THE FUNDAMENTALS OF EDM

by Bud Guitrau

INTRODUCTION

In this issue, I've been asked to revisit the very basic foundation of EDM operations and define the fundamentals of EDM. My apologies to any yawning Graybeards here, who may feel they already know all about this subject, but my editor has reminded me that we have a passel of young'uns and new readers out there and this most-basic of studies needs to be done.

We are going to go all the way back and revisit the same 9 stages or slides of the on- and off-time EDM cycle that was originally created by AGIE long ago and upon which several versions and updates have been used universally for decades by many companies, such as POCO Graphite and EDM writers like myself. Thanks to AGIE for these and more, which you will read more about shortly.

THE FUNDAMENTALS

When covering the fundamentals of EDM, we must also dabble a bit into EDM Theory, which in its entirety, is much deeper than I can easily take you. Simply put, I liken it somewhat to learning the ancient board game of "Go" or "Othello", because both are easy to learn, (theory), but difficult to master (practice). We'll come back to these after we first define the pursuit of our subject matter.

As I said, the complete examination of the EDM Fundamentals is a very deep study that involves terminologies such as, "the propagation of directional streamers" and "electron cascades or avalanches", and still involves at least four different dielectric breakdown theories in order of their predominance; the Bubble Theory, the Suspended Particle theory, the Electronic Breakdown theory and the Cavitation theory, but we're not going anywhere near those. We *do* need to know the basics of how EDM works, but this doesn't necessarily mean writing a thesis. Instead, we'll use the "Othello" analogy and keep it simple.

THEORY AND PRACTICE

Let's look up "*theory*" first, then "*practice*".

Theory – noun. *A supposition or a system of ideas intended to explain something, especially one based on general principles independent of the thing to be explained.*

Example: *Darwin's theory of evolution.*

Practice – noun. *The actual application or use of an idea, belief, or method, as opposed to theories about such application or use.*

Example: *The principles and practice of teaching evolution.*

In theory – idiom. *Used in describing what is supposed to happen or be possible, usually with the implication that it does not in fact happen.*

Example: *In theory, things can only get better; in practice, they may well become a lot worse.*

If you've ever played the game of "Othello", then you know how quickly things can go… shall we say, unplanned? Despite the strictest adherence to proper theory, the same unplanned game-changers of "Othello" can occur in EDM. After making this point, let's examine a serious subject.

ELECTRICAL DISCHARGE MACHINING

The terminologies; EDM and Electrical Discharge Machining, are the same and are interchangeable, as is *Electro* Discharge Machining, as EDM is often described within technical papers from Europe and Asia. WEDM is a newer acronym referring specifically to wire EDM. The fundamentals we will examine apply to both sinker and wire, regardless of the type of electrode or dielectric used.

EDM DEFINED

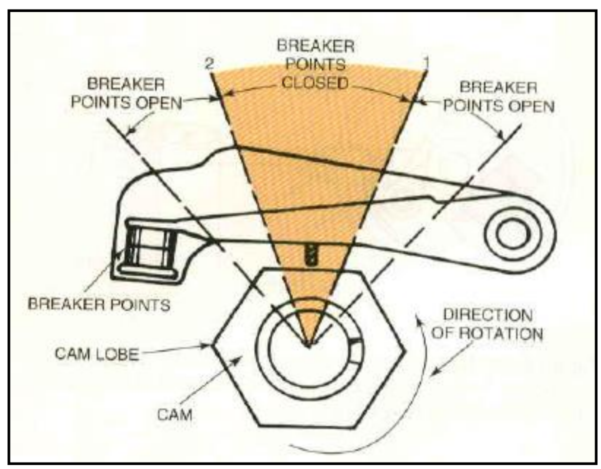
EDM is the process of removing material from a conductive work piece by applying a high-frequency pulsed, electrical current to it via a solid, shaped electrode or EDM wire. The electrode never touches the work piece but instead discharges its current through an insulating dielectric fluid (water or oil) across a very small spark gap (.0002”-.034” depending upon voltage, amperage, electrode material and dielectric type). The spark is plasma hot, reported to be in the range of 8000-12000° C, and it vaporizes and melts the work piece material before it.

The EDM process is used when the work piece material is too hard, or when the shape or location of the detail cannot easily be conventionally machined. This makes many formerly difficult projects more practical, and many times it can be the only feasible way to machine a part, shape or material.

EDM’S DISCOVERY

Not exactly germane to our topic, but let’s briefly examine the interesting background of EDM.

During WWII, all internal combustion engines utilized high-voltage ignition coils and rotary distributors. This is a sound design that is still in use today, but at that time was limited by the deterioration and eventual failure of faulty ignition or contact points. The T-34 was the Russian main battle tank and was among many tactical vehicles and aircraft critical to their survival and eventual victory and it was quite vexing to commanders with their tactical vehicles being sidelined by the premature failure of a 50-cent part.



Ignition points are simple, round contacts and part of a breaker switch within the distributor (called “breaker points” in this diagram). They are cam-actuated by lobes on the rotating distributor shaft and they opened and closed the spring-loaded arm to deliver the next spark from a condenser (not shown) to the distributer cap via a rotor. Although these points were made of tungsten, under current they would arc each time they made or broke contact. This resulted in the gradual melting of one side of a contact and this material was redeposited onto the other side, always polarity-driven. This created irregular contact surfaces which eventually resulted in reduced performance and premature failure of not just the contact points, but a badly needed combat vehicle.

THE LAZARENKOS

In 1941, Drs. Boris and Natalya Lazarenko were married scientists and professors at the All Union Electro Technical Institute at Moscow University where they were assigned to investigate and solve this small arcing, but serious strategic problem. Their experiments included submerging the points in various dielectrics, oil most notably, which proved to reduce the destructive arcing, but ultimately they failed to find a practical solution to this particular challenge. However, these researches lead indirectly to the discovery of the process we know today as, Electrical Discharge Machining.

In later research, the Lazerankos used their earlier findings to explore the controlled metal removal via this previously undesirable electrical arcing or sparking process. Using components from existing automotive ignition systems, they developed a spark-machining generator in 1943 called the "Lazarenko circuit", which became the standard for the first generation of all EDM power supplies – the Resistor/Capacitor circuit or the RC generator (also called "relaxation" circuit). More on this later.

Almost all versions of EDM's produced then were for hole drilling and the removal of broken taps and bolts in repair work. Without a drive or servo system, the electrode was advanced manually via a wooden or insulated handle, with the operator essentially "pecking" a hole by hand. Several hundred Lazarenko EDM's were produced during this period and the Lazeranko R/C circuit became the model of all EDM generators to follow.

The Lazarenko's next contribution was the development of a servo system that allowed the controlled machining of metals using spark erosion, but until the war was over and other countries and companies became interested, EDM use in the 1940's was almost exclusive to the USSR.

CONTINUED DEVELOPMENTS

One of these interested companies was the Ex-Cell-O Corporation of the United States, who also began EDM research in the '40's. Unconfirmed rumors have them acquiring the Lazaranko findings from the Soviets and beginning a secret wartime project of their own called, "Method X". Rumors or not, in 1950, they became the first company to offer a commercially available EDM that was called, XLO EDM. A few years later, Agie was founded in in Switzerland in 1954, and a company called les Ateliers des Charmilles produced their first machine in 1955.

Transistors were introduced in 1964 and this faster and more-precise switching circuitry almost immediately began to replace RC generators. While many different makes and models of sinkers evolved over the years, there were no big breakthroughs in EDM until 1969 when Prof. Bernd Schumacher of AGIE announced the development of the first wire EDM, the AGIECUT DEM-15, at left. (No, that is not Dr. Schumacher)

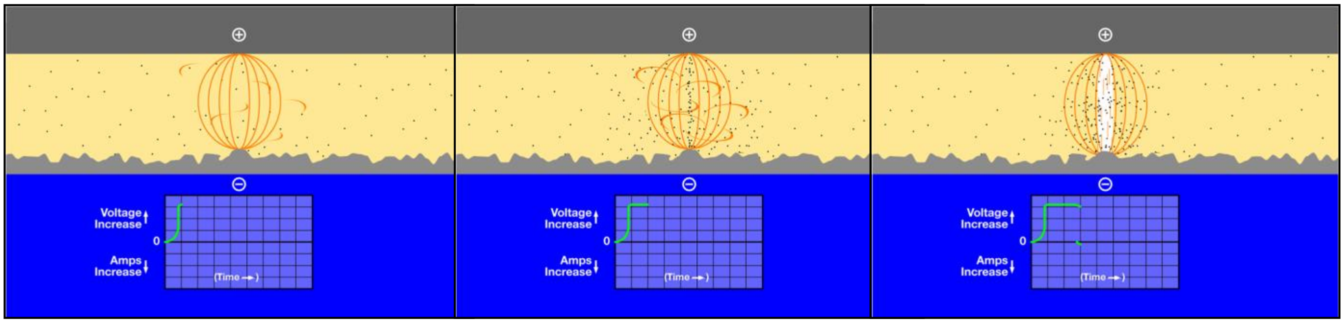
Not far behind in American WEDM development was David Dulebohn of Andrew Engineering in Minnesota who began his WEDM research in 1970. In 1972, they displayed a prototype wire machine at IMTS that used technologies from then-new plotters and tracing machines. This machine moved by optically following or tracing lines on a master drawing, but it wasn't accurate enough for die making. In 1975, they released the first American NC WEDM, the Linemaster Model 123, shown in the old photo on the right with their original applications engineer, Don Knutson.

EDM controls quickly advanced and progressed from optical systems to punched IBM cards, punched paper tape, off-line CAD and into the wireless, solid-model capabilities of today.

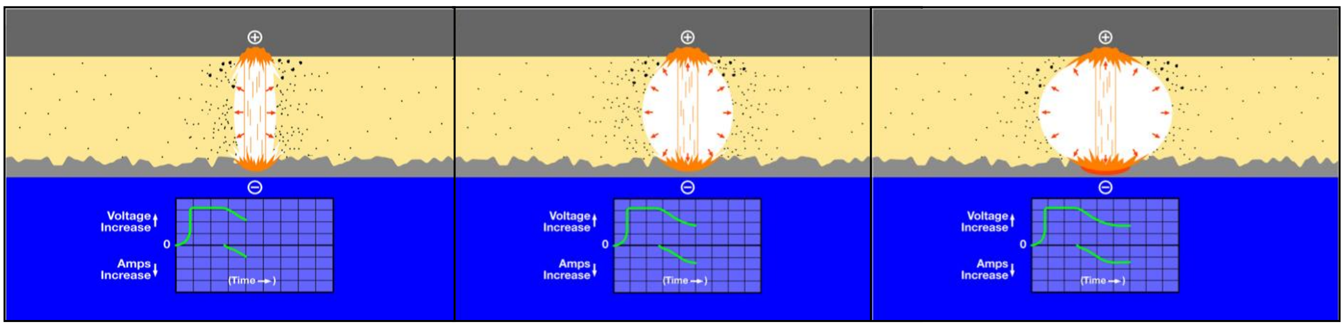
Likewise, all EDM generators have continued to improve – both sinker and wire – progressing from the Lazarenko circuit and banks of vacuum tubes, to modern solid-state transistors with nanosecond switching and mirror-finishing capabilities. From primitive hand-fed electrodes, to the simultaneous six-axes CNC machining on tilt and rotary tables. Like a late '60's, advertising campaign, "You've come a long way, baby!" Ok, enough history.

THE EDM SEQUENCE

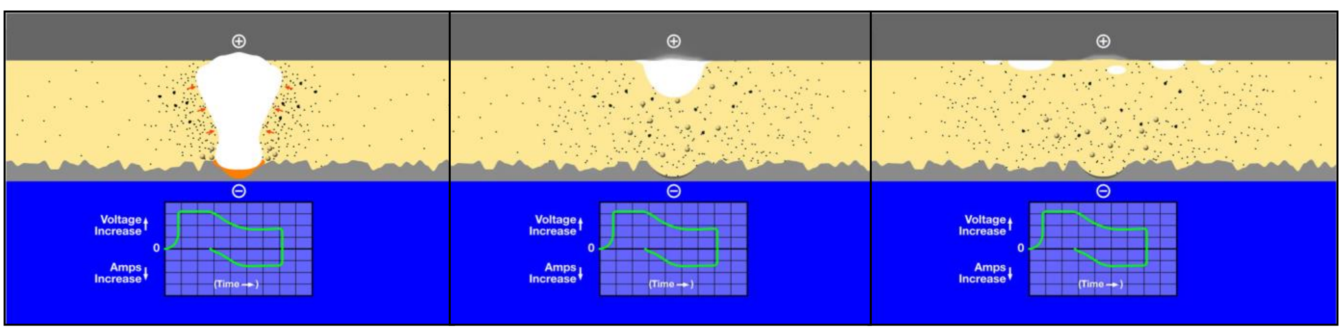
The graphics below simulate the stages of a single electrical discharge. Submerged within a dielectric, the positive electrode is shown on top and is slowly approaching the negative-polarity work piece. The tables within the blue fields show voltage and amperage running on a horizontal time table.



In the first panel, we have a high potential voltage or "open gap" voltage as the electrode is "cutting air". As it nears the work piece, it creates a strong electromagnetic field. In panel 2, this field increases, attracting and polarizing ions within the dielectric, reducing its resistivity. Open-gap voltage is at its maximum. In the 3rd panel, dielectric resistance is overcome and the potential voltage crosses the gap in the form of an arc. The volt meter drops to show "cutting voltage" and amperage can be measured as current is generated. On-time and electrical discharge machining has begun.



The plasma-hot spark vaporizes the work piece and everything it contacts, including the dielectric, so a sheath of vaporized gasses from the dielectric encases the spark and creates a rapidly expanding gas bubble. In the middle panel, both voltage and amperage begin to level off as the crater on the work piece and the gas bubble get larger. Dielectric damage and contamination begin to increase the dielectric's resistivity. On the far right, the dielectric has become too contaminated to support stable machining. At this point, without a change, a damaging arc or wire-break will occur.



This necessary change is switching the current off and entering the off-time phase of EDM. With the heat source of the spark removed, the gas bubble collapses and implodes upon itself and upon rebounding from this collision; hot, damaged and contaminated dielectric is ejected from the arc-site, aiding flushing. In the last two panels, the EDM'ed crater is visible but no work or machining is done during off-time to allow flushing and/or time for dielectric reionization and the repetition of this cycle.

FURTHER DEFINITION

The previous brief description was to quickly narrate a small slide-show demonstrating a single cycle of an EDM discharge. However, this is not nearly enough to truly understand or appreciate the intricacies of the EDM process, so we'll refine the slide narrations a bit only after examining a necessary element.

THE ROLE OF THE DIELECTRIC

Regardless of electrode and work piece polarity, the electrode is advanced into the workpiece through an insulating liquid medium, or dielectric. These are typically a hydrocarbon or silicon-based dielectric oil for sinker machines and deionized water for wire EDM machines, although presently there are several makes of WEDM that use oil as a dielectric. No longer available, there were several generations of WEDM's that had two dielectric systems and used water to rough and oil to finish. There were also at least two versions of sinkers that were released and recalled that used water instead of oil. (Note: There are many manual, bench-top sinkers that have been converted to water dielectrics and are used for fine-hole drilling in the semiconductor industry)

The dielectric fluid is integral to the EDM process as it provides insulation against premature discharging, cools the machined area, and is used to flush away heat, damaged dielectric and the EDM chips and debris. The slides demonstrated as the electrode or wire nears the work piece, an intense electromagnetic flux or "energy column" is formed around this gap. This field attracts the resistive ions in the oil and aligns them in the direction of electrode polarity like millions of tiny compass points or bar magnets. This field continues to increase in intensity until all the ions are polarized and aligned between the electrode and the work piece in a manner similar to the grain of organic wood.

When the trapped ions are in polar alignment and the resistivity of the fluid approaches it's lowest, a single spark is able to flow through this ionized "flux tube" and strike the workpiece. The voltage drops instantly and becomes "cutting voltage" as current is produced and the spark vaporizes anything in contact with it, including the dielectric fluid. The spark is encased in a rapidly expanding sheath of gasses composed of hydrogen, carbon, and dozens of other elements that have been released from the work piece and the electrode.

A component of an EDM dielectric is its *dielectric strength*. The stronger this is the more stable spark erosion will be. In EDM, dielectric strength is important for two reasons:

1) It must have the ability to resist premature discharge ignition to allow the generator to produce the spark at precisely the right time.

2) The second measure of good dielectric strength is it must be able to reionize and recover quickly to support the next spark.

During an electrical discharge, the dielectric in that area takes quite a beating, thermally and electro-chemically and it must be allowed to rest or be replenished. This is why we must use pulsed current.

THE SEQUENCE EXAMINED

The area of the work piece that is impacted by the spark will be vaporized and melted, forming a semi-hemispherical crater. In the process, the chain of ionized particles becomes contaminated with this material, disrupting the alignment of ions and causing dielectric resistivity to rapidly increase. (Imagine all of our tiny compass points or bar magnets wandering out of alignment). Cutting efficiency will begin to degrade when the voltage begins to rise and the current will lessen as resistivity continues to increase until the dielectric can no longer sustain a stable spark. At this point, the current must be switched off or a damaging arc or broken wire will occur.

The duration or amount of time that current flows through the spark gap is called "on-time". It is aptly named as this is literally, the length of time the spark is on or allowed to occur, and is usually measured in units of micro-seconds or *µ*sec. We'll examine on-time and other parameters closer within their proper sections, but first, let's complete the EDM process.

During on-time, the spark creates and is surrounded by fast-growing sheath of vapor or a gas bubble. This bubble formation is also integral to EDM Theory found in the physics of *vapor pressure.* Without room to adequately explain this, for EDM it simply means; the faster and larger the formation of this bubble, the better for EDM. Let's learn why.

During on-time, everything in proximity of the arc is reduced to elemental gasses and rapidly expands away from the heat source – the spark. When the current is switched off, the sheath of vapor that was around the spark will collapse and implode. This collapse creates a void or vacuum behind it and this draws in fresher, cooler dielectric to flush away chips, damaged dielectric and cool the area. This off period is logically called "off-time", and it allows for the reionization or replacement of the dielectric to provide favorable conditions for the next spark sequence. The length or duration of off-time must be sufficient enough for the dielectric to recover or cutting stability will be difficult to maintain.

This briefly describes one EDM cycle; and in order to machine with this process, it must be repeated over and over again, switching on and off hundreds of thousands of times per second. When EDM'ing with either type – sinker or wire, and when you can see an orange ring of sparks all around the entire electrode in a sinker and a line of blue sparks from top-to-bottom around the wire in a WEDM, you are seeing hundreds of thousands of sparks, but they are produced one spark at a time.

ON- AND OFF-TIME

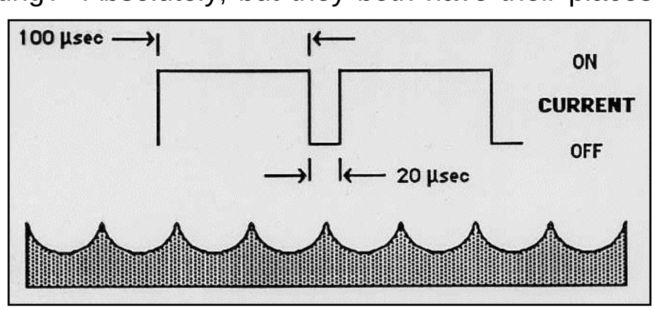
Knowing how EDM works isn't enough. We need to make it work *for* us. We need to know how to get good machining speed and good finishes with minimum wear and the lowest possible chances of arcing or wire breaks. We also need to know how to create settings that will allow us to overcome difficult materials or poor flushing conditions. These two parameters require further definition because on- and off-time are much more than names for a simple switching cycle.

ON-TIME DEFINED

On-time influences only three things, machining speed, electrode wear and surface finish. We will analyze these elements now.

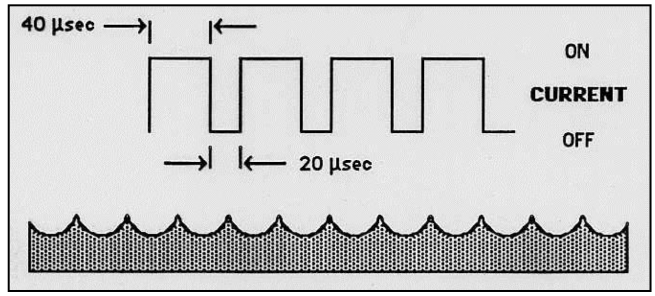
Machining Speed: *All* machining is done during the interval of on-time. The spark gap is bridged, current is generated and EDM'ing has begun. Initially, every impulse vaporizes the work piece and creates a small crater. Sparks of longer duration will cease to vaporize the work piece and will begin to melt it, as the surface area of the growing crater increases and sinks heat away from the EDM'ed area.

Is there a difference between vaporization and melting? Absolutely, but they both have their places. Ideally, for flushing purposes, the finest finishes and all-around "clean" burning, vaporization is always better than melting because most of the material that came from the work piece crater is reduced to a gas instead of re-solidified particles that increase gap contamination. However, melting of the work piece is quite acceptable and is where the largest part of our machining speed and electrode protection will come from. The graphic on the right shows a roughing setting with long on-time (100 *µ*sec), large craters and a rough finish.



Surface Finish: In the roughing example, it is easy to see how with longer spark durations, the MRR (Material Removal Rate) will be high and also resulting in large, deep craters. Obversely, shorter spark durations will leave smaller craters, removing less material and machining much slower and this produces finer and smoother surface finishes.

After roughing is completed, we will reduce the current, usually by half, and lower the on-time for shorter duration sparks. In this manner, we will orbit or skim the part to final size and finish. In the example of semi-finishing shown on the right, you can see the 40 μsec impulse simulations are closer together as are the craters, which are in turn, smaller in volume yielding a smoother finish. This is the usual sequence of steps taken to EDM or WEDM a given part. Only three cuts will be shown here, but there can be many more. Regardless, we will continue to reduce power and on-time in this manner until final dimensions and finish are met.



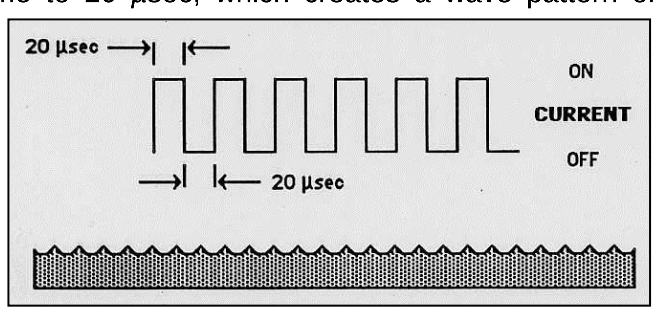
Electrode Wear: This will take some explaining and will apply mostly sinkers because except for wire breaks, we are less concerned about the wear of EDM wire. We'll examine the effects on-time has on electrode wear from the most aggressive roughing to fine finishing.

No-wear – When aggressively roughing using "no-wear" settings (on-times above 100 μsec), a phenomenon can occur known as "electrode plating". This is when a thin layer of graphitized work piece material becomes plated to the electrode. Although this plating protects the electrode from wear, it also slows machining because we are EDM'ing with like materials instead of the electrode itself. This plating is often easy to see on the electrode as it has a metallic sheen to it. In extreme conditions, this plating can build up irregularly, creating "nodules" and deformities that can affect size and tolerance.

Low- to Medium wear – When considering the expense of electrode-making – often taking longer to make than to use – everyone would like to enjoy zero electrode wear, but the "sweet spot" for EDM roughing is including a small amount of electrode wear, about 1%, via on-time. Settings just on the "wear side" of "no-wear" are proven to provide the fastest roughing speeds, the lowest amount of electrode wear and prevents the possibility of electrode plating. Without defining "medium wear" separately, I'll condense this description into, "the increasing degrees of higher wear" we will expect and encounter as further reductions in on-times are made in the course of finishing the part.

High-wear – Is encountered in fine-finishing sinker operations and in material-specific sinker applications, such as EDM'ing carbide or titanium. Although quite different, both operations require low off-times and we can conclude that low on-times will produce high electrode wear.

For our finishing example, we have reduced on-time to 20 μsec, which creates a wave pattern or frequency denser than the semi-finishing or rough cuts. These smaller, shorter sparks produce finer finishes and higher wear. Rule: For EDM, you rough with low frequencies and finish with high frequencies. Frequencies used to be an actual generator setting (kHz) on older machines, but is used only as a reference term today.



EDM wear in general – EDM has wear characteristics that are exactly opposite the tool wear experienced by the conventional machining methods of lathes, mills and grinders because our best "cutter" wear is realized during the heaviest roughing and is the worst during the finest finishing. How is this explained?

With not a scientific answer, but one that is technically correct; except in “no-wear” settings, *every single EDM spark will wear a microscopic particle from the electrode* – electrode wear. Electrode polarity and the type and density of the electrode material will affect this rate, but regardless of electrode material, the more sparks that are produced within a given unit of time, will also produce a proportionate amount of electrode wear.

If you review the wave form frequencies in the three graphics from roughing to finishing, this should be easier to grasp and is why EDM electrode wear behaves quite opposite of traditional rough and finish, chip generation. Again, more sparks = more wear.

OFF-TIME DEFINED

To be clear, off-time affects only two parameters of EDM; machining speed and machining stability.

Machining Speed: While the actual work or metal removal is accomplished only during on-time, the length of off-time required for reionization can significantly affect the speed of the operation. The longer the off-time, the longer the job will take. Unfortunately, off-time is a necessity and an integral part of the EDM process, but as a rule, the shorter the off-time duration, the faster the machining operation will proceed – to a point. Stability is just as important as speed.

Machining Stability: As important as machining speed is to an EDM operation, stability is the key to maintaining this speed. Although increasing the off-time will slow down the process, it can provide the necessary stability required to successfully EDM a given application. If the off-time is insufficient, it will cause erratic cycling and retraction of the advancing servo(s), resulting in a lot of lost-motion and slowing down the operation much more than a less-efficient, but stable off-time would.

Analogy: Would you rather travel in a car that could do 0-100 mph in random, unexplained stutter-step intervals or in a car that could do a smooth, steady, predictable 55 mph all day?

Minimal off-time is the key to machining speed and is the single, greatest influence after on-time, but unfortunately a sufficient amount of off-time is required to maintain any kind of machining stability. In this case, stability is more important than speed because maintaining any kind of sustained machining speed is nearly impossible without machining stability.

Electrode Wear: Ok… after already declaring that off-time affects only two parameters, speed and stability, why is this topic shown?

Only because there is still an occasional argument lingering that electrode wear is also influenced by off-time. Perhaps this erroneous perception is due to the reasoning: if 10% wear is incurred in 1 hour, if I doubled the off-time, the job would take about twice as long and the total wear should then be 20% (Misplaced logic: If the job takes twice as long, then there *must* be twice as much electrode wear).

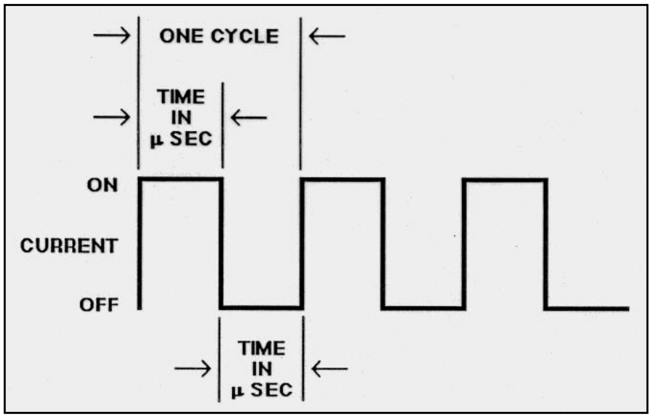
Based upon correctly-placed logic and undeniable physics, please consider; when the current is switched off, it is exactly that – *off.* Nothing, other than the reionization of the dielectric is occurring. While no work is being produced, neither can there be any accompanying electrode wear. If only the off-time is changed, only the time required to complete the job can change.

An abstract description of this might be: an imaginary cavity might require 1,000 individual sparks to complete. If these sparks are only 10 microseconds apart, the job should proceed in a normal fashion. If they are 10 *seconds* apart, the job will take much longer, but with no possible increase in electrode wear. 1,000 sparks are 1,000 sparks – no matter how far apart in time they are. Therefore and in conclusion, *the duration of off-time cannot affect wear, only machining time.*

THE EDM CYCLE

Together, the on- and off-time increments comprise a single cycle of electrical discharge machining. The duration of each parameter in actual use will depend upon the work piece material, electrode material, the quality of flushing, the machining speed required, and the surface finish required.

In a simplistic depiction of the basically-square EDM wave form at *left*, it displays the on-time at the top and the off-time on the bottom, with the timeline (in *µ*sec) running from left to right.



I said a "simplistic" depiction because in modern generators, dedicated circuitry can create different wave forms to serve different purposes. Some can have very quick, high-voltage "leader bolts" to "see if the coast is clear", for the next full discharge impulse. Others can have ramped or "leaning" impulse shapes to help reduce electrode wear.

We cannot examine every single cutting wave form, but we do know that regardless of the wave form shape, it has a beginning (on-time) and an end (the next on-time). Just like the pitch of a thread or a gear, a single EDM cycle is measured from one on-time to the next one.

Why do we care to know this? To me, this is the equivalent of a tachometer in a race car. In the case of a race car, we need to know where we are within our "power band" or "power curve", while in any gear. In EDM, the *relationship* of the on-time to the off-time is how we can measure our EDM efficiency, similar to an automotive tachometer. I'll explain.

THE DUTY CYCLE

The ratio of the on-time and off-time will yield the EDM "duty cycle", and this is your indicator to see and understand how and why your burn will progress. The duty cycle is calculated simply by adding the on-time and the off-time together and dividing this total into the on-time. Multiply this quotient by 100 to arrive at the percentage of efficiency, or the EDM duty cycle.

On the right are three examples of EDM steps that we will also use in the surface finish part of this study. These represent the duty cycles of an imaginary rough cut, a semi-finishing and a finish cut.

Why do this? Earlier, I offered an abstract analogy of a tachometer and our power curve. In the case of EDM, by looking at our duty cycles, we get an indication of any room for improvement. In this example, we know that our roughing cut, at 83% is already very efficient and needs little tuning (and may not readily accept any). At 66%, so is the semi-finishing ratio, although there may be room for some improvement. The finishing duty cycle is the least efficient at 50% and has the most room for improvement. However, the smaller spark gaps encountered during EDM finishing can often make flushing more difficult and may not allow for decreases in off-time.

On-time / total cycle time x 100 = Duty Cycle	
Examples:	
Rough	100 on / 20 off = .83 x 100 = 83%
Semi	40 on / 20 off = .66 x 100 = 66%
Finish	20 on / 20 off = .50 x 100 = 50%

Logically, we would always want to reduce the off-time to the smallest increment possible, but the interacting variables such as electrode material, work piece material, flushing conditions and dielectric condition, can affect and even interfere with the ability to maintain concurrent efficiency and stability.

ELECTRODE POLARITY

In EDM, polarity describes whether the electrode is positive or negative and from which side or direction the eroding electrons flow from – the electrode or the work piece.

Sinker generators can be control-switched to either positive or negative electrode polarity to favor the application's requirements. Generally speaking, outside of material-specific applications, most EDM jobs are executed using a positive electrode, sacrificing some potential machining speed in order to protect it from higher wear.

While negative electrode polarity is an option for high-speed material removal, it *must* be used when machining certain materials such as carbide, titanium, refractory metals and copper-family alloys. In these examples, electrode wear will be high, from 40-100% depending upon the work piece material and regardless of the electrode material.

On wire machines, electrode polarity is not usually control-switchable. Wires typically run with negative wire polarity because machining rates are much higher and unlike sinkers, there is little concern for electrode wear. Sinkers have a typically high electrode cost and therefore the need to protect it. A wire machine also has an electrode cost, but there is no expensive machine-time for fabricating the electrode or the electrode's wear and life to consider.

VOLTAGE

In EDM generators, there are two types: "open-gap" and "working", or machining voltage.

"Open-gap" voltage is the term for the high, preset electrical potential, measured in volts, while the electrode is "seeking" the work piece under power, but hasn't begun machining yet. After initialization and discharge, the open-gap voltage will drop sharply as amperage rises and machining begins.

"Working" voltage is the average voltage *during* machining and is lower than "open-gap" voltage, with about 35 volts being a theoretical optimum, but this can often be difficult to achieve because as voltage decreases, the spark gap will get increasingly smaller and becomes too difficult to flush.

Voltage selection is important in regulating the size of the spark gap or overcut. In high conductivity parts and electrodes, voltage can be set low, as low as 60 volts in the case of a copper electrode against an aluminum work piece. In low conductivity machining, such as using graphite electrodes against a carbide or PCD work piece, a much higher voltage is used, up to 300 volts. Many machines have dedicated high-voltage circuitry for these types of applications.

SERVO VOLTAGE

Servo voltage controls the machining voltage between the electrode and work piece and is not to be confused with servo speed. Servo voltage allows an operator to increase cutting speed or allow for better flushing because this parameter controls the spark gap via voltage. Lowering the servo voltage forces the electrode closer to the work piece in order for the spark to jump it. We increase cutting speed because, "the lower the voltage, the higher the amps".

Using servo voltage like this is called, "crowding the gap", and is routinely done by experienced operators to wring the last bit of speed from their cut. When doing EDM training, I describe servo voltage as your Vernier-scale, used to fine-tune any cut.

This gap control works both ways. In conditions that require just a teeny bit more flushing, the servo voltage can be increased, which will force a longer spark to jump a larger gap. This extra bit of space aids flushing and can often help reduce wire breaks. It will also reduce amperage, slow machining speed and consume more time and wire, but in cases like this, more often slower, but sustained machining is better than unpredictable machining performance and even no machining during wire breaks and threading recovery. "If you're not in the cut, you're not in the money".

SERVO SPEED

Also called "gain", this subject technically does not belong here because it is not a fundamental of EDM or part of its theory. Servo speed controls the speed of an advancing axis during machining operations and is not a direct electronic influence from the generator, but is mechanical or machine-driven. On a more conventional machine, this would be called "feed" or "feed rate" and must be carefully adjusted.

To better understand the behavior of servo speed and the degree of sensitivity that all EDM's require, I'll first ask you for tolerance with my following analogies about servo speed. After describing this process in many different ways and in many countries using simultaneous translation, the following explanation is consistently the one most easily understood.

Indulge me a bit and let's imagine that an advancing electrode in the Z-axis of a sinker is really a heavy weight and the ideal spark gap is maintained by a tiny man, standing in the spark gap with his hands up, physically preventing the electrode from striking the work piece (rotate this image 90 degrees for a wire example). A high or fast servo speed will permit the heavy weight to "fall" faster, causing the tiny man to bend from its weight and inertia and then continue to push against the sustained pressure.

A high gain is not as critical in a wire machine because once the proper gap distance is arrived at, too quickly or not, as long as it can recover, maintaining or managing it is easier because the load or weight against the spark gap is applied *steadily* in the direction of the cut and other compensations can kick in. This can however, be exceeded and cause problems.

This is much more of an issue in a sinker that uses peck-cycles, during which our tiny little man must stop the heavy falling weight over and over, throughout the length of the program. Fortunately for us, our tiny EDM man doesn't get tired, but he *is* forced to work harder than necessary.

If the servo is set too firm, it can interfere with steady discharges by physically encroaching into the intended spark gap from overshoot, especially when you consider the tiny gaps encountered in fine finishing. With the correct servo speed, the electrode can approach the work piece at a rate to give the control and servo system time to interact and process this feedback properly and control the process better.

When wire-cutting, sometimes we can use a low servo speed during final skims to help produce a straighter part. A slower feed rate in combination with a fast wire run-off speed will allow more on-size wire to pass across a given surface and "spark-out", reducing the amount of any taper caused by wire wear. An example of using soft servos in a sinker would be when discharge-dressing .015" diameter electrodes. This must be done using high-speed spindle rotation (1,000+ RPM) and soft servos to insure complete dressing.

A low gain or a "soft" servo will allow our EDM man to stop the "lighter" weight, mass and inertia more easily and once "caught", better balance and control it. A servo setting that is too low (or soft) will cause the advancing axis to practically "float" into the part instead of efficiently seeking the ideal spark gap and begin machining. This condition will cause longer cycle times and inconsistent cutting speeds. In this same example, our tiny EDM man is running all around the spark gap trying to "catch" a nearly-buoyant electrode, sometimes even bouncing off his hands. When servos speeds are set *too* low, the controlled axis will *retract* away from the cut. I suspect every EDM operator has done this, whether inadvertently or deliberately.

Again, sorry for the cartoon, but this visual has made it clear in any language to show how a separate generator and servo system can be made to work together, or harder than necessary and even against each other. C'mon… EDM is difficult enough.

SOME MACHINING TIPS

I say this often, but your single best source of cutting technology is right out of your WEDM machining manuals. For workarounds or tips and tricks, contact the experienced applications engineers that support your machine. These guys enjoy an EDM challenge and are anxious to help.

For Speed: EDM is usually a fine line of compromise. In the case of machining speed, this can typically conflict with machining stability. If your on-time parameters of overcut, wear, and finish are satisfactory and flushing is good, the machining speed of a stable EDM burn might be further pushed by slowly decreasing the off-time in small increments, from 1-5 μsec, until machining becomes erratic. At this point, increment increases in off-time back into the cycle until machining stability recovers.

Because we are gaining machining efficiency (from a better duty cycle), our cutting speed should also increase. This increased efficiency is revealed when the machining or gap voltage decreases on the voltmeter as the working current shown on the ammeter increases. This is good because it is amperage that does all the work. A final note on voltage and amperage: Voltage and amperage are related, but are not interchangeable in the sense that when one rises, the other falls, and vice-versa. Together, they reveal our machining efficiency.

Wire machines tend to be noisy, but if you are sinking with a thin-rib electrode and if the room is quiet enough, you can audibly hear the discharge frequency change as you increase or decrease the on- or off-time. While pushing the machine like this, try not to let the gap voltage drop below 35 to 40V as this is approaching the lowest threshold of safe EDM'ing, even with optimum flushing. More commonly, gap voltages can't be set lower than 100V without difficulty.

For Wear: Wear is not a serious consideration for wire EDM because variable wire speeds control this and the electrode is constantly renewed from the spool. For vertical EDM, leaving a minimal amount of work piece stock for finishing will help keep electrode wear to a minimum, while saving time. Protect the electrode by using no- and low-wear settings to remove most of the material, leaving the minimum safe amount of stock for finishing.

Side-bar – Since much of this has been on sinkers, here's a bit about electrode wear for the wire-guys:

Outside of a few tenths of wire wear that can leave a tall part slightly tapered, excessive electrode wear in a wire EDM is simply called, "a broken wire" and falls under "the 20% rule". The 20% rule is a threshold of physics, explained by; "when the wire is under tension, if 20% of its cross-section is consumed, it will propagate a crack and break", guaranteed. This guarantee is physics. That is why all of the wire run-off speeds that come up canned with the rest of your settings, will run just below this 20% threshold to provide the maximum use and economy of the wire without it breaking.

In a difficult application or in poor flushing conditions, sometimes increasing the wire run-off speed will reduce wire breaks. This will consume less of the wire's diameter and allow it to "make the journey" easier. Faster wire run-off speed can also help reduce tall part taper that is caused by normal wire wear, but both examples will increase your wire consumption costs.

Problem – Assuming that all machine PM is in order, how many times while roughing, have you encountered numerous, unexplained wire breaks, even after trying several different remedies?

Solution – Try reducing the wire tension by 5%. We can't change the physics of the 20% rule, but we can change the environment or conditions it operates in. Part of the 20% rule is "when the wire is under tension", meaning the full, recommended tension. Under the poor conditions described above, the wire may simply be at its maximum design limitations, but if part accuracy will allow a slight reduction in wire tension, this may allow the wire to survive the cut longer.

Example: If you hold a kite string tautly, it will easily part or be cut when touched with a knife. If you relax the string's tension even slightly, parting it is no longer possible and cutting it is more difficult. EDM wire behaves in the same way.

For Finish: In EDM, surface finishing is usually the most time consuming, therefore, the most expensive. Careful planning and preparation can help offset this. For both wire-cut and CNC sinkers, careful selection of the current and frequencies used and the amount of material left for each finishing step is critical. Whether you are skim-cutting with wire or orbiting in a sinker, the remaining amount of material for each step should be only slightly more than the maximum crater depth left by the previous cut. The old shop saying of, "Rough it out to size," *almost* applies here as long as the heat from the roughing operations does not affect the temper of the work piece immediately under the finished surfaces and there is enough stock remaining to remove all traces of the previous finish.

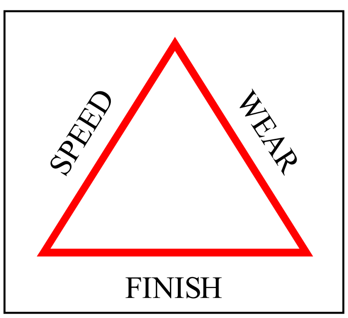
When attempting parts or details requiring very fine or "mirror finishes," you should not be concerned with metal removal in the final steps, as this is the role of the roughing and semi-finishing operations. At this point, your part or cavity should have the smallest amount of material left to clean up to its final size and finish. We are basically finished with metal removal and are now just changing the finish.

IT'S A DANCE

EDM can literally be a dance – arranging the choreography of the three sides of the EDM Triangle. Like music, all of the parameters just mentioned must blend together harmoniously, to give us the fastest cutting speeds and the finest finishes in the shortest time possible. However, even the most-skilled of EDM conductors can only *try* to make such sweet music, but the unyielding reality of physics and the variations of changing cutting and flushing conditions can often prevent the chords of perfect EDM harmony from being achieved.

THE EDM TRIANGLE

Do you remember the three sides of the fire-triangle we were taught in grade school – the three things necessary for fire? They are Heat, Fuel and Oxygen. I've crafted a similar triangle representing what EDM'ers pursue and are faced with. The three sides of the EDM Triangle are Speed, Finish and Wear.



Experienced EDM'ers know that we can very seldom have all sides equal at the same time. Many times, we can obtain two of them, but many times only one of them is possible. We know for example, that when roughing, we can achieve good speed and low wear, but we cannot have the finish-side of the triangle. In finishing operations, we can obtain high-quality surface finishes, but certainly not speed and good wear. Even when we're always seeking a *balance* of speed, wear and finish, a perfect EDM triangle seldom occurs.

MACHINING PARAMETERS

Fortunately for all users, generating machining parameters for EDM and WEDM is very easy. One simply goes to the correct programming screen and enters the job parameters – the electrode or wire type, the electrode undersize or wire diameter, work piece material and thickness or depth of cavity, the finish desired, etc. When this information is entered, the control refers to stored, "look up" tables of cutting conditions and selects the correct cutting parameters, including the offsets for orbits or skims. This machining-part of the program is then married to the CNC program for the rest of the codes for axes movement, ATC's and auto-threaders, etc.

This is a whole lot different and easier than the days of optical plotters and calculating spark frequencies in kilohertz.

SUMMARY

We have just reviewed the fundamentals of EDM and how EDM works mainly because you simply need to know this. More importantly, is so you never have to be satisfied with a canned setting. The elements of on-time, off-time, spark gap, polarity, servo voltage, etc. are all distinctly different, but all must be used together in concert to obtain the desired results.

We have also just covered how easy the control makes this for us, but you still must know how EDM works so you can push, troubleshoot or modify any canned setting that comes up. There is also a small reward for this that grows over time. Once proven, these settings can be renamed and saved as one of your go-to settings, requiring little refinement and you eventually build a private library of these tried and true cutting parameters.

As stated in the very beginning, EDM is like the ancient game of "Go" or its modern counterpart "Othello" in the sense that while it is relatively easy to learn, it can be difficult to master. One aspect of this premise is; the more you play the game, the better you will become. As you experience a flanking move being made by your opponent in the game, or you encounter a difficult cutting condition at the machine, both are a learning experience and something you will retain and refer to in the future for both. Come to think of it, EDM might be easier to master than the game… in EDM we have a computer to store all our winning moves.

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