

# PATENT SPECIFICATION

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## (54) EDM PARAMETER CONTROL SYSTEM

(71) We, INOUE-JAPAX RESEARCH INC., a Japanese body corporate, of 5289 Aza Michimasa, Nagatsudamachi, Midoriku, Yokohamashi, Kanagawaken, Japan, do hereby declare the invention, for which we pray that a patent may be granted to us, and the method by which it is to be performed, to be particularly described in and by the following statement:—

This invention relates to a system for controlling a parameter in electrical discharge machining (hereinafter referred to as "EDM") and to EDM apparatus including a said system, and also includes within its scope articles when machined by such EDM apparatus.

In the EDM process, electric pulses are passed intermittently across the machining gap formed in a dielectric, usually liquid, between a tool electrode and a workpiece, each pulse bringing about an electric discharge through the dielectric filled gap to remove material from the workpiece. As the material removal due to the machining proceeds, the tool electrode is advanced relative to the workpiece by a servo feed arrangement to maintain the machining gap at a given size. The servo arrangement may also function to respond to gap short circuit and arcing conditions to retract the electrode relative to the workpiece, thereby removing such conditions.

During the machining operation, small chips and particles, tar and other matter produced by the electric discharge are carried away by the dielectric liquid. The latter is generally circulated through the gap and forced to flow from or to be sucked into, a bore formed through the electrode and/or the workpiece and directly open to the machining region. In certain EDM applications, however, in which machining is to be performed under "no wear" conditions, requiring a minimization of the wear of the tool electrode by machining discharges, it has been found undesirable to forcibly circulate the dielectric liquid through the machining region, at least during the time in which a train of machining discharge pulses is produced across the

gap. Accordingly, in such applications, it has been the practice to interrupt the supply of machining pulses to the gap periodically and to effect the forced dielectric supply through the bored electrode or workpiece selectively during the interruption period. Another technique which has been used heretofore is to intermittently retract or reciprocate the electrode relative to the workpiece by means forming part of the EDM apparatus and independently of the gap-adjusting function of the servomechanism. This latter technique, in which relative retraction between the electrode and the workpiece is followed in each reciprocating cycle by returning them to the normal machining position, has been found to be an especially simple and advantageous method of effectively cleansing the gap of contaminants while permitting the machining action to proceed under the required no-wear conditions. In this case, one or more nozzles can be employed positioned externally of the machining gap and designed to direct a stream or streams of fresh dielectric liquid toward the machining region.

As the machining proceeds and the tool electrode penetrates progressively into the workpiece increasing the depth of a cavity being formed therein, the discharge conditions in the gap tend to become unstable generally, as a result of increasing difficulty in removing machined chips and other contaminants from the region of the gap cavity, thereby causing undesirable short-circuiting and sustained arcing to develop between the tool electrode and the workpiece and damage to either or both of them. In order to counter these difficulties, various corrective and programmed or anticipatory measures have been proposed and are being used in existing EDM machine tools. These measures include changing the rate of dielectric flow through the gap and the use of a reciprocatory movement as mentioned in the preceding paragraph in a controlled manner. Also, control of machining pulses has been found important. For such control, reference is here made to Kiyoshi Inoue United States Patent No.

3,539,755 issued November 10, 1970 and No. 3,536,881 issued October 27, 1970. These patents disclose concepts for adaptive control of the gap current by controlling machining pulse "on" time and/or "off" time in response to a signal derived from the gap to optimize the EDM process by protecting the gap against sustained arcing and other undesirable conditions or by maintaining the gap current density constant with the progress of machining. It has also been found desirable to alter, in the course of a machining operation, a threshold value settable in a servo-control circuit and in a machining pulse generator circuit in order for the problem as noted above to be obviated or alleviated effectively. For this type of control concept, reference is here made to Kiyoshi Inoue United States Patents Nos. 3,604,885 and 3,686,461 issued September 14, 1971 and August 22, 1972, respectively. Proposals have also been made in the art heretofore for changing controllably voltage and current magnitudes of a series of machining pulses, and waveform or configuration thereof, with the progress of machining or in response to the gap condition.

While, by virtue of these control concepts, significant advances have been made in the art of EDM to improve the quality of machining and it has become possible to automate an EDM operation, existing systems embodying these control concepts are found unsatisfactory in terms of machining efficiency which can be expressed by the time consumed to complete a given machining operation in order to produce a desired result. Furthermore, many EDM control systems now brought into practice are, in spite of their efforts, not successful to completely prevent or suppress any thermal arc which damages the workpiece or the tool electrode or both as noted previously. If successful, these efforts may result in an undue decrease in machining efficiency. In many commercial EDM machine tools, either the occurrence of the arcing damage could only be prevented by a skilled operator's supervision of the machine in operation or it could be terminated and its source removed only by stopping the machining operation. In summary, therefore, there are vital needs for a control system which provides an increased machining efficiency, ensures excellent machining results which are free from arcing damage and permits operation on a fully or substantially fully automatic basis.

According to the invention, in a first aspect thereof, a system for controlling an EDM parameter in the operation of an EDM apparatus comprises input circuit means having an input terminal for coupling to an EDM gap formed between a tool electrode and a workpiece for monitoring the state of EDM performance in the gap to provide a first signal

upon detection of the occurrence of a predetermined condition in the gap within a first time period and to provide a second signal upon non-detection of such a condition in the gap throughout a second time period, and timing means for causing the said second time period to have a duration greater than that of the said first period; memory means connected to the said input circuit means for receiving the said first and second signals and having a memory level arranged to be changed in accordance with the latest-received of these signals; and setting means with an ordered set of positions arranged to establish respective values of the said parameter corresponding to memory levels in the said memory means and to be altered in respective directions in the said ordered set in accordance with any change in corresponding directions of the memory levels of the said memory means.

According to the invention, in a second aspect thereof, an EDM apparatus includes a system in accordance with the said first aspect of the invention.

The invention also includes within its scope an article when machined by an EDM apparatus in accordance with the said second aspect of the invention.

Typical EDM parameters for control by the present system include the length of the intermittent relative retraction between the tool electrode and the workpiece which, as noted previously, is used desirably in many EDM operations to remove machining chips and other machining products from the machining gap regions, the time interval between adjacent cycles of the intermittent relative retraction, and the time interval between adjacent machining pulses, singly or in any combination of two or three of these. Where the two parameters of the intermittent relative electrode retraction are to be controlled, it has been found advantageous and effective to control them simultaneously in such a manner as to increase the length of the retraction while decreasing the time interval between retraction cycles in response to the first signal indicated above and to decrease the length while increasing this time in response to the second signal which is representative of a normality of the EDM gap state.

In accordance with specific features of embodiments of the present invention, the monitor means comprises detector means connected to the EDM gap for selectively detecting those pulses applied across the EDM gap which have an unfavourable result, e.g. such as short-circuiting or arc discharge. Counter means included on the detector means, are arranged to serve, upon counting up a preset number of the unfavourable pulses, to provide an output to supply the aforementioned first signal. More specifically, the de-

tector means may be arranged for selectively detecting those pulses applied across the EDM gap which have a favourable result, e.g. a desired discharge characteristic or machining quality, and for selectively detecting the unfavourable pulses, the detector means including first and second counter means for counting respectively the two kinds of pulses. The second counter means are here coupled to the first counter means and arranged to provide an output to supply the afore-mentioned first signal when this counter has counted up a preset number of the unfavourable pulses before the first counter has counted up a preset number of the favourable pulses.

The detector means may further include a third counter means for timing a time duration, corresponding to the aforementioned second period, the third counter means being coupled to the first and second counter means for providing an output to supply the aforementioned second signal in the absence of the first signal in said time duration. The third counter means may count the favourable gap pulses counted by, or the output of, the first counter means and provide its said output when it has counted up a preset number which is greater than the count number preset for the first counter means to provide its output. The third counter means, may, alternatively, be arranged to count pulses related to the intermittent relative retractions between the tool electrode and the workpiece to provide the output to supply the second signal upon counting up a preset number of the such pulses in the absence of the output of the said first signal. In this connection, it is desirable to control the frequency of the relative retractions as a function of an EDM gap variable such as the gap voltage. In such case, and generally, pulses counted by the third counter means, when coupled to the EDM gap, may be related to the machining performance at the EDM gap.

In accordance with further specific features of embodiments of the invention, the control means may include setting means having setting positions provided corresponding to preset different magnitudes of the EDM parameter and each position selectively actuable to establish the corresponding magnitude of the parameter in the EDM apparatus. Two signal means provided in the monitor means provide respectively the first and second signals, detected in the manner mentioned above and these signals, upon each occurrence thereof, are transmitted to the control means to change the setting means from one to another of the setting positions to establish a magnitude of the EDM parameter increased or decreased from the prior, lower or higher magnitude thereof in accordance with the signal. The control means may further include a memory means, which can be constituted by an up-down counter, coupled to said

two signal means to receive and store said first and second signals. The memory means has a possible number of memory levels, and possibly output stages, which corresponds to the number of the parameter setting positions and is adapted to receive said first and second signals to establish a memory level and provide an output to supply the setting means, the memory level and output being determined by the storage of the received signals and the newest one of them received by the memory means, said output actuating the setting position in the setting means preset to correspond to the output to establish the corresponding magnitude of the EDM parameter in the EDM apparatus.

The control means may further include a reference memory means which can again be constituted by an up-down counter and arranged to monitor the memory level of the first memory means and regulate the control output thereof. The reference memory means is here arranged to count a time, a third period, which is even longer than the time counted by the afore-mentioned third counter. More specifically, the reference memory means is arranged to lower its memory level by one increment when any gap abnormality has not been detected through monitoring the gap state over said third period after the coincidence of the memory level of the first memory means with the reference memory level, permitting the memory level of the first memory means to be lowered and supply a control signal to the setting means. When a gap abnormality is detected during a preset time, said third period, after the coincidence, the reference memory raises its memory level by one increment while permitting the memory level of the first memory means also to rise by one increment. At no time is the memory level of the first memory means, which provide a control command to the parameter setting means, reduced below the reference memory level variably established at the reference memory means. The regulation of the first memory means by the reference memory means provides a very stable control of the EDM parameter and effectively avoids excessive change in the magnitude thereof and thus results in an excellent machining performance and result.

One form of system and apparatus embodying the invention will now be described, by way of example only, with reference to the accompanying drawings in which:—

Figures 1 and 2 together represent a block diagram of the system;

Figure 3 shows wave forms appearing at various locations of the portion of the system shown in Figure 2; and

Figure 4 is a graphic representation of the progress of an EDM machining operation using the apparatus.

In Figures 1 and 2 various gates are shown

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which are referenced by prefixes denoting their function and suffix numerals distinguishing the various gates having the same function.

5 Referring to Figure 1, a counter *C1* is shown with its input connected to a terminal 1 that receives "OK pulse" signals from a discriminator circuit (not shown) which selectively gates or detects "OK pulses" among  
10 a series of pulses applied across the gap between the tool electrode and the workpiece. By the term "OK pulse" is meant herein a pulse which results in a satisfactory machining discharge. Whether each individual  
15 pulse applied across the machining gap is an "OK pulse" or not can be determined, for example, by measuring the voltage or current level of the pulse after the initiation of its current flow through the gap with respect  
20 to a threshold value which will serve for discriminating between a normal (desired) discharge pulse and a short-circuiting, arcing or other undesirable quality pulse. The counter *C1* with its associated input circuitry  
25 (not shown) is thus designed to receive and count OK pulses selectively. When it has counted up to a given number of the input pulses, say, eight (8) OK pulses, it is cleared to start counting again. When the counter *C1*  
30 is cleared, it transmits a "clear" signal to clear a second counter *C2*.

The second counter *C2* is shown with its input connected to a terminal 2 that receives  
35 "NG (No Good) pulse" signals from a discriminator circuit (not shown) which selectively gates or detects "NG pulses" among a series of pulses applied across the gap between the tool electrode and the workpiece. By the term "NG pulse" is meant herein a  
40 pulse which has an unfavourable result, usually every current pulse that is discriminated from an "OK pulse". The counter *C2* with its input circuitry is thus designed to count NG pulse selectively. And, when it  
45 has counted up to a given number of the input pulses, say, four (4) NG pulses, before receiving the "clear" signal from the counter *C1*, it provides at its output a trigger signal which indicates the condition of the machining  
50 gap as "abnormal", the signal triggering a monostable multivibrator or like timer *T1* to provide a "0" signal pulse at its output.

The counter *C2* is thereupon cleared and  
55 rendered ready to commence counting again. If, however, the counter *C2*, before it has counted up to the preset number of NG pulses, is cleared by the "clear" signal received from the counter *C1*, indicating that the  
60 preset number of OK pulses have occurred, no output will be generated to trigger the timer *T1* and the latter will maintain a "1" output. Thus, the time *T1* will have a brief "0" output signal indicative of a gap abnormality selectively when the counter *C2* counts  
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up to the preset number of NG pulses before the preset number of OK pulses are detected by the counter *C1*. These numbers of pulses to be preset will be determined in dependence upon the type of machining  
70 operation being performed, the materials of the tool electrode used and the workpiece to be machined and other machining factors.

A third input terminal 3, coupled to a  
75 third counter *C3* and a fourth counter *C4*, is in this embodiment designed to count a reciprocatory movement, i.e. a number of pulses each generated in synchronism with a retraction of the tool electrode relative to the  
80 workpiece, and, when a preset number of such movement-indicating pulses, say eight pulses, is counted by the counter *C3*, the latter provides an output signal.

This output signal is fed back to a clearing  
85 circuit of the counter *C3* through gates *NOT2* and *NAND1*, the latter gate having another input terminal connected to the output terminal of the timer *T1*. Accordingly, it is seen that the counter *C3* immediately clears, ready  
90 to restart counting the relative reciprocatory movement pulses, whenever a gap abnormality "0" signal is generated by the timer *T1* and received by the gate *NAND1*, as well as when the counter *C3* counts up the preset number  
95 of reciprocatory movement pulses, a count of eight in this embodiment. The counter *C3*, upon having counted this preset number, thus generates a "1" output signal, which indicates the condition of the gap as normal, when the  
100 preset number of NG pulses (four NG pulses) has not occurred and has not been counted by the counter *C2* during the time marked by the counter *C1*, i.e. the time to count  
105 eight OK pulses, this latter time being much shorter than the time in which the preset number of the reciprocation pulses is counted by the counter *C3*.

The output signal from the counter *C3* is fed, via one input of each of gates *NOR1*  
110 and *NAND2*, to the down terminal *dn1* of an up-down counter *UDC1* to have it count down one increment. This assumes that neither of the gates *NOR1* and *NAND2* has at its other input an inhibiting signal, being  
115 received respectively from a comparator *B* and a decoder *D1* which will be described.

The up-down counter *UDC1* is here designed to have ten coded count outputs 0 to 9  
120 corresponding to ten incrementally different magnitudes (to be selected respectively by the counter *UDC1*) of an electrical discharge machining parameter such as the time interval between adjacent machining pulses, the distance or length of the relative retraction of  
125 the tool electrode from the machining position in the reciprocatory movement or the time interval between adjacent retracting cycles, i.e. the time interval in which the electrode and the workpiece are held in  
130 machining position, or any other critical

machining parameter. These magnitudes of a parameter are established by ten corresponding positions provided in a setting device to be described, selectively switched over from one to another of the ten positions by the corresponding count outputs from the up-down counter *UDC1*.

The up-down counter *UDC1* has a count-up terminal *up1* to which the "0" output signal of the timer *T1* indicative of a gap abnormality when detected is fed via gates *NOT1* and *NAND3* to count up by one increment every time the timer generates the "0" signal, provided that there is not an inhibiting input 0 to the gate *NAND3* from the decoder *D1*.

The decoder *D1* decoding the output of the up-down counter *UDC1* provides inputs to gates *NAND2* and *NAND3* to inhibit the count-down command from the gate *NOR1* and the count-up command from the gate *NOT1* from passing through the gates *NAND2* and *NAND3* when the counter *UDC1* has reached the count levels 0 and 9, respectively.

The fourth counter *C4* is designed to provide an output signal when it has counted a preset number of the relative electrode retractions, i.e. reciprocatory movement pulses, which number is here much greater than the number preset for the counter *C3*, and is, say, a count of 128 of the relative retractions. In view of the size of this number, counter *C4* consists of two counters in series. The output signal of the counter *C4* is fed back to its clearing circuit via gates *NOT3* and *NAND4* connected in series. The latter has a second input terminal leading from the timer *T1* afore-mentioned and a third input terminal leading from a timer *T4* which in turn is connected to the comparator *E* which normally has a "0" output but, when the output is changed to "1", actuates the timer *T4* which then provides a brief "0" output signal. Accordingly, the counter *C4* immediately clears and restarts its counting when it has counted the preset number, the count of 128, or when a gap abnormality "0" signal is received by the gate *NAND4* from the timer *T1*, or when the gate *NAND4* receives the "0" output of the timer *T4* which indicated the output of the comparator *E* changing to "1". In terms of the operation, the counter *C4* starts counting upon the clearing of its previous count by the "0" output of the timer *T4* applied to the gate *NAND4*. When it has counted the 128 input pulses without a gap abnormality "0" signal from the timer *T1*, the counter *C4* will provide the "0" signal at the output of the gate *NOT3* and at one input terminal of gate *NOR2*. The other input terminal of the latter is fed by an inverter gate *NOT4* whose input terminal is connected to the comparator *E*. Thus it is seen that the "0" signal indicating

the completion of the 128 counts is admitted to the gate *NOR2* and provides a "1" signal at the output thereof only when the output of the comparator *E*, whose function will be described, is "1". The "1" signal derived from the admitted signal is in turn fed via a gate *NAND5* to the down command input *dn2* of an up-down counter *UDC2* to reduce its count level by one count. Decoder *D2* monitors the count level of the counter *UDC2* and issues a signal to the gate *NAND5* which inhibits the down command from being applied to the counter *UDC2* when the latter has reached the lowest (0) count level.

The comparator *E* is connected between the first and second up-down counters *UDC1* and *UDC2* and, as mentioned previously, has normally "0" output. It is designed to provide "1" output when the count level of the first up-down counter *UDC1* coincides with that of the second up-down counter *UDC2*. When the "1" signal is developed, the gate *NOR1* is disabled or closed thereby so that, if the count-down command is generated by the counter *C3*, this cannot cause count down of the counter *UDC1* and the latter must instead hold the existing count level. Thus at no time will the first up-down counter *UDC1* reduce its count level below that of the second up-down counter *UDC2*. As has been noted, the "1" output of the comparator *E* is also fed on the one hand to the timer *T4* to reset the counter *C4* and on the other to the gate *NOR2* via the inverter gate *NOT4*. It follows that the counter *C4* is allowed to start or restart counting pulses corresponding to the intermittent relative electrode retractions and the gate *NOR2* is enabled or opened as soon as the count level of the first up-down counter *UDC1* coincides with that of the second up-down counter *UDC2*, and that the count-down command is available at the input of the second up-down counter *UDC2* upon the counter *C4* completing the preset count number (128 counts) and if the coincidence of the count level is maintained between the two up-down counters *UDC1* and *UDC2*. If in the meantime a gap abnormality is detected by the counters *C1* and *C2* and the "0" signal is developed at the output of the timer *T1* accordingly, the counting operation by the counter *C4* is terminated and the latter is reset. Thus the count-down action of the second up-down counter is strictly regulated.

The count-up terminal *up2* of the up-down counter *UDC2* is connected to the output of the gate *NOT1* via gates *NOR3*, *NOT5*, *NAND6*, timer *T3* and gate *NAND7* in series, the gate *NOT1* providing the inverted gap normality "0" output and gap abnormality "1" output corresponding to the gap normality "1" output and gap abnormality "0" output of the timer *T1*. In this series circuit, the gate *NAND6* has one input ter-

minal connected to the output of a timer *T2* whose input is connected to the comparator *E*. As long as the latter has "0" output, the timer *T2* remains deactuated supplying  
 5 "0" output to the gate *NAND6* and thus holding this latter gate closed to its input signal from gate *NOT5* and as a result the input to the timer *T3* is held at "0" which  
 10 input is also fed back to the gate *NOR3*. When, however, the output of the comparator *E* is changed to "1" in response to the count level of the first up-down counter *UDC1* dropping to coincide with that of the second  
 15 up-down counter *UDC2*, the timer *T2* is actuated to open the gate *NAND6* and to hold it open for a pre-selected time interval, say 40 seconds, which depends on the purpose of the machining operation and materials of the electrode and the workpiece  
 20 and other machining factors. In this time interval, when a gap abnormality signal is detected by the gate *NOT1* and thus gate *NOR3* receives a "1" output therefrom, this signal is transmitted through  
 25 gates *NOT5*, *NAND6* and *NOT6* gates and develops "1" input to the timer *T3* to actuate it. The pulse generated by the timer *T3* is fed via the gate *NAND7* to the count-up terminal *up2* of the up-down counter  
 30 *UDC2* to raise its count level by one. Meanwhile, the same gap abnormality "1" output of the gate *NOT1* is also fed via the gate *NAND3* to the count-up terminal *up1* of the first up-down counter *UDC1* to raise  
 35 its count level by one. The first up-down counter *UDC1* may further raise its count level incrementally if and every time it receives a further gap abnormality "1" signal from the gate *NOT1*. As will be readily  
 40 apparent, however, the second up-down counter *UDC2* is here forbidden to raise its count level by more than one for said preset time interval, 40 seconds. After the beginning of the time interval, once a single  
 45 gap abnormality signal is received, the "1" signal developed at the output of the gate *NOT6* is fed back to the gate *NOR3* which is locked thereby and the resetting of the gate *NAND6* is inhibited until the timer  
 50 *T2* finishes timing the said interval and its output is returned to "0". After the timing of the interval has been finished the timer *T2* will remain deactuated until it receives a further "1" signal from the com-  
 55 parator *E* which indicates that the count level of the up-down counter *UDC1* again coincides with that of the up-down counter *UDC2*. And, of course, if no gap abnormality signal is received from the timer *T1* during the time interval established by the  
 60 timer *T2*, no count-up takes place in the up-down counter *UDC2*.

The significance of the functions of the second up-down counter *UDC2* which is used  
 65 herein as reference or regulator counter for

the first, machining-parameter control counter *UDC1* will be more fully understood from the description which follows.

Let it be assumed that the counter *UDC2* has now reached the *n*-th count level of the possible 0 to 9 incremental count levels while the control counter *UDC1* in response to the incoming signals is performing or repeating count-up and count-down in the range of count levels higher than the *n*-th level and is controlling switching between control positions of the setting device in accordance therewith, and thus controlling magnitudes of a machining parameter set by these positions. Following such a condition, the control  
 70 counter *UDC1* may lower its count level to coincide with the *n*-th level of the reference counter *UDC2*, in response to the gap signal received by its count-down terminal indicating that the machining performance at  
 75 the machining gap is improving. A new magnitude of the machining parameter is then established in the setting device to correspond to the *n*-th count level by the counter *UDC1* and used for subsequent machining. If the new parameter magnitude is in fact adequate to permit machining to proceed satisfactorily, there should, during the appropriate time interval established by the timer *T2*, develop no gap abnormality signal requiring  
 80 the count-up to be made to return the magnitude of the machining parameter to the previous one, and the system properly ensures the maintenance of the *n*-th count level and hence the *n*-th parameter magnitude until the appropriate time interval is terminated.

It is important to note that, after the count level of the control counter *UDC1* has coincided with the count level of the reference counter *UDC2*, a "gap normality" signal will again and repeatedly appear at the output of the counter *C3* and at the input of the gate *NOR1* which leads via the gate  
 85 *NAND2* to the count-down input terminal of the control counter *UDC1*. In the system provided, however, transmission of this signal is inhibited by the "1" output of the comparator *E* so that the control counter *UDC1* is locked against any further down-count command for a relatively long time interval,  
 90 namely until after a preset number of pulses, e.g. 128 pulses, have been counted by the counter *C4*. Thus, only after the completion of the latter count which results in the count-down by one of the count levels of the reference counter *UDC2* is the control counter  
 95 *UDC1* permitted to reduce its control count level by one in response to a gap normality signal, at which time the count levels of the two up-down counters coincide again. This effectively minimizes premature count-down of the control counter *UDC1* and thus eliminates such an excessive degree of change of the magnitude of the machining parameter as would have damaging results to the work-  
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piece and avoids an excessive reversed change of the parameter value or the consequent "hunting" condition.

After the coincidence of count level between the control counter *UDC1* and the reference counter *UDC2*, it is possible that the newly established magnitude of the machining parameter is, when used, inadequate to permit machining to go on satisfactorily but such a premature count-down is detected and corrected promptly. Upon the coincidence at the *n*-th count level between the two counters, the timer *T2* immediately initiates the monitoring period, e.g. 40 seconds during which period a gap abnormality signal, if developed, is transmitted by the timer *T1* to the count-up terminal of the control counter *UDC1* to return its count level to the previous one, the (*n*+1)th level. At the same time, the gap abnormality signal raises also the count level of the reference counter *UDC2* by one. Thus, the new reference level, the (*n*+1)th level, is established which prohibits the count level of the control counter *UDC1* from dropping therebelow. During the monitoring period mentioned above, a further gap abnormality signal may be detected and developed by the timer *T1* which will then raise the control counter *UDC1* to the (*n*+2)th count level which in turn readjusts the magnitude of the machining parameter accordingly so as to prevent the gap abnormality from recurring. The count level of the reference counter *UDC2*, however, remains at the (*n*+1)th level and waits for the count level of the control counter *UDC1* to drop to this reference level.

With the coincidence of the two counters *UDC1* and *UDC2* at the *n*-th count level, a situation will also arise which requires a temporary count-up of the count level of the control counter *UDC1*. Thus, if no gap abnormality signal is detected during the test period which commences upon the coincidence of the two counter's count levels and terminates upon the lapse of the time established by the timer *T2* (40 seconds), the two counters *UDC1* and *UDC2* will, after the termination of said test period, maintain the coincident *n*-th count level, the control counter *UDC1* providing the magnitude of the machining parameter defined thereby. Thereafter, if an abnormal condition occurs at the machining gap, the timer *T1* will provide the gap abnormality signal indicative thereof to cause the count level of the control counter *UDC1* to rise, by one count to the (*n*+1)th level while the count level of the reference counter *UDC2* is maintained at the *n*-th level. The (*n*+1)th count level of the control counter *UDC1* provides the new magnitude of the machining parameter and, if the abnormal gap condition is removed promptly, due to that parameter magnitude the counter *C3* will count up the preset number of pulses,

e.g. eight counts as noted previously, to return the control counter *UDC1* to the *n*-th level. If the abnormal gap condition is not cleared or another gap abnormality is created, a further signal indicative thereof will be developed by the timer *T1* to raise the control counter *UDC1* to the (*n*+2)th count level. Then, if the machining gap resumes acceptable discharge performance or other favourable machining conditions, the elevated count level is promptly reduced incrementally in response to the gap normality signals developed by the counter *C3* until it is returned to the *n*-th level.

At the right-hand side of Figure 1 there is shown a readout unit having a display decoder *D3* and a tube display *V* connected to the output terminal of the up-down control counter *UDC1* to provide a visual display of the output signal thereof, the control count level, which signal is also fed via the output terminal *OUT* to the parameter setting unit which will be described with reference to Figure 2.

In Figure 1 there is also shown a digital switch, indicated by the reference character *DS*, designed to permit the manual setting of the count level of each of the two counters *UDC1* and *UDC2*. The digital switch *DS* is associated with a selector switch *SW* used to connect selectively an "automatic" terminal *AUT* and a "manual" terminal *MANUT* with the two up-down counters *UDC1* and *UDC2* via gates *NOR4* and *NOT8*. This arrangement ensures that a manipulation of the digital switch *DS* is effective to set the counters *UDC1* and *UDC2* only when the manual terminal *MANUT* is set at the switch position, so that it is ineffective when the *AUT* terminal is in the switch position shown which locks the counters against the functioning of the digital switch *DS*. Use of the digital switch is required or desirable in certain types of machining operation which are advantageously to be started at an initial reference count level which is greater than the "0" level. In these operations, different initial reference levels are desirable or required to be used depending on the type of configuration of the tool electrode and the shape to be imparted to the workpiece as well as when switching from "rough" operation to "finish" operation in machining a single workpiece.

Reference character *CLT* designates an input terminal for providing a "clear" signal to counters *UDC1* and *UDC2* to return the count levels of these counters to 0 when desired, e.g. at the end of a given machining operation. The "clear" signal from the terminal *CLT* is fed to the counters via gates *NOT7* and *NAND8*, the latter having another input terminal *ONT* connected thereto. The input terminal *ONT* is here designed to provide a "clear" signal when the EDM

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power supply is switched on so that the previous count storage if any may be removed automatically at the start of a new machining operation.

5 Referring now to Figure 2 which illustrates an embodiment of a machining-parameter setting device suitable for use with the embodiment of Figure 1, the output of the control up-down counter *UDC1* which develops at its output terminal *OUT* is shown, proceeding from right to left in Figure 2, applied to a decoder *D4* which is designed to provide the control commands for controlling the magnitude of one or more controllable EDM parameters. More specifically, the decoder *D4* here is provided with 10 output stages to correspond to the 10 count levels of the control counter *UDC1* and to be selectively actuable by the occurrence of the corresponding counter level to select and establish one of the 10 different magnitudes for each of one or more of the EDM parameters. In the figure, only the *N*-th setting stage or circuit is shown coupled to the *N*-th output of the decoder *D4* for the sake of clarity and it will be understood that 9 similar setting circuits are coupled respectively to the other 9 outputs of the decoder *D4*. As noted previously, the critical EDM parameters include as typical the time interval between adjacent discharge machining pulses, the length of the relative retraction of the tool electrode away from the workpiece in the reciprocatory movement which is used and effected independently of the gap-adjusting servomechanism, the time interval between adjacent cycles or strokes of the reciprocatory movement, i.e. the time duration in which the electrode and the workpiece are held in machining position to permit discharges to take place, the reference voltage or control level in the servo feed control and the rate of the forced circulation of the dielectric liquid through the machining gap. In the description which follows, an explanation of the control system proposed according to this embodiment will be made using, by way of example, the two variables mentioned above of the reciprocatory movement.

Each setting circuit includes a pair of transistor switches *Tr1* and *Tr2* which are coupled to monostable multivibrators *M1* and *M2* respectively. As mentioned before, each setting circuit receives an input signal from the decoder *D4* selectively addressed thereto. Thus, the *N*-th setting circuit receives such a signal from the *N*-th output of the decoder *D4* when the control up-down counter has the *N*-th level, at which time no output signal develops at the other 9 outputs of the decoder *D4*. The transistor switches *Tr1* and *Tr2* are rendered and held conductive when and while they receive the input signal to make and hold the monostable multivibrators *M1* and *M2* operable. Here the first monostable multivibrator *M1*, if triggered, provides at

the terminal *UP* a pulse of a duration set to correspond to a given length of the relative retraction of the electrode from the workpiece in the reciprocatory movement. The second monostable multivibrator *M2*, if triggered, provides at the same terminal *UP* a pulse whose duration is set to define a given length of time, the machining timer interval, between adjacent reciprocatory cycles, more specifically between the time when the electrode is returned to the machining position and the time when the electrode is thereafter retracted to interrupt the machining. A circuit for triggering the second monostable multivibrator *M2* is designated by reference character *COT* and comprises a terminal *G* connected to the machining gap to sense the mean gap voltage, and a Schmitt trigger circuit *SM* which discriminates the mean gap voltage with respect to a threshold value and, when the gap voltage drops below this value, supplies a trigger signal to the multivibrator *M2* through gates *NAND9* and *NOT9*. The first multivibrator *M1* initiates its timing operation upon completion of the timing of the second monostable multivibrator *M2*. A second input of the gate *NAND9* leads from the first multivibrator *M1* and serves to hold the second multivibrator *M2* against actuation while the first multivibrator is in operation. The signals developed at the terminal *UP* are applied to a control circuit in the relative electrode drive system, e.g. control coils in the hydraulic servo feed system to supplant any servo signal then developing.

In Figure 3 there are shown waveforms encountered in the arrangement shown in Figure 2 for which waveforms the amplitude is plotted as the ordinate against time plotted as the abscissa; the waveform *A* represents the gap mean voltage appearing at the terminal *G*, waveform *B* represents the output of the Schmitt trigger *SM*, waveform *C* represents the output of the monostable multivibrator *M2* and waveform *D* represents the output of the monostable multivibrator *M1*.

Assume that the transistors *Tr1* and *Tr2* are switched on in response to the output of the decoder *D4* to render the multivibrators *M1* and *M2* ready for operation. Assume also that then the tool electrode has been retracted away from the workpiece. Thereupon, the tool electrode approaches the workpiece to narrow the gap between them. At time *t1* the first of a series of machining electrical discharges is shown to take place. The occurrence of the electrical discharges will initially be sporadic but with the further decrease of the gap spacing the number of them that occur per unit time approaches that of electrical pulses applied to the machining gap, with the resulting gradual decrease of the gap mean voltage as shown. At time *t2* it is shown that the gap spacing reaches an optimum value at which machining is to pro-

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ceed and the Schmitt trigger circuit *SM* in response to the reduction of the mean gap voltage below a preset level is operated to provide a digital "1" output which triggers the monostable multivibrator *M2* into actuation. The preset time constant in the multivibrator *M2* determines the machining time or the duration of the time for which the tool electrode and the workpiece are held in machining juxtaposition. At time  $t_3$ , upon termination of this time duration, the deactuation of the multivibrator *M2* triggers the multivibrator *M1* into actuation, providing at the terminal *UP* a signal pulse to retract the tool electrode away from the workpiece. At time  $t_4$ , the electrode retracting signal pulse is shown to terminate, at which time or shortly thereafter the electrode reaches its uppermost position (i.e. its position furthest from the workpiece). The servo signal will then allow the electrode automatically to reapproach the workpiece, permitting the aforesaid cycle to be repeated from the time  $t_5$  and the fixed machining time duration to restart at time  $t_6$ . The time interval between time  $t_4$  and time  $t_5$  or  $t_6$  which represents the time required for the servo signal to return the electrode automatically to the machining position is, as will be apparent, generally proportional to the length or other extent of the electrode retraction determined by the time interval between times  $t_3$  and  $t_4$ . A suitable means, however, may be employed to reduce or independently adjust the time interval  $t_4-t_5$  or  $t_4-t_6$  so that the machining interruption period or rest time  $t_3-t_5$  or  $t_3-t_6$  can be reduced or controlled as desired.

It should be understood that notwithstanding the use of the terms "machining interruption period" and "machining rest time" for the time interval between  $t_3$  and  $t_5$ , it is not intended to exclude the possibility of some electric discharges performing a machining function occurring during this time interval. In fact, if a length of retraction as short as 0.01 to 0.02 mm is used, a portion of applied electrical pulses may actually bring about electrical discharges across the widened gap during the time interval in question although the frequency of the discharges then is reduced sharply.

As noted previously, each of the ten setting circuits or stages respectively coupled to the ten outputs of decoder *D4* has the same construction and mode of operation as has been shown and described, with reference to the *N*-th circuit or stage, with the exception that the time settings of multivibrators *M1* to *M2* each vary from one setting stage to another progressively or incrementally to provide different magnitudes of the length of the electrode retraction and of the machining duration. Thus, in a typical example, the multivibrator *M1* in the *N*-th setting stage is designed to provide a magnitude of the length of the electrode retraction which is greater by a preset amount than the magnitude provided by the (*N*-1)th stage multivibrator *M1* and smaller by the same or different preset amount than the magnitude provided by the (*N*+1)th stage multivibrator *M1*. Similarly, the multivibrator *M2* in the *N*-th setting stage is designed to provide a magnitude of the machining duration (i.e. the time duration in which the electrode and the workpiece are held closely spaced in a desired machining position) which is shorter by a preset amount than the magnitude provided by the (*N*-1)th stage multivibrator *M2* and longer by the same or different preset amount than the magnitude provided by the (*N*+1)th stage multivibrator *M2*.

Although one of the two time setting means *M1* and *M2* in each setting stage can be employed to effect the control of either the length of the electrode retraction or the machining duration stepwise in response to the detecting and control system described with reference to Figure 1, it has been found to be particularly advantageous to employ both setting means and control these two parameters simultaneously and in combination by means of each control signal in the manner described, namely such as to increase the length of the electrode retraction and to decrease the machining duration as the ordinal number of the setting stages rises. This does, it has been found, effectively prevent arcing damage to the workpiece and the electrode and maintain the machining performance at an optimum level. An example of these parameter settings is shown in the following table:

TABLE I

|    | Setting Device<br>Positions | Retraction<br>Pulse Duration<br>( $t_3-t_4$ : ms) | Retraction<br>Length<br>(Rated: mm) | Machining<br>Duration<br>( $t_2-t_3$ : ms) |
|----|-----------------------------|---------------------------------------------------|-------------------------------------|--------------------------------------------|
| 5  | 0                           | 14                                                | 0.00                                | 450                                        |
|    | 1                           | 40                                                | 0.10                                | 400                                        |
|    | 2                           | 65                                                | 0.20                                | 355                                        |
|    | 3                           | 90                                                | 0.26                                | 310                                        |
|    | 4                           | 115                                               | 0.33                                | 260                                        |
| 10 | 5                           | 145                                               | 0.40                                | 215                                        |
|    | 6                           | 170                                               | 0.46                                | 170                                        |
|    | 7                           | 195                                               | 0.52                                | 120                                        |
|    | 8                           | 220                                               | 0.58                                | 73                                         |
|    | 9                           | 250                                               | 0.65                                | 25                                         |

15 The time interval between adjacent discrete electrical discharge pulses can be controlled similarly in accordance with an embodiment of the present invention. In this case, the pulse generator which provides signal pulses for creating these discharge pulses may be designed to have different time settings which are respectively actuable by outputs of the decoder *D4* so as to provide different preset magnitudes of the time interval respectively in accordance with different count levels that are reached by the control counter *UDC1*. Here, the different time setting means may each include a capacitor or resistor, constituting a time determining element therein, which is selectively switched and operable in the circuit responsive to the corresponding output of the decoder *D4* when the counter *UDC1* has the count level preset to correspond thereto.

35 It should be noted that the input to the terminal 3 in Figure 1 may not be limited to pulses related to the electrode reciprocatory movement mentioned earlier. As an alternative thereto, "OK signal pulses", or those forming the output of the counter *C1*, which are indicative of the gap normality can be the input to the terminal 3. The use of the "OK signal pulses" as the input to the counters *C3* and *C4* is particularly advantageous where the machining parameter to be controlled is the time interval between adjacent discrete discharge pulses.

#### EXAMPLE

50 With a paraffin as machining dielectric liquid and used not "circulated", a workpiece of S55C was immersed therein and was EDMed using a cylindrical copper electrode of a diameter of 20 mm. EDM pulses applied between the electrode and the workpiece had a pulse duration of 650 microseconds, an interpulse interval or rest time of 90 microseconds and a current amplitude (short-circuit current) of 70 amperes. A gap detector and control system generally as shown in and described in connection with Figures 1 to 3 was used to control, in the course of the machining operation, the intermittent retrac-

tive or reciprocatory movement of the electrode relative to the workpiece with the ten setting levels of the length of the retraction and the machining duration between adjacent reciprocatory cycles shown in the table I set forth earlier. Figure 4 shows the performance of the EDM operation in a graphic form in which time is plotted along the abscissa and the progress of machining represented by the depth of the cavity (mm) being formed in the workpiece (solid curve *L*) and the change of the count levels (count No. 0 to 9) of the control up-down counter *UDC1* (fluctuating curve *C*) are plotted along the ordinate. Bracketed reference numerals in the graph (0), (1), (2), (3), (4), (5) ... denote average or typical count levels of the counter *UDC1* which is shown are controlled to rise stepwise with the progress of machining.

As is apparent from the graph, the machining operation was started with the control counter *UDC1* and the reference counter *UDC2* both initially set at the 0 level and during time  $t_0$  to  $t_1$  the reference counter *UDC2* remained at the count level 0. It is seen that, during this period, a single count-up took place in the counter *UDC1* five times, as designated by reference *P1*, each time due to the detection by the timer *T1* and its associated circuitry of an abnormal condition in the machining gap, each count-up switching the setting device from the position 0 to the position 1 in the table I. It is seen that, upon each occurrence of this change, the count level was returned to 0 promptly. This shows that following the count-up no further abnormality signal was detected by the time the counter *C3* counted eight consecutive retractions of the electrode. It is seen that, shortly before time  $t_1$ , the counter *UDC1* raised its count level from 0 to 1 and from 1 to 2, in two steps. The raised level, denoted by reference *P2*, is shown to have then immediately dropped to 0 but the count level was thereupon raised again to 1 at time  $t_1$ . This rise shows that an abnormal gap condition was detected during the time the timer *T2* was in operation; thus

the reference count level, the count level of the reference counter *UDC2*, was also raised to 1.

In the second step (1), it is shown that the count level was dropped to 0 at point *P3*. This represents the fact that the counter *C4* counted 128 consecutive electrode retractions and no gap abnormality signal was detected in the meantime, causing the reference level to drop to 0. The count level of the control counter *UDC1* was also dropped to 0 due to the fact that the counter *C3* had counted 8 consecutive electrode retractions. The count-down to 0 is shown followed immediately by a count-up to 1 in the count level of both of counters *UDC1* and *UDC2*, which was caused by occurrence and detection of an abnormal gap condition. Similar count-down and count-up occurred at point *P4* and twice thereafter. Such repeated temporary count-down, however, has advantages and is highly significant here. It does hold the machining efficiency at a best possible level by removing an unnecessary count-up which would otherwise ensue under certain gap conditions and which is clearly a cause of a drop in machining efficiency. In spite of these efforts, it will be seen that at points *P5* a count-up was required in the counter *UDC1* and subsequently the count level of the reference counter *UDC2* elevated to 2. This means that a stable machining condition could no longer be maintained with the count level 1.

It will be appreciated that the reference counter provides an effective and advantageous means which ensures a stable and nearly sequential shifting as required, with the progress of an EDM operation, of the count level of the control counter, and hence of the control level of the parameter setting means without the level of fluctuating overmuch up and down, and thus results in an increased machining efficiency and a machining operation free from the danger of thermal arc discharges which damage the workpiece and the electrode.

While the illustration of an embodiment of the present invention has been made in the foregoing principally with reference to the control of the intermittent retractive or reciprocatory movement of the tool electrode relative to the workpiece employed to effect the removal of machining chips and other products from the gap regions, embodiments of the invention are equally applicable to any one or more of the other critical machining parameters such as, for example, the time interval between adjacent machining pulses. Manner of applying the invention, and of modification of the illustrated embodiment, to suit such other parameters will be clear to those skilled in the art.

From the foregoing, it will be appreciated that the embodiments described provide an

improved control system which controls a machining parameter in such a manner as promptly to clear an undesirable machining condition if created and substantially to prevent such condition from occurring with the mode of control continuously in adaptation to the changing state-of-the machining gap and through monitoring the gap state in an effective manner. These embodiments not only ensure an improved machining efficiency but have made possible the accomplishment of a given and required machining operation on a fully and completely automatic basis without the need for supervision by an operator while preventing the machining mode from shifting to a damaging thermal arc or other dangerous condition without failure and with a desired machining result.

#### WHAT WE CLAIM IS:—

1. A system for controlling an EDM parameter in the operation of an EDM apparatus, the system comprising input circuit means having an input terminal for coupling to an EDM gap formed between a tool electrode and a workpiece for monitoring the state of EDM performance in the gap to provide a first signal upon detection of the occurrence of a predetermined condition in the gap within a first time period and to provide a second signal upon non-detection of such a condition in the gap throughout a second time period, and timing means for causing the said second time period to have a duration greater than that of the said first period; memory means connected to the said input circuit means for receiving the said first and second signals and having a memory level arranged to be changed in accordance with the latest-received of these signals; and setting means with an ordered set of positions arranged to establish respective values of the said parameter corresponding to memory levels in the said memory means and to be altered in respective directions in the said ordered set in accordance with any change in corresponding directions of the memory levels of the said memory means.

2. A system according to Claim 1, wherein the said input circuit means includes a first present counter means with a said input terminal adapted to be connected in circuit with the said machining gap, the said first preset counter means being adapted, when connected in circuit with the said machining gap, to count electric pulses effected therethrough of a particular class selectively for issuing the said first signal upon counting up a preset number of such pulses within the said first period, the said first preset counter means being arranged for resetting upon termination of the said first period.

3. A system according to Claim 2, wherein the said circuit means further includes a second preset counter means with an input



the reference count level, the count level of the reference counter *UDC2*, was also raised to 1.

5 In the second step (1), it is shown that the count level was dropped to 0 at point *P3*. This represents the fact that the counter *C4* counted 128 consecutive electrode retractions and no gap abnormality signal was detected in the meantime, causing the reference level to drop to 0. The count level of the control counter *UDC1* was also dropped to 0 due to the fact that the counter *C3* had counted 8 consecutive electrode retractions. The count-down to 0 is shown followed immediately by a count-up to 1 in the count level of both of counters *UDC1* and *UDC2*, which was caused by occurrence and detection of an abnormal gap condition. Similar count-down and count-up occurred at point *P4* and twice thereafter. Such repeated temporary count-down, however, has advantages and is highly significant here. It does hold the machining efficiency at a best possible level by removing an unnecessary count-up which would otherwise ensue under certain gap conditions and which is clearly a cause of a drop in machining efficiency. In spite of these efforts, it will be seen that at points *P5* a count-up was required in the counter *UDC1* and subsequently the count level of the reference counter *UDC2* elevated to 2. This means that a stable machining condition could no longer be maintained with the count level 1.

35 It will be appreciated that the reference counter provides an effective and advantageous means which ensures a stable and nearly sequential shifting as required, with the progress of an EDM operation, of the count level of the control counter, and hence of the control level of the parameter setting means without the level of fluctuating overmuch up and down, and thus results in an increased machining efficiency and a machining operation free from the danger of thermal arc discharges which damage the workpiece and the electrode.

While the illustration of an embodiment of the present invention has been made in the foregoing principally with reference to the control of the intermittent retractive or reciprocatory movement of the tool electrode relative to the workpiece employed to effect the removal of machining chips and other products from the gap regions, embodiments of the invention are equally applicable to any one or more of the other critical machining parameters such as, for example, the time interval between adjacent machining pulses. Manner of applying the invention, and of modification of the illustrated embodiment, to suit such other parameters will be clear to those skilled in the art.

65 From the foregoing, it will be appreciated that the embodiments described provide an

improved control system which controls a machining parameter in such a manner as promptly to clear an undesirable machining condition if created and substantially to prevent such condition from occurring with the mode of control continuously in adaptation to the changing state of the machining gap and through monitoring the gap state in an effective manner. These embodiments not only ensure an improved machining efficiency but have made possible the accomplishment of a given and required machining operation on a fully and completely automatic basis without the need for supervision by an operator while preventing the machining mode from shifting to a damaging thermal arc or other dangerous condition without failure and with a desired machining result.

#### WHAT WE CLAIM IS:—

1. A system for controlling an EDM parameter in the operation of an EDM apparatus, the system comprising input circuit means having an input terminal for coupling to an EDM gap formed between a tool electrode and a workpiece for monitoring the state of EDM performance in the gap to provide a first signal upon detection of the occurrence of a predetermined condition in the gap within a first time period and to provide a second signal upon non-detection of such a condition in the gap throughout a second time period, and timing means for causing the said second time period to have a duration greater than that of the said first period; memory means connected to the said input circuit means for receiving the said first and second signals and having a memory level arranged to be changed in accordance with the latest-received of these signals; and setting means with an ordered set of positions arranged to establish respective values of the said parameter corresponding to memory levels in the said memory means and to be altered in respective directions in the said ordered set in accordance with any change in corresponding directions of the memory levels of the said memory means.

2. A system according to Claim 1, wherein the said input circuit means includes a first present counter means with a said input terminal adapted to be connected in circuit with the said machining gap, the said first preset counter means being adapted, when connected in circuit with the said machining gap, to count electric pulses effected therethrough of a particular class selectively for issuing the said first signal upon counting up a preset number of such pulses within the said first period, the said first preset counter means being arranged for resetting upon termination of the said first period.

3. A system according to Claim 2, wherein the said circuit means further includes a second preset counter means with an input



terminal adapted to be connected in circuit with the said machining gap, the said second preset counter means being coupled to the said first preset counter means and adapted, when connected in circuit with the said machining gap, to count electric pulses effected through the gap, of a class different from the said particular class selectively and arranged for resetting upon counting up a preset number of such pulses to define the said first period.

4. A system according to Claim 3, wherein the said circuit means further includes a third preset counter means adapted to be connected with a pulse source and arranged, when connected in circuit with the said machining gap, for resetting upon counting up a preset number of pulses to define the said second period.

5. A system according to Claim 4, wherein the said third preset counter means is coupled to the said first preset counter means and adapted, when connected in circuit with the said machining gap, to provide an output to supply the said second signal upon counting up a said preset number of pulses from the said pulse source in the absence of a said first signal.

6. A system according to Claim 5, wherein the said pulse source is defined by the electrical discharge machining gap and the said third counter means is adapted to count pulses related to the machining performance in the gap.

7. A system according to Claim 6, wherein the said third counter means has an input coupled to the input to the said second counter means and is adapted, when connected in circuit with the said machining gap, to provide an output to supply the said second signal upon counting up a preset number of the said different class of pulses which is greater than the said preset number of pulses for the said first preset counter means.

8. A system according to Claim 4, wherein the said third preset counter means has an input arranged, when connected in circuit with the said machining gap, for counting pulses related to intermittent relative retractions between the tool electrode and the work-piece, the said retractions defining the said pulse source.

9. A system according to any one of the preceding claims, wherein the said memory means comprises a first up-down counter means adapted to define the said memory level, the said up-down counter means having a first input terminal connected with the said input circuit means through a first gate means for permitting the gating of the said second signal to the said up-down counter means, the latter having a second input terminal receiving the said first signal to change the memory level thereof by one increment at a time in a predetermined direction.

10. A system according to Claim 9, wherein a second up-down counter means is connected with the said first up-down counter means through a comparator means and with the said input circuit means, the comparator means providing an output when the memory level of the said first up-down counter means coincides with that of the said second up-down counter means to permit the said second signal to be passed through the said gate means and injected into the said first up-down counter means to change the memory level thereof by one increment at a time in a predetermined direction opposite to the first-mentioned predetermined direction.

11. A system according to Claim 10, wherein the said second up-down counter means has a first input terminal connected with the said input circuit means through a second gate means adapted to receive the said first signal, the said second gate means being associated with a further timer means and the latter being connected with the said comparator means and actuable by the said output thereof to time a third time period being longer than the said second period and to open the said second gate means so that the said first signal, if produced, may be injected into the said first input terminal of the said second up-down counter means for changing the memory level thereof by one increment at a time in a said first-mentioned predetermined direction.

12. A system according to Claim 11, wherein the said second up-down counter means has a second input terminal connected with the said input circuit means through a third gate means adapted to receive the said first signal, the said third gate means being connected with the said comparator means and arranged to initiate the timing of a fourth time period being longer than the said third period upon receiving the said output of the comparator means and to open the said third gate means to provide an output into the said second input terminal of the said second up-down counter means for changing the memory level thereof by one increment at a time in a said second predetermined direction in the absence of a said first signal within the said fourth period.

13. A system according to Claim 11 or Claim 12, wherein the said further timer means is defined by a fourth preset counter means having an input terminal connected with the input to the said third preset counter means and arranged for resetting upon counting up a preset number of incoming pulses or upon receiving the said first signal.

14. A system for controlling an EDM parameter in the operation of an EDM apparatus, the system being constructed, arranged and adapted to operate substantially as hereinbefore described with reference to, and as

illustrated in, Figures 1 to 4 of the accompanying diagrammatic drawings.

15. An EDM apparatus includes a system according to any one of the preceding claims.

5 16. An EDM apparatus includes a system according to any one of Claims 1 to 14 and means for effecting intermittently relative retraction between the tool electrode and the workpiece, wherein the said parameter is the length of the relative retraction.

17. An EDM apparatus including a system according to any one of Claims 1 to 14 and means for effecting intermittently relative retraction between the tool electrode and the workpiece, wherein the said parameter is the time interval between adjacent cycles of the intermittent relative retraction.

15 18. An EDM apparatus including a system according to any one of Claims 1 to 14, wherein the said parameter is the time interval between adjacent machining pulses.

20 19. An EDM apparatus including a

system according to any one of Claims 1 to 14 and means for effecting intermittently relative retraction between the tool electrode and the workpiece, wherein the said parameter is a combination of two or three of the parameters defined by the length of the intermittent relative retraction, the time interval between adjacent cycles of the intermittent relative retraction and the time interval between adjacent machining pulses. 25 30

20. An article when machined by EDM apparatus according to any one of Claims 15 to 19. 35

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