Electrical Discharge Machining

What is it?

How does it work?

What are its advantages?

What are its limitations?
THE FUNDAMENTALS OF EDM

What is it?

It is the controlled machining of an electrically conductive material via a 3-D shaped or wire electrode using pulsed electrical current within a dielectric medium.
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WHAT?
In simple layman’s language…

it’s called,

Spark Erosion
Electrical Discharge Machining

What is it?

How does it work?
How Does It Work?

The electrode can be a solid, 3-D shape

or be in the form of a flexible, wire electrode
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How Does It Work?

First, we start off with “open-gap voltage”.

As the electrode gets close to the workpiece, it creates an intense electromagnetic field that attracts and aligns ions in the dielectric.
How Does It Work?

As the gap continues to get smaller and smaller, more and more ions are attracted and “polarized”.

This reduces the resistivity of the dielectric until...
How Does It Work?

... the potential voltage can overcome the dielectric’s resistivity and current can cross the gap through an ionized path or “discharge column”.

Current is generated and machining begins.
Spark erosion begins as the current increases and voltage decreases. The plasma-hot spark is encased in a sheath of rapidly-expanding, vaporized dielectric.
How Does It Work?

The gas bubble continues to grow as more dielectric and the workpiece vaporize. Both current and voltage begin to level off as resistivity increases due to dielectric damage.
The dielectric is now severely damaged and contaminated.

Resistivity within the gap continues to increase which causes machining instability.
How Does It Work?

The current must be switched off before an arc or wire break occurs.

With the heat source (the spark) eliminated, the gas bubble collapses and implodes on itself.
How Does It Work?

The collapsing gas bubble draws in fresh dielectric, and along with the “off” time and external flushing, the dielectric is “renewed”.

Reionization can begin and the cycle is repeated.
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How Does It Work?

“On-time”

Is the part of the EDM cycle when current is generated.

A crater is vaporized and melted in the workpiece and work is performed.
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How Does It Work?

“Off-time”

Is the part of the cycle when current is switched off to permit time (and flushing) for the dielectric to recover.

No work is being done.
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How Does It Work?

“Off-time”

Unfortunately,
off-time is required.

It performs no machining function except to allow the dielectric to recover.
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How Does It Work?

The Anatomy of the EDM Waveform
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How Does It Work?

“On Time” duration is measured in micro seconds
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How Does It Work?

... as well as

the “Off-time”

part of the cycle
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How Does It Work?

Together, they produce one EDM cycle.
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How Does It Work?

“On Time” influences:
1) Speed
2) Finish
3) Wear
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How Does It Work?

High or Long On-time
How Does It Work?

Using High On-times Produces:

- High metal-removal rates
- Rough surface finishes
- Little or “no-wear”
- Thicker recast and possible damage
- An oxide layer in water dielectric
THE FUNDAMENTALS OF EDM

How Does It Work?

Use High On-times:

When roughing and for high metal removal

When finish and surface integrity is unimportant

To reduce electrode wear

When workpiece is to undergo further processing
THE FUNDAMENTALS OF EDM

How Does It Work?

Medium On-time

<table>
<thead>
<tr>
<th>40 µsec</th>
<th></th>
</tr>
</thead>
</table>

| 20 µsec |  |

ON

CURRENT

OFF
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How Does It Work?

Using Medium On-times Produces:

- Lower metal removal rates
- Smoother surface finishes
- Increased electrode wear
- Thinner recast and reduced surface damage
- Reduced oxidation in water dielectric
How Does It Work?

Use Medium On-times When:

- When semi-finishing
- To improve surface finish
- To improve surface integrity
- When surface meets print criteria
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How Does It Work?

Low On-times

20 μsec

ON

CURRENT

20 μsec

OFF

[Diagram showing a repetitive cycle with on-time and off-time indicated]
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How Does It Work?

Using Low On-times Produces:

- Lowest metal removal rates
- Smoothest surface finishes
- Highest electrode wear
- Thinnest recast and best surface integrity
How Does It Work?

Use Low On-times When:

During finishing orbits and final skim cuts

When finish and surface integrity is important

When workpiece material warrants

When other methods are not practical
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How Does It Work?

But what about wear?

Ok… understanding speed and finish are easy.

Just seeing the visuals of the on-time diagrams make these points quite obvious.
How Does It Work?

Explaining Electrode Wear

But… how does on-time affect wear?

Because they’re easy to “see”,

we’ll use the visuals of the diagrams again.
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How Does It Work?

What about wear?
THE FUNDAMENTALS OF EDM

How Does It Work?

What about wear?
THE FUNDAMENTALS OF EDM

How Does It Work?

What about wear?
How Does It Work?

Explaining Electrode Wear

For discussion’s sake, and because it is much more complex than can be covered here, let’s just say that “every spark that is produced can cause electrode wear”.
How Does It Work?

Explaining Electrode Wear

100 $\mu$sec $\rightarrow$ $\leftarrow$

120 $\mu$sec

20 $\mu$sec

ON

CURRENT

OFF
How Does It Work?

Explaining wear

In the previous slide showing roughing, there is only one spark (one wear unit) produced within the 120 µsec duty cycle.

Let’s compare this to the finishing cycle of 20 µsec.
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How Does It Work?

Explaining Electrode Wear

20 μsec

120 μsec

ON
CURRENT
OFF
How Does It Work?

Explaining Electrode Wear

In the finishing example,

there are three sparks (three wear units)

produced within the same 120 µsec duty cycle.

Simply put, “More sparks means more wear”.
How Does It Work?

“Off-time” influences only:

1) Speed
2) Stability
How Does It Work?

Off-time

Off-time in EDM is required to allow the damaged and contaminated dielectric to recover and/or be replaced via flushing.
How Does It Work?

Off-time

The amount or duration of off-time that is required depends upon the current, on-time duration, the dielectric condition and flushing conditions.
**How Does It Work?**

**Off-time and Cutting Speed**

Off-time influences cutting speed because *no machining is done* during this “rest” cycle.

*Unfortunately, off-time is absolutely necessary.*
How Does It Work?

Off-time and Cutting Speed

Ideally,

we would like to keep the off-time increment

as small as possible without creating instability.

That brings us to the next point…
How Does It Work?

Off-time and Stability

... you can’t have predictable or reliable speed in unstable cutting conditions.

Stability is obtained by providing sufficient off-time to allow the dielectric to recover.
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How Does It Work?

Low Off-time

High metal removal rates

Improved machining efficiency

Lower part cycle-times
How Does It Work?

Use Low Off-times

For speed and efficiency

When flushing conditions are good

When material conditions allow

Overall conditions are favorable
How Does It Work?

High Off-times Produces:

- Safer machining conditions
- Lower metal removal rates
- Lower machining efficiency
- Longer part cycle-time
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How Does It Work?

Use High Off-times:

When flushing conditions are poor

When cutting sensitive materials

To reduce thermal damage in thin sections

Only when you have to
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How Does It Work?

Remember…

… **ALL** of the work is being done during **ON** Time
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How Does It Work?

While...

... NONE of the work is being done during OFF Time
How Does It Work?

As a rule...

We want the off-time duration to be as low or as small as stability and safety allow.
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How Does It Work?

The EDM Duty Cycle

*Is the measure of efficiency of an EDM frequency.*

*It is the percentage of on-time*

*relative to the sum of the on and off-time.*
How Does It Work?

Calculating The Duty Cycle

The duty cycle is calculated as follows:

\[ \frac{\mu\text{sec \ ON}}{\mu\text{sec \ ON + \mu\text{sec \ OFF}}} \times 100 = \text{Duty Cycle} \]
The Fundamentals of EDM

How Does It Work?

Calculating The Duty Cycle

Using our earlier roughing example of 100µsec ON and 20µsec OFF:

\[
\text{100µsec ON} \quad \frac{\text{ON}}{\text{ON} + \text{OFF}} = .83 \times 100 = 83\%
\]

100µsec ON + 20µsec OFF
How Does It Work?

Calculating The Duty Cycle

Our semi-finishing frequency of 40µsec ON and 20µsec OFF would be:

\[
\frac{40\mu\text{sec ON}}{40\mu\text{sec ON} + 20\mu\text{sec OFF}} = 0.66 \times 100 = 66\%
\]
How Does It Work?

Calculating The Duty Cycle

Our finishing frequency
of 20µsec ON and 20µsec OFF would be:

\[
\frac{20\mu\text{sec ON}}{20\mu\text{sec ON} + 20\mu\text{sec OFF}} = 0.50 \times 100 = 50\%
\]
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How Does It Work?

Effects Of The Duty Cycle

High duty cycle = High M.R.R.
Low wear
Rough finish

Low duty cycle = Low M.R.R.
High wear
Smooth finish
All EDM’ed surfaces will have a thermally altered surface. This is a thin layer of recasted material or “recast”
Oil and water produce very different recast layers
The recast layer produced in oil is typically very high in carbon and is usually harder than the parent material.

Hydrocarbons, tars and resins from the EDM oil are assimilated into the cooling, but still-molten material during the off-time.

OIL
THE FUNDAMENTALS OF EDM

Electrical Discharge Machining

The Recast Layer

Hydrogen and oxygen are released from the DI water and can cause rusting and oxidation in ferrous alloys.

The recast layer created in water is typically an oxide and is usually softer than the parent material.
Oil recast will appear “puddle-like” while water recast appears granular-looking.
When a detail is EDM’ed correctly, the thickness of the recast layer usually corresponds with the surface finish.
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Electrical Discharge Machining

What is it?

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What are its advantages?
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Electrical Discharge Machining

What Are EDM’s Advantages?

Machine hard and pre-hardened materials
Machine “impossible” shapes
Execute details with excessive l/d ratios
Machine sections as thin as .005”
Simplify tooling requirements
Eliminates deburring and 2nd operations
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Electrical Discharge Machining

What Are EDM’s Advantages?

Eliminate or reduce expensive “chip cutters”
Produce “split-tenth” accuracies
Produce sub-micron finishes
Generate different geometries top-to-bottom
Infinitely variable tapering
Routinely operate unattended and “lights out”
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Electrical Discharge Machining

What Are EDM’s Advantages?

Use tool changer as a parts carousel
Cut parts mounted in machine spindle
Multiple electrodes mounted on worktable
Make and redress electrodes in machine
Customizable orbiting patterns
Easily adapt machine to “extreme applications”
Electrical Discharge Machining

What is it?

How does it work?

What are its advantages?

What are its limitations?
Electrical Discharge Machining

What Are EDM’s Limitations?

Workpiece must be electrically conductive
The cut surface is thermally changed, called “recast”
Electrode fabrication can be expensive
Wire must pass through part
Hard-milling, creep-feed grinding, laser and water jet cutting can compete
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Electrical Discharge Machining

EDM’s Versatility

Do you remember when we were discussing EDM’s advantages?

One of them is the extreme versatility to creatively solve a manufacturing problem.
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Electrical Discharge Machining

EDM’s Versatility

Also, unlike most other conventional machines,

EDM’s are uniquely adaptable

and can be easily modified to meet a special purpose.
Let’s examine a few creative ideas and machine modifications that were devised to execute that “impossible” part.

Let’s start with an extreme wire application.
PROBLEM:

A high-nickel aircraft component required three precision slots 120° apart.

Milling required numerous expensive carbide end mills and resulted in unacceptably-high scrap rates.
Unique Wire Applications

PROBLEM:

Because the openings are 120° apart, manufacturing engineers logically presumed that this part could not be wirecut.
Unique Wire Applications

**SOLUTION:**

Using pre-existing flushcups and diamond guides, an inexpensive C-frame assembly was fabricated to allow part to be cut from the inside out.
Water for flushing is delivered to the cut through the C-frame itself. This also provided thermal stability to the C-frame.
Unique Wire Applications

RESULTS:

Machining time reduced over 50%

Scrap reduced by over 80%

Production increased 65%

Only 3 pre-drilled start holes

Cutter inventory eliminated

Deburring & polishing eliminated

Machining center now available
Unique EDM Applications

PROBLEM:
5-axes machined 3-D lap

- 17-4 ph SS
- 1 hr 16 min
- Tiny cutters
- Attended
- Deburred
- Heat treat
- 3 hrs polishing
Unique EDM Applications

Close up of prisms, radii and sharp corners
Unique EDM Applications

SOLUTION:

Wirecut dozens of inexpensive copper electrode inserts in 2 axes
Unique EDM Applications

In this axis, you can see the electrode face (standing insert) and the tooling surfaces, including the dovetail mount.
Unique EDM Applications

Matching dovetail slots were wirecut in electrode holder before pressing onto standard 20mm shank
Here, you can see the tooling and bearing surfaces that mate together to form a “one-piece” electrode.
Unique EDM Applications

Using a CNC sinker equipped with a C-axis, the spindle was rotated to match the traversing X-axis, "rolling" the electrode across the part blank.
Unique EDM Applications

RESULTS:
Cycle time reduced from: 1 hr 16 min to 17 min
No deburring
No polishing
No cutters
Only 16 hours total preparation
Unique EDM Applications

**PROBLEM:** Actuator Link for AIRBUS-300 series

- 718 Inconel
- High scrap
- Attended
- Deburred
- Heat treated
- Stress relieved
- Straightened
- Jig-ground
Unique EDM Applications

**SOLUTION:** Wirecut all 3 parts from a solid billet

- Grain-oriented
- No scrap
- Unattended
- Single set-up
- No heat treat
- No second opps
  - + $18k/month
- 1 opp remaining
RESULTS:

Using WEDM, this matched set of three, grain-oriented, aircraft actuator links is produced in only 19 hours…

… compared to 104 hours of conventional machining.

Remaining material is in slug form instead of oily chips. They are easily stackable and get highest recycle value.
This very large oil bearing was cut “outside the envelope” using extended upper and lower arms and high-performance EDM wire.
Specials

This is the slug from the part on the previous slide.

Cut at 10 degrees, it is 43 inches tall and is straight within .003” top-to-bottom.
Sinkers without a tool changer can execute a job like it had one, utilizing the C-axis with multiple electrodes mounted on indexable tooling.
Unique EDM Applications

Specials

This magnesium reader-head frame required a simple execution but presented difficult flushing conditions for a “dry” machine.
Unique EDM Applications

Specials

10 parts were ganged in a interchangeable fixture to allow production machining.
An older (meaning obsolete) machine can be easily and economically modified to cut two parts at a time.
The 10-part fixture is mounted in a flushing container or “flask” and cut submerged, eliminating the poor flushing conditions.
Unique EDM Applications

Specials

Modifying a WEDM is easier than you might think.

Here is a modification incorporating 3-heads
Used extensively in aircraft and aerospace applications, metallic honeycomb is available in many materials, cell-sizes and thickness.
Lightweight and strong, it is found in jet engines, wing sections, flooring, helicopter blades, engine casings, etc.
Impossible Applications

Structural Aircraft Honeycomb

Lightweight and strong, it is found in jet engines, wing sections, flooring, helicopter blades, engine casings, etc.
Lightweight and strong, it is found in jet engines, wing sections, flooring, helicopter blades, engine casings, etc.
Impossible Applications

*Structural Aircraft Honeycomb*

Honeycomb's light structure makes it nearly impossible to machine by conventional methods.
Impossible Applications

Structural Aircraft Honeycomb

This is the results of conventional machining. EDM is the only viable solution.
This results in hours of hand-repair using rotary grinders, files and hand tools, often taking longer to repair the detail, than the machining process that created it.

Impossible Applications

Structural Aircraft Honeycomb
Impossible Applications

Structural Aircraft Honeycomb

Results:
Fast
Accurate
No damage
No burrs
EDM does all this...

... and more!
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Electrical Discharge Machining

Summary

EDM remains one of the most versatile and accurate machining methods in the world and will continue to be so.

To be successful in any type of EDM business, you must continue to do what you have done today.

“Seek more knowledge”
Thank you for your valuable time

Are There Any Questions?