

Description

This invention relates to an electric discharge machining apparatus according to the preamble of the claim 1 and also to a method for electric discharge machining according to which a workpiece is machined by electric pulse discharge between a machining electrode and the workpiece according to claim 12.

When a machining pulse voltage is repeatedly applied across the discharge machining gap in diesinking or wire-cut electric discharge machining so as to machine a workpiece, particularly a cemented carbide workpiece, the application of normal machining pulses (i.e. pulses between a positively charged workpiece and a negatively charged machining electrode) is found to impede deionization at the machining gap increasingly as the machining progresses. As a result, the resistivity of the machining fluid becomes extremely low locally, especially at the center of the bottom surface of the diesinking electrode and other portions where chip discharge is inadequate.

When this state occurs, a large electrolytic current flows between the workpiece and the machining electrode through the low resistivity region. This produces irregularities on the surface of the workpiece and causes other problems. Moreover, electrolytic substances such as cobalt that electrolyze easily are melted out of the workpiece and form a surface layer (an "affected layer") differing in composition from the underlying workpiece material. Formation of an affected layer on a die being machined shortens the service life of the die and degrades the quality of products formed using the die.

Further, in certain types of diesinking electric discharge machines that use a water-based machining fluid containing a polymer, tar tends to form at the electric discharge machining gap. Since this tar is electrically conductive and locally reduces the impedance at the gap, an electrolytic or arc current arises at the low-impedance region and rapidly produces an oxide deposit. Since the adhering oxide material is an electrical insulator, it markedly lowers the machining speed and deteriorates the nature of the machined surface.

Another problem in this connection is that when tar forms in the electric discharge machining gap, the machining speed falls to such a very low level during finish machining that it may become impossible to continue the finish machining.

Tar also forms in the electric discharge machining gap when a kerosene type machining fluid is used. Since this hinders deionization at the gap, arc discharge is apt to occur. When this happens, the workpiece may suffer surface cracks and the like which greatly shorten the service life of the die

being machined.

As it is known that the tar forming at the electric discharge machining gap forms on the negative potential side, a well-known technique has been developed in which the polarity of the machining pulse voltage applied is changed for preventing tar adhesion and removing adhered tar at the gap.

For example, Japanese Patent Application Public Disclosure No. Sho 59-152017 (152017/84) includes a passage reading: "A conventional machining power supply for supplying positive pulses for making the workpiece side the anode and negative pulses for making the workpiece side the cathode was tested. However, since the power supply that was used supplied positive and negative pulses by turns or at a ratio such as 3 to 2, the machining speed decreased and it became impossible to control electrode consumption in the manner desired."

For overcoming these problems, the aforesaid Japanese Patent Application Public Disclosure No. Sho 59-152017(152017/84) teaches an electric discharge machining apparatus having a detector for detecting the electric discharge current flow across the machining gap and a switching means for switching the machining power supply so as to supply positive pulses to the gap during periods the detector detects a prescribed electric discharge current and to supply negative pulses to the gap during periods the detector does not detect the prescribed electric discharge current.

Even with this arrangement, however, electrode consumption is high and the machining speed is slow during the supply of positive pulses, particularly, in the non-electrode-consuming region.

Also, in cases where the machining electrode and the workpiece are made of different materials, e.g. where the electrode is made of copper and the workpiece of steel, the normal machining voltage in normal polarity is generally about 20 V and does not include a high-frequency component, whereas the normal machining voltage in reverse-polarity is 25 - 30 V and includes a high-frequency component.

Therefore, when abnormal discharge is detected using the reverse-polarity machining voltage as a reference for discriminating whether or not the machining voltage level is lower than the normal machining voltage, the normal polarity machining is constantly detected to be in a state of abnormal discharge. As a result, adaptive control is implemented even under normal operation, thus unnecessarily slowing the machining speed.

Further, the fact that the machining pulse voltage can be either positive or negative makes it difficult to determine the level thereof by direct detection of the voltage between the electrodes.

An electric discharge machining apparatus for machining a workpiece according to the preamble of the claim 1 is known from JP-B-59-26414. With this known discharge machining apparatus the machining is effected by repeatedly affecting pulse discharge in a machining gap between an electrode and the workpiece that is to be machined. The apparatus comprises a switch that supplies pulses of a set polarity to the machining gap and also a further switch that supplies pulses of the opposite polarity to the machining gap by switching a voltage supply on and off and which is also provided with a detection unit and a control unit. The detection unit detects when detection signals from the machining gap are above and below a reference level and the control unit affects in response to the detection result a change over of the operation of the two switches.

EP-A-0 176 224 discloses an EDM method and apparatus in which a succession of machining voltage pulses of regular polarity is applied from a first pulse supply between a tool electrode and a workpiece to produce erosive discharges across the EDM gap in the presence of a water flushing medium. A second pulse supply is also provided to apply one or more voltage pulses of reverse polarity during a time interval between successive machining voltage pulses of regular polarity across the EDM gap. A sensing circuit is provided to respond to a gap open-circuit condition and to provide an output signal representative thereof. This output signal is used to act on the second pulse supply so as to selectively trigger such one or more reverse polarity pulses or to temporarily modify the parameters of the reverse polarity pulse or pulses upon the occurrence of the gap open-circuit condition.

It is an object of the present invention to provide a novel apparatus and novel method for conducting electric discharge machining which prevent and suppress the formation of unneeded tar components, furthermore reliably preclude the formation of an affected layer on the workpiece and additionally minimize machining electrode consumption without reducing the electric discharge machining speed.

This object is solved according to the inventive apparatus in that the electric discharge machining apparatus comprises:

setting means for setting data indicating a first number of voltage pulses and data indicating a second number of voltage pulses; and
polarity control means for controlling the polarity switching circuit means so that either said first number of voltage pulses of the first polarity or said second number of voltage pulses of second polarity opposite to said first polarity are alternately applied across said machining gap.

Improved embodiments of the inventive electric discharge machining apparatus are disclosed within the subclaims 2 to 13.

The inventive method for realizing an electric discharge machining operation is characterized by the features of the claim 14.

Improved embodiments of the inventive method are disclosed within the subclaims 15 and 16.

In accordance with one of its embodiments, the invention provides a method and an apparatus wherein a machining voltage is repeatedly applied as pulses to an electric discharge machining gap formed between a workpiece and a machining electrode for electric discharge machining the workpiece and the polarity of the machining voltage pulses is alternated during the machining of the workpiece, each cycle of the alternation consisting of a first machining period during which voltage pulses of one polarity are continuously applied across the gap and a second machining period during which voltage pulses of the other polarity are continuously applied across the gap, the length of the periods being determined in terms of numbers of pulses respectively. In accomplishing this invention, the inventor focused on the fact that since the condition at the machining gap changes with each succeeding pulse of machining voltage applied thereto, it is necessary to control the machining pulse voltage applied across the machining gap based on the individual pulses applied across the gap as a unit. The invention is therefore constituted so as to enable the polarity of the machining voltage pulses applied across the gap to be reversed when the counted number of machining voltage pulses reaches a prescribed value. The optimum number of pulses determining the periods during which the positive and negative machining voltage pulses are applied across the gap can be determined by conducting appropriate tests or the like under the machining conditions concerned. As a result, it becomes possible to respond appropriately to the change in the condition at the electric discharge machining gap which occurs with each succeeding pulse discharge.

In accordance with another of its embodiments, the invention provides a method and an apparatus wherein separate electric discharge machining parameters are established for the case where the machine pulse voltage is applied across the machining gap in normal polarity and the case where it is applied thereto in reverse polarity. This arrangement enables the electrical machining conditions to be matched to the characteristics of positive and negative voltage application and, as such, makes it possible to conduct the machining with high efficiency.

In accordance with another of its embodiments, the invention provides a method and an apparatus

wherein the voltage at the input side of a polarity switching means for switching the polarity of the machining pulse voltage applied across the electric discharge machining gap is detected for obtaining information required for discerning the condition at the electric discharge machining gap.

In accordance with another of its embodiments, the invention provides a method and an apparatus wherein separate abnormal electric discharge detection levels are established for the case where machining is conducted at normal polarity and the case where it is conducted at reverse polarity, thereby enabling proper detection of abnormal electric discharge during machining in either polarity.

It is also possible to use an arrangement in which the machining pulse voltage is switched to the secondary polarity when the impedance at the electric discharge machining gap falls to or below a prescribed level during electric discharge machining with the machining pulse voltage applied across the gap in the primary polarity. In this case, since the period of application of machining pulse voltage in the secondary polarity is set on the basis of the number of machining voltage pulses generated, it is possible to control this period in single pulse increments.

Brief Description of the Drawings

Fig. 1 is a circuit diagram showing an embodiment of the electric discharge machining apparatus according to the invention,

Fig. 2 is a circuit diagram of a specific example of the polarity controller of the circuit of Fig. 1;

Fig. 3 is a timing chart for explaining the operation of the circuit of Fig. 1;

Fig. 4 is a circuit diagram showing a specific example of the on/off controller of the circuit of Fig. 1;

Fig. 5 is a timing chart showing the operation of the on/off controller;

Fig. 6 is a circuit diagram showing a specific example of the IP controller of Fig. 1;

Fig. 7 is a timing chart showing the operation of the IP controller of Fig. 6;

Fig. 8 is a circuit diagram showing a specific example of the detection circuit of Fig. 1;

Fig. 9 is a timing chart showing the operation of the detection circuit of Fig. 8;

Fig. 10 is a circuit diagram showing another specific example of the polarity controller;

Fig. 11 is a timing chart showing the operation of the polarity controller of Fig. 10;

Fig. 12 is a circuit diagram showing another specific example of the detection circuit; and

Fig. 13 is a timing chart showing the operation of the detection circuit of Fig. 12.

Best Mode for carrying Out the Invention

Fig. 1 is a circuit diagram illustrating an embodiment of an electric discharge machining apparatus according to the present invention.

The apparatus is provided with switching transistors T1, T2 for supplying machining voltage pulses across an electric discharge machining gap G between a machining electrode E and a workpiece W so as to electric discharge machine the workpiece W. The collectors of the switching transistors T1, T2 are connected through current limiter resistors 31a, 31b with the positive terminal of a dc power supply 30 and the emitters thereof are connected with a polarity switching circuit 10. The current limiter resistors 31a, 31b limit the amounts of electric discharge machining current supplied from the dc power supply 30 through the associated switching transistors and to the machining gap in a manner to be described later when the associated switching transistors are ON. These values are set such that a prescribed weighting can be established between the amounts of current flowing through the switching transistor T1, T2.

While the illustrated embodiment has two switching transistor-current limiter resistor pairs, it is alternatively possible to provide a larger number of pairs as found appropriate. The weighting can be incremented in a binary manner as 1, 2, 4, 8, 16 ... by the current limiter resistor values. By selective operation of the switching transistors T1, T2, therefore, it is possible to set the maximum electric discharge current at the electric discharge machining gap G to an appropriate value. If desired, the current limiter resistors 31a, 31b can be replaced with constant current sources having low resistance.

The polarity switching circuit 10 has transistors TN1, TN2 for applying machining pulse voltage to the machining gap G in normal polarity and transistors TR1, TR2 for applying machining pulse voltage to the machining Gap G in reverse polarity. As shown in the drawing, the transistors TN1, TN2, TR1, TR2 are connected in a bridge arrangement. The connection point X between the transistors TR1 and TN2 is connected with the machining electrode E and the connection point Y between the transistors TN1 and TR2 is connected with the workpiece W. The diode D1 inserted in the collector circuit of the transistor TR1 and the diode D2 inserted in the collector circuit of the transistor TN1 both serve as devices for preventing reverse current flow.

A polarity controller 20 to be explained later selectively turns one of the transistor pairs TR1, TR2 and TN1, TN2 on and the other pair off. When only the transistors TR1, TR2 are on, the potential of the workpiece W becomes negative with respect

to the machining electrode E, whereby the machining pulse voltage is applied across the electric discharge machining gap G in reverse polarity. In contrast, when only the transistors TN1, TN2 are on, the potential of the workpiece W becomes positive with respect to the machining electrode E, whereby the machining pulse voltage is applied across the electric discharge machining gap G in normal polarity.

The polarity switching circuit 10 carries out its control for switching the polarity of the machining pulse voltage applied across the gap G between normal and reverse in response to a signal received from the polarity controller 20.

The polarity controller 20 receives a first clock signal CLK1 from a first clock signal generator 80 and a second clock signal CLK2 from a second clock signal generator 90. It also receives settings R and N from a setting generator 70.

The setting data R indicates a number of machining voltage pulses corresponding to the period during which machining pulse voltage is to be applied across the electric discharge machining gap G in reverse polarity, while the setting N indicates a number of machining voltage pulses corresponding to the period during which machining pulse voltage is to be applied across the electric discharge machining gap G in normal polarity. The operator inputs the desired values of the setting data N and R in terms of numbers of pulses via the setting generator 70.

The polarity controller 20 also receives a gate signal GATE from an on/off controller 40 that will be explained later. The gate signal GATE determines the width of the individual electric discharge machining pulses to be applied across the electric discharge machining gap G.

In response to the input of this signal, the polarity controller 20 outputs a control signal RS for on/off control of the transistors TR1, TR2 and a control signal NS for on/off control of the transistors TN1, TN2, to thereby on/off control the transistors TR1, TR2 and TN1, TN2.

In the case where machining pulse voltage is applied across the electric discharge machining gap G in normal polarity, the setting generator 70 sends to the on/off controller 40 a setting data RON indicating the pulse-on time (i.e. the ON time of the gate signal GATE) and a setting data ROFF indicating the pulse-off time (i.e. the OFF time of the gate signal GATE). In the case where the machining pulse voltage is applied across the electric discharge machining gap G in reverse polarity, the setting generator 70 sends to the on/off controller 40 a setting data NON indicating the pulse-on time and a setting data NOFF indicating the pulse-off time. In addition to receiving the first clock signal CLK1, the on/off controller 40 is also supplied by a

detection circuit 50 (to be explained later) with a third clock signal CLK3 and a fourth clock signal CLK4.

The setting data RON, NON indicate the pulse-on time in terms of numbers of pulses of the third clock signal CLK3. For each of the pulse-on time intervals a number of third clock signal CLK3 pulses equal to that indicated by the setting concerned is counted, thus determining the pulse-on time of the gate signal GATE. Similarly, the setting data ROFF, NOFF indicate the pulse-off time in terms of numbers of pulses of the fourth clock signal CLK4. For each of the pulse-off times a number of fourth clock signal pulses CLK4 equal to that indicated by the setting data concerned is counted, thus determining the pulse-off time of the gate GATE.

The polarity controller 20 outputs a polarity signal RN indicating whether the pulse polarity selected within the polarity controller 20 is normal or reverse. This polarity signal RN is received by the on/off controller 40 which, depending on the polarity indicated by the signal, uses either the setting data RON, ROFF or the setting data NON, NOFF for generating the gate signal GATE.

The on/off controller 40 produces a first end signal ONEND at the end of ON period of the gate signal GATE and a second end signal OFEND at the end of the OFF period of the gate signal GATE. The first end signal ONEND and the second end signal OFEND are sent to the detection circuit 50.

The apparatus further has an IP controller 60 for controlling the peak value of the electric discharge machining current. The setting generator 70 supplies the IP controller 60 with a first peak value NIP for normal polarity machining and a second peak value RIP for reverse polarity machining. The IP controller 60 also receives the polarity signal RN and the gate signal GATE and outputs a control signal IP1 and a control signal IP2 for selectively on/off controlling the switching transistors T1, T2 so as to establish the peak value of the machining current for the machining polarity at that time during the ON period of the gate signal GATE.

The emitters of the switching transistors T1, T2 are connected with the diodes D1, D2 of the polarity switching circuit 10 and voltage dividing resistors 32a, 32b are connected in series between the emitter-diode connection point and the connection point between the emitters of the transistors TN2, TR2 and the negative terminal of the power supply 30. From the connection point between the voltage dividing resistors 32a and 32b there can thus be obtained a detection voltage VGS whose level is proportional to the voltage applied across the electric discharge machining gap G.

The detection voltage VGS is input to the detection circuit 50, which also receives the polarity

signal RN, the first clock signal CLK1, the gate signal GATE, and the first and second end signals ONEND, OFEND. Based on these inputs, the detection circuit 50 generates the third and fourth clock signals CLK3, CLK4.

Fig. 2 is a circuit diagram showing a specific example of the polarity controller 20 of Fig. 1.

The polarity controller 20 comprises a data selector 21 which responds to the setting data R, N and outputs one of these settings in response to the polarity signal RN output by a T flip flop circuit 24 and a counter 22 which counts the pulses of the gate signal GATE shown in Fig. 3. The count data obtained at the Q output of the counter 22 is applied to the B input of a comparator 23 which receives the setting data selected in the data selector 21 at the A input thereof. The comparator 23 constantly compares the values received through its A and B inputs and when it determines that $A = B$, it outputs a coincidence pulse AB from its A = B terminal.

The coincidence pulse AB is applied to the reset terminal RES of the counter 22 as a reset pulse and is also applied to the T input terminal of the T flip flop circuit 24 as a trigger pulse. As a result, the level of the polarity signal RN output by the T flip flop circuit 24 inverts every time the coincidence pulse AB is output. (See Fig. 3.)

The circuit further has a gate circuit 26 which receives the first clock signal CLK1 and is open/closed controlled by the gate signal GATE such that the first clock signal CLK1 is applied to the clock terminal CK of a D flip flop circuit 25 only when the level of the gate signal GATE is low. The polarity signal RN is applied to the D input of the D flip flop circuit 25 and the level of the D input is locked at the time the first clock signal CLK1 applied to the clock terminal CK thereof rises, causing a sync polarity signal M synchronized with the first clock signal CLK1 to be output from the output terminal thereof.

The sync polarity signal M is applied to a logic circuit 20A constituted of D flip flops 27, 28 and gate circuits 29R, 29N, wherein it is logically processed and the result is output as the control signals RS, NS. As shown in the drawing, the D flip flops 27, 28 of the logic circuit 20A are connected in tandem and receive the second clock signal CLK2 at their CK terminals. Further, the sync polarity signal M is input to the D input terminal of the D flip flop 27. The Q output of the D flip flop 28 is applied as a delayed output signal to one input of each of the gate circuits 29R, 29N, each of which receives the sync polarity signal M at the other input thereof.

The operation of the polarity controller 20 will now be explained with reference to Fig. 3.

Fig. 3 is a timing chart showing the operation of the polarity controller 20 in the case where the setting data R has a value of 2 and setting data N a value of 1.

At time t_0 , the gate signal GATE rises and a gap voltage VG is generated at the electric discharge machining gap G. Each time the gate signal GATE rises, the counter 22 counts the number of pulses thereof.

The coincidence pulse AB generated at time t_0 causes the output level of the T flip flop circuit 24 to become high, whereby the level of the polarity signal RN becomes high. The counter 22 is reset at this time, whereafter the count of the counter 22 is incremented by 1 each time the level of the gate signal GATE rises. When the count of the counter 22 becomes 2 at time t_1 , the comparator 23 sends a coincidence pulse AB indicating that $A = B$ to the T flip flop circuit 24 so that the level of the polarity signal RN becomes low. At this time, the coincidence pulse AB is also used as a reset signal for resetting the counter 22. When the level of the gate signal GATE becomes low at time t_1 , the gate circuit 26 opens to apply the first clock signal CLK1 to the clock terminal CK of the D flip flop circuit 25 and, as a result, the level of the sync polarity signal M becomes low at time t_2 .

When the output of the coincidence pulse AB at time t_1 causes the level of the polarity signal RN to become low, the data selector 21 selects the setting data N ($= 1$) and this value is input to the comparator 23.

Therefore, the counter 22 is incremented by the rise of the gate signal GATE at time t_3 and since this raises its count to 1, the comparator 23 outputs the coincidence pulse AB, causing the output level of the T flip flop circuit 24 to become high and the counter 22 to be reset. Then at the next rise of the first clock signal CLK1 at time t_4 the sync polarity signal M becomes high level.

In response to the output of the coincidence pulse AB at time t_3 , the data selector 21 selects setting R ($R = 2$). As a result, the operation just explained is repeatedly executed.

The operation of the logic circuit 20A will now be explained. The D flip flops 27, 28, which operate in response to the second clock signal CLK2 shown in Fig. 3, function to delay the sync polarity signal M by two pulses of the second clock signal CLK2. As will be understood from Fig. 3, this results in the generation of the delayed output signal B, which is the same as the sync polarity signal M but delayed with respect thereto by two pulses of the second clock signal CLK2.

The gate circuit 29R outputs a control signal RS according to the logical AND of the signals M and B, while the gate circuit 29N generates a high level output constituting the control signal NS only

when signals M and B are both low level.

As can be seen in Fig. 3, a delay period DT is established between the time that the pair of transistors TN1, TN2 is turned off by the control signal NS and the time that the pair of transistors TR1, TR2 is turned on by the control signal RS, i.e. during the switchover from normal to reverse polarity. The two transistor pairs of the polarity switching circuit 10 are thus protected from turning ON at the same time.

Fig. 4 shows a specific example of the circuit of the on/off controller 40 of Fig. 1.

The on/off controller 40 includes a data selector 41a which responds to a high level polarity signal RN indicating normal polarity by selecting the setting data NON and responds to a low level polarity signal RN indicating reverse polarity by selecting the setting data RON, and a data selector 41b which responds to a high level polarity signal RN indicating normal polarity by selecting the setting data NOFF and responds to a low level polarity signal RN indicating reverse polarity by selecting the setting data ROFF.

The outputs of the data selectors 41a, 41b are applied to another data selector 41c which forwards one or the other of the outputs of the data selectors 41a, 41b to the A terminal of a comparator 42.

The fourth clock signal CLK4 is input to a three-state buffer 44 which operates at high level to output an on-clock signal ONCK. On the other hand, the third clock signal CLK3 is input to a three-state buffer 45 which operates at low level to output an off-clock signal OFFCK. The on-clock signal ONCK and the off-clock signal OFFCK are supplied to the clock terminal CK of a counter 43 and the count data indicating the result of counting these clock pulses is output from the Q output of the counter 43 to the B terminal of the comparator 42.

When the comparator 42 determines that the data input to its A terminal coincides with the data input to its B terminal, it outputs a coincidence pulse COI which is applied to the counter 43 as a reset pulse and to a T flip flop 46 as a trigger signal.

The output of the T flip flop 46 is supplied to the exterior as the gate signal GATE and, moreover, is applied to the three-state buffers 44, 45 as a control signal and to the data selector 41c, as a control signal. More specifically, the data selector 41c operates in response to the gate signal GATE so that when the level of the gate signal GATE is high, the output of the data selector 41a is selected, and when the level of the gate signal GATE is low, the output of the data selector 41b is selected.

D flip flops 48a, 48b constitute a circuit which responds to the first clock signal CLK1 by delaying

the gate signal GATE by one pulse of the first clock signal CLK1. The output of the D flip flop 48b is input to a gate circuit 47a which in response outputs the second end signal OFEND indicating the end of the low level period of the gate signal GATE.

On the other hand, D flip flops 48c, 48d constitute a circuit which receives a signal obtained by inverting the gate signal GATE in an inverter 49 and delays the inverted signal by two pulses of the first clock signal CLK1. The outputs of the D flip flop 48c and the D flip flop 48d are input to a gate circuit 47b which in response outputs the first end signal ONEND indicating the end of the high level period of the gate signal GATE.

The operation of the on/off controller 40 will now be explained with reference to Fig. 5.

Fig. 5 is a timing chart showing the operation of the on/off controller 40 in the case where the setting data RON has set a value of 4, setting data NON has set a value of 5, setting data ROFF has set a value of 2 and setting data NOFF has set a value of 4.

Since the value of polarity signal RN is 1 at time ta, the data selector 41a outputs 4 as the setting data RON. Similarly, the data selector 41b outputs 2 as setting data ROFF. The output level of the T flip flop 46 at this time is low and the data selector 41c outputs the value it receives from the data selector 41b, i.e. it outputs 2 as the setting data ROFF. As the three-state buffer 45 is operating at this time, the third clock signal CLK3 is input to the counter 43 as the off-clock signal OFFCK.

Next, at time tb, since the counter 43 counts the second pulse of the off-clock signal OFFCK so that the value output by the data selector 41c coincides with the value output by the counter 43, the comparator 42 outputs the coincidence pulse COI indicating A = B. The coincidence pulse COI is input to the T flip flop 46, whose output level thus becomes high, and to the reset terminal RES of the counter 43, which is reset thereby.

As a result, the level of the gate signal GATE is inverted, the rise thereof causing the output of the second end signal OFEND at time tb. The high level of the gate signal GATE also causes the data selector 41c to output 4 as the setting data RON to the A terminal of the comparator 42 and, in addition, actuates the three-state buffer 44 to start supplying the on-clock signal ONCK to the clock terminal CK of the counter 43.

As can be seen in Fig. 5, the coincidence pulse COI is output when the count of the counter 43 reaches 4 at time tc. Thus the counter 43 is reset and the output level of the T flip flop 46 is inverted, causing the level of the gate signal GATE to become low. The fall of the gate signal GATE at time tc causes the output of the first end signal

ONEND at time t_c .

The low level of the gate signal GATE at time t_c causes the data selector 41c to once again select the setting data ROFF, so that the operation just explained is repeatedly executed.

When the level of the polarity signal RN becomes low at time t_d , reverse polarity machining is initiated. Since the level of the gate signal GATE is low at this time, the setting data NOFF (= 4) is applied to the A terminal of the comparator 42. As a result, the coincidence pulse COI is output at the time t_e marked by the fourth pulse of the off-clock signal OFFCK after time t_d , whereby the level of the gate signal GATE becomes high. The setting data NON (= 5) is therefore applied to the A terminal of the comparator 42, the coincidence pulse COI is output at time t_f marked by the fifth pulse of the on-clock signal ONCK, and the gate signal GATE is returned to low level. From this point on, normal polarity machining is carried out in the same manner.

Fig. 6 shows a specific example of the circuit diagram of the IP controller 60 of Fig. 1.

The IP controller 60 has a selector 61 which receives the polarity signal RN and in accordance with the polarity indicated by this signal selects either the first peak value NIP or the second peak value RIP. The peak value of the machining current selected by the selector 61 is applied to AND circuits 62a - 62n which are open/close controlled by the gate signal GATE. When the level of the gate signal GATE becomes high, therefore, one or more of IP1 - IPn are output in accordance with the data indicating the machining current peak value, whereby the corresponding switching transistors (only two shown in Fig. 1) are turned on.

The operation of the IP controller 60 will now be explained with reference to Fig. 7.

Fig. 7 is a timing chart showing the operation of the IP controller 60 in the case where the second peak value RIP has set a value of 2 and the first peak value NIP has set a value of 1.

Since the level of the polarity signal RN is high at time t_g , the selector 61 selects the second peak value RIP, whose content is (10). Thus since only one input of the AND circuit 62b is at 1, the signal IP2 is output to turn on the associated switching transistor T2 only in the case where the level of the gate signal GATE is high. In other words, the peak value of the machining current in the case of reverse polarity machining is that determined by the second peak value RIP.

When the polarity signal RN becomes low level at time t_h , the selector 61 selects the first peak value NIP, whose content is (01). Thus since only one input of the AND circuit 62a is high, the signal IP1 is output to turn on the associated switching transistor T1 only in the case where the level of the

gate signal GATE is high. In other words, the peak value of the machining current in the case of normal polarity machining is that determined by the first peak value NIP.

The invention thus enables the machining condition, i.e. the maximum machining current value, to be separately set depending on the polarity of the machining pulse voltage applied, namely depending on whether normal polarity machining or reverse polarity machining is being conducted.

Fig. 8 is a circuit diagram of a specific example of the detection circuit 50 of Fig. 1.

The detection circuit 50 has a comparator 51a which compares the detection voltage VGS with a reference voltage V1 and produces a high level output when the detection voltage VGS is equal to or lower than the reference voltage V1, and a comparator 51b which compares the detection voltage VGS with a reference voltage V2 (< V1) and generates a high level output when the detection voltage VGS is equal to or lower than the reference voltage V2.

The outputs of the comparators 51a, 51b are respectively input to the A input and B input of a selector 52 controlled by the polarity signal RN to select the output of the comparator 51a when the level of the polarity signal RN is high (reverse polarity machining) and to select the output of the comparator 51b when the level of the polarity signal RN is low (normal polarity machining).

The output of the selector 52 is applied to one input of an AND circuit 54, the other input terminal of which receives the output of an AND circuit 55 to which the gate signal GATE and the first clock signal CLK1 are applied.

Reference numeral 53 designates an R-S flip flop circuit comprising logic devices 53a, 53b. The second end signal OFEND is applied to the R-S flip flop circuit 53 as a reset signal and the output of the AND circuit 54 is applied thereto as a set signal SET. The output of the R-S flip flop circuit 53 is obtained as a trouble signal NG which is forwarded to three-state buffers 57, 58 as an operation control signal. The first clock signal CLK1 is input to the three-state buffer 57 and the output of a rate multiplier 56 which operates in response to the first clock signal CLK1 is input to the three-state buffer 58. The outputs of the two three-state buffers 57, 58 constitute the third clock signal CLK3. The fourth clock signal CLK4 is obtained by outputting the first clock signal CLK1 as it is.

Fig. 9 is a timing chart showing the operation of the detection circuit 50.

While the gap voltage VG across the electric discharge machining gap G is represented in Fig. 9 as a pulse wave form that swings positive and negative about a center of zero volt owing to polarity switchover, the detection voltage VGS is repre-

sented as a pulse voltage which always occurs on the positive side irrespective of polarity switchover. This is because the detection voltage VGS is the divided voltage across the resistor 32b which is connected in series with resistor 32a on the input side of the polarity switching circuit 10.

Referring to the gap voltage VG, P1 indicates a period of normal discharge during reverse polarity machining, P2 a period of normal discharge during normal polarity machining, P3 a period of abnormal discharge in reverse polarity machining and Pn a period of abnormal discharge in normal polarity machining.

During period P1, since the level of the polarity signal RN is high and the input signal VGS input to the comparator 51a is greater than V1, the output level of the selector 52 is low. Therefore, the level of the set signal SET output by the AND circuit 54 is high so that the R-S flip flop circuit 53 is not set. As a result, the frequency of the third clock signal CLK3 is the same as that of the first clock signal CLK1.

During the period P2, since the level of the polarity signal RN is low, the output signal of the selector 52 is that received from the comparator 51b. As the detection voltage VGS is greater than the reference voltage V2 at this time, the output level of the selector 52 is low. Therefore, since the R-S flip flop circuit 53 is not set and the level of the trouble signal NG is low, the first clock signal CLK1 is output via the three-state buffer 57 as the third clock signal CLK3.

During period P3, the level of the polarity signal RN is high so that the selector 52 selects the output of the comparator 51a. As the detection voltage VGS is equal to or lower than reference voltage V1 at this time, the output level of the selector 52 is high. Therefore, since the AND circuit 54 passes the first clock signal CLK1 only when the level of the gate signal GATE is high, the output signal of the R-S flip flop circuit 53, i.e. the trouble signal NG, is at high level.

At time t_j , moreover, the frequency of the third clock signal CLK3 becomes 10 times that of the first clock signal CLK1 owing to frequency multiplication by the rate multiplier 56. The third clock signal CLK3 having a frequency increased by a factor of 10 relative to the first clock signal CLK1 continues to be output from time t_j to time t_k at which the second end signal OFEND is reset. Thus, in case of malfunctioning of the electric discharge machining, the machining pulse rest period is increased ten fold, whereby deionization is promoted at the electric discharge machining gap G.

The operation of the circuit shown in Fig. 1 will now be explained with reference to Fig. 3.

During periods S1, S2, S3, S4, ... when the level of the gate signal GATE is high, the switching

transistors T1, T2 are turned on by the signals IP1, IP2. Machining pulse voltage is thus applied to the electric discharge machining gap G. As a result, electric discharge occurs at the electric discharge machining gap G.

Fig. 3 shows one example of theoretical waveforms of the gap voltage VG at the electric discharge machining gap G and the machining current IG across the electric discharge machining gap G at this time.

On the other hand, the polarity controller 20 counts the pulses of the gate signal GATE and, in accordance with the setting data R, N set by the setting generator 70, outputs the control signal RS for applying machining pulse voltage across the electric discharge machining gap G in reverse polarity and the control signal NS for applying machining pulse voltage across the electric discharge machining gap G in normal polarity. As was explained in detail with reference to Fig. 2, switchover between the control signals RS, NS is controlled by the polarity switching circuit 10 on the basis of the delay period TD so as to ensure that no problem of the transistors TR1, TR2, TN1, TN2 all becoming conductive at the same time will occur.

As a result, when a number of machining voltage pulses equal to the value indicated by the setting data R has been applied across the electric discharge machining gap G in reverse polarity, the polarity switching circuit 10 waits for the delay period TD and then switches over the operating state, whereby a number of machining voltage pulses equal to the value indicated by the setting data N is applied across the electric discharge machining gap G in normal polarity.

The pulse-on width and the pulse-off width of the gate signal GATE during the periods S1, S2, S4 is determined by the setting data RON, ROFF from the on/off controller 40, while the pulse-on width of the gate signal GATE during the period S3 is determined by the setting data NON, NOFF from the on/off controller 40. Further, the maximum current during the periods S1, S2, S4 is determined by the second peak value RIP from the IP controller 60, while the maximum current during the period S3 is determined by the first peak value NIP from the IP controller 60.

In other words, the electrical machining conditions (parameters) for the discharge machining are set separately between the case where the machining pulse voltage is applied in reverse polarity and the case where it is applied in normal polarity. As a result, the removal of tar from between the electrodes can be conducted with high efficiency, making it possible to carry out the desired machining at high speed and low electrode consumption.

Moreover, as was explained in detail with reference to Figs. 8 and 9, since the reference level used in detection of abnormal discharge is set separately between machining at normal potential and machining at reverse potential, abnormal discharge can be reliably detected irrespective of the machining polarity. In this case, since the resistors 32a, 32b for detecting the condition at the machining gap are provided on the input side of the polarity switching circuit 10, the electric discharge machining condition can be detected with a detection circuit 50 of simple circuit configuration.

Another embodiment of the polarity controller 20 is shown in Fig. 10.

This polarity controller, designated by reference numeral 200, differs from that shown in Fig. 2 in that it operates in response to the output of a detection circuit 500 shown in Fig. 12 to switch from machining in one polarity defined as the primary polarity to machining in the other polarity defined as the secondary polarity when the no-load machining pulse voltage falls to or below a prescribed value, applies a number of machining pulses indicated by a setting data TRN to the electric discharge machining gap G in the secondary polarity, and then resumes machining in the primary polarity.

The components in Fig. 10 corresponding to those in Fig. 2 are assigned the same reference symbols as those in Fig. 2 and will not be explained again here.

The polarity controller 200 receives from the setting generator 70 the setting data TRN indicating the machining time in secondary (normal) polarity in terms of a number of pulses of the gate signal GATE. The setting data TRN is applied directly to the A terminal of the comparator 23.

When the no-load machining pulse voltage at the electric discharge machining gap falls to or below a prescribed level, the detection circuit 500 (to be explained later) outputs a trouble pulse NGP to one input of an OR circuit 201 of the polarity controller 200, the other input of which is input with the coincidence pulse AB from the comparator 23. The output of the OR circuit 201 is applied to the T input terminal of the T flip flop circuit 24 and the output TFFO of the T flip flop circuit 24 is applied both to the D input terminal of the D flip flop circuit 25 and through an inverter 202 to the reset terminal RES of the counter 22.

The operation of the polarity controller 200 will now be explained with reference to Fig. 11.

Fig. 11 is a timing chart showing the operation of the polarity controller 200 in the case where the setting data TRN has a value of 2 and the primary polarity is reverse.

Assume that abnormal discharge occurs at time t_n in the course of the reverse polarity ma-

chining, this being detected from the fact that the no-load voltage across the gap G falls below a prescribed value of, say, 80 V. In this case, the polarity controller 200 receives the trouble pulse NGP from the detection circuit 500, causing the level of the T flip flop circuit 24 output TFFO to become high and the D flip flop circuit 25 to assume a standby state. Since the level of the gate signal GATE is high in this case, the level of the gate circuit 26 output is low.

Then when the level of the gate signal GATE falls at time t_0 , the gate circuit 26 outputs a clock signal GCLK of the same frequency as the first clock signal CLK1. Moreover, the output of the D flip flop circuit 25 latches the output TFFO of the T flip flop circuit 24 and outputs the signal M.

The signal M is processed by the logic circuit 20A and, as shown in Fig. 11, the level of the control signal NS falls with the fall of the second clock signal CLK2 immediately after t_0 and, after a two-pulse delay (TD), the level of the control signal RS rises.

As a result, normal polarity machining is commenced and, the counter 22, whose resetting has been released, once again counts the pulses of the gate signal GATE.

When the counter 22 counts the second pulse of the gate signal GATE at time t_q , the comparator 23 outputs the coincidence pulse AB so that the level of the output TFFO of the T flip flop circuit 24 becomes low, this low level state being latched by the D flip flop circuit 25 in response to the clock signal GCLK.

As a result, the level of control signal RS falls at time t_q and, after the delay period TD, the level of the NS signal rises. This causes a reverse polarity machining pulse voltage to be applied across the electric discharge machining gap G. This state is maintained until the next trouble pulse NGP is received.

Fig. 12 shows a detection circuit 500 which is another example of the detection circuit 50. The detection circuit 500 is intended for use in combination with the polarity controller 200 shown in Fig. 10.

The detection circuit 500, which has a voltage comparator 501 for comparing the detection voltage VGS with a prescribed voltage V3, discriminates whether or not the no-load voltage across the electric discharge machining gap G is greater than the prescribed value V3 (e.g. 80 V). The output of the voltage comparator 501 is inverted by an inverter 502 and the inverted output voltage NGV is applied to one input terminal of an AND circuit 505.

The gate signal GATE is input to a D flip flop 508 which operates in response to the first clock signal CLK1. The output of the D flip flop 508 is input to another D flip flop 509 to which the first

clock signal CLK1 is applied after inversion by an inverter 503. The outputs of the D flip flops 508, 509 are applied to a gate circuit 507, the output of which is applied to an AND circuit 506 which also receives the polarity signal RN after level inversion by an inverter 504. The AND circuit 506 therefore outputs a sampling gate pulse PC immediately after the rise of the gate signal GATE (see Fig. 13). The sampling gate pulse PC is applied to the other input of the AND circuit 505.

Thus at the time that the sampling gate pulse PC is output, the level of the inverted output voltage NGV is output from the AND circuit 505 as the trouble pulse NGP.

According to the foregoing arrangement shown in Fig. 13, when the no-load voltage level of the detection voltage VGS is larger than voltage V3, i.e. when the electrolytic current is not greater than the prescribed level, the level of the inverted output voltage NGV is low so that no trouble pulse NGP is output. On the other hand, if the detection voltage VGS is lower than the voltage V3 at the time when the sampling gate pulse PC is output, the trouble pulse NGP is output. Since output of the trouble pulse NGP causes a switchover to reverse polarity machining, the level of the polarity signal RN becomes high so that the AND circuit 506 is closed. Thus the sampling gate pulse PC is not output during reverse polarity machining.

Thus when the polarity controller 200 and the detection circuit 500 are used, if the no-load voltage across the machining gap falls to or below a prescribed value during electric discharge machining in normal polarity (the primary polarity), the system switches over to machining in reverse polarity (the secondary polarity). Then, after a number of pulses of the gate signal GATE equal to that prescribed by the setting TRN have been applied to the electric discharge machining gap G, the machining reverts to normal polarity.

The aforesaid operations are thereafter carried out repeatedly for repeatedly conducting normal and reverse polarity machining, thereby enabling electric discharge machining of the workpiece W to be carried out at low electrode consumption while achieving excellent performance in the removal of tar at the machining gap. Industrial Applicability

As described above, the electric discharge machining method and apparatus according to the invention can be applied not only to die sinking but also to wire-cut electric discharge machining.

Claims

1. An electric discharge machining apparatus for machining a workpiece (W) by means of electric discharges by repeatedly applying a train of machining voltage pulses across a machin-

ing gap (G) formed between a machining electrode (E) and the workpiece as an electrode being machined, said machining gap being filled with a machining fluid, the electric discharge machining apparatus comprising:

a power supply (30) for supplying electrical energy for machining,

means (40) for producing a gate signal (GATE);

a switching circuit (T1, T2) responsive to said gate signal for controlling the application of the voltage pulse from said power supply across said machining gap; and

polarity switching circuit means (10) for allowing the pulse voltage to be applied across said machining gap with the machining electrode being positively poled and the workpiece being negatively poled and for allowing the voltage pulse to be applied across said machining gap with the machining electrode being negatively poled and the workpiece being positively poled,

characterized in that said electric discharge machining apparatus additionally comprises:

setting means (70) for setting data indicating a first number of voltage pulses and data indicating a second number of voltage pulses; and

polarity control means (20) for controlling the polarity switching circuit means so that either said first number of voltage pulses of the first polarity or said second number of voltage pulses of second polarity opposite to said first polarity are alternately applied across said machining gap.

2. An electric discharge machining apparatus as claimed in claim 1, wherein the switching circuit comprises at least one series circuit consisting of a semiconductor switching device (T1, T2) and a resistance element (31a, 31b) connected in series therewith.
3. An electric discharge machining apparatus as claimed in claim 2, wherein the switching circuit comprises a plurality of the series circuits (T1, T2; 31a, 31b) connected in parallel and maximum current control means (60) is further provided for selectively switching the semiconductor switching devices of the series circuits on and off.
4. An electric discharge machining apparatus as claimed in claim 2 or 3, wherein the resistance values of the resistance elements of the series circuits are appropriately weighted.

clock signal CLK1 is applied after inversion by an inverter 503. The outputs of the D flip flops 508, 509 are applied to a gate circuit 507, the output of which is applied to an AND circuit 506 which also receives the polarity signal RN after level inversion by an inverter 504. The AND circuit 506 therefore outputs a sampling gate pulse PC immediately after the rise of the gate signal GATE (see Fig. 13). The sampling gate pulse PC is applied to the other input of the AND circuit 505.

Thus at the time that the sampling gate pulse PC is output, the level of the inverted output voltage NGV is output from the AND circuit 505 as the trouble pulse NGP.

According to the foregoing arrangement shown in Fig. 13, when the no-load voltage level of the detection voltage VGS is larger than voltage V3, i.e. when the electrolytic current is not greater than the prescribed level, the level of the inverted output voltage NGV is low so that no trouble pulse NGP is output. On the other hand, if the detection voltage VGS is lower than the voltage V3 at the time when the sampling gate pulse PC is output, the trouble pulse NGP is output. Since output of the trouble pulse NGP causes a switchover to reverse polarity machining, the level of the polarity signal RN becomes high so that the AND circuit 506 is closed. Thus the sampling gate pulse PC is not output during reverse polarity machining.

Thus when the polarity controller 200 and the detection circuit 500 are used, if the no-load voltage across the machining gap falls to or below a prescribed value during electric discharge machining in normal polarity (the primary polarity), the system switches over to machining in reverse polarity (the secondary polarity). Then, after a number of pulses of the gate signal GATE equal to that prescribed by the setting TRN have been applied to the electric discharge machining gap G, the machining reverts to normal polarity.

The aforesaid operations are thereafter carried out repeatedly for repeatedly conducting normal and reverse polarity machining, thereby enabling electric discharge machining of the workpiece W to be carried out at low electrode consumption while achieving excellent performance in the removal of tar at the machining gap. Industrial Applicability

As described above, the electric discharge machining method and apparatus according to the invention can be applied not only to die sinking but also to wire-cut electric discharge machining.

Claims

1. An electric discharge machining apparatus for machining a workpiece (W) by means of electric discharges by repeatedly applying a train of machining voltage pulses across a machin-

ing gap (G) formed between a machining electrode (E) and the workpiece as an electrode being machined, said machining gap being filled with a machining fluid, the electric discharge machining apparatus comprising:

a power supply (30) for supplying electrical energy for machining,

means (40) for producing a gate signal (GATE);

a switching circuit (T1, T2) responsive to said gate signal for controlling the application of the voltage pulse from said power supply across said machining gap; and

polarity switching circuit means (10) for allowing the pulse voltage to be applied across said machining gap with the machining electrode being positively poled and the workpiece being negatively poled and for allowing the voltage pulse to be applied across said machining gap with the machining electrode being negatively poled and the workpiece being positively poled,

characterized in that said electric discharge machining apparatus additionally comprises:

setting means (70) for setting data indicating a first number of voltage pulses and data indicating a second number of voltage pulses; and

polarity control means (20) for controlling the polarity switching circuit means so that either said first number of voltage pulses of the first polarity or said second number of voltage pulses of second polarity opposite to said first polarity are alternately applied across said machining gap.

2. An electric discharge machining apparatus as claimed in claim 1, wherein the switching circuit comprises at least one series circuit consisting of a semiconductor switching device (T1, T2) and a resistance element (31a, 31b) connected in series therewith.
3. An electric discharge machining apparatus as claimed in claim 2, wherein the switching circuit comprises a plurality of the series circuits (T1, T2; 31a, 31b) connected in parallel and maximum current control means (60) is further provided for selectively switching the semiconductor switching devices of the series circuits on and off.
4. An electric discharge machining apparatus as claimed in claim 2 or 3, wherein the resistance values of the resistance elements of the series circuits are appropriately weighted.



5. An electric discharge machining apparatus as claimed in claim 3, wherein the maximum current control means (60) selectively turns the semiconductor switching devices (T1, T2) selected thereby on and off in a prescribed pattern, whereby machining current across the machining gap is controlled to a prescribed maximum value.
6. An electric discharge machining apparatus as claimed in claim 5, wherein the maximum current control means (60) is a circuit means responsive to a maximum current setting (NIP, RIP) received from the outside for selectively supplying a control signal (IP1, IP2) for on/off controlling the semiconductor switching device (T1, T2) designated by the maximum current setting.
7. An electric discharge machining apparatus as claimed in claim 6, wherein the at least one maximum current setting includes a maximum positive current setting (NIP) for normal polarity machining and a maximum negative current setting (RIP) for reverse polarity machining and setting selection means (61) is further provided for selecting one or the other of the maximum positive current setting and the maximum negative current setting in accordance with the machining pulse voltage application polarity (RN) selected by the polarity control means (20).
8. An electric discharge machining apparatus as claimed in claim 1, wherein the polarity control means (20) comprises counting means (22) responsive to the gate signal (GATE) for counting pulses of the gate signal, comparison means (23) for comparing settings with the count of the counting means (22) and means (24) responsive to an output (AB) of the comparison means (23) for outputting a control signal (RN) for controlling the polarity switching circuit means (10).
9. An electric discharge machining apparatus as claimed in claim 1, further comprising a voltage detection unit (32a, 32b) for detecting electric discharge machining voltage across the machining gap (G) and discriminating means (50) for discriminating on the basis of the voltage (VGS) detected by the voltage detection unit (32a, 32b) whether or not electric discharge machining is proceeding normally, a pulse-off time controlled by the gate signal (GATE) being prolonged in response to the discriminating means (50) when the electric discharge machining is not proceeding normally.
10. An electric discharge machining apparatus as claimed in claim 9, wherein the voltage detection unit (32a, 32b) is provided on an input side of the polarity switching circuit means (10).
11. An electric discharge machining apparatus as claimed in claim 9, wherein the discriminating means (50) discriminates whether or not electric discharge machining is proceeding normally by comparing the voltage (VGS) detected by the voltage detection unit (32a, 32b) with a first reference voltage (V2) if normal polarity electric discharge machining is in progress and with a second reference voltage (V1) different from the first reference voltage if reverse polarity electric discharge machining is in progress.
12. An electric discharge machining apparatus as claimed in claim 1, wherein said setting means (70) is formed for supplying a setting indicating in terms of a number of pulses of the machining pulse voltage a period during which the machining pulse voltage is to be applied across the machining gap in a secondary polarity opposite from the primary polarity, and further comprising:
 - gap condition detection means (500) for detecting whether or not a prescribed electrical condition is present at the machining gap, and
 - polarity inversion control means (200) responsive to the gap condition detection means (500) for controlling the polarity switching circuit means (10) to apply the pulse voltage for machining across the machining gap (G) in the primary polarity when the prescribed electrical condition is present at the machining gap (G) and to apply the pulse voltage for machining across the machining gap (G) in the secondary polarity when the prescribed electrical condition is not present at the machining gap (G).
13. An electric discharge machining apparatus as claimed in claim 12, wherein the gap condition detecting means (500) is an impedance detecting means for detecting whether or not the impedance across the machining gap (G) is at or below a prescribed value (V3).
14. An electric discharge machining method for electric discharge machining a workpiece (W) by repeatedly applying a machining pulse voltage through a machining fluid across a machining gap (G) formed between a machining electrode (E) and the workpiece, the electric discharge machining method comprising:



a counting step for counting pulses of the machining pulse voltage applied across the machining gap,

a first electric discharge machining step conducted in response to the result of the counting step for applying the machining pulse voltage across the machining gap in one polarity for a period of time corresponding to a first prescribed and settable number of pulses, and

a second electric discharge machining step conducted after the first electric discharge machining step in response to the result of the counting step for applying the machining pulse voltage across the machining gap in the other polarity for a period of time corresponding to a second prescribed and settable number of pulses,

the first and second electric discharge machining steps being conducted repeatedly.

15. An electric discharge machining method as claimed in claim 14, wherein parameters for the first electric discharge machining step and parameters for the second discharge machining step are established separately.

16. An electric discharge machining method as claimed in claim 14, wherein the impedance across the machining gap is detected, and

a prescribed and settable number of pulses of the machining pulse voltage in the other polarity is applied across the machining gap (G) when it is detected that the impedance across the machining gap (G) is at or below a prescribed value.

Patentansprüche

1. Funkenerosionsbearbeitungs-Apparat bzw. Elektroerosiv-Bearbeitungsapparat zur Bearbeitung eines Werkstückes (W) mittels elektrischer Entladungen, indem wiederholt ein Bearbeitungsspannungs-Pulszug über einen Bearbeitungsspalt (G) angelegt wird, der zwischen einer Bearbeitungselektrode (E) und dem Werkstück, als eine Elektrode, die bearbeitet wird, ausgebildet ist, wobei der Bearbeitungsspalt mit einem Bearbeitungsfluid gefüllt bzw. ausgefüllt ist, und wobei der Funkenerosionsbearbeitungs-Apparat folgendes aufweist:

eine Leistungsquelle bzw. Stromversorgung (30), um elektrische Energie für eine Bearbeitung zu liefern,

eine Einrichtung (40) zur Erzeugung eines Torsignals bzw. Gatesignals (GATE);

eine Schalt-Schaltung bzw. Umschalt-Schaltung (T1, T2), die auf das Torsignal anspricht, um das Anlegen eines Spannungspul-

ses von der Leistungsquelle über dem Bearbeitungsspalt zu steuern; und

eine die Polarität schaltende Schaltungseinrichtung (10), um zu ermöglichen, daß die Pulsspannung über dem Bearbeitungsspalt angelegt wird, wobei die Bearbeitungselektrode positiv gepolt ist und das Werkstück negativ gepolt ist, und um zu ermöglichen, daß der Spannungspuls über dem Bearbeitungsspalt angelegt wird, wobei die Bearbeitungselektrode negativ gepolt ist und das Werkstück positiv gepolt ist,

dadurch gekennzeichnet, daß der Funkenerosionsbearbeitungs-Apparat zusätzlich folgendes aufweist:

eine Einstelleinrichtung bzw. Sollwerteinrichtung (70) zum Setzen von Daten bzw. für Sollwertdaten, die eine erste Zahl an Spannungspulsen anzeigen und zum Setzen von Daten bzw. für Sollwertdaten, die eine zweite Zahl von Spannungspulsen anzeigen; und

eine Polaritätssteuereinrichtung (20) zum Steuern der die Polarität schaltenden Schaltungseinrichtung, so daß entweder die erste Zahl an Spannungspulsen der ersten Polarität oder die zweite Zahl an Spannungspulsen der zweiten Polarität, die der ersten Polarität entgegengesetzt ist, abwechselnd über dem Bearbeitungsspalt angelegt werden.

2. Funkenerosionsbearbeitungs-Apparat, wie in Anspruch 1 beansprucht, bei welchem die Schalt-Schaltung bzw. Umschalt-Schaltung wenigstens eine Reihenschaltung aufweist, die aus einem Halbleiter-Schaltbauelement (T1, T2) und einem Widerstandselement (31a, 31b) besteht, das damit in Serie geschaltet ist.

3. Funkenerosionsbearbeitungs-Apparat, wie in Anspruch 2 beansprucht, bei welchem die Schalt-Schaltung bzw. Umschalt-Schaltung eine Anzahl der Reihenschaltungen (T1, T2; 31a, 31b) aufweist, die parallel geschaltet sind, und bei welcher weiterhin eine Einrichtung (60) zur Steuerung des maximalen Stroms bereitgestellt ist, um selektiv die Halbleiter-Schaltbauelemente der Reihenschaltungen ein- und auszuschalten.

4. Funkenerosionsbearbeitungs-Apparat, wie in Anspruch 2 oder 3 beansprucht, bei welchem die Widerstandswerte der Widerstandselemente der Reihenschaltungen geeignet gewichtet bzw. verteilt sind.

5. Funkenerosionsbearbeitungs-Apparat, wie in Anspruch 3 beansprucht, bei welchem die Einrichtung (60) zur Steuerung des maximalen



- Stroms selektiv die Halbleiter-Schaltbauelemente (T1, T2), die dadurch ausgewählt werden, in einem vorgeschriebenen Muster ein- und ausschaltet, wodurch der Bearbeitungsstrom über dem Bearbeitungsspalt bis zu einem vorgeschriebenen maximalen Wert gesteuert wird.
6. Funkenerosionsbearbeitungs-Apparat, wie in Anspruch 5 beansprucht, bei welchem die Einrichtung (60) zum Steuern des maximalen Stroms eine Schaltungseinrichtung ist, die auf einen Stromeinstellwert bzw. Sollwert für einen maximalen Strom (NIP, RIP) anspricht, der von außen empfangen wird, um selektiv ein Steuerungssignal (IP1, IP2) für eine Ein-/Aussteuerung des Halbleiter-Schaltbauelements (T1, T2) zu liefern, das durch den maximalen Stromeinstellwert bzw. Sollwert für den maximalen Strom bestimmt ist.
 7. Funkenerosionsbearbeitungs-Apparat, wie in Anspruch 6 beansprucht, bei welchem der wenigstens eine maximale Stromeinstellwert bzw. Sollwert für einen maximalen Strom einen Sollwert bzw. Einstellwert (NIP) für einen maximalen positiven Strom für eine Bearbeitung bei normaler Polarität und einen Sollwert bzw. Einstellwert (RIP) für einen maximalen negativen Strom für eine Bearbeitung bei reverser bzw. umgekehrter Polarität beinhaltet und bei welchem weiter eine Sollwert- bzw. Einstellwertauswähleinrichtung (61) zum Auswählen des einen oder des anderen des Einstellwerts für den maximalen positiven Strom und des Einstellwerts für den maximalen negativen Strom bereitgestellt wird, und zwar in Übereinstimmung mit der angelegten Polarität bzw. Anwendungspolarität (RN) der Bearbeitungspulsspannung, die durch die Polaritätssteuereinrichtung (20) ausgewählt wird.
 8. Funkenerosionsbearbeitungs-Apparat, wie in Anspruch 1 beansprucht, bei welchem die Polaritätssteuereinrichtung (20) eine Zähleinrichtung (22), die auf das Torsignal bzw. Gatesignal (GATE) zum Zählen der Pulse des Torsignals bzw. Gatesignals anspricht, eine Vergleichseinrichtung (23) zum Vergleichen von Einstellwerten bzw. Sollwerten mit dem Zählwert der Zähleinrichtung (22) und eine Einrichtung (24), die auf ein Ausgangssignal (AB) der Vergleichseinrichtung (23) zur Ausgabe eines Steuerungssignals (RN) zum Steuern der die Polarität schaltenden Schaltungseinrichtung (10) anspricht, aufweist.
 9. Funkenerosionsbearbeitungs-Apparat, wie in Anspruch 1 beansprucht, der weiter eine Spannungsfeststelleinheit bzw. Spannungsdetektionseinheit (32a, 32b) zum Detektieren der Funkenerosionsbearbeitungs-Spannung über dem Bearbeitungsspalt (G) und eine Unterscheidungs- bzw. Diskriminatoreinrichtung (50) aufweist, um auf der Grundlage der Spannung (VGS), die durch die Spannungsdetektionseinheit (32a, 32b) detektiert wurde, festzustellen, ob die Funkenerosionsbearbeitung normal voranschreitet oder ob nicht, wobei eine Pulsauszeit, die durch das Torsignal (GATE) gesteuert wird, in Abhängigkeit von der Unterscheidungseinrichtung (50) verlängert wird, wenn die Funkenerosionsbearbeitung nicht normal voranschreitet bzw. verläuft.
 10. Funkenerosionsbearbeitungs-Apparat, wie in Anspruch 9 beansprucht, bei welchem die Spannungsdetektionseinheit (32a, 32b) auf einer Eingangsseite der die Polarität schaltenden Schaltungseinrichtung (10) bereitgestellt wird.
 11. Funkenerosionsbearbeitungs-Apparat, wie in Anspruch 9 beansprucht, bei welchem die Unterscheidungseinrichtung (50) unterscheidet, ob die Funkenerosionsbearbeitung normal verläuft oder ob nicht, und zwar indem die Spannung (VGS) durch die Spannungsdetektionseinheit (32a, 32b) mit einer ersten Bezugsspannung (V2) verglichen wird, falls eine Funkenerosionsbearbeitung mit normaler Polarität abläuft, und mit einer zweiten Bezugsspannung (V1), die sich von der ersten Bezugsspannung unterscheidet, verglichen wird, falls eine Funkenerosionsbearbeitung mit reverser bzw. umgekehrter Polarität abläuft.
 12. Funkenerosionsbearbeitungs-Apparat, wie in Anspruch 1 beansprucht, bei welchem die Sollwerteinrichtung bzw. Einstelleinrichtung (70) ausgebildet ist, um einen Sollwert bzw. Einstellwert zu liefern, der in der Form einer Zahl von Pulsen der Bearbeitungspulsspannung einen Zeitabschnitt anzeigt bzw. ausdrückt, während dem die Bearbeitungspulsspannung über den Bearbeitungsspalt in einer sekundären bzw. Neben-Polarität anzulegen ist, die der primären bzw. Haupt-Polarität entgegengesetzt ist, und der weiter folgendes aufweist:
 - eine Spaltzustands-Detektionseinrichtung (500), um zu detektieren, ob oder ob nicht ein vorgeschriebener elektrischer Zustand bzw. eine vorgeschriebene elektrische Bedingung am Bearbeitungsspalt vorliegt, und
 - eine Polaritätsinversions-Steuereinrichtung (200), die auf die Spaltzustands-Detektionsein-



richtung (500) anspricht, um die die Polarität schaltende Schaltungseinrichtung (10) zu steuern, um die Pulsspannung zur Bearbeitung über dem Bearbeitungsspalt (G) in der primären bzw. Haupt-Polarität anzulegen, wenn die vorgeschriebene elektrische Bedingung bzw. der vorgeschriebene elektrische Zustand am Bearbeitungsspalt (G) vorliegt, und um die Pulsspannung zur Bearbeitung über dem Bearbeitungsspalt (G) in der sekundären bzw. Neben-Polarität anzulegen, wenn der vorgeschriebene elektrische Zustand bzw. die vorgeschriebene elektrische Bedingung am Bearbeitungsspalt (G) nicht vorliegt.

13. Funkenerosionsbearbeitungs-Apparat, wie in Anspruch 12 beansprucht, bei welchem die Spaltzustands-Detektionseinrichtung (500) eine Impedanz-Detektionseinrichtung ist, um zu detektieren, ob oder ob nicht die Impedanz über dem Bearbeitungsspalt (G) bei oder unter einem vorgeschriebenen Wert (V3) liegt.

14. Funkenerosionsbearbeitungs-Verfahren zur elektrischen Entladungsbearbeitung eines Werkstücks (W), indem wiederholt eine Bearbeitungspulsspannung durch ein Bearbeitungsfluid über einen Bearbeitungsspalt (G) angelegt wird, der zwischen einer Bearbeitungselektrode (E) und dem Werkstück ausgebildet ist, wobei das Funkenerosionsbearbeitungs-Verfahren folgendes aufweist:

einen Zähler Schritt zum Zählen der Pulse der Bearbeitungspulsspannung, die über dem Bearbeitungsspalt angelegt ist,

einen ersten Funkenerosionsbearbeitungs-Schritt, der in Abhängigkeit von dem Ergebnis des Zähler Schritts durchgeführt wird, um die Bearbeitungspulsspannung über dem Bearbeitungsspalt in einer Polarität für einen Zeitabschnitt anzulegen, der einer ersten vorgeschriebenen und einstellbaren Zahl von Pulsen entspricht, und

einen zweiten Funkenerosionsbearbeitungs-Schritt, der nach dem ersten Funkenerosionsbearbeitungs-Schritt in Abhängigkeit von dem Ergebnis des Zähler Schrittes durchgeführt wird, um die Bearbeitungspulsspannung über dem Bearbeitungsspalt in der anderen Polarität für einen Zeitabschnitt anzulegen, der einer zweiten vorgeschriebenen und einstellbaren Zahl von Pulsen entspricht,

der erste und zweite Funkenerosionsbearbeitungs-Schritt wird wiederholt durchgeführt.

15. Funkenerosionsbearbeitungs-Verfahren, wie in Anspruch 14 beansprucht, bei welchem Parameter für den ersten Funkenerosionsbearbei-

tungs-Schritt und Parameter für den zweiten Funkenerosionsbearbeitungs-Schritt bzw. Entladungsbearbeitungs-Schritt getrennt festgesetzt werden.

16. Funkenerosionsbearbeitungs-Verfahren, wie im Anspruch 14 beansprucht, bei welchem die Impedanz über dem Bearbeitungsspalt detektiert wird, und

eine vorgeschriebene und einstellbare Zahl an Pulsen der Bearbeitungspulsspannung in der anderen Polarität über dem Bearbeitungsspalt (G) angelegt wird, wenn es detektiert wird, daß die Impedanz über dem Bearbeitungsspalt (G) bei einem vorgeschriebenen Wert oder unterhalb eines vorgeschriebenen Wertes liegt.

Revendications

1. Dispositif d'usinage par étincelage pour usiner une pièce à usiner (W) au moyen de décharges électriques en appliquant de façon répétée un train d'impulsions de tension d'usinage à travers un intervalle d'usinage (G) formé entre une électrode d'usinage (E) et la pièce à usiner qui est usinée en tant qu'électrode, ledit intervalle d'usinage étant rempli avec un fluide d'usinage, le dispositif d'usinage par étincelage comprenant:

- une source d'énergie (30) pour fournir de l'énergie électrique pour l'usinage;
- un moyen (40) pour produire un signal de déclenchement (GATE);
- un circuit de commutation (T1, T2) sensible au signal de déclenchement pour commander l'application de l'impulsion de tension, depuis ladite source d'énergie à travers ledit intervalle d'usinage; et
- un moyen (10) formant circuit de commutation de polarité pour permettre à la tension d'impulsion d'être appliquée à travers ledit intervalle d'usinage, l'électrode d'usinage étant de polarité positive et la pièce à usiner étant de polarité négative; et pour permettre à l'impulsion de tension d'être appliquée à travers ledit intervalle d'usinage, l'électrode d'usinage étant de polarité négative et la pièce à usiner étant de polarité positive;

caractérisé en ce que ledit dispositif d'usinage par étincelage comprend de plus:

- un moyen de réglage (70) pour régler des données indiquant un premier nombre d'impulsions de tension et des données indiquant un second nombre d'impulsions de tension; et



- un moyen de commande de polarité (20) pour commander le moyen formant circuit de commutation de polarité, de telle sorte que, soit ledit premier nombre d'impulsions de tension de la première polarité, soit ledit second nombre d'impulsions de tension de la seconde polarité opposée à ladite première polarité, soit alternativement appliqué à travers ledit intervalle d'usinage. 5 10
- 2. Dispositif d'usinage par étincelage selon la revendication 1, dans lequel le circuit de commutation comprend au moins un circuit en série constitué d'un dispositif de commutation (T1, T2) à semi-conducteurs et d'un élément de résistance (31a, 31b), connectés ensemble en série. 15
- 3. Dispositif d'usinage par étincelage selon la revendication 2, dans lequel le circuit de commutation comprend une pluralité de circuits en série (T1, T2, 31a, 31b) connectés en parallèle, et un moyen (60) de commande de courant maximal est de plus prévu pour commuter de façon sélective les dispositifs de commutation à semi-conducteurs des circuits en série ouverts et fermés. 20 25
- 4. Dispositif d'usinage par étincelage selon la revendication 2 ou 3, dans lequel les valeurs de résistance des éléments de résistance des circuits en série sont pondérées de façon appropriée. 30
- 5. Dispositif d'usinage par étincelage selon la revendication 3, dans lequel le moyen (60) de commande de courant maximal tourne de façon sélective les dispositifs de commutation (T1, T2) à semi-conducteurs, sélectionnés de ce fait en circuits ouverts et fermés selon un modèle prescrit, grâce à quoi le courant d'usinage à travers l'intervalle d'usinage est commandé à une valeur maximale prescrite. 35 40
- 6. Dispositif d'usinage par étincelage selon la revendication 5, dans lequel le moyen (60) de commande de courant maximal est un moyen formant circuit sensible à un réglage de courant maximal (NIP, RIP) reçu depuis l'extérieur pour fournir de façon sélective un signal de commande (IP1, IP2) pour commander l'ouverture/fermeture du dispositif de commutation (T1, T2) à semi-conducteurs conçu pour le réglage du courant maximal. 45 50 55
- 7. Dispositif d'usinage par étincelage selon la revendication 6, dans lequel le au moins un réglage de courant maximal comporte un réglage de courant positif maximal (NIP) pour l'usinage avec polarité normale, et un réglage de courant négatif maximal (RIP) pour l'usinage avec polarité inversée, et un moyen de sélection de réglage (61) est de plus prévu pour sélectionner l'un ou l'autre du réglage du courant positif maximal et du réglage du courant négatif maximal, selon la polarité d'application (RN) de la tension d'impulsion d'usinage sélectionnée par le moyen de commande de polarité (20).
- 8. Dispositif d'usinage par étincelage selon la revendication 1, dans lequel le moyen de commande de polarité (20) comprend un moyen de comptage (22) sensible au signal de déclenchement (GATE) pour compter les impulsions du signal de déclenchement, un moyen de comparaison (23) pour comparer les réglages avec le compte du moyen de comptage (22), et un moyen (24) fonctionnant en réponse à un signal de sortie (AB) du moyen de comparaison (23) pour délivrer un signal de commande (RN) afin de commander le moyen formant circuit de commutation de polarité (10).
- 9. Dispositif d'usinage par étincelage selon la revendication 1, comprenant de plus une unité de détection de tension (32a, 32b) pour détecter une tension d'usinage par étincelage à travers l'intervalle d'usinage (G), et un moyen de discrimination (50) pour discriminer, sur la base de la tension (VGS) détectée par l'unité de détection de tension (32a, 32b), si l'usinage par étincelage se déroule normalement ou non, une période d'arrêt d'impulsions commandée par le signal de déclenchement (GATE) étant prolongée en réponse au moyen de discrimination (50) quand l'usinage par étincelage ne se déroule pas normalement.
- 10. Dispositif d'usinage par étincelage selon la revendication 9, dans lequel l'unité de détection de tension (32a, 32b) est prévue sur un côté d'entrée du moyen formant circuit de commutation de polarité (10).
- 11. Dispositif d'usinage par étincelage selon la revendication 9, dans lequel le moyen de discrimination (50) détermine si l'usinage par étincelage se déroule normalement ou non, en comparant la tension (VGS) détectée par l'unité de détection de tension (32a, 32b) avec une première tension de référence (V2) si l'usinage par étincelage avec polarité normale est en progression, et avec une seconde tension de



référence (V1), différente de la première tension de référence, si l'usinage par étincelage avec polarité inverse est en progression.

12. Dispositif d'usinage par étincelage selon la revendication 1, dans lequel ledit moyen de réglage (70) est formé pour fournir un réglage indiquant, en termes de nombre d'impulsions de la tension d'impulsion d'usinage, une période pendant laquelle la tension d'impulsion d'usinage doit être appliquée à travers l'intervalle d'usinage dans une polarité secondaire, opposée à la polarité primaire, et comprenant de plus:
- un moyen de détection (500) des conditions d'intervalle pour détecter si une condition électrique prescrite est présente ou non à l'intervalle d'usinage, et
 - un moyen de commande d'inversion de polarité (200) fonctionnant en réponse au moyen de détection (500) des conditions d'intervalle, pour commander le moyen formant circuit de commutation de polarité (10), afin d'appliquer la tension d'impulsion pour usiner à travers l'intervalle d'usinage (G) dans la polarité primaire quand la condition électrique prescrite est présente à l'intervalle d'usinage (G), et afin d'appliquer la tension d'impulsion pour usiner à travers l'intervalle d'usinage (G) dans la polarité secondaire quand la condition électrique prescrite n'est pas présente à l'intervalle d'usinage (G).
13. Dispositif d'usinage par étincelage selon la revendication 12, dans lequel le moyen de détection (500) des conditions d'intervalle est un moyen de détection d'impédance, pour détecter si, oui ou non, l'impédance à travers l'intervalle d'usinage (G) est égale ou inférieure à une valeur prescrite (V3).
14. Procédé d'usinage par étincelage pour usiner par étincelage une pièce à usiner (W), en appliquant de façon répétée une tension d'impulsion d'usinage par un fluide d'usinage à travers un intervalle d'usinage (G) formé entre une électrode d'usinage (E) et la pièce à usiner, le procédé d'usinage par étincelage comprenant:
- une étape de comptage pour compter les impulsions de la tension d'impulsion d'usinage appliquée à travers l'intervalle d'usinage;
 - une première étape d'usinage par étincelage, conduite en réponse au résultat de l'étape de comptage pour appliquer la tension d'impulsion d'usinage à travers

l'intervalle d'usinage dans une certaine polarité pendant une période de temps correspondant à un premier nombre prescrit et réglable d'impulsions; et

- une seconde étape d'usinage par étincelage, conduite après la première étape d'usinage par étincelage, en réponse au résultat de l'étape de comptage pour appliquer la tension d'impulsion d'usinage à travers l'intervalle d'usinage dans l'autre polarité pendant une période de temps correspondant à un second nombre prescrit et réglable d'impulsions;
 - les première et seconde étapes d'usinage par étincelage étant conduites de façon répétée.
15. Procédé d'usinage par étincelage selon la revendication 14, dans lequel les paramètres pour la première étape d'usinage par étincelage et les paramètres pour la seconde étape d'usinage par étincelage sont établis séparément.
16. Procédé d'usinage par étincelage selon la revendication 14, dans lequel l'impédance à travers l'intervalle d'usinage est détectée, et un nombre prescrit et réglable d'impulsions de la tension d'impulsion d'usinage dans l'autre polarité est appliqué à travers l'intervalle d'usinage (G) quand il a été détecté que l'impédance à travers l'intervalle d'usinage (G) est égale ou inférieure à une valeur prescrite.

