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DEFINITION OF EDM

Electrical Discharge Machining (EDM) is the process of machining electrically conductive materials by using precisely controlled sparks that occur between an electrode and a workpiece in the presence of a dielectric fluid. The electrode may be considered the cutting tool. Figure 1-1 illustrates the basic components of the EDM process.

Die-sinking (also known as ram) type EDM machines require the electrode to be machined in the exact opposite shape as the one in the workpiece. Wire-cut EDM machines use a continuous wire as the electrode. Sparking takes place from the electrode wire-side surface to the workpiece.

EDM differs from most chip-making machining operations in that the electrode does not make physical contact with the workpiece for material removal. Since the electrode does not contact the workpiece, EDM has no tool force. The electrode must always be spaced away from the workpiece by the distance required for sparking, known as the sparking gap. Should the electrode contact the workpiece, sparking will cease and no material will be removed. There are some EDM machines that do allow the electrode to contact the workpiece. These machines are used primarily for removing broken taps and drills and are not considered die-sinker or wire-cut types of EDM machines.

Another basic fundamental of the process is that only one spark occurs at any instant. Sparking occurs in a frequency range from 2,000 to 500,000 sparks per second causing it to appear that many sparks are occurring simultaneously. In normal EDM, the sparks move from one point on the electrode to another as sparking takes place. Figure 1-2 illustrates that each spark occurs between the closest points of the electrode and the workpiece.
The spark removes material from both the electrode and workpiece, which increases the distance between the electrode and the workpiece at that point. This causes the next spark to occur at the next-closest points between the electrode and workpiece. Figure 1-3 illustrates how this works.

EDM is a thermal process; material is removed by heat. Heat is introduced by the flow of electricity between the electrode and workpiece in the form of a spark. Material at the closest points between the electrode and workpiece, where the spark originates and terminates, are heated to the point where the material vaporizes.

While the electrode and workpiece should never feel more than warm to the touch during EDM, the area where each spark occurs is very hot. The area heated by each spark is very small so the dielectric
fluid quickly cools the vaporized material and the electrode and workpiece surfaces. However, it is possible for metallurgical changes to occur from the spark heating the workpiece surface.

A dielectric material is required to maintain the sparking gap between the electrode and workpiece. This dielectric material is normally a fluid. Die-sinker type EDM machines usually use hydrocarbon oil, while wire-cut EDM machines normally use deionized water.

The main characteristic of dielectric fluid is that it is an electrical insulator until enough electrical voltage is applied to cause it to change into an electrical conductor. The dielectric fluids used for EDM machining are able to remain electrical insulators except at the closest points between the electrode and the workpiece. At these points, sparking voltage causes the dielectric fluid to change from an insulator to a conductor and the spark occurs. The time at which the fluid changes into an electrical conductor is known as the ionization point. When the spark is turned off, the dielectric fluid deionizes and the fluid returns to being an electrical insulator. This change of the dielectric fluid from
an insulator to a conductor, and then back to an insulator, happens for each spark. Figure 1-4 illustrates the EDM spark occurring within an ionized column of the dielectric fluid.

Dielectric fluid used in EDM machines provides important functions in the EDM process. These are:

- controlling the sparking-gap spacing between the electrode and workpiece;
- cooling the heated material to form the EDM chip; and
- removing EDM chips from the sparking area.

As each spark occurs, a small amount of the electrode and workpiece material is vaporized. The vaporized material is positioned in the spark-
ing gap between the electrode and workpiece in what can be described as a cloud. When the spark is turned off, the vaporized cloud solidifies. Each spark then produces an EDM chip or a very tiny hollow sphere of material made up of the electrode and workpiece material. Figures 1-5, 1-6, and 1-7 illustrate the spark producing the vapor cloud, the cloud in suspension, and the vaporized cloud being cooled and forming into an EDM chip.

For efficient machining, the EDM chip must be removed from the sparking area. Removal of this chip is accomplished by flowing dielectric fluid through the sparking gap.

EDM is sometimes referred to as spark machining, arc machining, or even burning. Spark machining and arc machining are accurate descriptions of the process since they indicate precision and control of the sparks used in the machining process. Burning is not an apt description as it implies a process where combustion takes place. The term “burning” also gives the impression that fire is involved. EDM requires
Figure 1-5. Spark ON: electrode and workpiece material vaporized.

Figure 1-6. Spark OFF: vaporized cloud suspended in dielectric fluid.
a very precise flow of electricity in the form of a spark; fire is not an accurate or acceptable description of the EDM machining process.

**DEVELOPMENT OF EDM**

This section will cover the early development stages of both the die-sinker and wire-cut methods of EDM.

**DIE-SINKER EDM**

EDM originated from the need to perform machining operations on difficult-to-machine metals. The process was developed almost simultaneously in the USSR and the USA at the beginning of World War II.
EDM Development in the USSR

In 1941, the USSR was involved in World War II and critical materials needed to be conserved. Tungsten was widely used as electrical contact material for automotive-engine, distributor-breaker points. As pitting occurred, the engines required maintenance. It was probable that military vehicles would not be in service when needed. Even the replacement of the breaker points caused valuable tungsten to be discarded. To address this issue, the government assigned Moscow University Professors Dr. Boris Lazarenko and Dr. Natalya Lazarenko at the All Union Electro Technical Institute to investigate whether the life of the components could be extended by suppressing sparking between the breaker points.

As part of their experimentation, the Lazarenkos immersed the breaker points in oil. They observed that, while the oil did not eliminate the sparking, it did create more uniform and predictable sparking and pitting, as compared to operating the breaker points in air. Figure 1-8 illustrates the immersion of the contacts.

The Lazarenkos’ experiment was not successful because it did not develop a means for extending the life of the automotive breaker points due to sparking. But the Lazarenkos, being very observant engineers, decided to investigate the possibility of controlled-metal removal through the use of sparks. Their interest intensified as they observed that sparks could be used to remove material from tungsten. In 1943, the Lazarenkos developed a spark-machining process with an electrical circuit that used many of the same components as the automobile ignition system. This process became one of the standard EDM systems in use throughout the world. Since the Lazarenko EDM system used resistors and capacitors, it became known as a resistor-capacitor (R-C) circuit for EDM. Figure 1-9 illustrates this system.

The Lazarenkos continued to develop their machining system, eventually designing an electrode-servo system that automatically maintained the electrode-to-workpiece sparking gap during the EDM machining cycle.

Many Lazarenko EDM machines were produced during the World War II-years, which allowed practical machining of difficult-to-machine metals, such as tungsten and tungsten carbide. When the process of machining with sparks gained recognition outside the USSR, the
Description and Development of Electrical Discharge Machining (EDM)

Figure 1.8. Lazarenko experiment with auto-ignition system.
Electrical Discharge Machining

Lazarenko EDM system served as the model for most of the EDM machines produced in Europe and Japan.

R-C-type EDM machines are still produced and used around the world. Their use is centered on applications that require a fine surface and the drilling of small, precise orifices.

**EDM Development in the USA**

At nearly the same time as when the Lazarenkos were beginning to experiment with spark machining, and without knowledge of what was taking place in the USSR, a company in the USA discovered a need for a machine to remove broken taps and drills. Their products included hydraulic valves with aluminum bodies. During the production process, many drills and taps were being broken within the valve body. The parts, used in aircraft applications, were costly. So, three employees—Harold Stark, Victor Harding, and Jack Beaver—were assigned a project to find a way to remove the broken taps and drills and salvage the parts.

Timing of the US project directly corresponded to that of the one undertaken by the Lazarenkos in the USSR. But the two groups’ experimental approaches greatly differed. Harding, an electrical engineer, came up with the idea of using sparks to erode the taps and drills.
from the valve bodies. Originally, an electric-etching tool was used to produce the sparks. The etching-tool electrode was placed on the broken tap or drill and then withdrawn. As the electrode was lifted from the tap or drill, a spark occurred. The spark melted a small portion of metal, allowing the broken tap or drill to be removed in pieces. The procedure worked, but was much too slow to be of any practical value in salvaging the hydraulic-valve bodies. To improve the speed of the process, they built a more powerful sparking version of the etching tool. Figure 1-10 illustrates this design.

The higher-sparking power unit was able to remove the taps and drills, but it produced hot molten material that had to be removed from the sparking area. Removing the molten material with compressed air produced only limited success. This approach used very large quantities of compressed air and left considerable metal in the sparking area. After considerable experimentation, it was determined that water could be used as a coolant and machining time was reduced to a point where the system was practical.

![Diagram of early EDM experiment](image_url)

*Figure 1-10. Stark, Harding, and Beaver: early EDM experiment.*
To make it even more efficient, Stark, Harding, and Beaver were requested to automate the process. The machine they developed consisted of a movable quill with an electrode attached. The quill was free to move in an up-and-down direction. Above the quill was an electromagnet that, when energized, would pull the quill up and away from the workpiece. When the electricity was off, gravity caused the quill to slide back down and into contact with the workpiece surface. Figure 1-11 illustrates the quill in the down position.

As the machine was manually switched on, electricity flowed through the electromagnet, the electrode, and the workpiece. This caused the electromagnet to be energized and the quill was pulled upward. During the upward movement, the electrode separated from the workpiece, producing a spark. (Figure 1-12 illustrates this movement.) As the electrode separated from the workpiece, the open distance acted like an automatic switch turning off the electricity. Without electricity, the electromagnet lost its magnetism and the quill with the electrode dropped down to touch the workpiece. This caused the electricity to start flowing again and another cycle was in progress. Many of these machines were built and used during the World War II era in the USA.

Stark, Harding and Beaver eventually left the valve company and were allowed to patent their system. Their work became the basis for the vacuum-tube EDM machine and an electronic-circuit servo system that automatically provided the proper electrode-to-workpiece spacing for sparking, without the electrode contacting the workpiece. The vacuum tube made it possible to increase spark frequency from 60 times per second to thousands of sparks per second. Figure 1-13 illustrates a simple diagram of the vacuum-tube, EDM-sparking circuit.

WIRE-CUT EDM

It is difficult to establish a time when wire-cut EDM came into being. The development of the process took place over a period of approximately 10 years ranging from the early 60s to the early 70s. In all probability, the developers and users of the die-sinker EDM machines started imagining how the machined electrodes could be replaced with something less labor-intensive and costly. In trying to solve the problem, they may have reasoned that a stationary wire could serve as an electrode, but spark erosion on the electrode surface would weaken
Figure 1-11. Electrode touches workpiece with electricity off.
Figure 1-12. Spark occurs as electrode automatically retracts.
the wire to the breaking point. However, a wire that continuously traveled past the surface being machined would solve the wire breakage problem.

The first major event in the evolution of wire-cut EDM was numerical control (NC). Accurate axis positioning was achieved by having the EDM machines read perforated tape to control operational movements. These tapes became very long and most of the smaller machine shops did not have programming capabilities. In the 1960s, some of the larger die-making machine shops that had punched-tape programming facilities converted their conventional vertical milling machines into wire-cut EDM machines. These machines used power supplies from the die-sinker type of EDM machines. The EDM rate on these machines was reported to be approximately .750 in. (19.05 mm) per hour when machining .250-in. (6.35-mm) thick, hardened die steel. This machining rate would be unacceptably slow if compared to later wire-cut machines.

![Figure 1-13. Electronic EDM system developed by Stark, Harding, and Beaver.](image-url)
In 1967, a wire-cut EDM machine produced in the USSR was displayed at a machine exposition in Montreal, Quebec, Canada. This machine featured numerical control with positioning by means of stepping motors. Machining accuracy was .0008 in. (0.020 mm). The time required to produce a cut of 5 in. (127 mm) in length through 0.5-in. (12.7 mm) steel was three hours.

A portion of an engineering report describing the USSR wire-cut machine included the following comment: “This is a beautifully engineered piece of equipment and will produce through-hole and two-dimensional contours to a commercial accuracy with a good surface finish in a reasonable time with no electrode required. However, it is limited in usefulness for general-purpose work because of the requirements for NC and tape programming. This is a current market restriction, which lessens every day as NC continues to grow.”

The USSR wire-cut EDM machine was probably the first commercially available unit to be marketed.

During the 1960s, another noteworthy event took place. A group headed by David H. Dulebohn developed an optical-line following system. This system required an accurate master drawing of the shape to be machined. The optical-line follower traced over the drawing, transferring it to the X-Y positioning system of a machine tool. Many of these systems were produced and adapted to milling machines and jig grinders.

In using the optical-line follower system, the master drawing determined the final accuracy of the shape being machined. It was determined that greater drawing accuracy would be possible through the use of a computer-generated drawing. Based on this knowledge, software and hardware were developed to produce a computer-numerical-controlled (CNC) system for plotting the master drawing.

During the time of development of the program for the CNC-plotter system, wire-cut-EDM machining came to the attention of the Dulebohn group. They reasoned that the newly developed CNC-drawing-plotter system could be used, along with the optical-line follower mechanism, to automatically control the shape to be machined by the wire-cut EDM process. In 1974, a wire-cut EDM machine controlled by the optical-line following system was introduced.

Eventually, the optical-line follower, wire-cut EDM machine concept was set aside. The Dulebohn group found that the same computer program used to control the CNC-plotting system also could
control the machine itself. This eliminated the need for the master drawing and the optical-line following mechanism. Based on this engineering approach, a computer-numerical-controlled, wire-cut machine was developed in 1976.

Many things happened in a fairly short period of time, starting in the early 1970s, which made wire-cut EDM a practical machining system. Numerical control was replaced by computer-numerical control, eliminating the need for punched tape. Ball screws became available, which allowed for an anti-backlash, anti-friction means of table-axis movement. Anti-friction, pre-loaded table ways became available, which reduced stick friction in the table movement. Servo motors with encoder and tachometer-feedback capability made table-axis feed and position control practical. These items were developed for the more conventional chip-making machines, but their availability was perfectly timed for computer-numerical-controlled, wire-cut EDM. With all of the hardware available for the wire-cut EDM system in place, the final, and possibly most important, item was developed—wire-cut, process-computer software. In its original form, the software was difficult to use. But with time, the programming software was refined and simplified to the point that it was acceptable even to shops without CNC programming specialists. Simplification of the programming brought about nearly universal acceptance of the wire-cut EDM process. As a result, wire-cut EDM has become the EDM process of first choice for through-hole applications, such as stamping and extrusion dies.

**COMPARISON OF DIE-SINKER AND WIRE-CUT MACHINES**

Both die-sinker and wire-cut EDM machines use sparks to remove electrically conductive material. But while both types are electrical discharge machines, there are differences in their use and operation. Some of these differences are listed in the following text.

Dielectric fluid:

- die-sinker EDM machines use hydrocarbon oil and submerge the workpiece and spark in the fluid; and
- wire-cut EDM machines normally use deionized water and contain only the sparking area in the fluid.
Applications:

- die-sinker EDM machines are normally used for producing three-dimensional shapes;
- these shapes utilize either cavity-type machining or through-hole machining; and
- wire-cut EDM machines are always used for through-hole machining, since the electrode wire must pass through the workpiece being machined.

Die-sinker and wire-cut sparking:

- die-sinker machines produce sparks that occur between the electrode end and the workpiece. Figure 1-14 illustrates this sparking; and
- wire-cut machines produce sparks that occur between the electrode-side surface and the workpiece. Figure 1-15 illustrates this sparking.

Sparking area:

- die-sinker sparking occurs across the end surface and from the corners of the electrode (see Figure 1-16). Spark length is set by the machine controls. Sparks occur from the electrode corners, producing a clearance between the electrode corner and the sidewalls of the workpiece. The machined clearance between the electrode corner and the workpiece sidewall is the spark overcut. The electrode-end sparking surface, plus the sidewall-overcut distance, is the sparking area; and
- wire-cut sparking occurs between the side and machined surfaces of the workpiece (see Figure 1-17). Spark length is set by the machine controls. The sparking area consists of only the front 180° of the electrode diameter as it progresses into the cut. A clearance equal to the spark length is machined on each side of the wire electrode. This side clearance is the spark overcut. The total width of the machined opening consists of the electrode diameter, plus two times the spark length. The total width of the machined opening is the kerf.

Both die-sinker and wire-cut machines use sparking to remove electrically conductive material. However, they do not normally use the same kind of dielectric fluids or electrodes. While the machines are
Figure 1-14. Die-sinker sparking from electrode end.

Figure 1-15. Wire-cut sparking from electrode side.
Electrical Discharge Machining

Figure 1-16. Die-sinker sparking area.

Figure 1-17. Wire-cut sparking area.
similar, they are not identical. Operational data and charts, therefore, must be specific for the type of machine being used.

**ACCEPTANCE OF THE EDM PROCESS**

EDM was not as readily accepted in the US as it was in most other parts of the world. This was primarily because the US did not sustain damage to its industrial factories during World War II. In addition, the US had highly skilled workers trained on existing equipment. EDM required new thinking and an acceptance of using electricity as a method of metal removal. With its industrial base so well established and productive, US industry saw no reason to switch to a new process. As a result, it took some time for EDM to be accepted.

Japan was not so fortunate in the aftermath of World War II. The Japanese industrial base was, for all practical purposes, destroyed. As a result, industry in Japan was very willing to accept EDM. A great deal of research was put into developing EDM machines to suit its needs. One of the leaders in this research and development in Japan was Dr. Kiyoshi Inoue.

European countries also accepted EDM almost from the beginning. Most of the early EDM machines were based on the Lazarenko developments. By the end of World War II, most of the machines sold worldwide were of European manufacture, with the exception of those sold in the USA.
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