RECENT DEVELOPMENTS IN EDM MONITOR AND CONTROL SYSTEMS

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1. Fundamentals

1.1 Model of thermal erosion

One of the ways of removing stock from a solid (stone, metal, glass etc) is to heat up a small spot of its surface and bring it to a temperature of at least the melting point, or even the boiling point of the material.

If the molten material is evaporated or ejected by some means (1), there remains a crater in the original surface. The dimensions of the crater can be calculated if the following data are known: heat conductivity and specific heat capacity of the material, size, power and duration of the heat source.

Generally speaking, the volume of the crater increases when the applied power is increased and the duration held constant. If the power is held constant and the duration is variable, the result depends of the nature of the material. The volume of molten material has been calculated for steel and copper for a heat source of 100 W and a radius varying with time according to

$$r = \alpha \cdot t^{0,25}$$

The results are given in figure 1 for different coefficients of α. The calculated curves are compared to the results obtained in spark erosion machining; In the case of steel the calculated curve for α = 12.5 fits reasonably well the practical results, the volume of the crater increases steadily with the duration of the pulse. In the case of copper the tendency only of the calculated curves and the practical values is the same. The model is therefore qualitatively good but quantitatively unsufficient, but it explains the mechanism of no wear spark erosion.

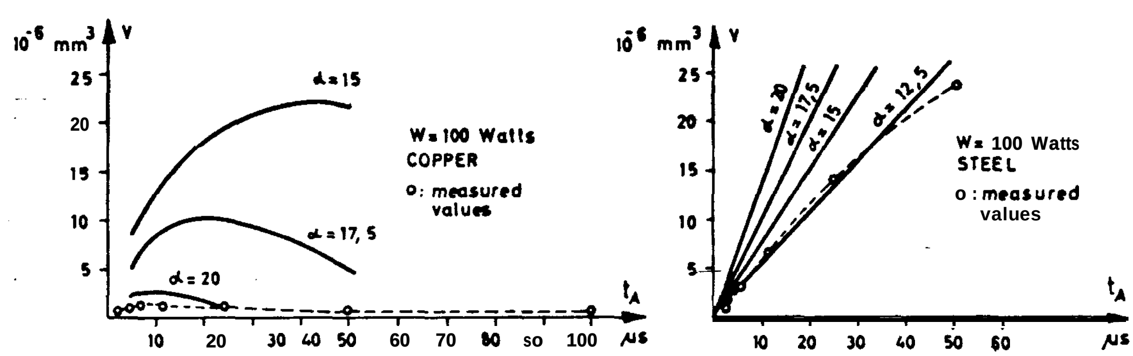

Figure 1

The heat sources must be selected according to the material to be treated. Electrically isolating materials can be eroded with laser beams, e.g., but for eroding metals the most commonly used heat source is:

1.2 The Electric Spark

The correct name of this physical phenomenon is arc discharge. This

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means that electric current flows from one pole to the other through a so called plasma channel. An electrician can measure some of its caracteristic parameters: The amperage, the voltage and, if the phenomenon is limited in time, its duration, The product of the amperage and the voltage gives its instantaneous power, this power multiplied by the duration defines its energy. The physicist knows that one can distinguish three different caracteristic regions of an arc discharge. One of them, already mentioned, is the plasma channel, There, ions of either polarity, the positive ones moving to the cathode and the negative ones to the anode, are responsible for the electric current flow which can be measured with an ammeter. What is special in that region is that there is practically no voltage drop across the plasma channel, and therefore no heat produced. The voltage, measured by the electrician is developped near the electrodes, exactly between the electrode surface and the beginning (or the end) of the plasma channel. Specialists call it the anode and the cathode voltage drop. Thus, one part of the heat is developped directly on the cathode surface, the other part on the anode surface. The nature of the electrode material, as well as the polarity, determine the proportion of power applied to the electrode we want to machine and the other for which the wear must be as low as. possible. This is what is commonly called the polarity effect.

1.3 More about the arc discharge

An arc discharge can take place in vacuum as well as in an isolating medium, a so called dielectric. In spark erosion practice, a liquid dielectric is used, mostly based on hydro carbones (transformer oils or special EDM brands) or deionized water in some applications. The arc discharge is initated by applying a voltage between the two electrodes. If locally the electric field strength (voltage divided by the distance) is high enough, the molecules of the dielectric are ionized, and the current begins to flow, thus creating an avalanche of more ions and finally the establishment of the plasma channel. (2) As the temperature of the cathode surface gets higher, electron-emission takes place and the current conduction continues.

The ionisation is governed by the laws of probability. The dielectric being an inhomogenous mixture, (on a macroscopic basis a mixture of liquid, gas, metallic and other debris, on a microscopic basis a mixture of molecules of different composition and size) the electric field strength at a particular point is continuously varying, and it is therefore a question of probability that'the value of the field strength exceeds the value for ionisation at one particular point. This explains the time lag we observe between the application of the voltage and the corresponding current build up. (3) (4).

1.4 Some definitions commonly used by EDM specialists

In the following chapters we will call ELECTRODE or TOOL the electrode which has the shape of the cavity-to be reproduced and which, during the erosion process, should have as little WEAR (0) as possible. The WORKPIECE is the electrode in which the cavity is to be machined and this happens at a certain REMOVAL RATE (M). The distance between these two electrodes is called GAP, and the depth of the craters in the workpiece is commonly called SURFACE FINISH.

We call basic parameters the duration of the discharge, (t_A), the peak

value of the discharge current ($\hat{I}$), the average machining current ($\bar{I}$), and secondary parameters the duration of the interval between two discharges (t_B) and the ignition delay (t_d).
The relation between these parameters is given by:

$$\bar{I} = \frac{\hat{I} \cdot t_A}{t_A + t_B + t_d}$$

1.5 Influence of the basic parameters t_A and $\hat{I}$ on the electrode removal rate and the electrode wear.

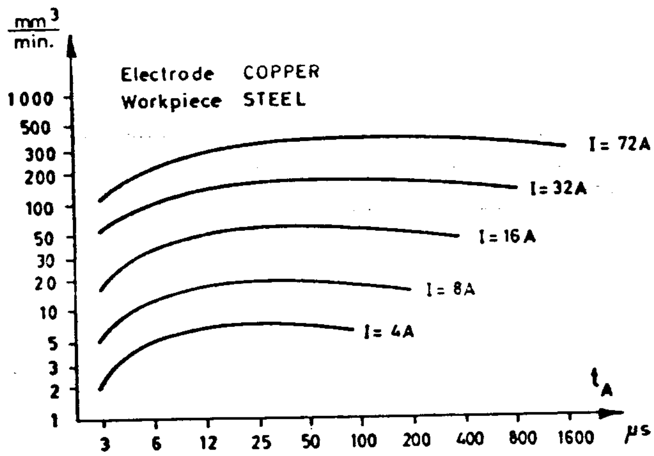


Figure 2

These data are normally given in the technology books of the spark erosion manufacturers. Generally speaking, the removal rate increases with increasing peak current, according to the thermal model of chapter 3.

The removal rate goes through a maximum when increasing the duration of the discharge (see figure 2). This maximum lies at 25 µs for a discharge current of 4A and at 200 µs for a discharge current of 70A, the workpiece being steel.

The electrode wear ratio (electrode wear as a percentage of the removal rate), is represented in figure 3 for different electrode materials and polarities.

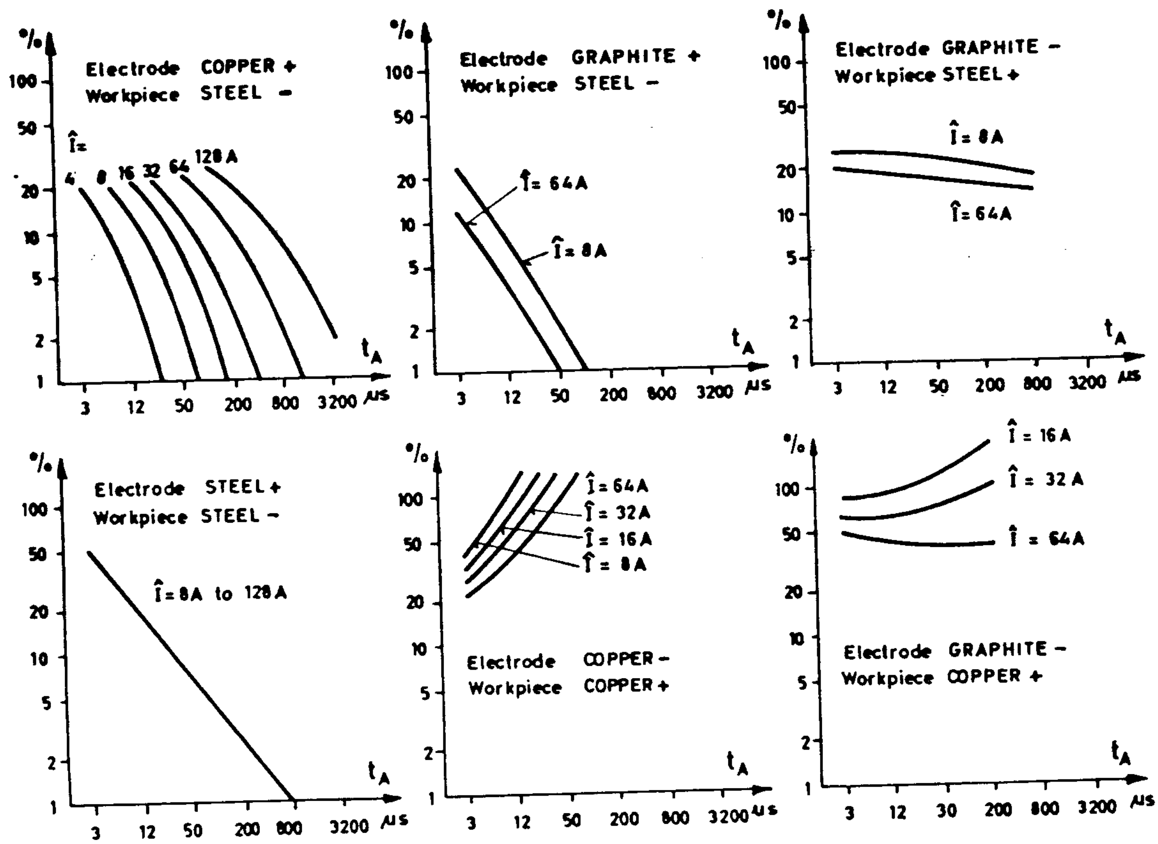
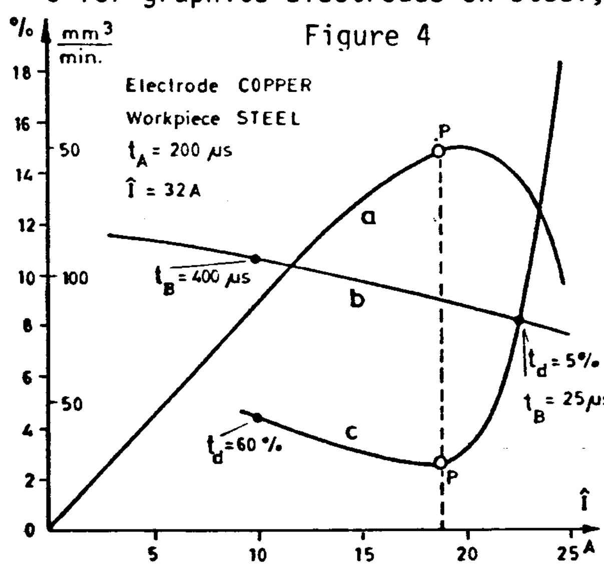


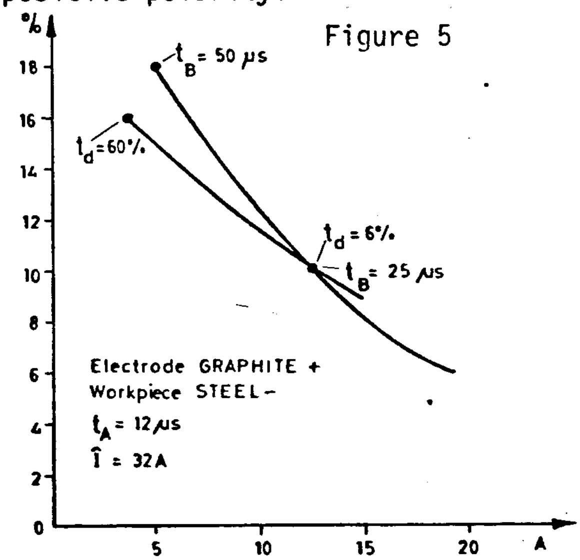
Figure 3 relative Electrode wear ratio

1.6 Influence of the secondary parameters t_B and t_d on the metal removal rate and the electrode wear

The average machining current can be varied by varying either of the two secondary parameters, t_B or t_d (or both, naturally). t_B can normally be preset by the operator on the generator, the average ignition delay t_d is a result of different parameters and settings, especially the servo reference setting. The figure 4 is a typical diagram which must always be kept in mind when machining with low electrode wear is needed. Electrode is copper, workpiece steel. Curve (a) is removal rate in function of the machining current, varied by means of t_d, with t_B constant at 25 µs. The corresponding electrode wear is shown in curve (b). The minimum wear ratio is obtained at a current giving about maximum material removal rate! Curve (c) shows the electrode wear ratio of the same electrode pair, but the current is varied by means of t_B, with t_d constant at 5 % of t_A + t_B.

Similar curves relating to the electrode wear ratio are given in figure 5 for graphite electrodes on steel, positive polarity.





1.7 A closer look at the discharges

With the hope of breaking the mystery of spark erosion, we began, some years ago, to take a closer look at the discharges. The only practical way to do so is to observe their voltage. The first fundamental results have been obtained with the instrumentation described in (5) and (6) comprising a minicomputer for storing and computing the results. For each recorded discharge, the distance between the electrodes is recorded simultaneously with the particular parameter to be analysed. In that way the ignition voltage with voltages up to 3000 V, the ignition delay t_d, the voltage of the discharge at any programmed instant of the discharge have been analysed, and different types of discharges could be distinguished.

It is, here again, a question of probability whether, for a given distance, the discharge will be a short circuit, a low voltage discharge or a high voltage discharge. Figure 6 shows a three-dimensional plot of the number N of events (discharges) occurred at a voltage V and a distance D.

The discharges of the higher voltage type are supposed to be the desired ones. With the apparition of the lower voltage type of discharges, the

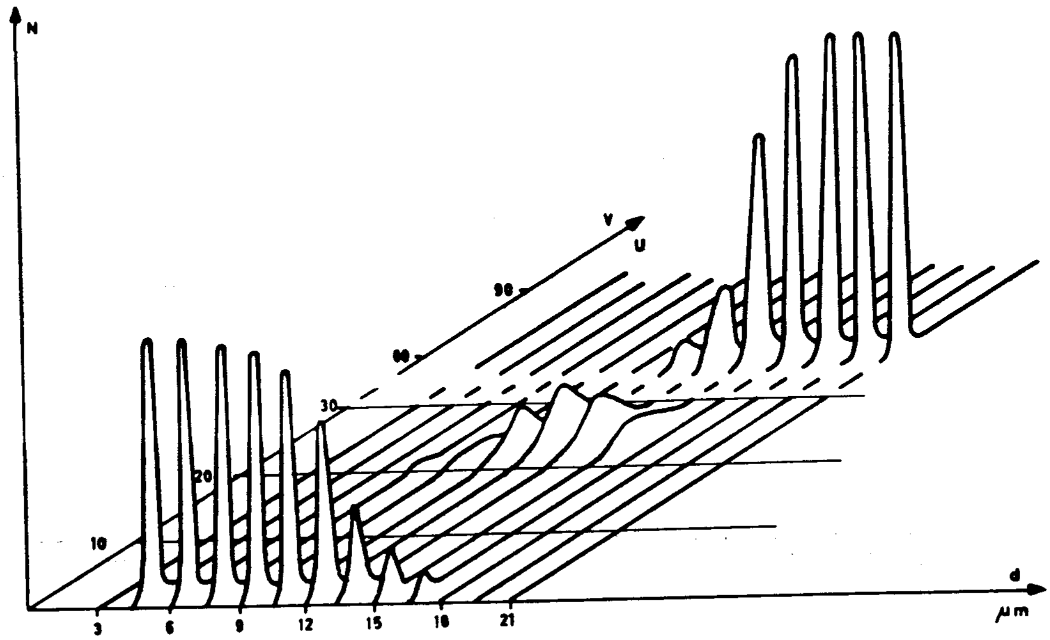


Figure 6

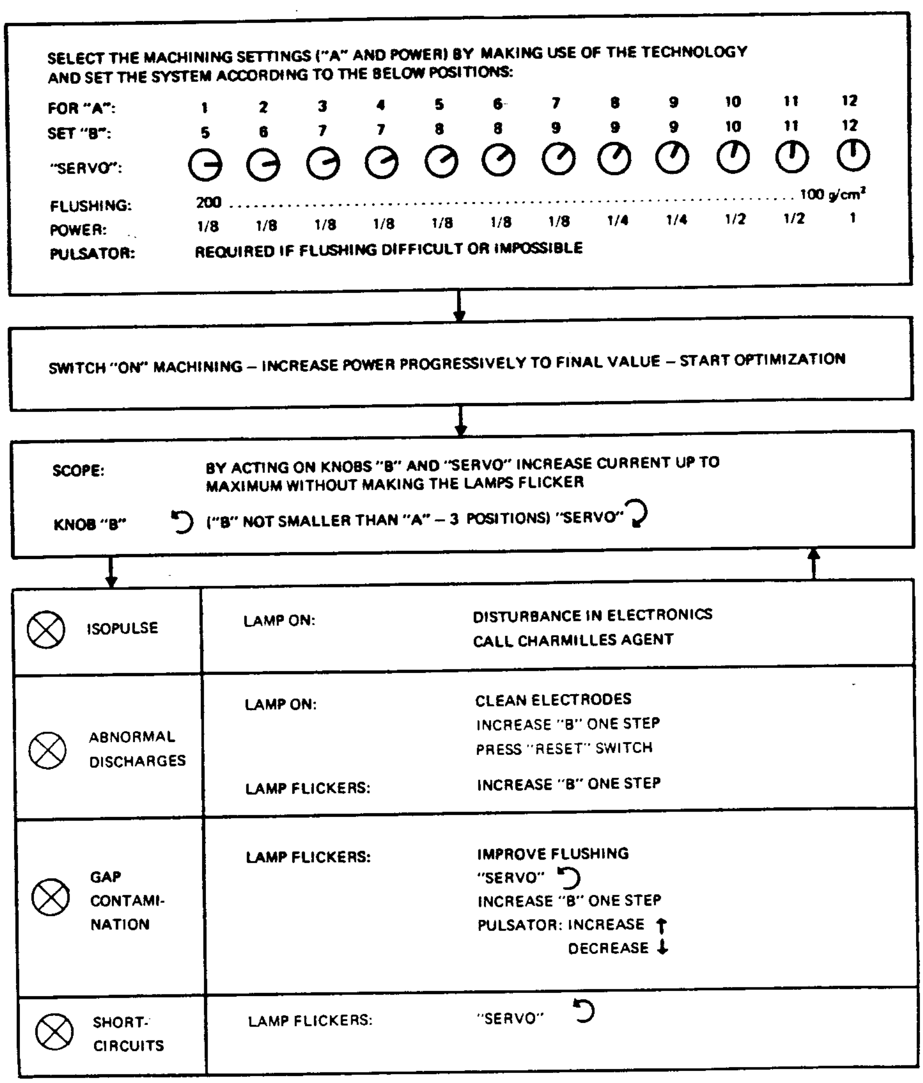


Figure 7

electrode wear is increasing. A test, in which all the discharges which were announcing to be of the low voltage type were suppressed, proved that this type of discharge is present when the electrode wear is high, but that they are not responsible for the high electrode wear. The detection of these discharges is useful for predicting excessive electrode wear, and an adequate intervention can be made.

Another test was to determine the correlation of a certain type of discharges with their location on the surface of the electrodes. (7) It has been found that "good machining" was obtained when the successive discharges jumped from one place to another over a distance of several centimeters. When the successive discharges occurred around the same spot, they showed to be of a certain type (voltage - time - characteristic) and the electrodes could be damaged at this place by what is commonly called d-c arcing.

The detection of this type of discharge allows to predict, or prevent the degeneration of the machining to d-c arcing.

And now a word about short-circuits.

There are different types to be distinguished. Let us imagine a sequence of N discharges and observe what may occur after the Nth discharge. The gap between the electrodes is filled with eroded metallic particles and decomposition products of the dielectric fluid (precipitated carbon). The resistance of the gap at that moment is very high if the particles do not touch and bridge the gap, and at the application of the next voltage pulse the probability is high that, after a certain ignition delay, a so called good discharge will occur.

The resistance is low if the particles, either metallic or carbon debris, touch and line up and thus bridge the gap. At the application of the next voltage pulse, the current begins to flow immediately, and according to the resistance of contact there is enough heat produced to melt or even evaporate the bridge, and the discharge, which began in a short circuit condition, can become a good working discharge.

The resistance between the electrodes is very low when the gap is bridged by a solid weld between the electrodes. This can happen at any time, when using metallic electrodes. The probability that this may occur naturally increases with decreasing gap width. The phenomena has been investigated by (8) and it has been shown that it is molten copper, and not molten steel, which forms the bridge. This bridge can be destroyed mechanically by retracting the electrode from the workpiece, or by applying a current pulse of high intensity. In combining both actions, the bridge is destroyed with a great probability at an up-movement of smaller amplitude than what is necessary without applying a current pulse.

In all three cases of short circuit it would be wrong to interrupt the current pulses after detection of a short circuit.

2. The Isopulse-Monitron System

2.1 The Monitron philosophy

Whatever the reasons may be, (lack of knowledge, prudence or others) we are aware that most of our spark erosion machines work far below the optimum performance (optimum performance is maximum removal rate at minimum electrode wear at a given surface finish).

In order to aid our customers in using their spark erosion equipment with maximum profit, we added an instrument to the system which shows the operator how he can improve the machining in given conditions.

This 'instrument, called MONITRON, is essentially designed to teach and help, and if the operator follows the indications he can easily find the optimum settings.

If for any reason, the conditions change during machining, and the machining becomes erratic, the MONITRON tries to improve the situation by interrupting the machining current periodically. If the fault persists, the MONITRON, after a few attempts to correct it, stops the machine in order to prevent burning of the electrode or of the workpiece. This feature is very useful especially when the machine works without supervision.

2.2 How the MONITRON works

A multitude of electronic circuits measure the characteristic values, as described in the first part, of each discharge. Some measurements are made at very precise instants after the ignition of the discharge, others are made during the whole duration of the discharge. Some measured values are stored and the value of the next discharge is compared to that of the previous one.

All these measurments are compared to reference values and thus "ones" or "zeros" are generated as a result of the comparison.

These "ones" and zeros" are then computed in a logic circuit, sorted out and mixed, and as an output we get an indication by a lamp on:
- the amount of abnormal discharges,
- the gap contamination,
- the amount of short circuits.

The brightness of the lamps is directly proportioned to the amount of faults detected.

If the amount of abnormal discharges exceeds a fixed limit during a period of some milliseconds, or the amount of contamination or short circuits exceeds a fixed limit for some tens of milliseconds, the MONITRON interrupts the machining for 300 milliseconds, which makes the electrode retract and, if pulsed flushing is selected, flush the gap with new dielectric.

If this pulsation, as we call it, has been asked for by the abnormal discharge detection circuit, a binary counter is incremented. If after pulsation the fault has disappeared, that means that the fault is not detected any more, this counter is reset to zero. If the fault persists, the MONITRON pulses again, and the counter counts the successive pulsations and orders the definite interruption of the machining after four successive pulsations. The lamp "abnormal discharges" then remains lit.

2.3 How to use the MONITRON

According to the flow chart, the simplified version of which is represented in figure 7, the operator must try to machine with maximum current but without letting the MONITRON lamps light up.

If any of the lamps flicker, the chart tells the operator which intervention he must carry out.

In optimising in the above manner, the machining is finally set to the point P of the curves of figure 4.

2.4 The MONITRON "AA"

A further development in the Monitron family has been named "AA". This stands for "automatic adaption", but "aeronautic application" fits as well. It has essentially been developped for deep hole drilling (aeronautic application) but works well for all difficult machining problems. The detection circuits are the same as in the standard Monitron, and by means of a switch it is possible to select normal Monitron or AA behavior. With the switch in the AA position, the time constants of the detection circuits as well as the pulsation period are shortened. In this way, at the apparition of a machining fault, the Monitron interrupts the machining current for a short period and the electrode is withdrawn from the work-piece by a few hundredths of a millimeter. The average current is thus reduced and is adapted to the working conditions in the gap, allowing the machine to continue machining in the given conditions. If the frequency of the correcting action becomes too high, a long pulsation is initiated, the counter incremented and the action is the same as described before.

The Monitron AA allows machining with higher average current than what is normally recommended, because it reduces it if the necessity arises.

3. The MHD

In the equipment developped for microhole drilling, a device which is similar to the Monitron AA watches over the machining with the electronically controlled condenser-discharge spark generator.

A particularity of this generator is that its output is divided into 16 channels, which permits the use of more total power to be distributed to the electrodes.

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