ELECTRICAL MACHINING PROCESSES

With the introduction of unique mechanisms and exotic materials in recent years, it has been found necessary to develop new methods of efficiently machining metals. Parts made out of cemented carbide or difficult-to-machine metals were previously shaped by the costly process of diamond wheel grinding. *Electro-chemical machining*, *electrical discharge machining*, and *electrolytic grinding* are three methods which have been developed recently. All remove metal by some form of electrical discharge.

ELECTRO-CHEMICAL MACHINING

Electro-chemical machining, more commonly called ECM, differs from conventional metal cutting techniques in that electrical and chemical energy are used as the cutting tools. This process machines metal easily, regardless of the work hardness, and is characterized by its "chipless" operation. A non-rotating tool the shape of the cavity required is the *cutting tool*; therefore square or difficult-to-machine shapes can easily be cut in a workpiece. The wear on the cutting tool is hardly noticeable since the tool *never* touches the work. Electro-chemical machining is particularly suitable for producing round through holes, square through holes, round or square blind holes, simple cavities which have straight, parallel sides, and planing operations. ECM is especially valuable when metals that exceed a hardness of 42 Rockwell C (400 BHN) are machined. Sharp corners, flat bottom sections, or true radii are difficult to maintain because of the slight overcut which occurs during this process. A significant advantage of ECM is that the surfaces and edges of workpieces are not deformed and are left burr-free.

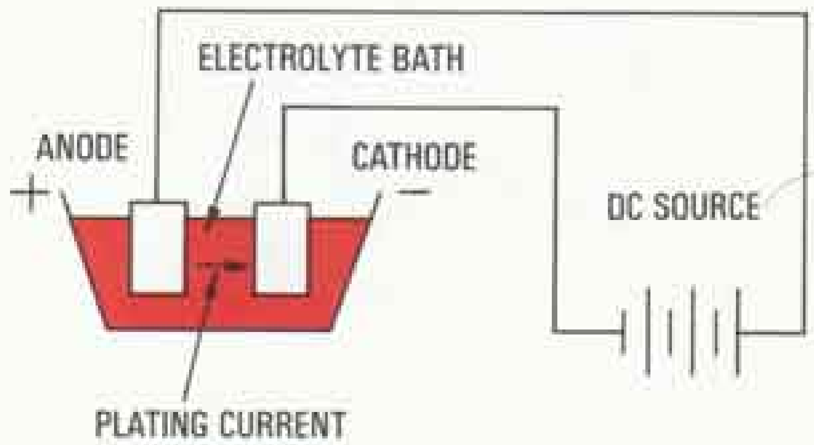


Fig. 19-1 Principle of a simple plating bath

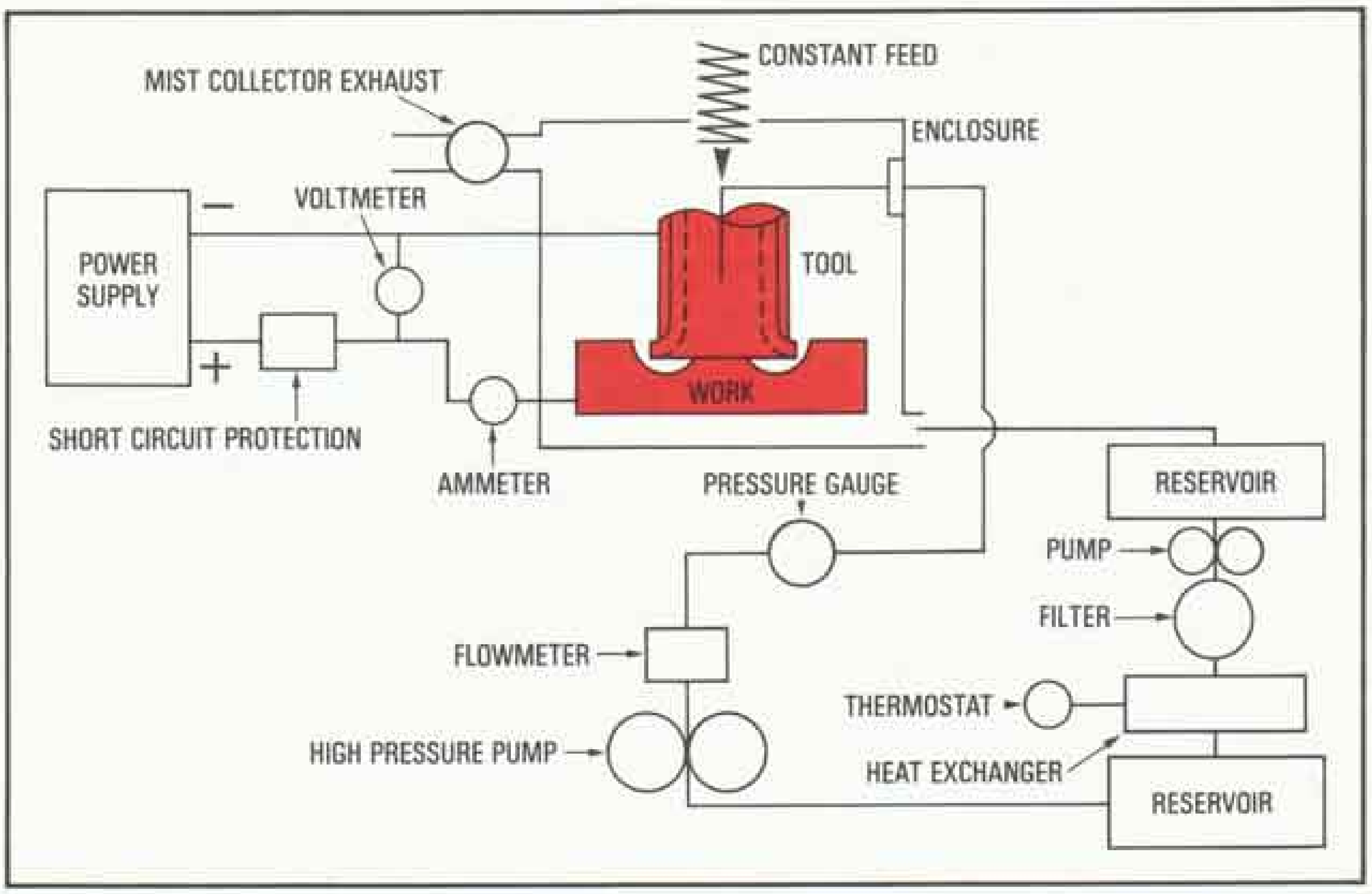
THE PROCESS

For years, metal in a solution has been transferred from one metal to another by means of electro-plating baths. Since ECM evolved from this process, it may be wise to examine the electro-plating principle (Fig. 19-1).

a) Two bars of unlike metal are immersed in an electrolyte solution.
b) One bar is fastened to a negative lead on a battery while the other is fastened to the positive lead.
c) When the circuit is closed, direct current passes through the electrolyte between the two bars of metal.
d) Chemical reaction transfers metal from one bar to the other.

Electro-chemical machining differs from the plating process in that an electrochemical reaction dissolves metal *from a workpiece* into an electrolyte solution. A direct current is passed through an electrolyte solution between the electrode tool (the shape of the cavity desired), which is negative, and the workpiece, which is positive. This causes metal to be removed ahead of the electrode tool as the tool is fed towards the work. Chemical reaction caused by the direct current in the electrolyte dissolves the metal from the workpiece (Fig. 19-2).

The *electrode* for ECM is not a simple bar of metal, but a precision insulated tool which has been made to a specific shape and exact size. The electrode (tool) and workpiece, although located within 0.05 mm to 0.08 mm, never contact each other. The *electrolyte solution* is a controlled, swiftly flowing stream which carries the current. The *direct current* used may at times be as high as 1550 A/cm^2 of work material. All these factors affect the successful operation of the electro-chemical machining process and will be discussed in greater detail.



Courtesy Cincinnati Milacron Inc.

Fig. 19-2 Schematic diagram of a typical electro-chemical machining system

THE ELECTROLYTE

The electrolyte is a solution of water to which salt, mineral acid, caustic-potash, or caustic soda has been added to increase the electrical conductivity. A weak supply of the electrolyte solution will result in two disadvantages:

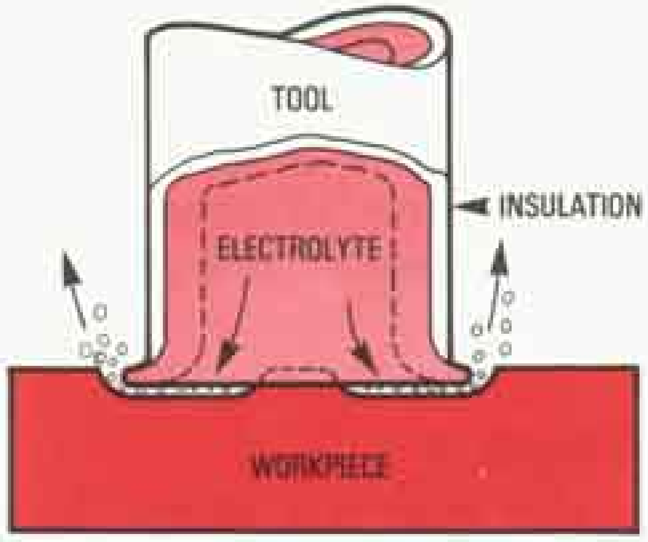
a) Metal removal rates will be low.
b) Excessive heat at the machining area will destroy the effectiveness of the solution.

Electrical energy which starts a chemical reaction in the electrolyte solution results in the formation of gas between the tool and workpiece and dissolves metal from the workpiece. The gas escapes into the atmosphere while the dissolved metal is carried away in the solution. As there is some resistance to current flow and chemical reactions occur, heat is generated in the machining area. The electrolyte is introduced into the machining area in great quantities to dissipate the heat and wash away the dissolved metal. Filters placed in an electro-chemical machining system remove the dissolved metal from the electrolyte and ensure a fresh flow of solution to the machining area.

The electrolyte is introduced to the machining area *through* the electrode tool; therefore, the amount of flow is affected by the electrode length, diameter, and shape. As much flow as possible is desirable, and some applications have been known to use as much as 760 *l*/min at pressures up to 2070 kPa.

THE ELECTRODE

The *electrode tool*, which is always the *negative terminal* of the electrical circuit, is an insulated tool made to the size and shape of the cavity desired. The electrolyte solution is fed to the machining area by a hole through the centre of the electrode. Because it is necessary that the electrolyte flow completely around the electrode and allowance be made for the overcut which occurs during the ECM process, the tool is made approximately 0.12 mm per side smaller than the hole it produces. The periphery of the electrode is insulated (Fig. 19-3) to prevent the sides from cutting as the tool extends deeper into the hole.



Courtesy Cincinnati Milacron Inc.

Fig. 19-3 Electrolyte flowing through the electrode tool

One of the chief purposes of the electrode tool is to impart its shape to the workpiece. For example, a square electrode will produce a square hole, while a round hole is produced by a round electrode. The shape of the cavity which can be produced through ECM is limited only by the shape which can be cut on the electrode. The material used to make the electrode tool should possess the following characteristics.

a) It must be machinable.
b) It must be rigid.
c) It must be a good conductor of electricity.
d) It must be able to resist corrosion.

Copper, brass, and stainless steel have generally been found to be good electrode materials for electro-chemical machining.

Copper, an excellent conductor of electricity, is not recommended for manufacturing electrodes for thin-walled sections or deep holes. Because of its softness and tendency to bend, it is difficult to machine long or thin sections.

Brass, while not as good a conductor of electricity as copper, can be used for electrode material with good results. The greater strength of brass, its ease in machining, and its lower cost make it an ideal material for most electrodes.

Stainless steel is used when large volume flow and high pressures of electrolyte are necessary. It is stronger than the other two materials; however, its high initial cost and difficulties encountered in machining limit its use as an electrode material.

METAL REMOVAL

In the electro-chemical process, the distance between the electrode and the work (the machining gap) (Fig. 19-3) is important. In order to encourage efficient electrical transmission, the tool and the work must be as close as possible to each other yet never come into contact. For most conditions, this gap will vary from 0.02 mm to 0.07 mm (or .001 in. to .003 in.). Because of the high current levels used, serious damage to both the electrode tool and the work will occur if there is any physical contact between them.

The rate of metal removal is directly proportional to the current passing between the tool and the workpiece. Current densities ranging from a minimum of 155 A/cm^2 to a maximum of 1550 A/cm^2

Courtesy Cincinnati Milacron Inc.

Fig. 19-4 Electro-chemical machining applications

have been used in ECM applications. The use of high current will result in a high rate of metal removal, while low current will result in a low rate of metal removal.

The amount of overcut (the difference between the tool size and the hole produced) depends upon various cutting conditions and may vary from 0.20 mm to 0.30 mm (.008 in. to .012 in.). Once the amount of overcut is known for a given tool, hole sizes will be repeated to within at least 0.04 mm to 0.01 mm of roundness.

The rate of penetration varies with the type of operation being performed, the type of work material, the cross-section of the electrode, and the current density used. ECM rates of penetration may vary from 6.4 mm to 11 mm (or .250 in. to .430 in.).

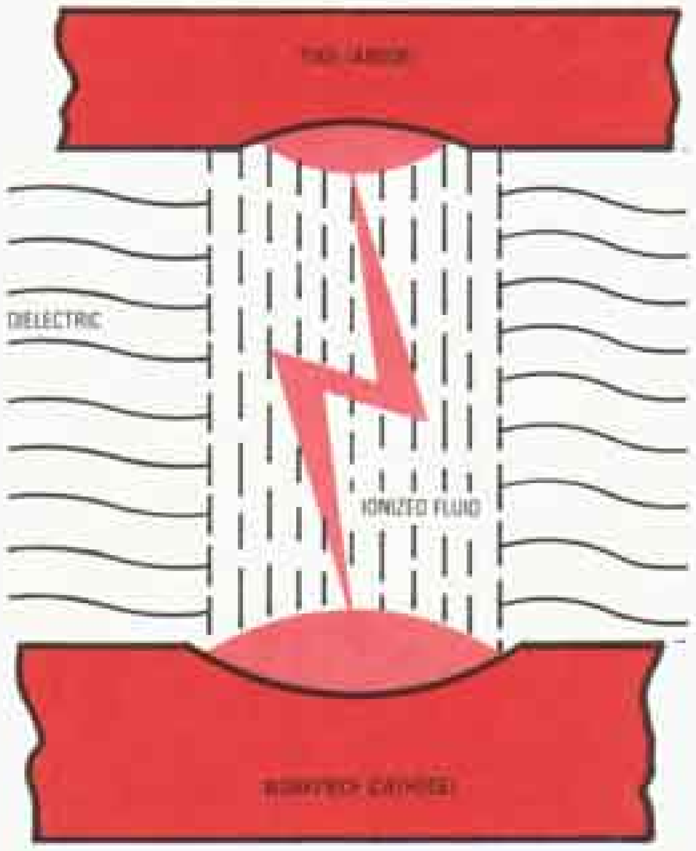
ADVANTAGES OF ECM

Electro-chemical machining is one of the metal cutting processes which has contributed to the machining of space-age metals. Some of its characteristics and advantages are:

a) Metal of any hardness can be machined.
b) It competes with drilling and some through-hole milling operations, especially if the work exceeds 42 Rockwell C hardness.
c) No heat is created during the machining process; therefore, there is no work distortion.
d) It machines metal without tool rotation.
e) Tool wear is insignificant as the tool never touches the work.
f) Because the tool never touches the work, thin fragile sections can be machined without distortion.
g) The workpiece is left burr-free.
h) Intricate forms, difficult to machine by other processes, can be produced easily (Fig. 19-4).
i) It is suitable for production type work where multiple holes or cavities may be machined at the same time.
j) Surface finishes of 0.60 μm (or 25 microinches) or less may be obtained.

ELECTRO-CHEMICAL MACHINING QUESTIONS

1. How does ECM differ from conventional machining techniques?
2. Describe briefly the process of ECM.
3. Name four suitable electrolytes.
4. Explain fully the purpose of the electrolyte solution.
5. Explain what part the electrolyte plays in the electro-chemical machining process.
6. What are the characteristics of a good electrode tool?
7. Name three electrode materials suitable for ECM and state the advantage of each.
8. Define: a) machining gap
   b) overcut
   c) rate of penetration
9. State seven main advantages of electro-chemical machining.



Courtesy "American Machinist"

A controlled spark removes metal during electrical discharge machining

ELECTRICAL DISCHARGE MACHINING

Electrical discharge machining, commonly known as EDM, is a process that is used to remove metal through the action of an electrical discharge of short duration and high current density between the tool and the workpiece. This principle of removing metal by an electric spark has been known for quite some time. In 1889, Paschen explained the phenomenon and devised a formula which would predict its arcing ability in various materials. The EDM process can be compared to a miniature version of a lightning bolt striking a surface, creating a localized intense heat, and melting away the work surface.

Electrical discharge machining has proved especially valuable in the machining of super-tough, electrically conductive materials such as the new space-age alloys. These metals would have been difficult to machine by conventional methods, but EDM has made it relatively simple to machine intricate shapes that would be impossible to produce with conventional cutting tools. This machining process is continually finding further applications in the metal cutting industry.

PRINCIPLE OF EDM

Electrical discharge machining is a controlled metal-removal technique whereby an electric spark is used to cut (erode) the workpiece, which takes a shape opposite to that of the cutting tool or electrode (Fig. 19-5). The *cutting tool (electrode)* is made from electrically conductive material, usually carbon. The electrode, made to the shape of the cavity required, and the workpiece are both submerged in a *dielectric fluid*, which is generally a light lubricating oil. This dielectric fluid should be a nonconductor (or poor conductor) of electricity. A *servo mechanism* maintains a gap of approximately 0.02 mm between the electrode and the work, preventing them from coming into contact with each other. A *direct current* of low voltage and

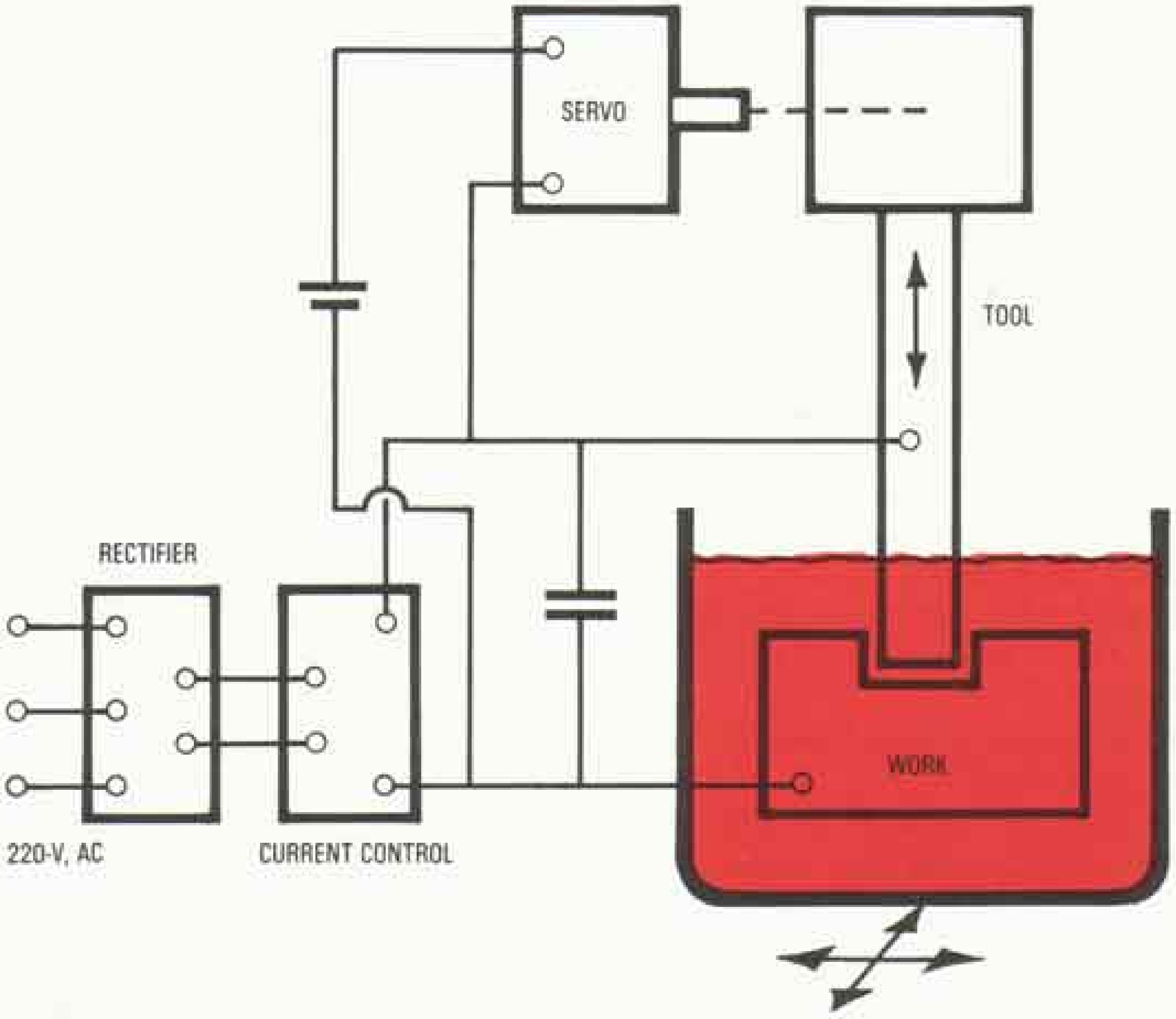


Fig. 19-5 Basic elements of an electro-discharge system

high amperage is delivered to the electrode at the rate of approximately 20 000 Hz. These electrical energy impulses become sparks which jump the gap (Fig. 19-6) between the electrode and the workpiece through the dielectric fluid. Intense heat is created in the localized area of the spark impact; the metal melts and a small particle of molten metal is expelled from the surface of the workpiece. The dielectric fluid, which is constantly being circulated, carries away the eroded particles of metal and also assists in dissipating the heat caused by the spark.

TYPES OF ELECTRICAL DISCHARGE CIRCUITS

Several types of electrical discharge power supply have been used for EDM. Although there are many differences between them, each type is used for the same basic purpose, that is, the precise, economical removal of metal by electric spark erosion.

The following types of electrical power supplies have been used.

a) resistance-capacitance power supply
b) pulse-type power supply
c) rotary impulse generator power supply
d) static impulse generator power supply

The resistance-capacitance and the pulse-type direct current power supplies are most commonly used; therefore, only these two will be explained in greater detail.

Resistance-capacitance power supply, also known as the *relaxation-type power supply,* was widely used on the first EDM machines. It is still the power supply used on many of the machines of foreign manufacture.

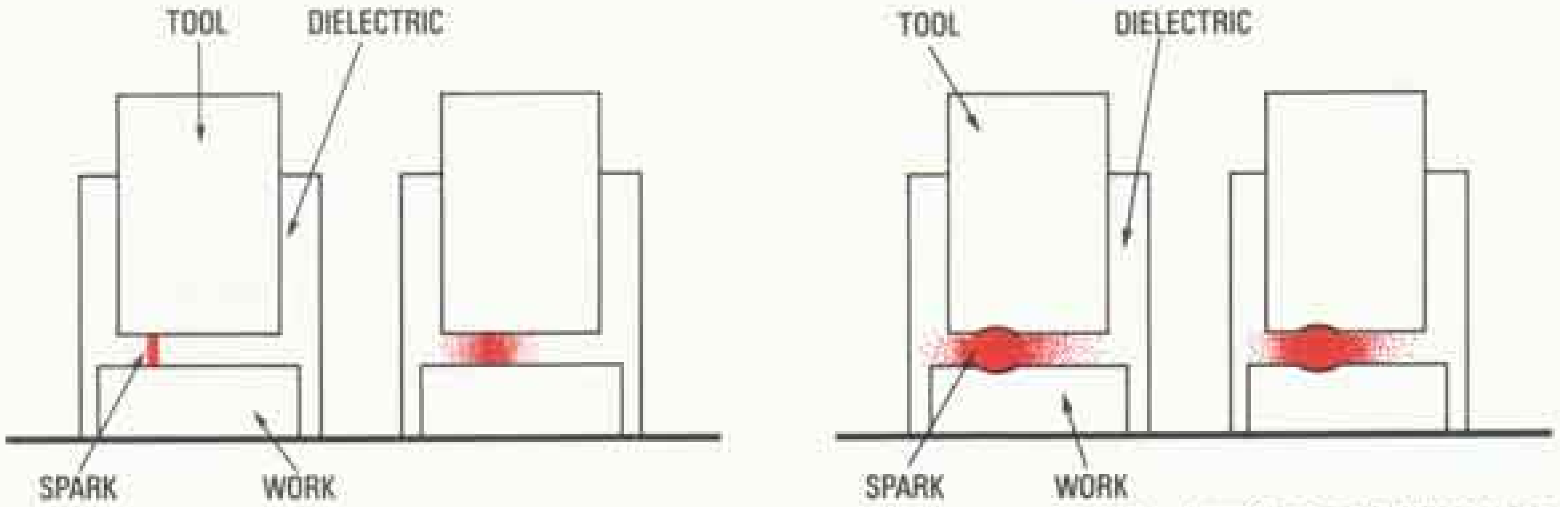
As illustrated in Fig. 19-7A, the capacitor is charged through a resistance from a direct current voltage source that is generally fixed. As soon as the voltage across the capacitor reaches the breakdown value of the dielectric fluid in the gap, a spark occurs. A relatively high voltage (125 V), high capacitance of over 100 μF (microfarads) for roughing cuts, low spark frequency, and high amperage are characteristics of the resistance-capacitance power supply.

In resistance-capacitance circuits, an increase in metal removal rates depends more on larger amperage and capacitance than on increasing the number of discharges per second. The combination of low frequency, high voltage, high capacitance, and high amperage results in:

a) a rather coarse surface finish
b) large overcut around the electrode (tool)
c) larger metal particles being removed and more space being required to flush out particles

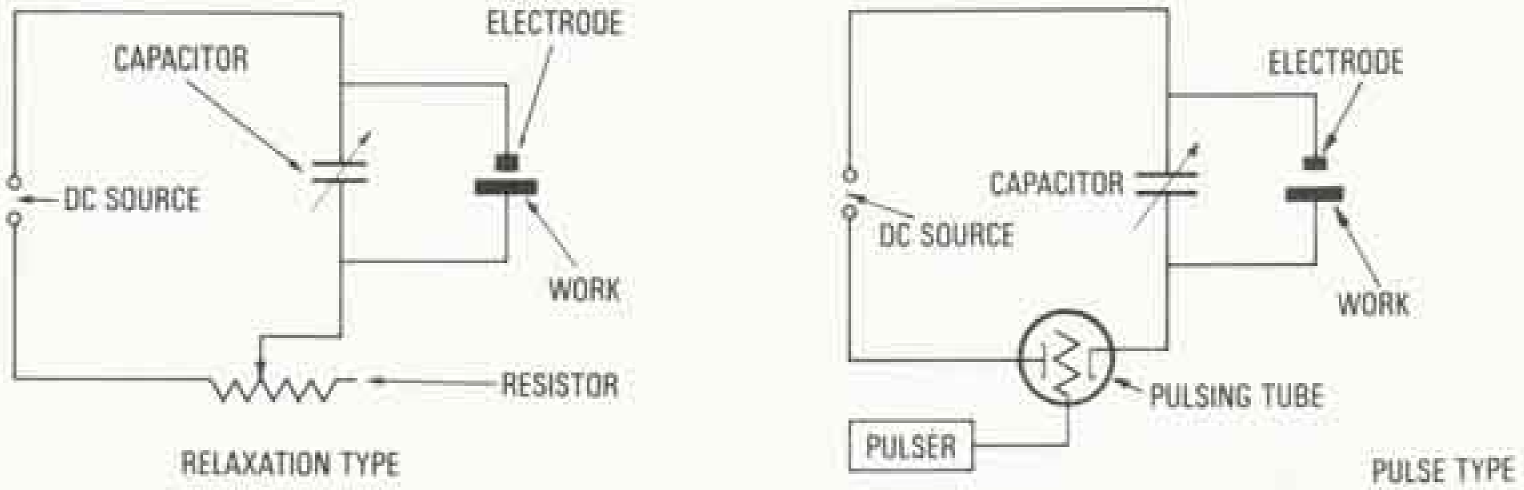
The advantages of the resistance-capacitance power supply are:

a) The circuit is simple and reliable.
b) It works well at low amperages, especially with milliampere currents required for holes under 0.12 mm (.005 in.) in diameter.



Courtesy Cincinnati Milacron Inc.

Fig. 19-6 Stages of a single spark discharge



A **Resistance-capacitance circuit**

B **Pulse type circuit**

Courtesy Cincinnati Milacron Inc.

Fig. 19-7 Electro-discharge power supply circuits

Pulse type power supply is used almost exclusively by American manufacturers. It is similar to the resistance-capacitance type; however, vacuum tubes or solid state devices are used to achieve an extremely fast pulsing switch effect (Fig. 19-7B). The pulse width and intervals may also be accurately controlled by switching devices. The switching is extremely fast and the discharges per second are 10 or more times greater than with the resistance-capacitance power supply at low frequencies. The results of more discharges per second are illustrated in Fig. 19-8. With more discharges per second, and using the same current (10 A), it is clear that smaller craters are created, producing a finer surface finish while still maintaining the same metal removal rate.

Pulse type power supply circuits are usually operated on low voltages (70 to 80 V), high frequency (sparks at the rate of 260 000 Hz), low capacitance (50 μF or less), and low energy spark levels.

The main advantages of the pulse-type circuit are:

a) It is extremely versatile and can be accurately controlled for roughing and finishing cuts.

b) Better surface finish is produced as less metal is removed per spark since there are many sparks per unit of time.

c) There is less overcut around the electrode (tool).

THE ELECTRODE

The *electrode* in electrical discharge machining is formed to the shape of the cavity desired. As in conventional machining, some materials have better cutting and wearing qualities than others. Electrode materials must, therefore, have the following characteristics.

a) Be good conductors of electricity and heat.

b) Be easily machined to shape at a reasonable cost.

c) Produce efficient metal removal from the workpiece.

d) Resist deformation during the erosion process.

e) Exhibit low electrode (tool) wear rates.

Much experimentation has been carried out to find a good, economical material for the manufacture of electrical discharge machining electrodes. Tungsten carbide, copper tungsten, silver tungsten, yellow brass, copper, chrome-plated materials, graphite, and zinc alloys are some of the materials which have found certain applications as electrode materials. None of these electrode materials has general purpose application; each machining operation dictates the selection of the electrode material. *Yellow brass* has been used primarily as electrode material for pulse-type circuits because of its good machinability, electrical conductivity, and relatively low cost. *Copper* produces better results in the resistance-capacitance circuits where higher voltages are employed.

High-density and high-purity carbon, or *graphite*, is a relatively new electrode material which is gaining wide acceptance. It is commercially available in various shapes and sizes, is relatively inexpensive, can be machined easily, and makes an excellent electrode. Its tool wear rate is much less and its high metal removal rate is almost double that of any other metal. Development of superior graphite electrodes has increased the use of graphite electrodes because of their low cost and ease of fabrication.

THE ELECTRICAL DISCHARGE MACHINING PROCESS

The use of electrical discharge machining is increasing as more and more applications are found for this process. As new, important technological advances in equipment and application techniques become available, more industries are adopting the process. It is necessary, therefore, to discuss the various aspects of electrical discharge machining in more detail.

THE SERVO MECHANISM

It is important that there is no physical contact between the electrode (tool) and the workpiece; otherwise arcing will occur, causing damage to both the electrode and the workpiece. Electrical discharge machines are equipped with a servo control mechanism that automatically maintains a constant gap of approximately 0.02 mm (or .001 in.) between the electrode and the workpiece. The mechanism also advances the tool into the workpiece as the operation progresses and senses and corrects any shorted condition by rapidly retracting and returning the tool. Precise control of the gap is essential to a successful machining operation. If the gap is too large, ionization of the dielectric fluid does not occur and machining cannot take place. If the gap is too small, the tool and workpiece may weld together.

Precise gap control is accomplished by a circuit in the power supply comparing the average gap voltage to a preselected reference voltage. The difference between the two voltages is the input signal which tells the servo mechanism how far and how fast to feed the tool and when to retract it from the workpiece.

When chips in the spark gap reduce the voltage below a critical level, the servo mechanism causes the tool to withdraw until the chips are flushed out by the dielectric fluid. The servo system should not be too sensitive to "short lived" voltages caused by chips being flushed out; otherwise the tool would be constantly retracting, thereby seriously affecting machining rates.

Servo feed control mechanisms can be used to control the vertical movement of the electrode (tool) for sinking cavities. It can also be applied to the table of the machine for work requiring horizontal movement of the electrode (tool).

CUTTING CURRENT (AMPERAGE)

The EDM power supply provides the direct current electrical energy for the electrical discharges which occur between the tool and the workpiece. As the pulse-type power supply is the more commonly used in North America, only the characteristics of this type will be discussed.

CHARACTERISTICS OF PULSE TYPE CIRCUITS

a) low voltages (normally about 70 V which drop to about 20 V after the spark is initiated)
b) low capacitance (about 50 μF or less)
c) high frequencies (usually 20 000 to 30 000 Hz but may be as high as 260 000)
d) low energy spark levels

THE DISCHARGE PROCESS

Upon application of sufficient electrical energy between the electrode (cathode) and the workpiece (anode), the dielectric fluid changes into a gas, allowing a heavy discharge of current to flow through the ionized path and strike the workpiece. The energy of this discharge vaporizes and decomposes the dielectric fluid surrounding the column of electric conduction. As the conduction continues, the diameter of the discharge column expands and the current increases. The heat between the electrode and the work surface causes a small pool of molten metal to be formed on the work surface. When the current is stopped, usually only for microseconds, the molten metal particles solidify and are washed away by the dielectric fluid.

These electrical discharges occur at the rate of 20 000 to 30 000 Hz between the electrode and the workpiece. Each discharge removes a minute amount of metal. Since the voltage during discharge is constant, the amount of metal removed will be proportional to the amount of charge between the electrode and the work. For fast metal removal, high amounts of current should be delivered as quickly as possible to melt the maximum amount of metal. This, however, produces large craters in the workpiece, resulting in rough surface finish. To obtain smaller craters and therefore finer surface finishes, smaller charges of energy can be used. This results in slower stock removal rates. If the current is maintained but the number of hertz is increased, this also results in smaller craters and better surface finish. The surface finish is proportional to the number of electrical discharges (cycles) per second (Fig. 19-8).

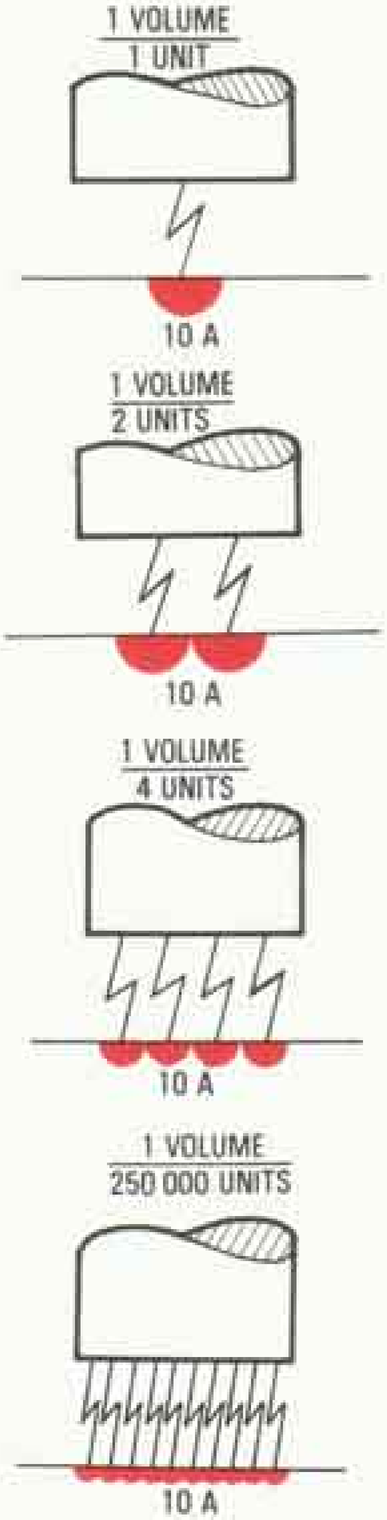


Fig. 19-8 Effects on cratering and surface finish using various frequencies of spark discharge

THE DIELECTRIC FLUID

The dielectric fluid used in the electrical discharge process serves several main functions.

a) Helps to initiate the spark between the electrode and the workpiece.
b) Confines the spark path to a narrow channel.
c) Serves as an insulator between the tool and the workpiece.
d) Flushes away the metal particles to prevent shorting.
e) Acts as a coolant for both the electrode and the workpiece.

TYPES OF DIELECTRICS

Many types of fluids have been used as dielectrics, resulting in various rates of metal removal. They must be able to ionize (vaporize) and deionize rapidly and have a low viscosity that will allow them to be pumped through the narrow machining gap. The most commonly used EDM fluids, proven to be satisfactory dielectrics, have been various petroleum products, such as light lubricating oils, transformer oils, silicon-base oils, and kerosene. These all perform reasonably well, especially with graphite electrodes, and are reasonable in cost. In certain cases, dielectrics such as carbon tetrachloride and certain compressed gases have been used.

The selection of the dielectric is important to the electrical discharge machining process since it affects the metal removal rate and electrode wear. Industry is continually searching for new and better dielectric fluids for this process. A fluid consisting of triethylene glycol, water, and monoethyl ether of ethylene glycol has been used in research with superior results, especially with metallic electrodes. It is quite likely that many new dielectric fluids will be developed to improve the electrical discharge machining process.

METHODS OF CIRCULATING DIELECTRICS

The dielectric fluid must be circulated under constant pressure if it is to flush away efficiently the metal particles and assist in the machining process. The pressure used generally begins with 35 kPa and is increased until optimum cutting is attained. Too much dielectric fluid will remove the chips before they can assist in the cutting action and thereby cause slower machining rates. Too little pressure will not remove the chips quickly enough and thereby cause short circuits.

Four methods are generally used to circulate the dielectric fluid. All methods must use fine filters in the system to remove the metal particles so that they are not recirculated.

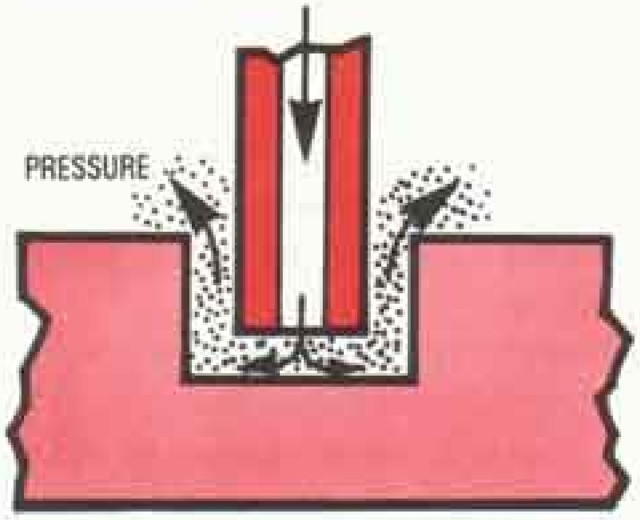


Fig. 19-9A Circulating dielectric fluid down through the electrode

Down through the electrode (Fig. 19-9A): A hole or holes are drilled through the electrode, and the dielectric fluid is forced through the electrode and between it and the workpiece. This rapidly washes away the metal particles from the machining area. On cavities, a small standing slug or core remains which must be ground away after the machining operation has been completed.

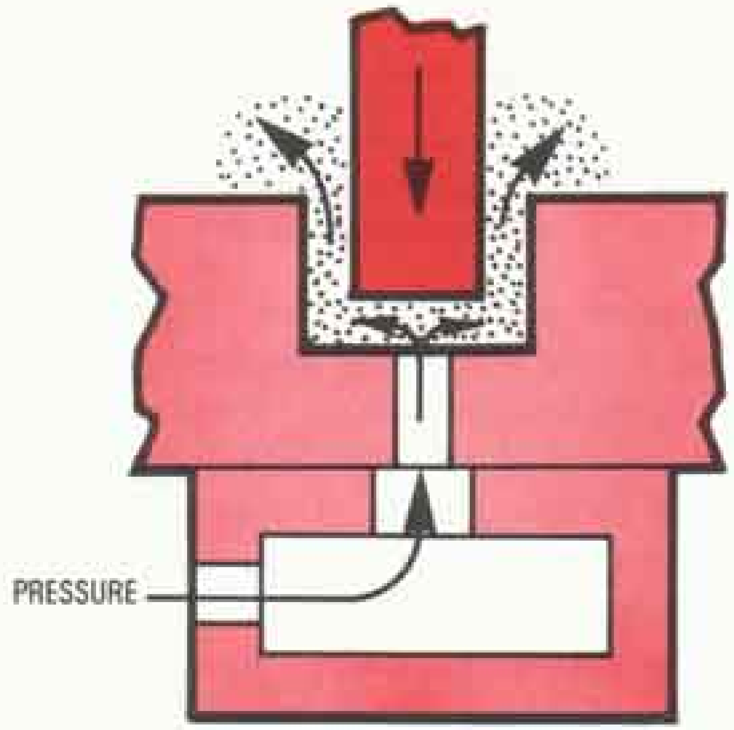


Fig. 19-9B Circulating dielectric fluid up through the workpiece

Up through the workpiece (Fig. 19-9B): Another common method is to cause the fluid to be circulated up through the workpiece. This type of flushing is limited to through-hole cutting applications and to cavities having holes for core or ejector pins.

Vacuum flow (Fig. 19-9C): A negative pressure (vacuum) is created in the gap which causes the dielectric to flow through the normal 0.02 mm (or .001 in.) clearance between the electrode and the workpiece. The flow can be either up through a hole in the electrode or down through a hole in the workpiece. Vacuum flow has several advantages over other methods in that it improves machining efficiency, reduces smoke and fumes, and helps to reduce or eliminate taper in the workpiece.

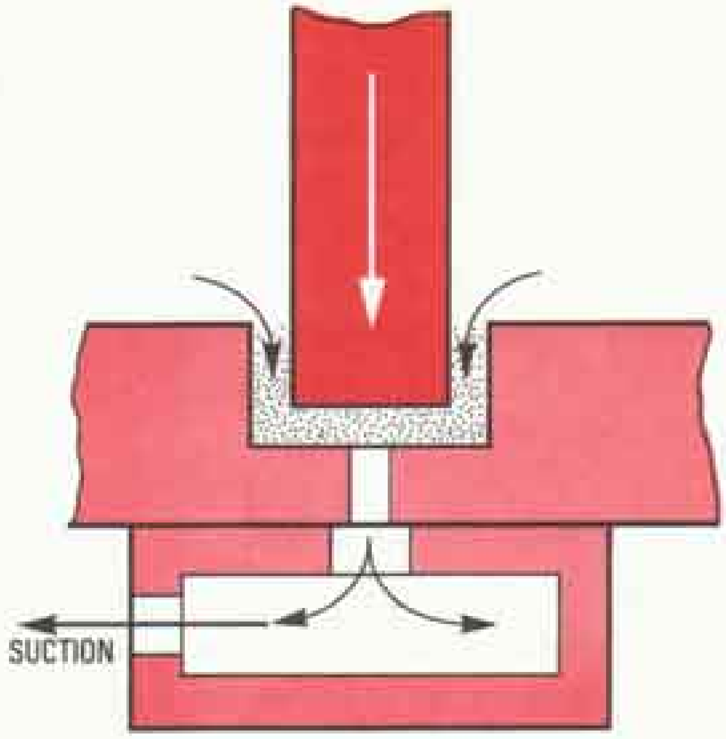


Fig. 19-9C Circulating fluid down through the workpiece by suction

Vibration (Fig. 19-9D): A pumping and sucking action is used to cause the dielectric to disperse the chips from the spark gap. The vibration method is especially valuable for very small holes, deep holes, or blind cavities where it would be impractical to use other methods.

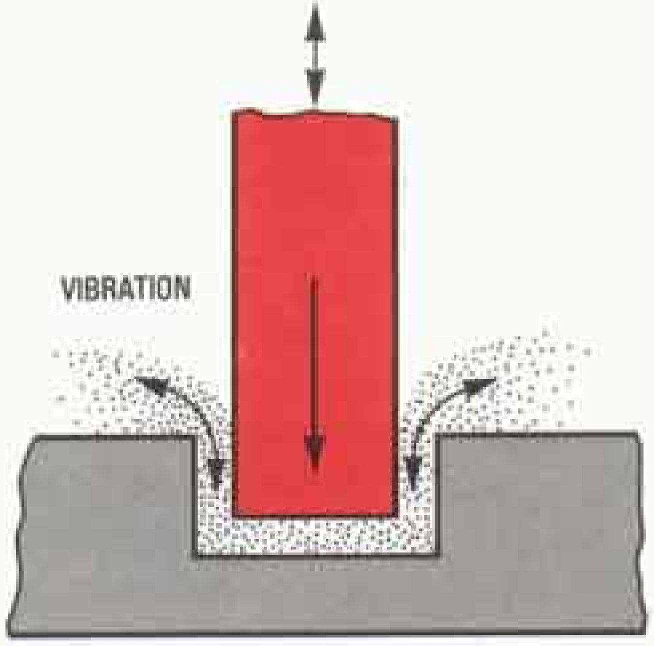


Fig. 19-9D Circulating dielectric fluid by vibration

METAL REMOVAL RATES

Metal removal rates for EDM are somewhat slower than with conventional machining methods. The rate of metal removal is dependent upon the following factors.

a) amount of current in each discharge
b) frequency of the discharge

c) electrode material
d) workpiece material
e) dielectric flushing conditions

The normal metal removal rate is approximately 16 cm^3 of work material per hour for every 20 A of machining current. However, metal removal rates of up to 245 cm^3/h are possible for roughing cuts with special power supplies.

ELECTRODE (TOOL) WEAR

During the discharge process, the electrode (tool) as well as the workpiece is subject to wear or erosion. As a result, it is difficult to hold close tolerances as the tool gradually loses its shape during the machining operation. At times it is necessary to use as many as five electrodes to produce a cavity of the required shape and tolerance. For through-hole operations, stepped electrodes are often used to produce roughing and finishing cuts in one pass.

The rate at which the tool wears is fortunately considerably less than that of the workpiece. An *average wear ratio* of the workpiece to the electrode is 3 to 1 for metallic tools, such as copper, brass, zinc alloys, etc. With graphite electrodes, this wear ratio can be greatly improved to 10 to 1.

Much development and research remains to be done to reduce the wear ratio of the electrode. *Reverse polarity machining*, a relatively new development, promises to be a major breakthrough in reducing electrode wear. With this method, molten metal from the workpiece is deposited on a graphite electrode about as fast as the electrode is worn away. Thus minute electrode wear is continually being replaced by a deposit of the work material. Reverse polarity machining operates best on low spark discharge frequencies and high amperage. It improves the metal removal rates and greatly reduces electrode wear.

OVERCUT

Overcut is the amount the cavity in the workpiece is cut larger than the electrode used in the machining process. The distance between the surface of the work and the surface of the electrode (overcut) is equal to the length of the sparks discharged, which is constant over all areas of the electrode.

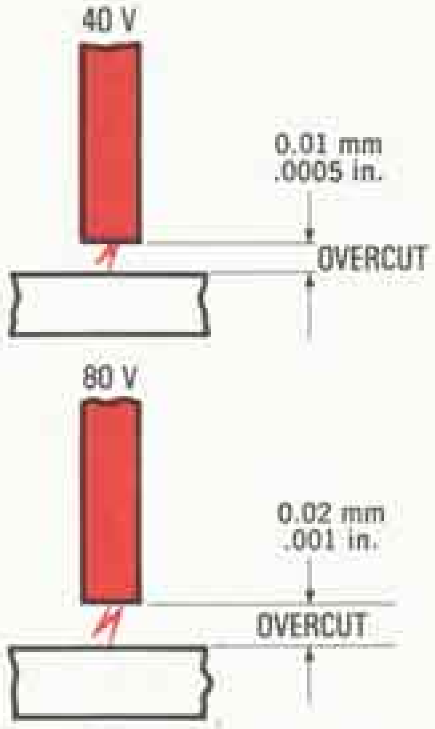


Fig. 19-10 Example of overcut produced by different voltages in EDM

The amount of overcut in EDM ranges from 0.005 mm to 0.18 mm (or .0002 in. to .007 in.) and is dependent upon the amount of gap voltage. As illustrated in Fig. 19-10, the overcut distance increases with the increased gap voltage. Therefore, the amount of overcut can be controlled fairly accurately. The amount of overcut is generally varied to suit the metal removal rate and the surface finish required, which in turn determines the size of the chip removed.

Most manufacturers of EDM machines provide overcut charts to show the amount of clearance produced with various currents. The charts make it possible to accurately determine the electrode size required to machine an opening to within 0.002 mm (or .0001 in.).

The size of the chips removed is an important factor in setting the amount of overcut because:

a) Chips in the space between the electrode and the work serve as conductors for the electrical discharges.
b) Large chips produced with higher amperages require a larger gap to enable them to be flushed out effectively.

Therefore, overcut depends upon the gap voltage and the chip size, which vary with the amperage used.

SURFACE FINISH

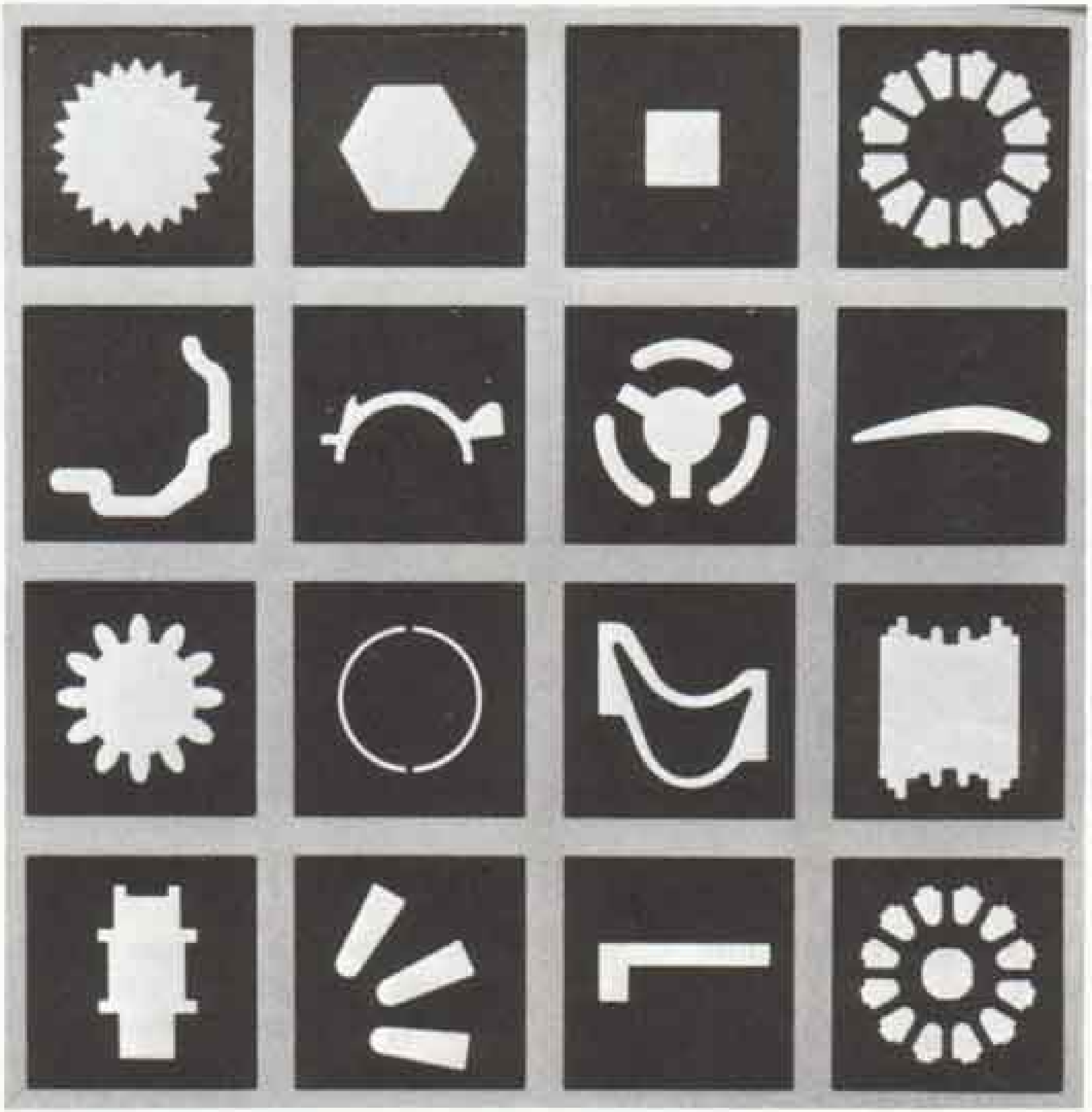
In the last few years, major advances have been made with regard to the surface finishes that can be produced. With the low metal removal rates, surface finishes of 0.05 µm to 0.10 µm (or 2 to 4 microinches to .000 004 in.) are possible. With high metal removal rates (as much as 245 cm^3/h) finishes of 25 µm (1000 microinches) are produced.

The type of finish required determines the number of amperes which can be used, the capacitance, frequency, and the voltage setting. For fast metal removal (roughing cuts), high amperage, low frequency, high capacitance, and minimum gap voltage are required. For slow metal removal (finish cut) and good surface finish, low amperage, high frequency, low capacitance, and the highest gap voltage are required.

ADVANTAGES OF THE EDM PROCESS

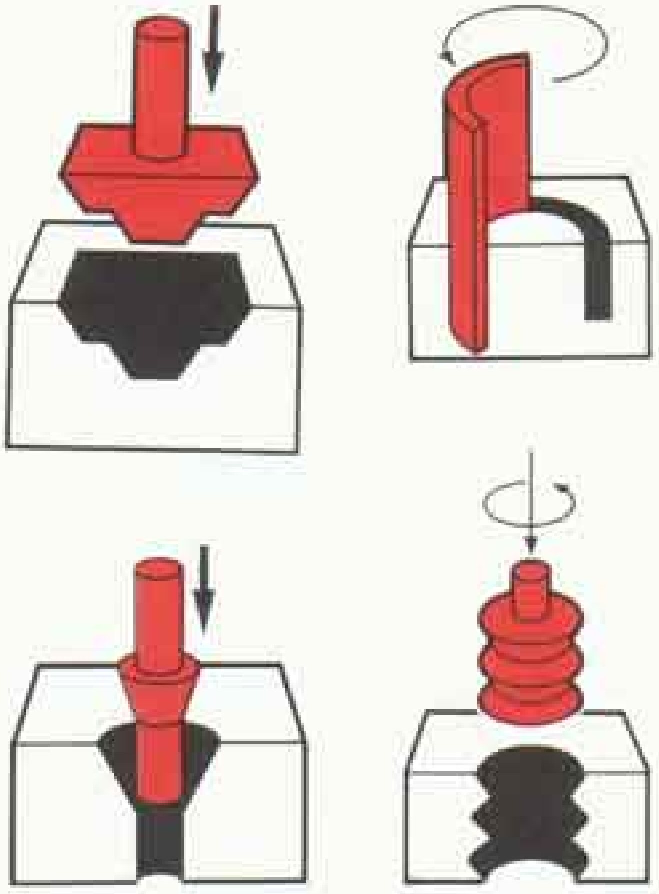
Electrical discharge machining has many advantages over conventional machining processes.

a) Any material that is electrically conductive can be cut, regardless of its hardness. It is especially valuable for cemented carbides and the new supertough space age alloys that are extremely difficult to cut by conventional means.
b) Work can be machined in a hardened state, thereby overcoming the deformation caused by the hardening process.
c) Broken taps or drills can readily be removed from workpieces.
d) It does not create stresses in the work material since the tool (electrode) never comes in contact with the work.
e) The process is burr-free.



Courtesy Cincinnati Milacron Inc.

Fig. 19-11A Examples of work produced by electro-discharge machining



Courtesy Cincinnati Milacron Inc.

Fig. 19-11B Tool movement required to produce various shaped cavities

f) Thin, fragile sections can be easily machined without deforming.
g) Secondary finishing operations are generally eliminated for many types of work.
h) The process is automatic in that the servo mechanism advances the electrode into the work as the metal is removed.
i) One person can operate several EDM machines at one time.
j) Intricate shapes, impossible to produce by conventional means, are cut out of a solid with relative ease (Fig. 19-11A).
k) Better dies and molds can be produced at lower costs.
l) A die punch can be used as the electrode to reproduce its shape in the matching die plate, complete with the necessary clearance.

LIMITATIONS

Electrical discharge machining has found many applications in the machine trade; however, it does have some limitations.

a) The metal removal rates are low.
b) The material to be machined must be electrically conductive.
c) Cavities produced are slightly tapered, but can be controlled for most applications to as little as 0.002 mm (or .0001 in.) in every 6 mm (or 1/4 in.).
d) Rapid electrode wear can become costly in some types of EDM equipment.
e) Electrodes smaller than 0.07 mm (or .003 in.) in diameter are impractical.
f) The work surface is damaged to a depth of 0.005 mm (or .0002 in.), but it is easily removed.
g) A slight case hardening occurs. This, however, may be classed as an advantage in some cases.

CONCLUSION

Since electrical discharge machining was first put to practical application, its use has been expanding by virtue of its ability to perform economically jobs which are extremely difficult or impossible to perform by conventional machining methods. Research and development are continuing to improve tool wear ratios, to increase metal removal rates without the surface finish suffering, and to improve power supplies and machine tool components. Wider recognition of this process and its possibilities will lead to increasing the importance of electrical discharge machining (EDM) in the future.