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PRINCIPLES OF ELECTRIC-SPARK METALWORKING

Cand Tech Sci B. R. Lazarenko
Stalin Prize Winner

Electrical Methods of Metalworking

The electrochemical working of metals is based on the laws of electrolysis, established by Faraday, and on the phenomenon of polarization.

Polarization always accompanies the process of electrolysis, appearing as a consequence of a number of causes which inhibit the discharge of ions from the electrodes. By increasing the density of the current, the concentration of ions of metal in a layer of electrolyte adjoining the anode increases and inhibits anodic diffusion. Sometimes the anodic polarization reaches such proportions that passivation of the anode takes place, that is, the current falls to zero, by reason of inhibited diffision of ions from the anode. The anode may also cease to function because a passive film forms on it.

In order to support the electrochemical process, the film formed must be continually removed from the highest points on the anodic surface by force of the electrical field. In the process of anodic corrosion of metals, the density of the current is so great that the film being formed cannot adhere to the anodic surface, and, in the process of forming, continuously tears away from the entire surface by the action of the electrical field. As a result of this process, the anodic surface is self-finishing.

The electrochemical polishing of metals can be accomplished only when complete polarization and anodic corrosion do not occur. The composition of the electrolyte and working factors (electric, temperature, and time) must assure the breaking off of the polarized film only on the crests of the surface (where the force lines of the electric field are always more highly concentrated) and not disrupt its depressions. Since the crests which are being removed have a height of only 0.2-0.3 micron, it is obvious that the

[illegible] as to method and [illegible] must be extremely rigid and different for different materials. In order to obtain the greatest concentration of electrical field on the crests of the surface being worked, it is necessary to decrease the diffusion capacity of the bath by increasing the size of the cathode. In some cases, its area should be 15-20 times that of the anode. The electrolytes used must be highly concentrated in order to prevent chemical corrosion of the surface being worked.

Composition of Electrolytes and Working Factors in the Electrochemical Polishing Process

Composition of the Electrolyte	Percent by Weight	Percent by Volume
Sulfuric acid	40	--
Orthophosphoric acid	44	42
Chromic anhydride	3	--
Glycerin (specific gravity 1.25)	--	48
Water	13	10
Working Factors of the Process		
Voltage	12 - 15	12 - 15
Current (amp per sq dm)	30 - 60	10
Temperature of bath (°C)	70 - 90	100
Duration of polishing (min)	10 - 20	5

Carbon steel, stainless steel, copper, brass, tin, bronze, nickle, zinc, aluminum, or Monel metal can be polished by the electrochemical method. All of these metals can be in the shape of sheets, bars, wires, forged pieces, or dies.

The electrochemical method is particularly effective when polishing stainless steel.

The process consists of the following operations: (1) preliminary grinding with abrasives, (2) chemical corrosion for removal of dross and pitchings, (3) polishing, (4) washing in cold water, (5) washing in alkali for final removal of acid, (6) washing in cold running water, and (7) wiping and drying.

A surface which has been polished by the electrochemical method has a very high reflecting power (anodic luster); even at a 2,500-X magnification, not a single scratch can be seen on the surface.

For polishing, parts are suspended on bronze or copper hooks in a bath, which is kept at a specific temperature. Since the process of working in an electrolyte evolves heat, the bath is equipped with cooling coils or jackets.

The bath container also has a ventilator for drawing off harmful fumes; personnel work in safety goggles and rubber gloves.

Electrodynamic (Electric-Spark) Method of Metalworking

Erosion is the process of partial or complete disintegration of material under the influence of external factors.

Electric erosion of metal is defined as a physical phenomenon, consisting of the direct ejection of material from the electrodes under the action of an independent electric discharge flowing between the electrodes.

[illegible] spark discharge is accompanied by the destruction of the electrode gap, and has a negative volt-ampere characteristic, that is, a sudden drop in the voltage on the electrodes is brought about with the release of the current. The spark discharge is a typical electronic process. At the moment of the sparkover of the electrode gap, the electrons, breaking away from the cathode, pass to the anode. All the energy stored in the circuit passes through the channel of through conductivity which is formed, surrounded by ions, and in so passing creates a current impulse by its movement. The magnetic field arising from this current intensifies the compression around the channel and results finally in huge forces flowing through extremely narrow through-conductivity channels, which are concentrated on the electrode-anode and bring about its disintegration.

The spark impulse (electrical impact), which has a duration measured in millionths of a second, is accompanied by extremely minute thermal effects which in practice do not heat the piece being worked. In addition, inasmuch as the point of application of the impulse is always strictly localized, it is possible to work the metal on a designated spot with great precision by means of the spark method.

The spark form of electrical discharge can be achieved by two methods. In the first, the voltages used are so low that the formation of an arc of disrupted currents of any strength is in practice impossible (so-called minimum arc-stream voltage). In air, for the greatest number of metals, this does not exceed 18 volts. Replacing the gas medium with liquid dielectrics makes it possible to increase somewhat the value of the minimum arc-stream voltage (up to a maximum of 30 volts). Certain suspensions and solutions of phosphate, silicate, and borate show such activity. Since this method of achieving the spark form of electrical discharge requires an extremely high current, measured in hundreds of amperes, and an especially powerful feed sources, its application in, say, cutting and grinding metal, is limited.

The second method for obtaining a spark discharge involves measures to prevent arc formation of the electrical discharge before its transformation into arc form and absorbing the magnetic energy in the circuit, which is given off in the form of an extracurrent at the break. These objectives are usually achieved by means of a capacitor set up parallel to the electrodes between which the discharge passes. The capacitor blocks the rise of the voltage on the electrodes at the proper time after its drop during the sparkover and allows additional time necessary for the rise of the potential on the condenser; this seems to have a favorable effect on the process of bringing the interelectrode medium into the stage preceding the sparkover.

The absence of a capacitor in the circuit makes it possible to obtain great amounts of power from extremely weak sources of current and to expend them instantly on the spot being worked.

The current impulses can very easily be regulated to suit the degree of finish required on the surface being worked.

Since the amount of electricity stored on the condenser depends mainly on the voltage, a constant attempt to work at high voltages (tens and hundreds of volts) should be made.

In working of metal by the electric-spark method, the spark discharge should flow in a liquid medium in accordance with the following considerations:

the work piece (anode) is broken loose as a spark and deposited on the tool (cathode), which alters the shape of the work piece. The liquid medium obstructs the path of the flying particles of metal and protects the tool.

2. The greater the crossover resistance of the spark-metal, the greater the brisance of the spark impulse. The liquid medium (dielectric or suspension, which are constantly forming insulating films on the electrodes and being pierced by the spark) increase the crossover resistance.

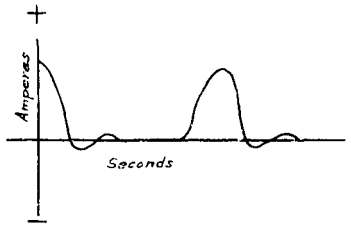
3. The powder obtained in the process of working remains partially suspended in the liquid medium, and with the application of the potential across the electrodes the particles are drawn by the electrical field into the electrode gap. Their cohesive action allows a considerable increase in the working gap between the electrodes.

In the electrospark method of working metals the tool and the part being worked form the electrodes of an oscillating circuit which is tuned to operate not with a fixed electrical discharge but with a spark discharge. Thus the emission of metal from the electrode work piece, which is the anode, takes place either with contact or noncontact closing of the circuit of the discharge path in the liquid medium.

The noncontact method, in which closing of the circuit path is accomplished by a sparkover of the electrode gap and the working of the material is performed without the material being touched (at a distance), has, in comparison with the contact method of working, these essential advantages: the kinematic system of the machine tool is simplified as a result of eliminating from it one of the moving systems and much greater working speeds are made possible. This is because the speed of the electric-spark operations is proportional to the frequency of the discharge path formation. In the contactless method, the frequency of individual discharges of the oscillating circuit is determined not by the kinematic system of a machine tool but by the speed of the voltage rise on the plates of the condenser to the voltage necessary for sparkover of the electrode gap; this voltage and speed of working can be regulated over extremely wide range.

When the discharge circuit is closed by the contact or contactless methods, the current impulse knocks material directly off the electrode work piece or to the electrode tool. The oscillations which accompany the discharge of the circuit have an extremely large decrement of attenuation, that is, the area under the positive discharge curve is considerably greater than that under the negative curve (Figure 1).

Figure 1. Oscillograph of the Spark Process



For this reason, the amount of material [illegible] moved from the anode when the electrodes are of the same material will be considerably greater than the amount being removed from the cathode.

The work indicated by the negative part of the curve is harmful in that it causes wearing of the tool.

The process of transferring material by means of a spark discharge is subject to the following laws, on which future study and application of this process will be based:

1. Electrical erosion is an inherent property of any current-conducting materials; for this reason any such material can be worked by the electric-spark method regardless of its hardness.

2. The weight quantity of material being emitted by the electrodes as a result of the effect of the spark impulse is strictly proportional to the quantity of current flowing during the duration of the impulse and the degree of the steepness of the impulse front.

3. One and the same quantity of current, flowing during a given impulse, removes from the electrodes various weight quantities of material depending on the chemical composition of the electrodes; the resistance of metals to electroerosion decreases as the atomic weight of the element increases.

The governing factor in the electric-spark process is the stability of the volt-ampere relationship, as indicated by a thermic ammeter in the discharge circuit. The stability of the process determines the maximum amount of metal which can be removed by the action of a single impulse, and also determines the degree of surface finish and precision of machining. The speed of electric-spark processing of metals is the integral value of the impulses, the mean effective value of which is gaged by the amount of current in the discharge circuit.

The speed of machining various materials is calculated in the number of impulses required to drill a hole 10 millimeters in diameter through a plate of the material 10 millimeters thick, with a short circuit of current of 30 amperes, a voltage of 110 volts, and a capacitance of 400 microfarad. The material of the electrode tool is brass:

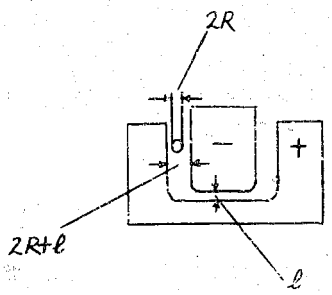
Material	No of Impulses
Tin	8,064
Bismuth	8,316
Lead	8,404
Cadmium	8,736
Aluminum	9,240
Zinc	9,786
Brass	41,580
Copper	52,500
Copper-graphite alloy	52,800
Nickel	63,210
Steel Kh 12M	71,190
Iron	102,270
Molybdenum	125.580
Graphite	191,520

It has been shown that the faster the rate of machining the coarser the surface finish. In order to get a surface finish of high precision in the shortest possible time, the hole should first be bored out at high speed

[redacted] accomplished in a single operation with only one tool.

In bringing together the electrode tool and the electrode work piece Figure 2 to a specified proximity "l," the gradient of the field reaches such an amplitude as to cause a sparkover of the electrode gap, which is filled with the liquid medium. As a result of this impulse, a particle of metal comes free of the anode shank, and in the liquid medium assumes a spherical shape having the radius "R".

Figure 2. Gap Formation in Electric-Spark Machining



The dynamic forces of the electrical field and the pressure of the gases generated in cooling the particle (which do not have time to condense due to the extreme brevity of the sparkover) impart forward motion to the particle which throws it at tremendous speed from the anode. The moving particle induces additional electrical discharges between the side surfaces of the tool and the part and at the same time causes the creation of a gap between the electrodes, the size of which is equal to 2R plus l.

Since the size of "R" is conditioned by the current of the discharge circuit, the size of the gap or the precision achieved in the operation is determined by the heaviness of the cutting load attempted. For any given load there is an amplitude constant depending only on the chemical composition of the elements involved in the discharge process.

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