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Mironoff

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[45] **July 1, 1975**

[54] **ELECTRIC DISCHARGE MACHINING CIRCUIT INCORPORATING MEANS FOR PRE-IGNITION OF THE DISCHARGE CHANNEL**

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[21] Appl. No.: **364,640**

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Oct. 25, 1972	Switzerland	15429/72

[52] **U.S. Cl.** **320/1;** 219/136; 307/108

[51] **Int. Cl.** **B23k 9/06;** H03k 3/72

[58] **Field of Search** 320/1; 307/108, 109; 219/136

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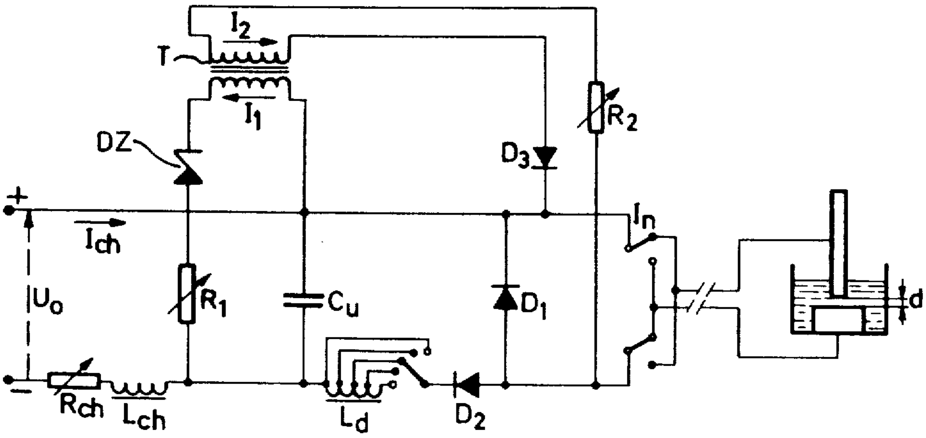
Primary Examiner—Stuart N. Hecker
Attorney, Agent, or Firm—Werner W. Kleeman

[57] **ABSTRACT**

An electric discharge machining circuit utilizing for the production of erosive current pulses, discharges delivered by electric energy accumulation means, at least a part of which consists of a capacitive type element based upon the voltage/current ratio and intended to store and return the energy, wherein the voltage provided with the inception of each discharge is higher than the voltage used to charge said element.

11 Claims, 10 Drawing Figures



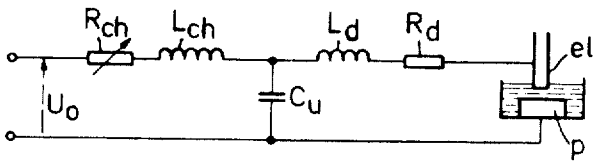


FIG. 1
PRIOR ART

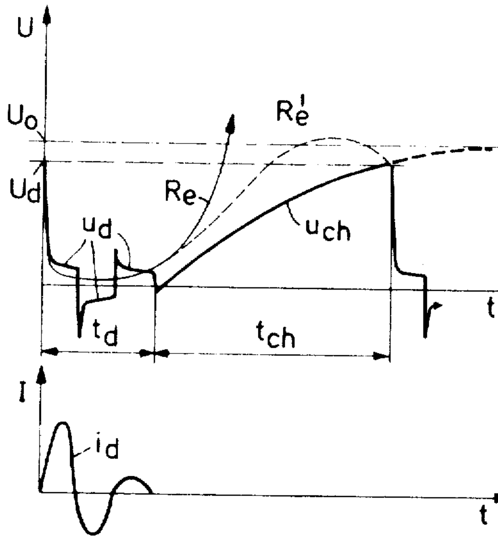


FIG. 2a
PRIOR ART

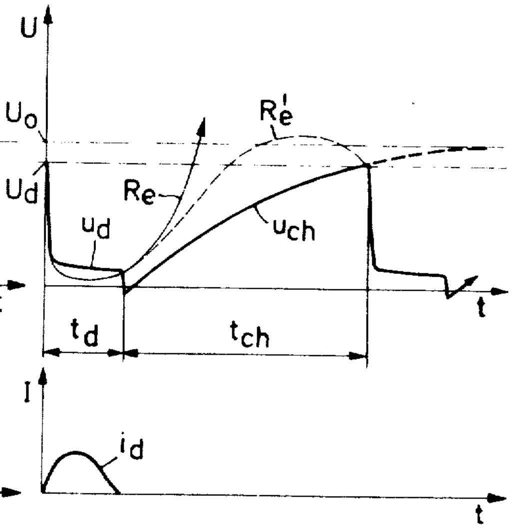


FIG. 2b
PRIOR ART

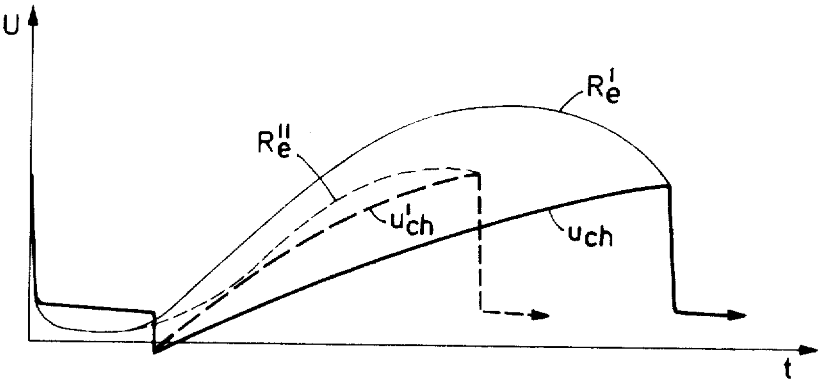
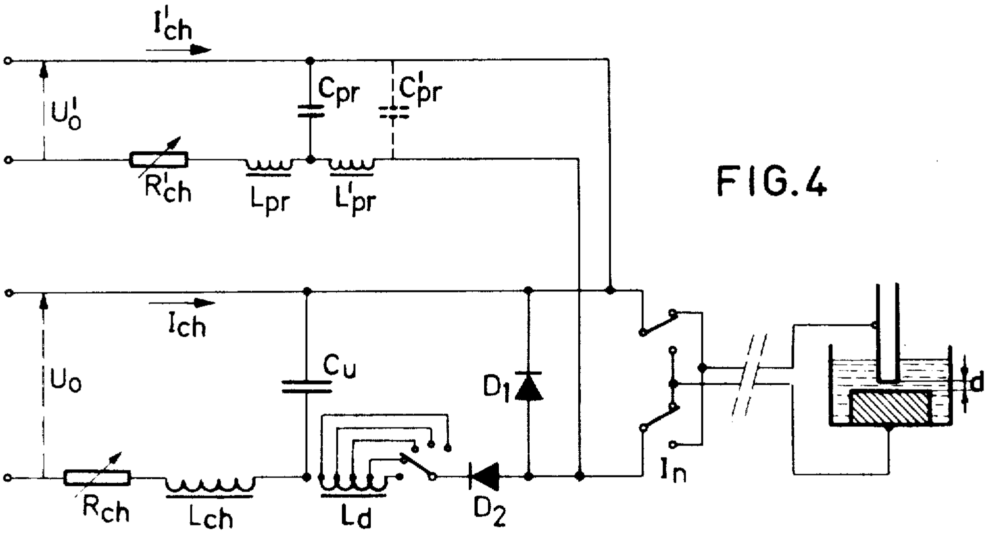


FIG. 3
PRIOR ART


I'_{ch}
U'_o
C_{pr}
C'_{pr}
R'_{ch}
L_{pr}
L'_{pr}
I_{ch}
U_o
C_u
D_1
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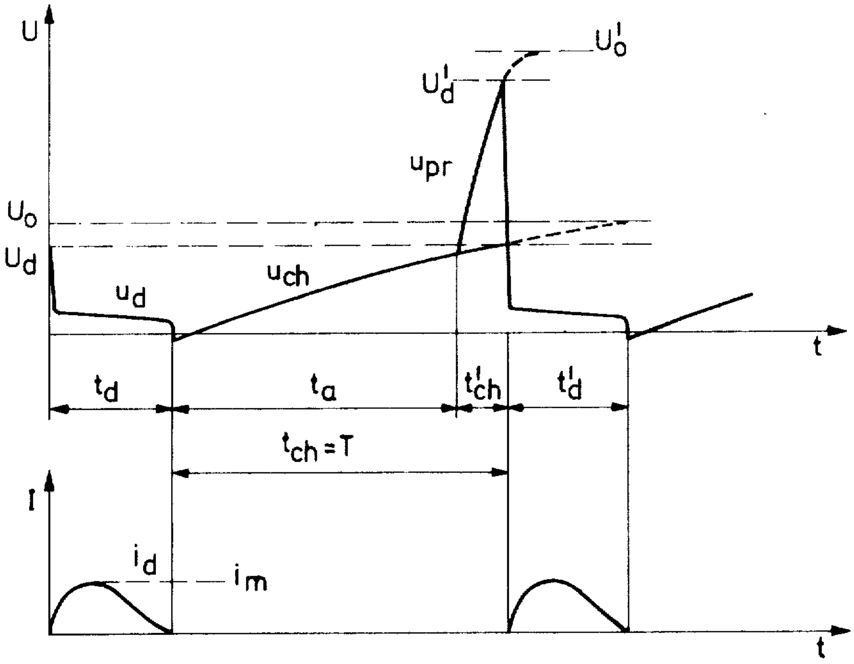
L_{ch}
L_d
D_2
I_n
d

FIG.4


U
U'_o
U'_d
u_{pr}
U_o
U_d
u_{ch}
u_d
t
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t_a
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$t_{ch} = T$
I
i_d
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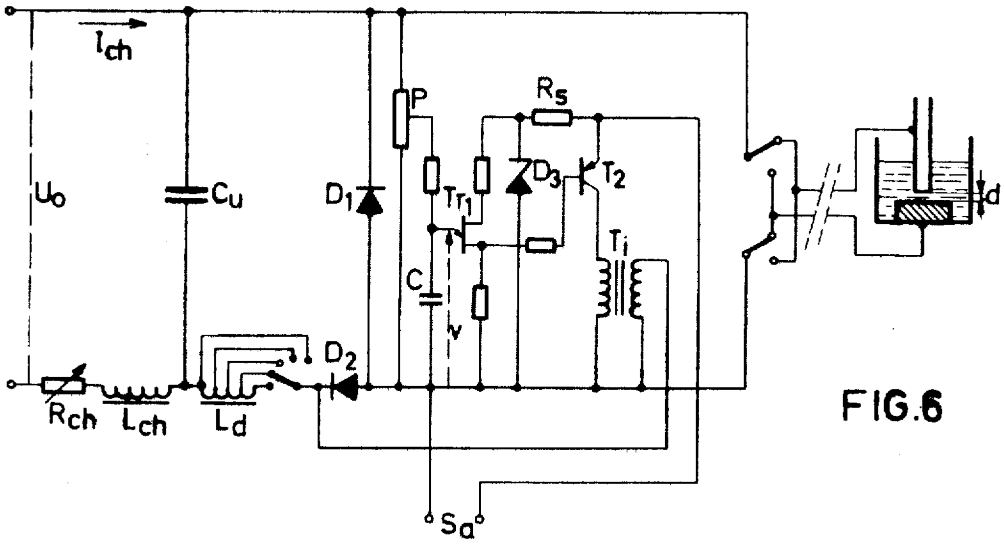
FIG. 5


Ich
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Cu
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D3
T2
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Ti
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Rch
Lch
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Sa
d

FIG.6

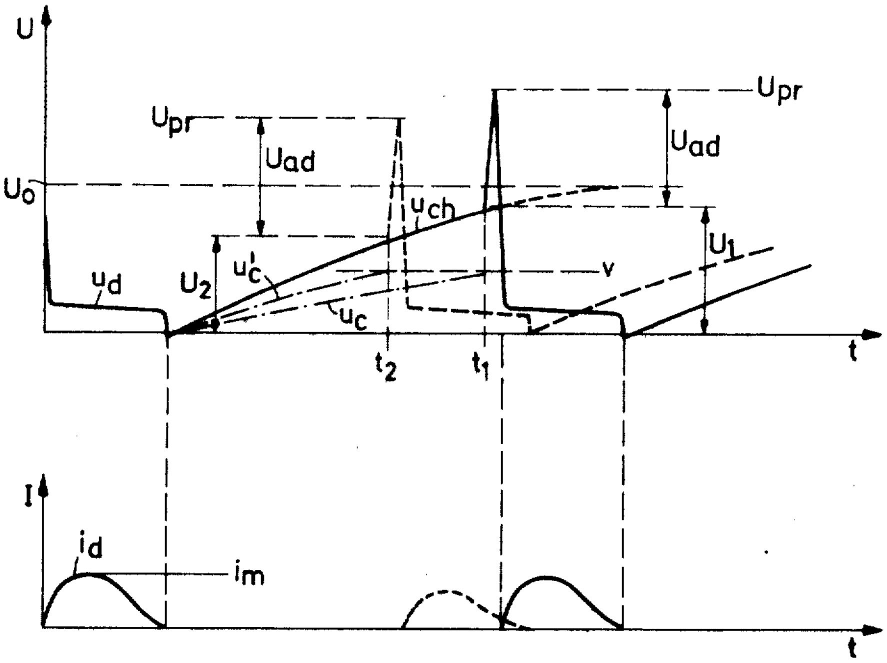
U
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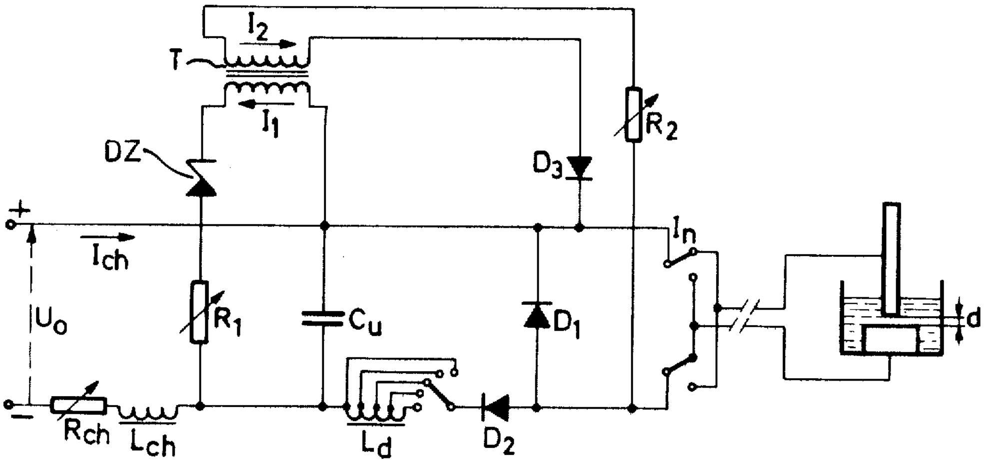
FIG.7


I2
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Ich
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Cu
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D2

FIG.8

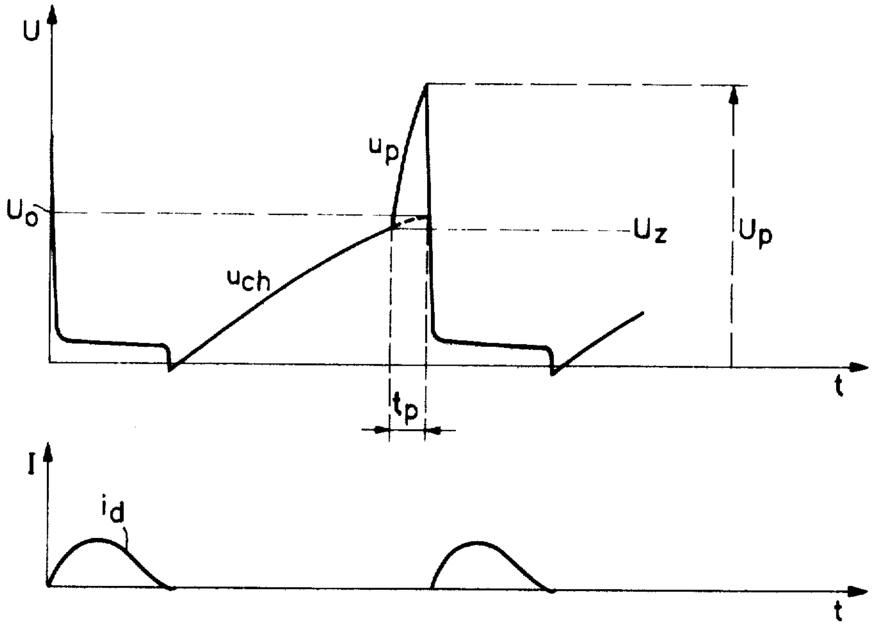
U
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FIG.9

ELECTRIC DISCHARGE MACHINING CIRCUIT INCORPORATING MEANS FOR PRE-IGNITION OF THE DISCHARGE CHANNEL

BACKGROUND OF THE INVENTION

The present invention relates to electric discharge machining circuits (EDM) and, more particularly, to circuits based on the relaxation principle.

It should be recognized that in these circuits the current pulses causing material removal—hereafter called erosive or erosion pulses—are generated with periodic discharge of an electric energy accumulator, such as a capacitor. When the charging voltage of the capacitor reaches a certain value, called the breakdown voltage, there appears in the dielectric liquid separating the electrode-tool from the workpiece localized ionization of this liquid, creating a high electric conductivity channel.

Through this channel there flows the discharge current producing the erosive pulse. After the discharge, the channel de-ionizes, and the liquid resumes its dielectric stability or rigidity, thus allowing a new charge of the capacitor.

In spite of the great advantages of relaxation circuits, such as their great simplicity, the reliability of all their components, the possibility of producing discharges of extremely short duration, these circuits are associated with considerable drawbacks. Among these, there should be mentioned their low efficiency, the difficulty of stabilizing the machining process, and the impossibility of producing pulses of long-duration of relatively low current intensity, which is a primary condition for the reduction of the wear of the electrode-tool.

In order to more fully appreciate the concepts of this invention consideration will be given to FIGS. 1 - 3 relating to a prior art system, and wherein specifically FIG. 1 is a schematic circuit diagram of a well known relaxation circuit, in which reference character C_u is a capacitor, R_{ch} a resistor limiting the charging current of the capacitor, L_{ch} the self-inductance of the charging circuit, R_d and L_d the resistor and the self-inductance respectively, of the discharge circuit, U_o the (no load) voltage of a DC-source, E1 the electrode-tool, and *p* the workpiece.

FIGS. *2a* and *2b* show voltage and current diagrams of the discharge produced by this circuit, wherein U_o is the charging voltage, U_d the breakdown voltage, and t_d and t_{ch} the discharge and charge times respectively of the capacitor.

If the parameters of the discharge circuit assume the ratio

$$\frac{C_u R_d^2}{4 L_d} > 1$$

the discharges take the form of damped oscillations, as shown in FIG. *2a*.

If these parameters assume the ratio

$$\frac{C_u R_d^2}{4 L_d} > 1$$

the discharges are aperiodical, as shown in FIG. *2b*.

In both cases, the process of ionization and deionization of the discharge channel can be schematically depicted by a curve representing the equivalent resistance of the channel. At the end of the discharge, if the latter is not followed by a new charge of the capacitor, the channel is quickly deionized and its equivalent resistance increases according to the curve R_e. If, as is the case in a continuous working process, the capacitor is again recharged, the increasing voltage of this charge u_{ch} will brake the deionization of the channel, the equivalent resistance of which acquires the aspect of the curve R'_e.

In increasing the charging current of the capacitor, the curve of its charging voltage increases more rapidly and increasingly brakes the deionization process of the channel of the preceding discharge. FIG. 3 illustrates this phenomenon. The charging voltage curve u_{ch} becomes u'_{ch} and that of the equivalent resistance of the channel R'_e becomes R''_e. Both curves approach one another and may overlap. The channel deionization then only partially occurs, the discharges follow each other irregularly, their recurrent frequency increases, and finally, the charging current of the capacitor easily transforms into a short-circuit throughout the inter-electrode gap. The working process is then interrupted, and the short-circuit arc damages the machined surface. Extinction of the short-circuit arc by raising or retraction of the electrode-tool becomes that more difficult as the intensity of the charging current is greater.

This explains why relaxation circuits require quite considerable charging times of the capacitor with regard to the duration of the discharge. The ratio t_d/t_{ch} (FIGS. *2a* and *2b*) is unfavorable, thus limiting the effective working power.

On the other hand, if the discharge voltage U_d is too low, the gap separating the electrode-tool from the workpiece becomes very small. The increase of the charging voltage of the capacitor increasingly influences the deionization process of the previous discharge channel and the working process becomes even more unstable. If the charging voltage U_d drops below a predetermined value, the machining process becomes practically impossible.

Thus, the operation of a relaxation circuit is limited, on the one hand, by the ratio t_d/t_{ch}, constituting an important limitation of the working power at a relatively low level, and, on the other hand, is also limited by a high breakdown voltage U_d, and, finally, by the discharge energy itself, because if the capacitance of the capacitor exceeds a certain limit, the intensity of the charging current, in case of a short-circuit, leads to an arc, causing significant damage to the surface of the workpiece.

Accordingly, the characteristics of the erosive pulses produced by relaxation circuits are determined by the above-mentioned conditions. These pulses are characterized by a great current intensity and a very short duration of the pulse. The density of the calorific energy on the anodic and cathodic spots of the discharge, resulting from the Joule effect of the current, then becomes too high. The temperature of these spots reaches a value considerably beyond the fusion point of the workpiece and electrode-tool materials. Under these conditions the removal of material practically results in vaporization thereof. There thus results significant wear of the electrode-tool and unjustified loss of energy.

Experience has shown that the optimal efficiency in electro-erosion machining as well as the minimum wear of the electrode-tool are dependent upon a predetermined ratio of a maximum intensity of the pulse current and the duration of this pulse. Experience also has shown that this ratio cannot be attained with a relaxation circuit. Hence, manufacturers of electro-erosion machines have been prompted to use other means for generating erosive pulses, using various electronic circuits which are often intricate and expensive.

SUMMARY OF THE INVENTION

A primary object of the present invention is to utilize current pulses generated by simple energy accumulators of the electrostatic or electromagnetic type, imparting to these pulses parameters corresponding to the best working conditions, said pulses not being associated with the limitations discussed above.

In accordance with the invention, this is attained by an electric discharge machining circuit which utilizes, for the production of erosive current pulses, discharges delivered by electrical energy accumulation means, of which at least a part consists of an element based upon the voltage/current ratio of a capacitive type, and which element is intended to store and return or discharge the energy, wherein the voltage provided with the inception of each discharge is higher than the voltage used to charge said element.

Thus, the discharges of an energy accumulator are not initiated by its charging voltage, but by a higher voltage. Since the breakdown voltage of a dielectric is a function of the inter-electrode gap, the charging voltage of the accumulator will not provoke its discharge; this discharge will be solely conditioned by the momentary application of a higher voltage. Thus, the charging and discharging process of the energy accumulator becomes two independent phenomena; this will be that much more pronounced as the difference between the charging voltage of the accumulator and the breakdown voltage of the gap will be greater.

Application of a momentary breakdown voltage—hereafter termed pre-ignition voltage—is obtained by an independent pulse of very low energy, not affecting the surface of lower the workpiece, nor that of the electrode-tool, but sufficient to provoke incipient ionization of the discharge channel. The equivalent resistance of this channel then drops to a value allowing for the passage of the discharge current of the accumulator charged at a low voltage. During the discharge time, the high conductivity of the channel is maintained by the intensity of the pulse current. As soon as the channel fades away with the end of the pulse, the dielectric liquid rigidity in the inter-electrode gap again quickly re-establishes or sets up, the low charging voltage of accumulator having less influence upon the process of channel deionization.

The operation of such a circuit offers desirable advantages compared with existing circuits which resort to the use of a permanent oscillation of a high frequency voltage superimposed upon a lower charging voltage of an energy accumulator. This high voltage oscillation was intended to increase the inter-electrode gap in order to facilitate removal of waste products. It indirectly caused pre-ignition of the channel. However, the energy supplied by this superimposed voltage oscillation could, to a certain degree, maintain the ionization of the channel after the discharge, which rendered the discharge frequency unstable and increased the short-circuit danger.

Now, the unstable discharge frequency is another cause of poor efficiency of the machining: discharges separated by too short a frequency spacing gasify the liquid in the inter-electrode gap. This prevents the hydro-dynamic effect of the discharge from occurring normally. This effect, consisting of an explosion followed by an implosion of the gaseous cavity produced by the high temperature of the channel, is indeed responsible for the ejection of melted metal out of the impact zone.

Experience shows that to reach an optimal working efficiency there is required a well determined frequency spacing. A precise setting of the ratio t_d/t_{ch} between the pulse duration and the waiting time, and maintaining this ratio is a factor of great importance.

The discharge pre-ignition embodiment in accordance with the invention, allows this setting on a large scale and insures the evenness of the ratio t_d/t_{ch} with good precision.

BRIEF DESCRIPTION OF THE DRAWINGS

The invention will be better understood and objects other than those set forth above, will become apparent when consideration is given to the following detailed description thereof. Such description makes reference to the annexed drawings wherein:

FIG. **1** is a schematic diagram of an electro-erosion machining circuit of the classical relaxation type;

FIGS. **2***a*, **2***b* and **3** are explanatory diagrams of operation of the circuit depicted in FIG. **1**;

FIG. **4** is a schematic diagram of an electro-erosion machining circuit according to the invention;

FIG. **5** is an explanatory diagram of operation of the circuit of FIG. **4**;

FIG. **6** is a schematic diagram of another embodiment of the circuit according to the invention;

FIG. **7** is an explanatory diagram of operation of the circuit according to FIG. **6**;

FIG. **8** is a schematic diagram of a third embodiment of electro-erosion machining circuit according to the invention; and

FIG. **9** is an explanatory diagram of the operation of circuit of FIG. **8**.

DETAILED DESCRIPTION OF THE PREFERRED EMBODIMENTS

Describing now the invention in terms of FIGS. **4** to **9**, it is to be understood that in the embodiment of electro-erosion machining circuit depicted in FIG. **4** a capacitor C_u serves as energy accumulator. This capacitor is charged to a voltage U_o through the ballast resistor R_{ch} which regulates the charge current intensity I_{ch}. In this circuit there also may be included a self-inductance L_{ch} which renders the charging voltage curve of the capacitor practically linear. The discharge circuit of capacitor C_u comprises an adjustable self-inductance L_d, the value of which determines the duration of the pulse. A diode D_1 suppresses the negative discharge arch or portion, rendering it unipolar.

The pre-ignition is obtained by means of a separate DC source which charges the capacitor C_{pr} to a voltage U'_o which is greater than the voltage U_o. The variable resistor R'_{ch} regulates the charging current intensity I'_{ch}. The capacitor C_{pr} is preceded and followed by self-inductances L_{pr} and L'_{pr}. This cell or unit forming a delay line, of course can be followed by other identical cells: C'_{pr}, L''_{pr}, etc. The diode D_2 directs the high voltage pulse U'_o in the discharge circuit.

When the pre-ignition voltage U'_o reaches the breakdown point of the dielectric then the discharge of the capacitor (s) C_{pr} ionizes the channel in the inter-electrode gap, through which there then flows the discharge current of capacitor C_u.

During the discharge time the equivalent resistance of the channel is very low, the current I'_{ch} is added to the discharge current of capacitor C_u and does not charge the capacitor (s) C_{pr}. At the end of the discharge, the channel extinguishes and the equivalent resistance of the inter-electrode gap quickly increases. The capacitances of the capacitor (s) C_{pr} and the value of the self-inductances L_{pr} determine the pause preceding the next pre-ignition discharge.

FIG. 5 shows the rate of voltage and current curves across the discharge gap. U_o and U'_o are respectively the charging voltage of the capacitor C_u and the capacitor (s) C_{pr}; U_d and U'_d represent the breakdown voltage of capacitors C_u and C_{pr} respectively; u_d the voltage of the discharge arc; u_{ch} the charging voltage of capacitor C_u (function of the charge current I'_{ch}); t_d the duration of the erosive discharge; t_a the charge time of the pre-ignition capacitor C_{pr}; t'_{ch} the charge time of capacitor C_{pr}; $t_{ch} = T$ represents the charge time of capacitor C_u equal to the time separating two consecutive discharges; i_d is the erosive discharge current; and i_m is the maximum intensity of this current.

Since the capacitor C_u is charged with a voltage which is less than the breakdown voltage, it cannot discharge without the aid of the pre-ignition pulse. The waiting time of the pre-ignition which is determined by the values of C_{pr} and L_{pr}, can be regulated, but remains invariable during the machining process.

Owing to the low capacitance of capacitor (s) C_{pr} and the comparatively important value of the self-inductances L_{pr}, the increase of the charging voltage u_{pr} presents a very steep wavefront, resulting in the very short time of this charge (t'_{ch}) with regard to the charging time (t_{ch}) of capacitor C_u. Thus, the moment of the erosive discharge is determined with sufficient accuracy to enable good stability of the discharge frequency.

The essential parameters of the erosive discharge pulse, i.e. the ratio of the maximum intensity of the pulse current i_m and its duration t_d—which determine the density of the calorific energy on the spots of the discharge—is regulated by the adjustable self-inductance L_d, the value of which determines the duration of the erosive pulse t_d. The maximum current intensity of this pulse i_m depends upon the capacitance of the capacitor C_u and its charging voltage U_o.

The various machining rates, which are a function of the energy of each discharge, are either obtained by changing the capacitance of the capacitor C_u or by varying its charging voltage U_o.

With this circuit, erosive discharges of different polarities can be obtained by means of the inverter I_n.

Another embodiment of the invention is schematically shown in FIG. 6. In this example, the moment of pre-ignition is fixed not in terms of the waiting time, as in the previous embodiment, but in terms of the charging voltage of the capacitor C_u.

The charging and discharging circuits of the capacitor C_u are identical to those of the circuitry of FIG. 4. The pre-ignition is obtained as follows:

A low capacitance capacitor C is charged by the charging current of capacitor C_u through a potentiometer P. When the charging voltage of capacitor C reaches a certain value (v), the unijunction transistor Tr_1 starts to conduct and renders conductive the transistor Tr_2 supplied with a low voltage current by means of an auxiliary source S_a. This current then flows through the primary of a pulse transformer T_i. The secondary of this transformer delivers a high voltage pulse which is superimposed upon the charging voltage of capacitor C_u and pre-ignites the discharge channel. The moment of pre-ignition is regulated by the potentiometer P, which allows attaining the voltage (v) of the emitter of the unijunction transistor Tr_1 at a moment corresponding to a chosen value of the charging voltage of capacitor C_u. The avalanche (hereinafter termed Zener) diode D_3 and the resistor R_s stabilize the supply voltage of the unijunction transistor Tr_1. The opposite oscillation portion or arch of the pre-ignition pulse is blocked by the diode D_2.

FIG. 7 shows voltage and current diagrams across the discharge gap, according to the second embodiment of the invention.

If the potentiometer P is regulated in such a way that the charging voltage of the capacitor C follows the curve u_c, this voltage reaches the value (v) at the moment t_1 when the charging voltage of capacitor C_u is equal to U_1. The pre-ignition pulse is then released and capacitor C_u discharges.

If the regulation of the potentiometer P results in the voltage curve u'_c, then the voltage reaches the value (v) at the moment t_2, and the pre-ignition pulse is released when the voltage u_{ch} reaches the value U_2. The additional pre-ignition voltage U_{ad} will be the same in both cases, but the absolute pre-ignition voltage U_{pr} will depend on the feed voltage U_o and on the release moment of the pre-ignition pulse.

The main desirability of this last embodiment is that, if the pre-ignition moment is regulated in terms of the charging voltage of the capacitor C_u, then the discharge of this capacitor C_u always corresponds to a well defined value of its charging voltage, and this, regardless of the capacitance of the capacitor C_u, and regardless of the intensity of the charge current I_{ch}.

In the above-mentioned embodiment, with the pre-ignition voltage U_{ad} being constant, the machining power, i.e. the discharge frequency, can be varied without readjusting the pre-ignition circuit. Thus, the maximum machining power at a given working rate—which is dependent upon the minimum time separating consecutive discharges—can be obtained by means of a simple regulation of the intensity of the charging current. This simplifies the application of an automatic regulation device in electro-erosion machining.

The previously described embodiments, although meeting the main requirements of the invention, are nonetheless associated with the following difficulties:

1. they require a separate power supply, and
2. they generate pre-ignition pulses of a given energy, the value of which can be adjustable, but is not subordinate to the variations of machining conditions such as, for instance, the changes of the machining rate.

In fact, in order to ionize a channel through which will pass the discharge current of a capacitor charged to a voltage lower than the breakdown voltage of the inter-electrode gap, the pre-ignition voltage not only must be high enough, but the pre-ignition pulses also must be of sufficient energy to open wide enough the channel of electric conductivity, and thus insure a regular sequence of the capacitor discharges at the precise moment corresponding to a determined value of its charging voltage.

Experience shows that the energy necessary for an effective pre-ignition of the discharge channel increases together with the machining power. The pulse pre-ignition energy must, then, be greater with powerful (roughing) machining rates than for lower powered machining rates (finishing rates).

This is due to the fact that the inter-electrode gap increases with the growth of the energy of the discharges.

It is obvious that the energy of the pre-ignition pulse has to be greater to ensure for sufficient ionization of the discharge channel when said channel becomes longer.

Experience furthermore shows that if the pre-ignition pulses corresponding to the roughing rates are used in the finishing rates, their energy would be excessive compared with the energy of the discharge pulses. The voltage of the pre-ignition pulses being high, these pulses would produce additional wear of the electrode-ool. Hence, to maintain the same machining conditions in all the machining rates, the energy of the pregnition pulses must be correlated to the discharge pulse energy.

Thus, a further object of the invention is to provide he pre-ignition of the discharge channel in terms of the charging voltage of the capacitor, attaining this by simple means which, on the one hand, allow for easy reguating of all the pre-ignition pulse parameters, without esorting to a separate power supply, and which, on the other hand, insure for an automatic adaptation of the energy of these pulses to the various machining rates.

An embodiment of the invention suitable for these purposes is shown in FIG. **8.** The charging and disharging circuits of the capacitor C_u, as those menioned above, consist of a resistor R_{ch} limiting the intenity of the charge current, if desired a self-inductance $_{ch}$ as a charging voltage smoothing means, and an adjustable self-inductance L_d regulating the duration of he discharge pulses. The diode D_1 eliminates the negative portion or arch of the pulses, rendering them uniolar.

The pre-ignition circuit consists of a transformer T, he primary of which is connected across the positive nd negative terminals of the capacitor C_u, by means of n adjustable resistor R_1 and a Zener diode DZ. The econdary of the transformer T is connected to the disharge circuit by means of an adjustable resistor R_2 and diode D_3.

FIG. **9** shows the voltage and current curves across he discharge gap.

When the charging voltage u_{ch} of capacitor C_u eaches the value U_z which is slightly beneath its chargng value U_0, the Zener diode DZ starts to conduct. The lient feature of the Zener diode consists in a sharp se of the current I_{cc}, as soon as the typical Zener voltge is reached. The intensity of this current is regulated y the resistor R_1. The sharp rise of this current in the rimary induces in the secondary a current pulse I_2 at voltage U_p higher than the charging voltage of capacior C_u. The intensity of this current is adjustable by means of the resistor R_2. The diode D_2 allows to direct the additional voltage of the pre-ignition pulse which is equal to $U_p - U_0$, in the inter-electrode gap d. The diode D_3 separates the pre-ignition circuit from the discharge circuit during the charging time of the capacitor C_u.

The release of the current I_{cc} by the Zener diode DZ occurs in an extremely short time, and the charging voltage of the capacitor C_u, as well as the moment of its discharge are fixed, resulting in an automatic stabilization of the energy of each discharge pulse and of their frequency.

The bias (or slope) of the pre-ignition voltage u_p, and accordingly, the time t_p between the moment of release of the current I_{cc} by the Zener diode DZ and the start of the discharge are determined by the self-inductance of the windings of the transformer T. In reducing the number of turns of the primary and the secondary, the time t_p can be reduced to a minimum and the pre-ignition of the discharge channel can become practically instantaneous.

The ratio of the charging voltage of the capacitor and the pre-ignition voltage is determined by the transformation ratio of the transformer T. Since the pre-ignition voltage determines the breakdown gap, the variation of the number of turns of the secondary (which can be made by various taps or studs on the secondary) allows to vary the inter-electrode lateral gap in each rate of machining—this being an important technological factor in EDM.

The pre-ignition pulse energy is regulated by the resistors R_1 and R_2.

When one machining rates is switched to another, for instance from a low power rate to a higher one, the capacitance of the capacitor C_u and the charging current intensity I_{ch} are increased. The current intensity I_{cc} released by the Zener diode DZ, increases then in the same proportion, which automatically increases the energy of the pre-ignition pulse.

The circuit thus allows to select the best parameters of the pre-ignition pulses and the energy of these pulses then automatically vary in terms of the machining rate.

This pre-ignition circuit works without any additional adaptation means, whatever the polarity of the discharge. The setting of this polarity is obtained by means of the inverter I_n.

While there is shown and described present preferred embodiments of the invention, it is to be distinctly understood that the invention is not limited thereto but may be otherwise variously embodied and practiced within the scope of the following claims. Accordingly,

What is claimed is:

1. An electrical discharge machining circuit for generating and automatically applying recurrent erosive pulses across a machining gap defined by an electrode tool and a workpiece, comprising an electrical circuit incorporating:

electric energy accumulator means for recurrently storing electrical energy and discharging such electrical energy across said machining gap in the form of erosive current pulses via a conductive circuit, said electrical energy accumulator means including a capacitor coupled in parallel with the machining gap for recurrently storing electrical energy and returning said stored electrical energy to the machining gap, which capacitor has a voltage which increases and decreases correlatively with said stored electrical energy,

pre-ignition voltage delivering circuit means connected in circuit with said electric energy accumulator means and including voltage threshold means coupled to said capacitor and responsive to the voltage thereon, and inductive transformer means having a primary winding and a secondary winding, said primary winding being coupled to said voltage threshold means and to said capacitor for causing a current to pass through said primary winding only when said voltage of said capacitor reaches a predetermined value in relation to said voltage threshold means and said current in said primary winding causing a voltage to appear across said secondary winding, and

diode means coupled between said machining gap and said capacitor for applying across said machining gap the higher of two voltages, the one of which is a voltage delivered only from said capacitor via said conductive circuit and fed to said gap without passing through said secondary winding as a main erosive pulse voltage, and the other of which is a voltage delivered at least from said secondary winding as a pre-ignition voltage.

2. The electric discharge machining circuit as defined in claim **1**, wherein said pre-ignition voltage delivering means applies to said gap a pre-ignition, high voltage, low-current pulse of low energy defining a pre-ignition pulse, said pre-ignition voltage possessing a magnitude sufficient to pre-ignite a channel of erosive pulse, said main erosive pulse voltage being the voltage across said capacitor applied to said gap as an erosive pulse of lower voltage capable of producing a high-intensity discharge in said gap when the latter has just been pre-ignited by said pre-ignition pulse.

3. The electric discharge machining circuit as defined in claim **2**, further including means for independently adjusting the voltage magnitude of said pre-ignition pulse whatever may be the voltage at which said capacitor is charged.

4. The electric discharge machining circuit as defined in claim **2**, wherein said pre-ignition voltage delivering means are arranged for causing said secondary winding to deliver a voltage in the form of a pre-ignition pulse voltage having a constant peak value, said pulse of constant peak value being added to said voltage across said capacitor for forming said pre-ignition voltage applied by said diode means as said pre-ignition pulse alternately with said main erosive pulse voltage applied in other instants as a lower-voltage high-intensity pulse.

5. The electric discharge machining circuit as defined in claim **2** including means for recharging said capacitor as a predetermined rate each time a main erosive pulse discharge ends in correlation with a deionisation in said gap occurring upon each discharge of said capacitor, when said voltage across said capacitor approaches zero, and

further including means for regulating, as a function of said predetermined rate, the time interval between the end of said discharge and a next automatic reoccurrence of a said pre-ignition pulse.

6. The electric discharge machining circuit as defined in claim **2**, further including means for varying the energy of said pre-ignition pulse.

7. The electric discharge machining circuit as defined in claim **2**, wherein said pre-ignition voltage delivering means are arranged for causing said secondary winding to deliver a voltage in the form of a short-duration pulse sufficient to pre-ignite a discharge channel in said gap, said pre-ignition pulse being obtained by causing said current to pass through said primary winding at an instant when, during a recharging of said capacitor, said voltage across said capacitor reaches a predetermined desired value, said inductive transformer means transforming a rapid increase of said current flowing through its primary into a voltage pulse on its said secondary winding, of a greater voltage than said predetermined desired value for the charging voltage of said capacitor.

8. The electric discharge machining circuit as defined in claim **7**, wherein said transformer means comprises a step-up transformer.

9. The electric discharge machining circuit as defined in claim **7**, wherein said primary winding is connected in series in a circuit branch connected across said capacitor, said circuit branch incorporating a Zener diode in series with said primary winding of said transformer means, said Zener diode forming said threshold means and controlling the flow of said current through said primary winding, the breakdown Zener voltage of said Zener diode corresponding to said predetermined desired value.

10. The electric discharge machining circuit as defined in claim **7**, wherein said transformer means has a transformation ratio selected to control the ratio of predetermined desired charging voltage of the capacitor and the voltage of said pre-ignition pulse.

11. The electric discharge machining circuit as defined in claim **10**, further including a resistor in series with said primary winding for regulating said pre-ignition pulse energy and limiting the current in this circuit branch, and a further resistor in series with said secondary winding of said transformer means.

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UNITED STATES PATENT AND TRADEMARK OFFICE
CERTIFICATE OF CORRECTION

PATENT NO. : 3,893,013

DATED : July 1, 1975

INVENTOR(S) : Nicolas Mironoff

It is certified that error appears in the above-identified patent and that said Letters Patent are hereby corrected as shown below:

Please delete "[73] Assignee: Bovard & Cie, Bern, Switzerland"

Signed and Sealed this

Twenty-second **Day of** *November 1977*

[SEAL]

Attest:

RUTH C. MASON
Attesting Officer

LUTRELLE F. PARKER
Acting Commissioner of Patents and Trademarks