressure	711 mm Vacuum to 480 kPa
Tool Materials	Cu, Brass, Cu-W Alloy; Ag-W Alloy; Graphite
Work Materials	All Electrically Conducting Materials
Tool-Workpiece Or Spark Gap	10 – 125 μm
Spark Frequency	0.05 – 500 kHz
Voltage	40 – 400 V DC
Current	0.5 – 400 A
Maximum MRR	5 x 10^3 mm^3/min
Specific Power Consumption	1.8 W/mm^3/min
MRR/TWR	0.1 to 10
Critical Parameters	Voltage, Capacitance, Spark Gap, Dielectric Circulation, Melting Temperature



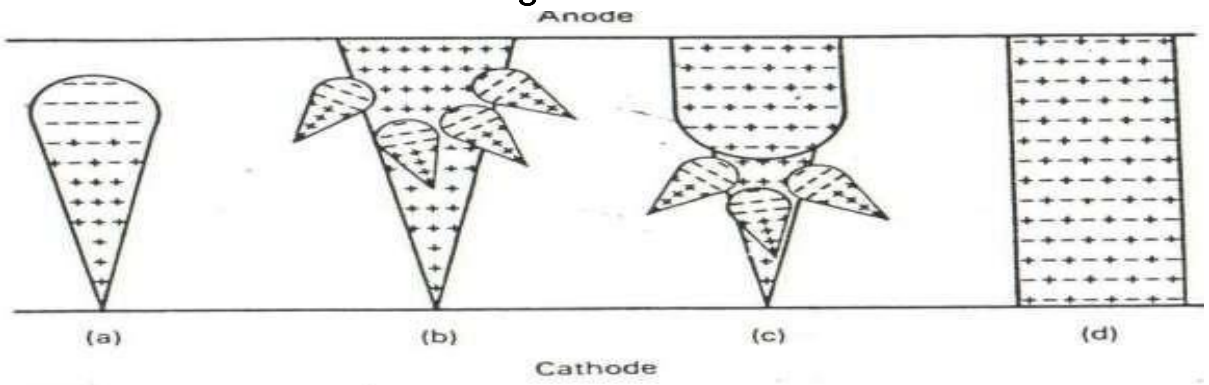
Effect of current on EDM process (*Source*: courtesy, Hansvedt EDM Division, Urbana, Ill).



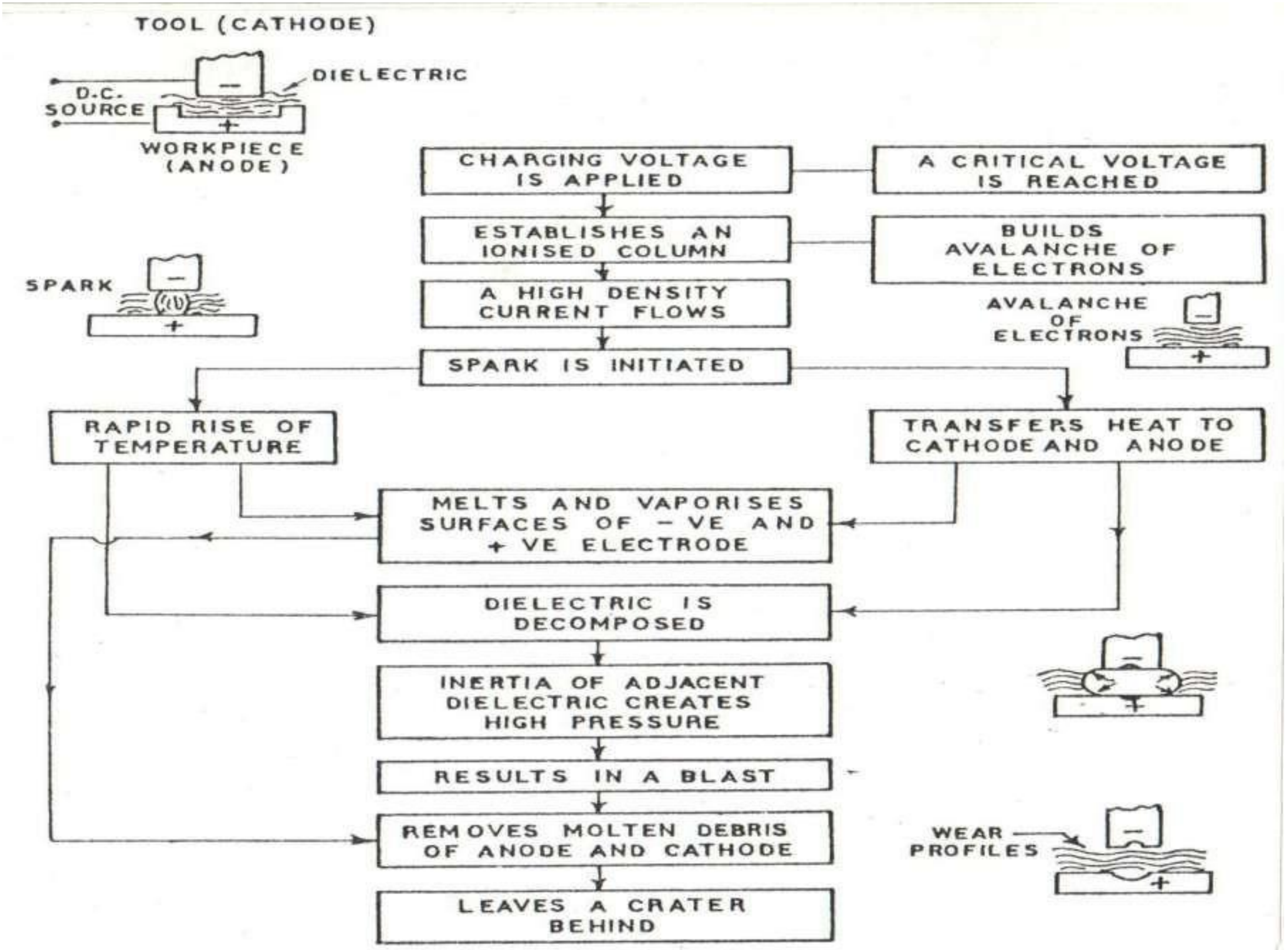
Effect of spark frequency on surface finish (*Source*: courtesy, Hansvedt EDM Division, Urbana, Ill.)

MECHANISM of MATERIAL REMOVAL in EDM

- When a Suitable Voltage is Built up Across the Tool and Workpiece, an **Electrostatic Field of**
- **Sufficient Strength is Established → Cold Emission of Electrons from the Cathode**
- **Electrons Accelerate Towards** the **Anode** (Workpiece)
- After Gaining Sufficient Velocity, **Electrons Collide** with the **Molecules** of the **Dielectric Fluid**
- **Breaking** them into **Electrons and Positive Ions**
- A **Narrow Column** of **Ionized Dielectric Fluid Molecules** is Established at the **CLOSEST Spot** between **Anode** and **Cathode →** Causes **an Avalanche of Electrons** which is **Normally Seen** as a **Spark**, since **Conductivity** of the **Ionized Column** is Very **Large**
- As **Result of Spark**, a **Compression Shock Wave** is Generated and **Very High Temperature**
- **(10,000 – 12,000 ^{0}C)** is **Developed** on the **Electrodes**
- **Very High Temperature** Causes **Melting and Vaporization** of the **Electrode Materials**
- **Molten Material** is **Evacuated** by a **Mechanical Blast** Causing **Craters** on the **Both Electrodes**



Mechanism of sparking in EDM. (After Meek and Craggs, 1953.)
(a) Avalanche of electrons.
(b) Positively ionized gas in gap.
(c) Secondary avalanches.
(d) Streamer development.



Stages of EDM Action

when power is applied:

- ✓ condenser voltage Vc increases exponentially to supply voltage, Vs
- ✓ gap behaves as an open circuit
- ✓ no current flows
- ✓ dielectric fluid acts as insulator
- ✓ Vc builds and reaches gap breakdown voltage, Vg (determined by gap width and dielectric fluid)

at gap breakdown voltage, Vg:

- ✓ a spark is produced across the gap
- ✓ dielectric fluid deionizes
- ✓ dielectric fluid acts as conductor
- ✓ current flows
- ✓ condenser is discharged.

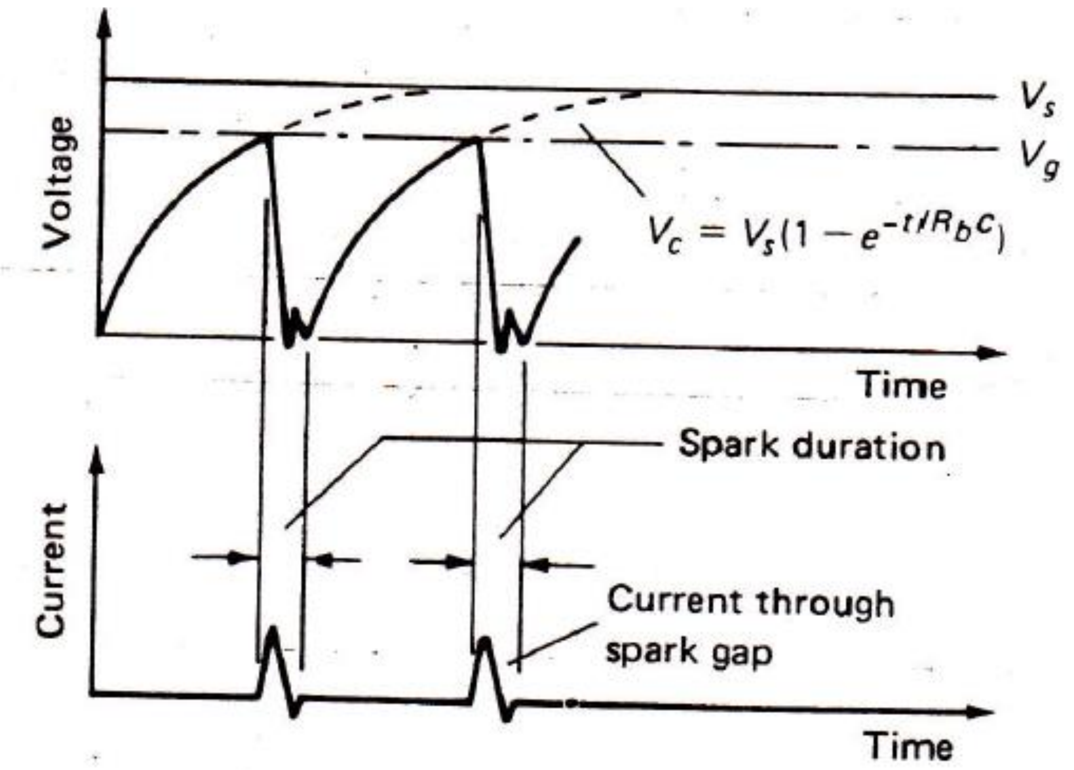


FIG. 2 Voltage and current in electrical-discharge machining.

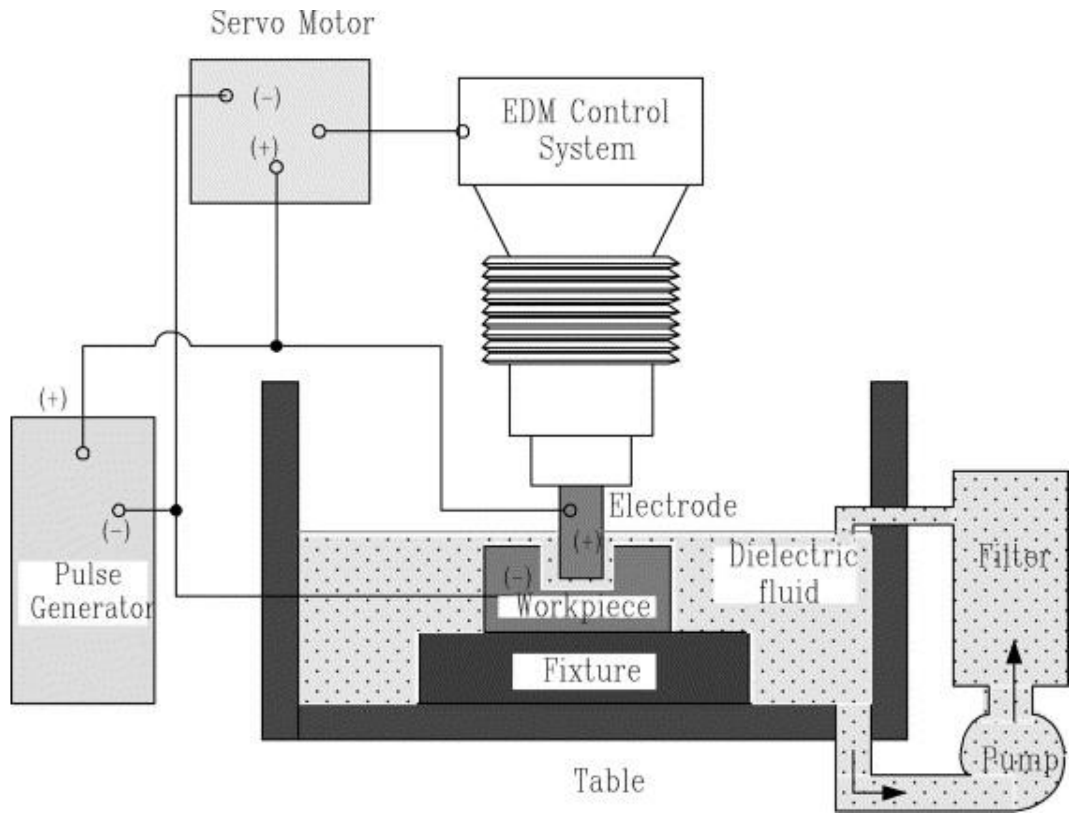
PRINCIPLE (cont)

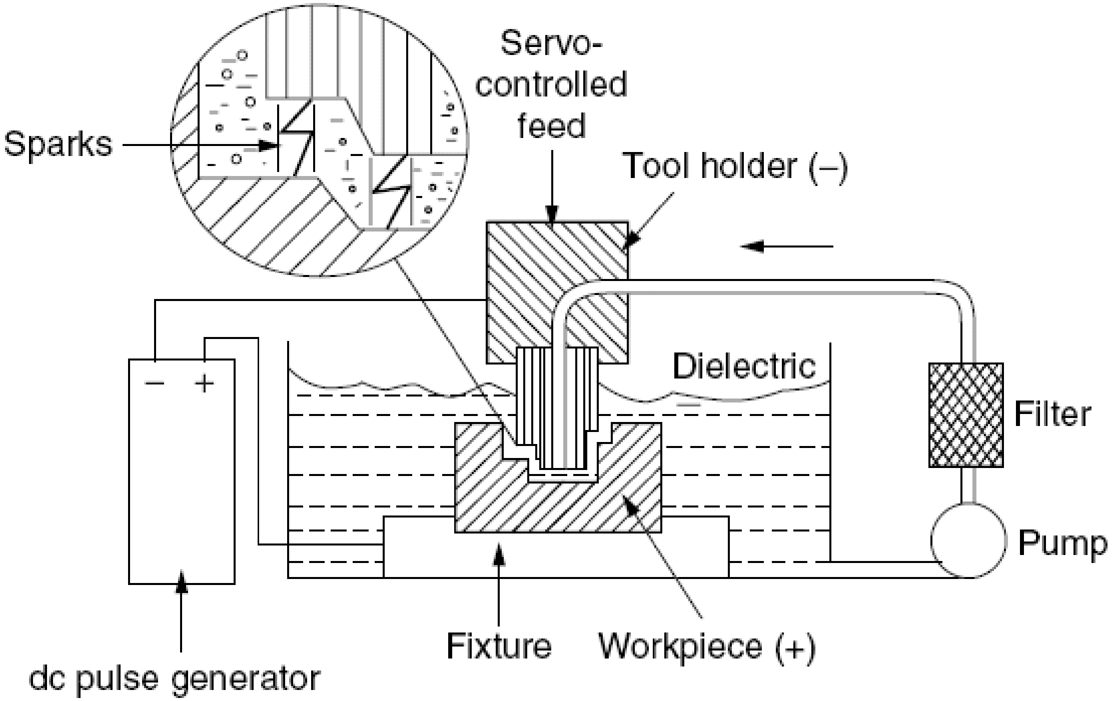
- The spark generates very high **localised temperature** (≈ 12,000 °C).
- The spark energy causes particles of workpiece to **melt** and **vapourise** to form small pocket (**crater**) in workpiece.
- This cycle repeats thousands of time per second (interval between sparks ≈ 100 μs).
- Since sparks always occur between points on tool and workpiece that are closest together, high spots on work are gradually eroded, and tool form is reproduced on the work.
- These particles immediately **resolidify** into small spheres and are flushed away by the dielectric fluid. Some may form **re-cast** layer.
- As metal is eroded, tool is fed in by **servo controlled feed** mechanism.

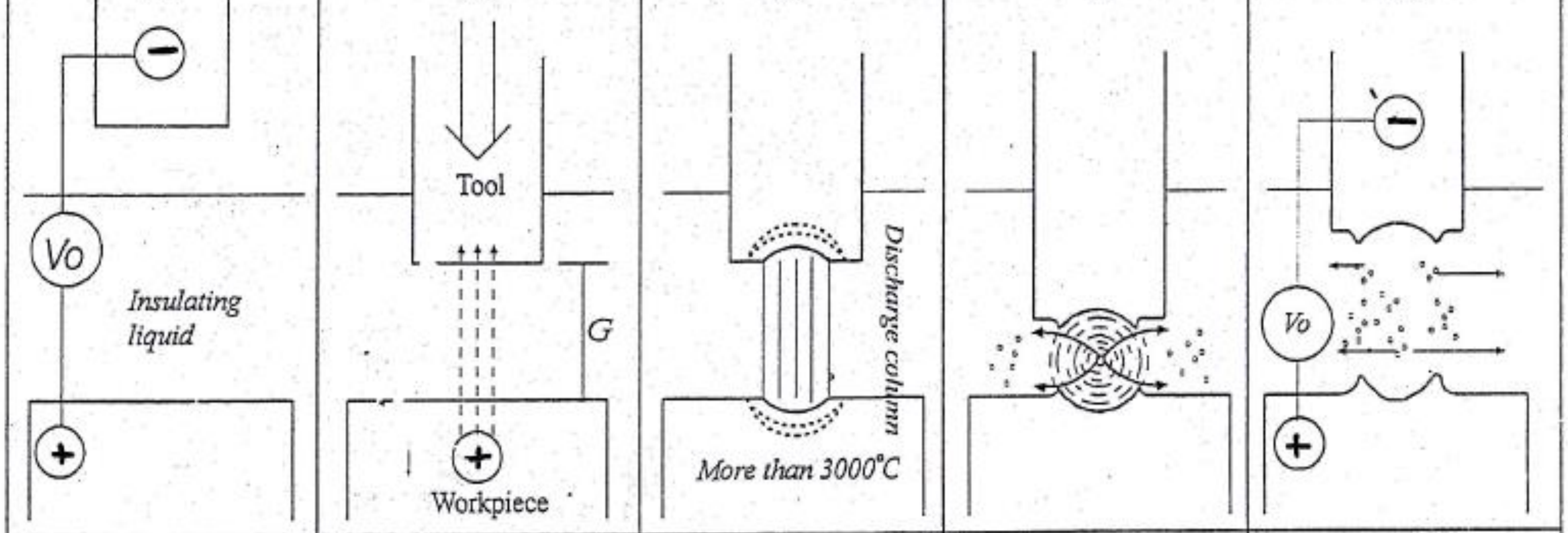
Sinker EDM [*Sodick*]

Small hole EDM [*Sodick*]

- A high speed small hole driller that machines difficult to cut carbide and heat treated workpieces. Sodick’s patented Vitol machining fluid allows EDMing at much faster speeds than small hole machines that use water as a dielectric fluid


Servo Motor
(–)
(+)
EDM Control System
(+)
(–)
Pulse Generator
Electrode
(+)
(–)
Workpiece
Dielectric fluid
Filter
Fixture
Pump
Table


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



(1)	(2)	(3)	(4)	(5)
No-load DC voltage Vo is applied between both electrodes	Both electrodes approach each other until the discharge gap G is attained before causing dielectric breakdown. G value: Several millimicrons for finishing. Several tens of milimicrons for roughing.	The gap is bridged by the discharge column, the base becomes hot, causing the metal to melt. The discharge column is maintained for several microseconds to 1 milliseconds.	Explosion occurs between both electrodes forming craters on the electrodes surface. Metallic particles, tars, gases, ions, etc. are diffused.	After the diffusion of the parts, the gap voltage is restored for the next discharge.

Figure 1: Transition Of Discharge In EDM

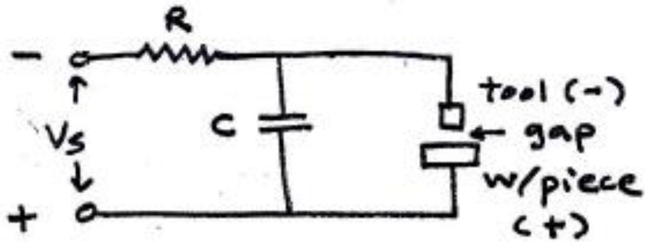
Performance Characteristics of EDM

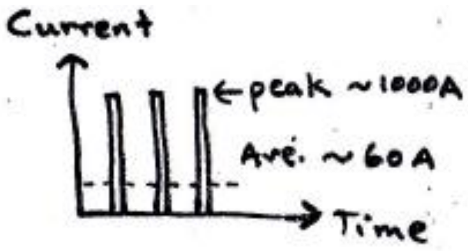
Comparative Study with other processes

Process	Capital investment	Tooling	Power required	Efficiency	Tool consumption
USM	Low	Low	Low	High	Med.
AJM	V. Low	Low	Low	High	Low
ECM	V. High	Med.	Med.	Low	V. Low
CHM	Med.	Low	Low	Med.	V. Low
EDM	Med.	High	Low	High	High
EBM	High	Low	Low	V. High	V. Low
LBM	Med.	Low	V. Low	V. High	V. Low
PAM	V. Low	Low	V. Low	V. Low	Low
Milling	Low	Low	Low	V. Low	Low

CIRCUITS for electrical discharge machine (cotd)

1. ROTARY IMPULSE GENERATOR CIRCUIT





Tool and workpiece immersed in dielectric, connected to capacitor, charged from DC voltage.

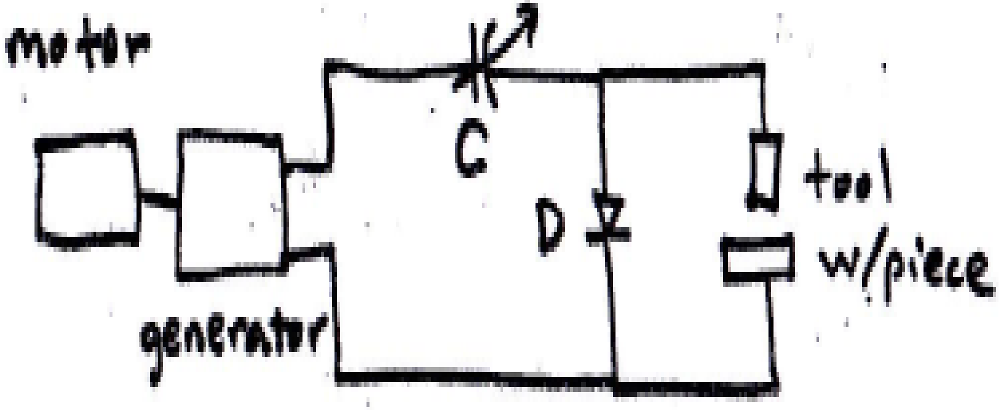
- Simplest circuit, cheap
- Low overall efficiency, low MRR
- High tool wear
- Fine finish only obtainable at the expense of MRR

Maximum MRR: 3 cm^3/hr (for low power machine)

60 cm^3/hr (for high power machine)

CIRCUITS for electrical discharge machine

2. ROTARY IMPULSE GENERATOR CIRCUIT

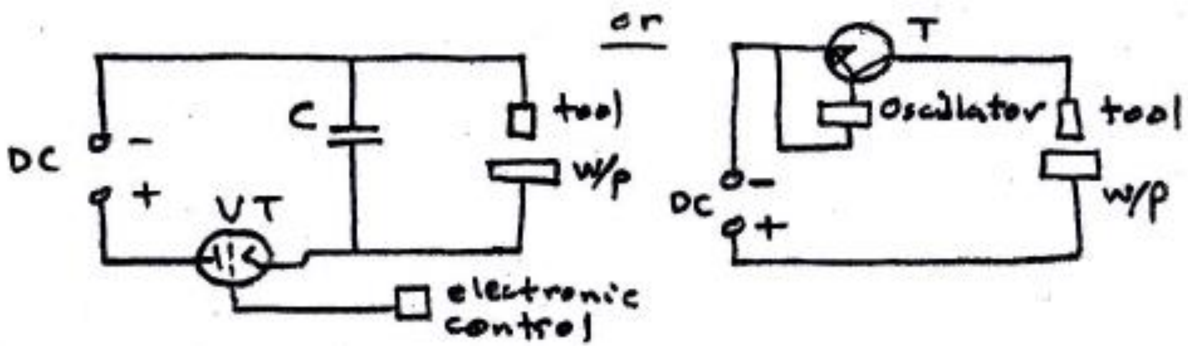


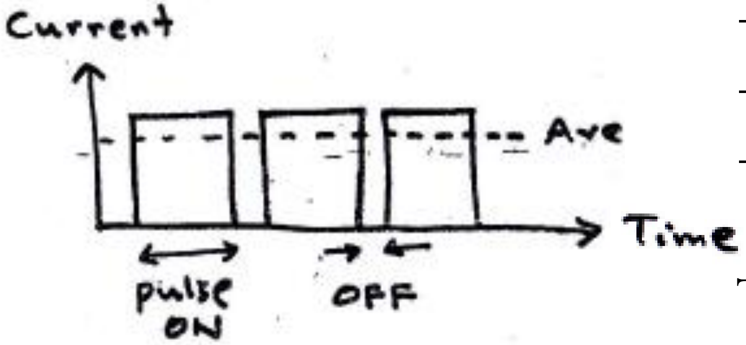
First half cycle: capacitor is charged through diode.

Second half: $V_{generator} + V_{capacitor}$ is applied through gap

- High MRR
- Does not produce good finish

3. CONTROLLED PULSED CIRCUIT





- reduced peak current
- increased spark duration
- higher average current

Typical pulse time:

ON: 200 µs

OFF: 0.1 – 10 µs

[**DIELECTRIC SYSTEM:** Consists of **Dielectric Fluid, Delivery Devices, Pumps, and Filters**

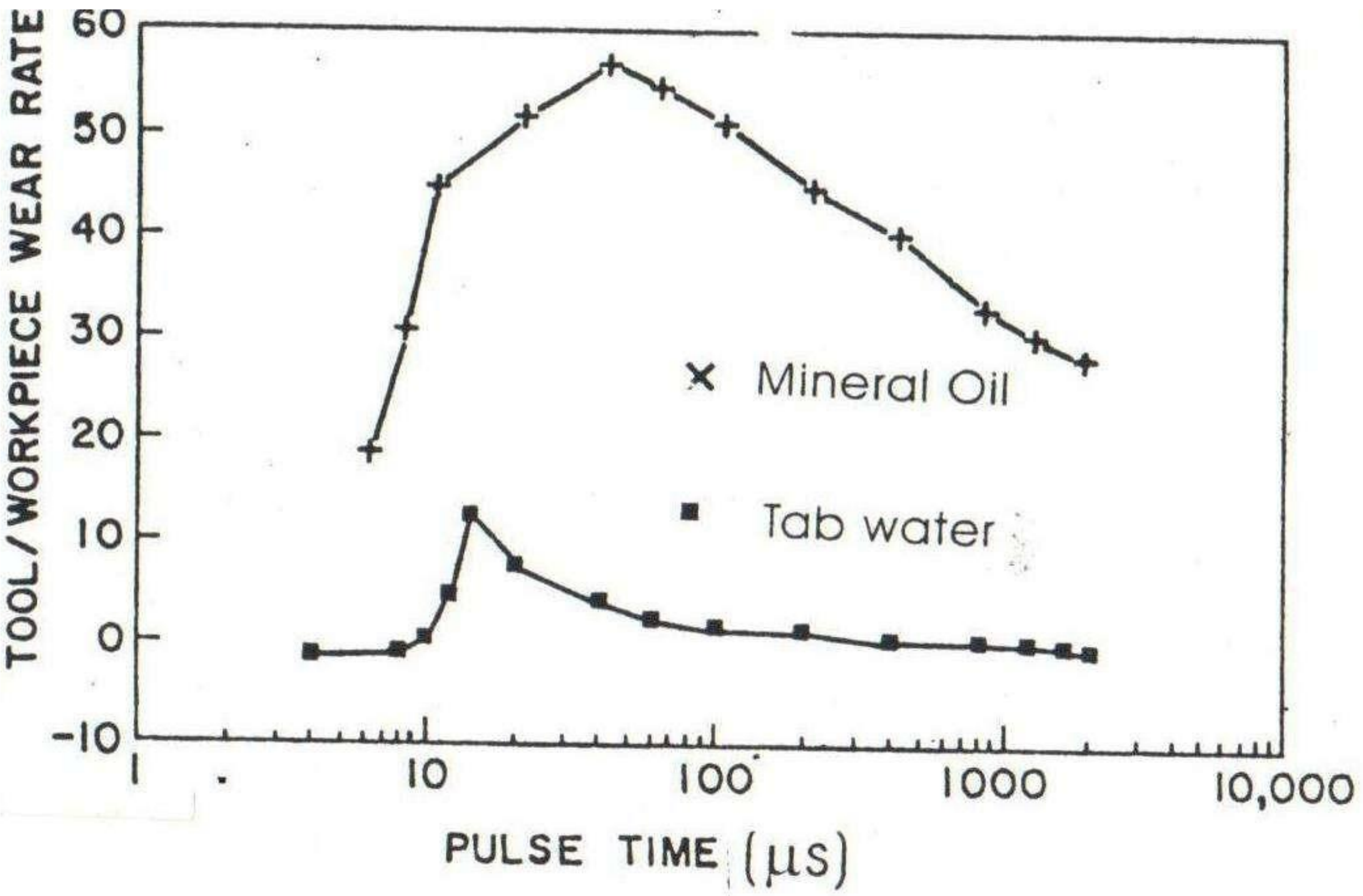
DIELECTRIC FLUID:

Universiti Malaysia PAHANG
Engineering • Technology • Creativity

Role of the Dielectric	Desirable Characteristics
To *Remain* ***Electrically Non-Conducting*** Or to **Act as *Insulator*** between the **Tool and Workpiece** Until the **Breakdown Voltage** is Reached	**High Dielectric Strength**
To Act as ***Flushing Medium*** to **Remove Material by-Products** from the **Tool-Workpiece Gap**	**Low Viscosity**
To Act as ***Coolant*** to Remove the Heat from	**High Thermal Conductivity**
To Provide **High Sparking Frequency**	Should **Deionize Rapidly** After the **Discharge**
Should **Not React** with the Machine Elements	**Chemical Neutrality**
Absence of Toxic Vapors	**Non-Toxic**
Should **Not Cause Fire Hazards** i.e. **Should Not Contain Oxygen** for Liberation during the Process	**Absence of Inflaming Tendency**
Economically Suitable	**Low Cost**

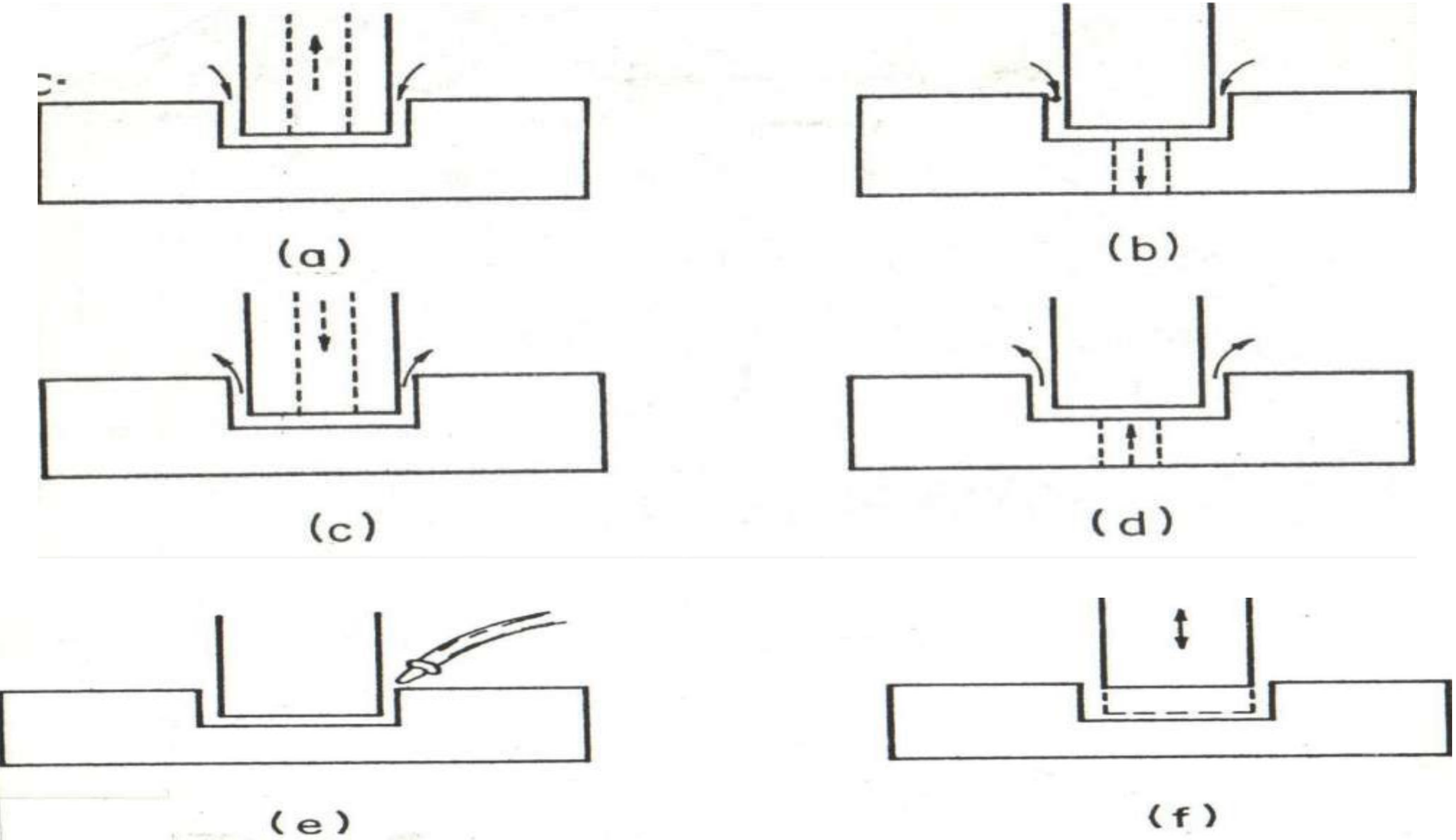
Most Commonly Used Dielectric:

- **Hydrocarbon Oils** such as **Paraffin or Light Transformer Oils**
- **Kerosene**
- **Silicon-Based Oils**
- **De-ionized Water**
- **Distilled Water**
- **Gas**



Comparison of EDM performance while using water and mineral as dielectric. Dielectric pressure = 70 psi (tap water); = 50 psi (mineral oil); Tool polarity -ve (tap water) and +ve (mineral oil) [*Godinho and Noble*]

METHODS of FLUSHING the DIELECTRIC:



Various methods for dielectric flushing: (a) suction through electrode, (b) suction through workpiece, (c) pressure through electrode, (d) pressure through workpiece, (e) jet flushing, (f) periodic cycling of electrode [*HMT, Bangalore, Catalogue*].

SERVO SYSTEM:

- **PRIMARY FUNCTION:** To **Control** the **Infeed** of the **Electrode or Workpiece** to **Precisely Match** the **Rate** of **Material Removal**

- **AUXILIARY FUNCTIONS:** **Most Often** Used in **Drilling Applications**

  Tough-off Sensing:

  Breakthrough Sensing:

  Electrode Refeed: Used to **Compensate for Reduced Tool Length due to Wear**

  Moving the **Wire Electrode Out** to a **Fixed Reference Point** or **Starting Position** After **Drilling Each Hole**

  Commanded by the **Gap Voltage Sensor System** in the **Power Supply**

- Type of **Dielectric Flushing Technique** has a **Direct Effect** on the **Function of the Servo-System**

- If the **Flushing Technique** is **Not Efficient** in Removing the Products of Machining from the Tool-Workpiece Gap, then Servo-mechanism may have to **Spend More Time in Reversing and Allowing the Clearance of the Gap** → **Longer Cycles**

TOOL ELECTRODE:

Desirable Characteristics

- **High Electrical Conductivity**
- **Thermal Conductivity**
- **High Melting Temperature**
- **Easier Manufacturability**
- **Cheapness**

Selection of Tool Material Depends on

- **MRR**
- **Wear Ratio (MRR/TWR)**
- **Ease of Shaping the Electrode**
- **Cost**

Commonly Used Tool Materials

- **Metallic Electrodes**
  - COPPER:→
  - BRASS:→
  - COPPER-TUNGSTEN:→
  - COPPER-BORON:→
  - CHROMIUM COPPER or TELLURIUM COPPER:→
  - ALUMINIUM:→
  - ALUMINIUM ALLOY (SILUMIN):→
  - SILVER TUNGSTEN:→
  - STEEL:→

[Commonly Used Tool Materials

- **Non-Metallic**
  - GRAPHITE:→
- **Combined Metallic and Non-Metallic**
  - COPPER-GRAPHITE:→
- **Metallic Coating on Insulators**
  - COPPER-on-CERAMIC:→
  - COPPER On MOLDED PLASTIC:→

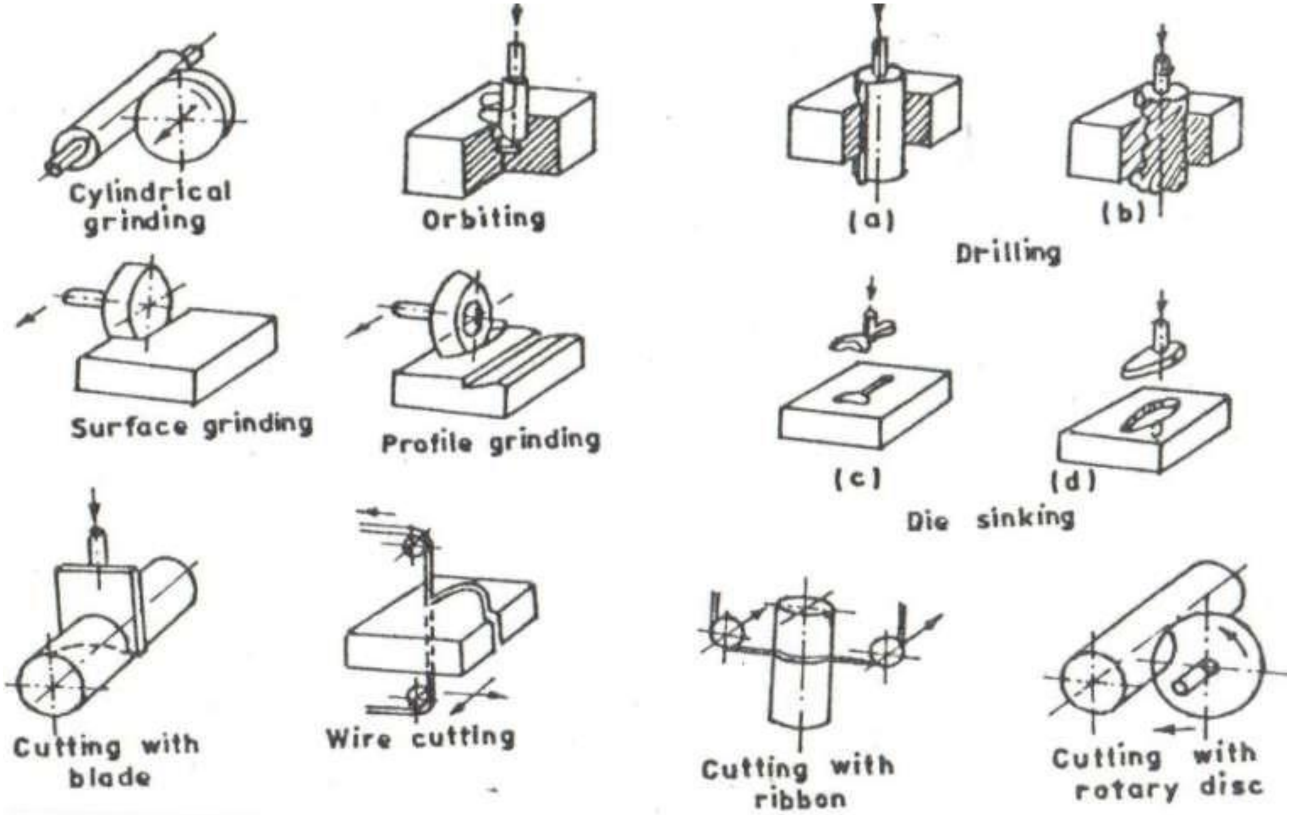
APPLICATIONS of EDM

SHAPE APPLICATIONS

- 2D-Profiling
- 3D-Contouring (Die Making of Complicated Profile)
- Stamping of Tool Dies
- Making Blind Complex Cavities
- Drilling of Various Hole Shapes
- Drilling of Micro-Holes for Nozzles & Aerofoil Blade
- Drilling of Inclined Holes as Shallow as 20^0
- Through Cutting of Non-Circular Holes
- Cutting of Narrow Slots

MATERIAL APPLICATIONS

- All Electrically Conducting Metals and Alloys
- Supper Alloys
- Tungsten Carbide and Hard Carbides
- Refractories



Different EDM Operations

SUMMARY of PROCESS CAPABILITIES and OPERATIONAL CHARACTERISTICS of EDM PROCESS

Type	Capability/Characteristics		Common Value/Range (Attainable)
Finishing Capabilities	Surface Roughness [CLA in μm]		**0.8 – 12.5 (0.2)**
	Dimensional Tolerance or Accuracy [± μm]		**12.5 – 125 (2.5)**
	Minimum Corner Radii (mm)		**0.4 mm (0.025 mm)**
	Minimum Overcut (mm)		**0.01 – 0.5 mm**
	Minimum Surface Damage (μm)	Chemical Damage	**No**
		Mechanical Damage	**25.0 (μm)**
		Thermal Damage	**25.0 – 250.0 (μm)**
Drilling Capabilities	Hole Diameter (mm)		**0.127 – 6.35 (0.1)**
	Aspect Ratio		**10 - 30 (100)**
	Hole Depth (mm)		**3.175 - 50 mm (63.5 mm)**
	Minimum Taper (μm /mm)		**0.5 – 5.0**
	Maximum No. of Holes that can be Drilled Simultaneously		**200**
	Minimum Angle of Inclination Hole Axis with Surface		**20^o**
Cutting Capabilities	Width of Cut (mm)		**0.1 (0.05) mm**
	Thickness of Cut (mm)		**3.175 - 50 mm (63.5 mm)**
	Range of Cutting Rate (mm/min)		**12.5 (Depends on Material Thickness)**
Economic Aspects	Initial Investment or Capital Cost		**Medium**
	Tooling and Fixtures Cost		**High**
	Power Consumption Cost		**Very Low**
	Tool Consumption Cost		**High Tool Wear**
Environmental Aspects	Safety		**Normal Problem**
	Toxicity		**Normal Problem**
	Contamination of Machining Medium		**Normal Problem**

ADVANTAGES

- **Hardness** of workpiece has no effect on process. Rather than machine a part before heat treatment, it can be done after heat treatment, eliminating risk of distortion
- No physical **contact** between tool and workpiece, hence no **cutting forces**. Fragile workpieces can be machined
- **Complex** shapes in dies and moulds can be produced. Making a male electrode is far easier than the complementary female form
- MRR is comparable to conventional machining processes
- With absence of cutting forces, high **aspect ratio** can be machined
- Though material removed by heat produced by spark, **thermal damage** can be controlled to a minimum
- EDM process is highly **automated**, requires little operator skills
- EDM surface consists of small craters which help **retention of lubricants**

DISADVANTAGES

- Electrode **wear** rate considerably high, may be necessary to use more than one electrode
- Workpiece should be electrically **conductive**
- Requires higher **energy** than conventional processes
- Causes **Thermal Damage** as it **Produces Recast Layer and Heat Affected Zone (HAZ)**
- **Complex Electrode Shapes** Can **Take Long Fabrication Time**
- **Lacks Flexibility for Quick Changes in Hole Shapes**

Dr Sunil Pathak, PhD - IIT Indore (MP) India
Senior Lecturer
Faculty of Engineering Technology
University Malaysia Pahang, Kuantan Malaysia
https://www.researchgate.net/profile/Sunil_Pathak4
https://scholar.google.co.in/citations?user=9i_j3sMAAAAJ&hl=en