March 31, 1970 A. L. LIVSHITS ETAL 3,504,152

METHOD FOR HIGH-FREQUENCY ELECTRIC-IMPULSE METAL FINISHING AND AN APPARATUS FOR ACCOMPLISHING THE SAME

Filed Aug. 8, 1963 2 Sheets-Sheet 1

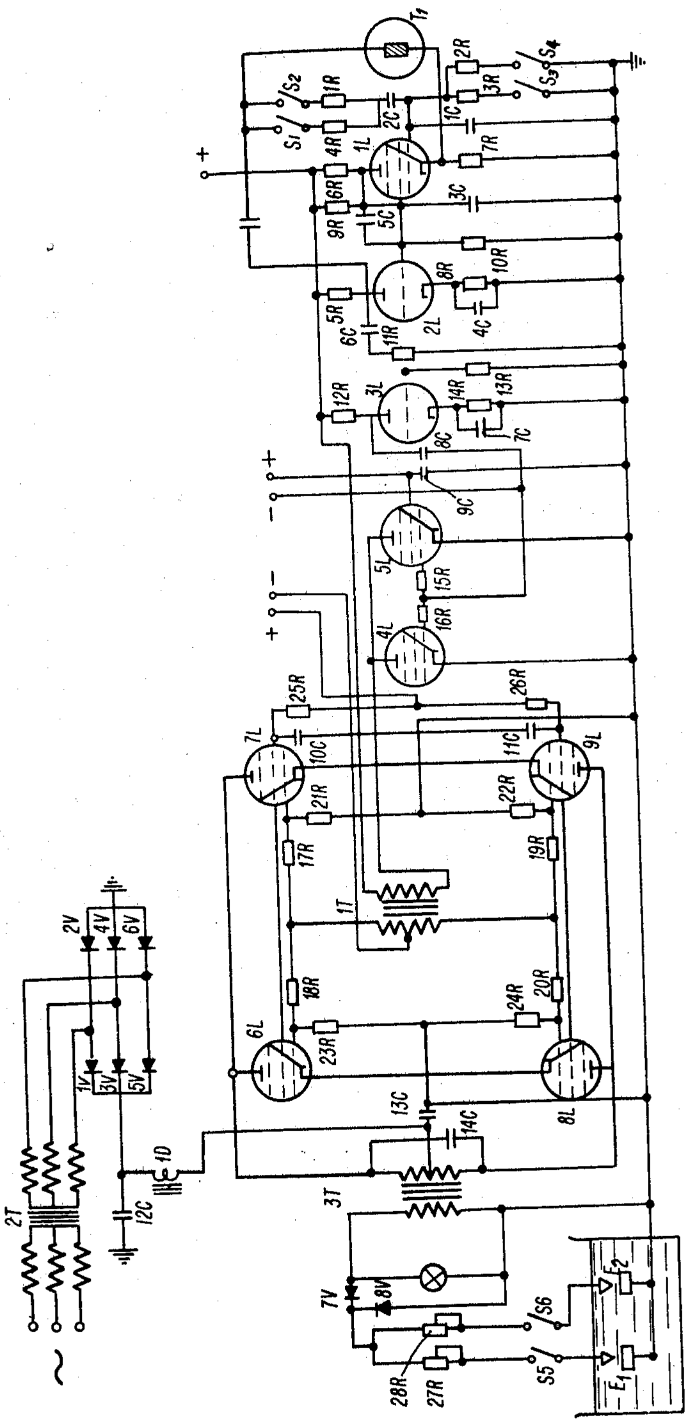

FIG. 1

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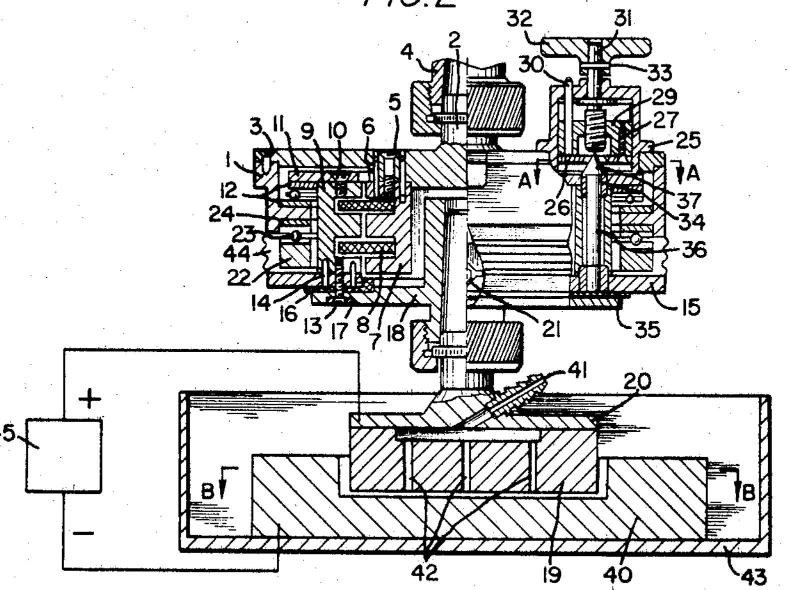
FIG. 2



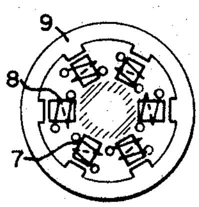


FIG. 3

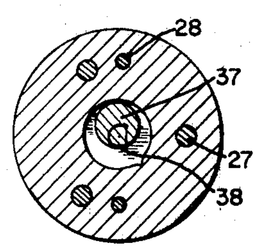


FIG. 4

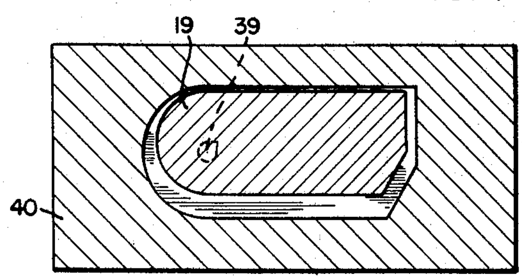


FIG. 5

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METHOD FOR HIGH-FREQUENCY ELECTRIC-IMPULSE METAL FINISHING AND AN APPARATUS FOR ACCOMPLISHING THE SAME

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U.S. Cl. 219—69 6 Claims

ABSTRACT OF THE DISCLOSURE

A method for high-frequency electric-impulse metal finishing by an electrode-tool acting as an anode, between which and the work, acting as a cathode, electric impulse discharges are excited by unipolar voltage pulses with an amplitude ranging from 100 to 600 volts, said electric impulse discharges being characterized by a ratio of a single pulse to average energy over a cycle lying within 1 to 5. The method characterized by the above parameters is implemented by the provision of an apparatus comprising an oscillator, a power amplifier, an output transformer, two semiconductor valves and a nonlinear resistance.

This invention is related to a novel electric erosion treatment—a method of high frequency electric-impulse working and an apparatus to accomplish said method.

A very important problem in the art of electric erosion treatment nowadays is to improve the purity of the worked surface. This is an important problem for both electric-spark and electric-impulse (electric) erosion treatment.

It has been found that generally, in any kind of electric erosion treatment, the roughness of the finished surface depends upon the energy of discharges which influence said surface (becoming rougher with the increase of impulse energy), and the total metal take-off is determined by the average amount of the energy supplied to the work. Therefore there is a tendency, when it is desired to improve the purity, to conduct finishing by dropping the energy of an individual impulse and increasing the impulse common sequence frequency.

It would be quite natural, in increasing discharge sequence frequency, to maintain an average power at a high level of rough running conditions. It would seem possible to obtain the efficiency of rough running conditions but with a greater surface purity. However, two interconnected factors prevent this in reality.

The first factor is that, with an equal energy introduced into the finishing area, energy consumption of the process is greater, the higher is the frequency and consequently the higher is dispersion of metal, that is with an equal general energy introduced at low and high frequencies in the latter case there will be less metal take-off.

The second factor is that amount of roughness is approximately proportional to the discharge energy raised to the third power. Therefore, to decrease roughness, for instance, two-fold, that is by one class according to national and foreign standards, the impulse energy should be dropped $2^3=8$-fold. To raise the surface purity from the first to the eighth class, that is by seven classes, the impulse energy must be dropped at least by 2^{21}, that is approximately 2.5 million times, and therefore the upper frequency limit (considering 400 cycles as the impulse frequency in rough running conditions) must be made 10^6 kilocycles, and this is about a few thousand times greater than has been obtained for the time being experimentally or in industry. At the same time the action of the first factor is manifest to a still greater extent, that is energy consumption increases.

Therefore, in view of technical difficulties in obtaining heavy current periodic impulses (due to the absence of adequate electronic and semi-conductor devices, the difficulty of frequency supply in the range of megacycles to the tool and the work, low efficiency and the like), generally, together with the increase of frequency within reasonable bounds, impulse energy is also controlled at the expense of dropping its amplitude, that is at the expense of decrease in the total energy introduced into the finishing area. And this still more greatly reduces the difference between fine and rough running conditions.

In connection with the abovementioned factors reduction of the energy consumption of the process at high frequencies is of primary importance.

Energy consumption of the process largely depends on the state of metal removed from the recess—in vapourous or liquid state. Naturally, in the first instance energy consumption of the process is greater as part of the energy is spent to make metal boil and turn it into vaporous state. In turn, as experiments and theoretical considerations show, the state, into which metal removed from the recess is brought, depends on the ratio of the energy of an individual impulse (W_i) to its average value over a repetition cycle (W_m) $\mu=W_i/W_m$.

Here, two fundamentally different methods may be distinguished, one of which (high-frequency electric-spark finishing) is widely known and is used in the USSR and abroad, and the other of which (high-frequency electric-impulse finishing) is the object of the present invention.

The known method of high-frequency electric-spark working is characterized by a frequency ranging from a few kilocycles to hundreds of kilocycles.

Here, the value $\mu=W_i/W_m$ ranges approximately within 10 to 100. As a result, the ratio of the current impulse duration to its amplitude (sec./amp) is very small, that is with a short time of impulse application the spark discharge has a very lagre instantaneous power, and this results in a preferably electronic process (that is preferable heat generation due to the braking energy of electrodes on the anode work), high instantaneous temperatures of the anode spot (above 10,000° C.), mostly explosion evaporation of metal (a "vaporous" stage—metal is removed in the shape of vapours and vapour jets), elevated, due to this fact, energy consumption, optimal, from the point of view of wear and the rate of take-off, direct polarity of electrodes corresponding to the electronic process (the tool serves as a cathode and the worked article as an anode).

As a result of a large ratio of impulse energy to the average energy within a cycle (μ is great) the thermal wear of the tool cathode is increased. Therefore, it is not the practice to utilize high-resistant carbon-graphite electrodes which at these high temperatures of the cathode spot no longer possess sufficient thermal strength and do not restore by themselves due to carbon compounds obtained in pyrolysis of a working fluid and deposited on the carbon-graphite electrode tools. For this reason metal electrode tools (such as: made of copper, brass) are used in this method of working, these being more expensive and more workable than carbon-graphite electrode tools. A outcome of the same factor (high instantaneous temperatures caused by high values of μ is the levelling (alignment) of take-off rates in working the materials with very distinctive thermophysical properties. It is known, for instance, that the take-off rate for steel comes down to the level of the take-off rate for metal-ceramic solid alloys sharply reducing the efficiency of finishing steel articles by this method.

Stability of the finishing process on a large area also is reduced because metal evacuation through a very narrow long slit in vaporous state is obstructed—at high metal dispersion the particles are cooled faster and thus their energy is given up quicker to the surrounding space and the electrode surface.

A characteristic feature of high-frequency electric-spark working also consists in utilization of alternating reversed voltage and current impulses, as at such high instantaneous powers the effect of a back wave is by far not the main one from the point of view of its influence on wear. As a result of this fact, the impuse generators are provided, as a rule, with a capacitance energy accumulator (capacitor) discharging through a thyratron to the primary winding of the impulse transformer, an erosion load being connected to its secondary winding. Generally the circuit of impulse generators for high-frequency electric-spark working resembles the known means of impulse radar modulation.

The proposed novel method of high-frequency electric-impulse working is also characterized by a frequency ranging from a few kilocycles to hundreds of kilocycles.

However, the value of μ at the same frequencies and the same mean power is smaller at least by one order ($1\ \mu\ 5$). Hence, the ratio of impulse duration to its amplitude (sec./amp.) is accordingly by one order greater. The result of this is that the ion process dominates in the proposed method of working, that is heat generates mostly due to ion bombardment on the cathode work and the metal is taken off not in a vaporous state, but mainly in a liquid state, causing smaller energy consumption in the process. In this case reversed polarity of electrodes is optimal with respect to the compared process of known high-frequency electric-spark working, that is the tool serves as an anode and the work as a cathode. This fact necessitates the utilization of a carbon-graphite tool, as together with the temperature drop on the anode spot, the electrode tool is self restored by pyrolysis of the working fluid taking place in the working process.

Thermophysical properties of materials, like in the case of low frequency, considerably affect the rate of metal take-off; the ratio of the steel take-off rate to that of a solid alloy becomes 5 to 10 times greater, which fact determines the serviceability of the method proposed for finishing shaped steel articles. Metal take-off in a liquid state facilitates its evacuation in tooling large areas.

A distinctive feature of the proposed method for high-frequency electric-impulse treatment is also the uttilization of unipolar (instead of alternating reversed impulses used in electric-spark working) voltage and current impulses, which fact, together with the small value of the factor of μ, determines the principal changes in generator circuits; the capacitance energy accumulator becomes unessential and the output transformer is materially simplified; however, for obtaining unipolar impulses, rectifiers should be provided at the output of the generator. Thus, generators for high-frequency electric-impulse treatment are fundamentally different in their block-diagram from the known generators for high-frequency electric-spark working.

Aonther fact should be mentioned. In current use now rough electric-impulse work is carried out preferably at a low frequency (within 1 kilocycle), but motor-generators at a frequency of 400 cycles are actually used. Unipolar arc impulses are used in this working method, the article being connected to the cathode and the electrode to the anode at small values of μ ($1<\mu, \leq 5$). Existing theoretical concepts on the nature of electric erosion treatment lie in that if absolute impulse duration is reduced approximately to quantities less than 10^{-4} sec. electronic process occurs in the main with all the features described above arising from the process of high-frequency electric-spark treatment, including the obligatory connection of the work to the anode. Therefore it was supposed that in the event of a sharp increase of frequency, by several orders, while known electric-impulse low-frequency working, a coincidence of the, physical and technological characteristics of the two kinds of electric erosion treatment—electric-spark and electric-impulse treatments would take plae. This is why all the explorers and inventors in the USSR and abroad have heretofore used μ values within the range of electric-spark treatment ($10 \leq \mu \leq 100$) at the increase of frequency, and till now no attempts have been made to create impulse generators for high-frequency electric-impulse treatment. Therefore the effect of transfer of the abovesaid peculiarities characteristic of low-frequency electric-impulse treatment of high frequency was not foreseen, lie the novelty was not in the fact that the absolute impulse duration determined the character of the process (electronic or ionic polarity of electrodes, take-off rate in working steel and solid alloys, the possibility of working large areas and so on), but the ratio of the energy of an individual impulse, W_i, to the average energy over a cycle, W_m, and the consequent ratio of duration of a current impulse to its amplitude (sec./amp.)

The abovementioned distinctive features of the method we propose to raise the efficiency of finishing shaped steel articles ten-fold as well as reduce several times the wear of the tool and to accomplish finishing of large parts having a finishing area of scores of thousand square millimeters.

To achieve the proposed method of sizing, unipolar voltage impulses of negative polarity (the work as a cathode, the tool as an anode) with an amplitude within 100 to 600 volts are supplied to the machined work from an impulse generator, for instance, of the type described hereinafter; in the erosion process the ratio of the energy of an actuating current impulse should be maintained within the limits from 0.2 to 0.9. The frequency of the impulse sequence is selected in dependence upon the required surface purity and is established within the limits from 2 to 1,000 kilocycles. In this case sizing running conditions are controlled at first by frequency (from lower frequency to higher frequency) and then by the mean current (from heavier current to weaker current) till the predetermined surface purity is obtained. Adjustment from lower frequency to higher frequency is essential because it provides for greater efficiency in preliminary metal take-off at a lower wear of the tool.

As the increase of impulse frequency is accompanied by certain rise in relative tool wear, it is preferable to take-off the minimum allowance at a higher frequency. Further current drop at a maximum frequency does not cause an increase in the wear and ensures higher surface purity, but at a correspondingly lower efficiency. Therefore in the proposed system of adjustment minimum allowances and metal take-off are provided for unfavourable running conditions from the point of view of wear and efficiency, which fact in general provides for obtaining the predetermined surface purity for minimum possible time and at minimum absolute wear of the electrode tool.

In the course of operation, the electrode and the work are brought so closely to each other as to cause a breakdown of the dielectric when voltage impulses are supplied to the electrode. Depending on the electric running conditions, on the dimensions and the shape of the worked surface, in order to stabilize the process, the electrode tool is actuated to perform oscillatory motion relative of the work or the work is actuated to perform oscillatory motion relative of the electrode tool.

The oscillatory motion may be performed in the direction of feeding and on a plane perpendicular to said direction, in particular in the two inter-perpendicular directions. The amplitude of oscillations in the direction of feeding may range from 0 to 0.1 mm., and the amplitude of oscillations on a plane perpendicular to the direction of feeding may reach several millimeters.

For removing erosion by-products during operation, fluid is forced into the space between the electrode tool and the work, or is sucked out of this space.

For realization of the proposed method a generator is required to obtain exclusively negative voltage impulses and currents with a small μ ratio, which are able to cause discharges between the tool and the work, and a means is essential to impart oscillatory motions to the electrode tool and the work.

Hereinafter we describe one of the preferred modifications of these units with reference to the appended drawings.

FIG. 1 shows a principal electric diagram of a unipolar impulse generator able to accomplish the proposed method of electric impulse high-frequency metal working.

FIG. 2 shows a general view of a mechanical means for imparting oscillations to the electrode tool and the work.

FIG. 3 shows a diagrammatic arrangement of drive electromagnets which compose said means.

FIGS. 4 and 5 show sectional views along A—A and B—B in FIG. 2.

The impulse generator, shown in FIG. 1, comprises an oscillation exciter, a voltage amplifier, a power amplifier, an output transformer and a rectifier block.

The oscillation exciter comprises two tubes—a pentode **1L** and a triode **2L**.

The frequency of oscillations is established within a wide frequency range by means of condensers **1C**, **2C** and resistors **1R**, **2R**, **3R** and **4R**, switched over by switches S_1, S_2, S_3 and S_4.

To stabilize the amplitude of impulses a non-linear resistor (a thermistor **T1**) is connected to the cathode circuit tube **1L**. Resistors **5R** and **6R** provide an anode load on the exciter. The grid bias is obtained automatically as a result of the anode current flowing through resistors **7R** and **8R**. The screen grid is fed through resistor **9R**; condenser **3C** serves for disconnecting the screen grid, condenser **4C** is a blocking element, condenser **5C** is a duct capacitor and connects the anode of the tube **1L** with the grid of the tube **2L**, resistor **10R** serves as a leakage for tube **2L**.

Voltage from the exciter, through a duct condenser **6C** and by means of potentiometer **11R** controlling the signal level from zero to maximum, is delivered directly to the voltage amplifier grid arranged on the triode **3L**. This amplifier amplifies primary oscillations up to the rated value.

Resistor **12R** acts as anode load of the voltage amplifier (or of the tube **3L**). The grid bias is provided at the expense of the voltage drop at the cathode resistor **13R**. Condenser **7C** is a blocking element, resistor **14R** acts as a leakage for tube **3L**.

Amplified oscillations are supplied to the power amplifier sub-final stage through the condenser **6C**, said amplifier being mounted on two pentodes **4L** and **5L**. The tube grids are separated by resistors **15R** and **16R**. Condenser **9C** is connected in between the screen grids and the cathodes.

The grid bias is supplied from an individual power source manufactured in accordance with common circuits.

The power amplifier sub-final stage serves to amplify the level and the power amplifier terminal or output stage.

Connection with the terminal stage is achieved by an interstage transformer **1T** whose core is assembled from laminations up to 0.1 mm. thick.

Voltage in opposite phases is delivered from two secondary windings of the transformer **1T** to the power amplifier terminal stage, said amplifier being connected to four pentodes **6L**, **7L**, **8L** and **9L**, arranged according to a two-way circuit with two tubes in each arm.

The power amplifier terminal stage functions in the grid current duty. To avoid self-excitation the tube grids are separated by resistors **17R**, **18R**, **19R** and **20R**.

Resistors **21R**, **22R**, **23R** and **24R** are used as tubes leakage.

The screen grids of tubes **6L** to **9L** are supplied through resistors **25R** and **26R**. Condensers **10C** and **11C** are connected in between the grids and the cathodes of the tubes.

Anode circuits of the terminal stage of tubes **6L**, **7L**, **8L** and **9L** are supplied from a high-voltage rectifier comprising diodes **1V** to **6V** in accordance with a six-phase circuit. To reduce pulsations a filter is provided in the high-voltage circuit, said filter comprising a choke D and a condenser **12C**.

Alternating voltage is delivered to diodes **1V** to **6V** from a high-voltage transformer **2T**. The anode feed circuit is connected with the tube cathodes through condenser **13C**.

Grid bias is delivered to the grids of tubes **6L** to **9L** of the terminal stage from a separate rectifier manufactured in accordance with common circuits.

The generator output voltage is transmitted to the load or the erosion gap through an output transformer **3T**, whose primary winding is shunted by condenser **14C**.

The magnetic core of the output transformer is composed of high-frequency steel laminations less than 0.1 mm. thick of high magnetic permeability.

The laminated magnetic core of the transformer is manufactured with a stepped section to allow winding on cylinder frames, to rise technological features of the construction and to somewhat reduce consumption of active materials.

To reduce magnetic core saturation which influences the shape of an output impulse, the transformer magnetic core is provided with a gap. To avoid breakdown in transient processes the transformer windings are filled with an epoxy resin.

Voltage from the transformer secondary winding is supplied to a rectifier comprising two diodes **7V** and **8V**, which transforms alternating current to unipolar impulses.

As the generator is intended to operate at high frequencies regular power diodes do not ensure a satisfactory complete cutoff of the second half-wave. Therefore another diode **8V** is connected discordantly with the first diode **7V** parallel with erosion gaps E_1 and E_2.

Since in idle running the entire load occurs on the tube anodes, which may thereby be put out of order, they should be protected.

For this purpose a non-linear resistor, more particularly an incandescent lamp L, is connected in parallel with the secondary winding of transformer **3T**, and the anode voltage is selected to be 0.7 to 0.8 of the rated value for the tubes.

Current amplitude is controlled by resistors **27R** and **28R** connected in series with the erosion gap. FIG. 1 shows an example of operation with two electrodes. The generator also permits operation with one electrode. The switching over is achieved by switches S_5 and S_6.

A mechanical means for imparting oscillations to the electrode tool and the work (FIGS. 2 to 5) is manufactured as a convenient compact structure. As is understood from FIG. 2, it comprises a body **1**, said body may be easily fixed in a spindle **4** by means of a cone **2** connected with the body by screws **3**. The mechanical means may also be easily arranged in the tool head of an electric erosion machine. The cores of electromagnets **7**, excited by coils **8**, are fixed on the flange of cone **2** by screws **5** and pins **6**. The armatures **9** of the electromagnets are bolted to the ring **11** by screws **10**, said ring resting upon a projection of the body **1** by means of a thrust ball bearing **12**. A central part **18** is coupled with the electromagnet armatures from beneath by screws **13** and pins **14** through an intermediate steel ring **15** and rings **16** and **17** made of insulating material, the electrode tool **19** fixed in a holder

20 fastened to said central part. In the upper part the ring **15** is provided with two V-shaped grooves furnished on both sides of the central opening, and a movable connection of the ring **15** with the ring **22** is achieved by means of said grooves and balls **21**. Ring **22** is provided with four V-shaped grooves: two grooves on the lower side, the direction of said grooves coinciding with the direction of the grooves of ring **15** for connection through balls **21** with ring **15**, and two grooves on the upper side, said grooves being arranged in the direction perpendicular to the direction of the grooves of the ring **15**. Ring **22** is moveably connected with ring **24** by the upper grooves and the balls **23**, ring **24** being fixed in the body **1**. Thus, the central part **18** freely moves in two perpendicular directions, but cannot rotate.

A cup **25** is fastened on the flange of cone **2**, a flat former **26** being placed inside said cup **25**. The former is bolted by screws **27** and pins **28** to a nut **29**. A pin **30**, passing through cup **25** and nut **29**, prevents former **26** from turning. Former **26** can move towards the axis of screw **31** by means of screw **31** rotated by a handle **32**, linked with the screw by a pin **33**. A pivot **36** with a cone head **37** is mounted in rings **11** and **15** on bearings **34** and **35**. The purpose of former **26** and pivot **36** is to limit the travel of central part **18** on a plane perpendicular to the direction of the electrode tool fed towards the work. Voltage is intermittently supplied to the coils of electromagnets **8**, so that the armatures **9** of the electromagnets move central part **18**. It moves on until head **37** of pivot **36** approaches former **26**. The sequence of connecting the electromagnets is selected in such a way that pivot **36** may be enabled to slide on the surface of former **26** gradually feeling its surface. As a result of the rigid connection between pivot **36** and central part **18**, the latter moves along the same trajectory. This will be readily seen on FIGS. 4 and 5. Trajectory **38** of the pivot in FIG. 3 is similar to trajectories **39** of any point of tool **19**.

The former **26** may be of any complicated shape and therefore the electrode tool may be supplied any complicated trajectory. In shaping the former similar to the contour of the worked holes, preserving the angles of the given drawings, the electrode tool may intermittently feel the worked surface completely reproducing the surfaces of the required shape with the given acute angles on the workpiece **40**. If high precision of acute angles is not required the former is manufactured as a ring.

Due to the movement of the electrode tool on the worked surface, the gap between the electrode tool and the work occasionally varies from a quantity corresponding to the value of the breakdown gap and up to quantities considerably greater than this value (up to several millimeters). Thus, the outlet is occasionally freed to release erosion by-products from the working area.

In the course of working, the dimensions of the worked surface may be increased without the electrode tools being changed by increasing the amplitude of oscillatory motions of the electrode tool by means of handle **32**, which moves the former **26**.

Dielectric fluid is pumped through a pipe connection **41** and holes **42** in the electrode tool. Work **40** and electrode tool **19** are immersed in a dielectric fluid bath **43**. To prevent inside penetration of fluid contaminated by erosion by-products, a flexible packing **44** is provided. The electrode tool is connected to the positive pole of the abovedescribed impulse generator **45**, while the workpiece is connected to its negative pole. The entire arrangement is linked with the functional feed mechanism of the electric erosion machine.

An arrangement similar to the above described apparatus may be mounted on the electric erosion machine table to impart oscillations to the worked part.

What we claim is:

1. An impulse generator for high-frequency electric metal finishing by electric impulse discharge excited by unipolar voltage impulses of an amplitude from 100 to 600 volts with a ratio of the energy of a single impulse to an average impulse over a cycle ranging from 1 to 5, comprising an exciter including a phantastron, means including a voltage amplifier connected directly to the output of said exciter for amplifying primary oscillations up to rated value, a power amplifier having its input connected to said voltage amplifier, a magnetic core output transformer having an air gap in its magnetic core and its primary winding connected to the output of said power amplifier, said transformer having a secondary winding, and two output terminal circuits connected to said secondary winding, one of said output terminal circuits comprising a semiconductor valve preventing flow of current during one half of a cycle and allowing flow of current therethrough to a metal finishing load circuit during the other half cycle of each operating cycle, the other of said output terminal circuits comprising a second semiconductor valve connected across a series circuit formed of said secondary winding and said first semiconductor valve.

2. An impulse generator for high-frequency electric-impulse metal finishing according to claim **1**, wherein a non-linear resistor is connected in parallel with the secondary winding of an output transformer.

3. An impulse generator for high-frequency electric-metal finishing according to claim **1**, wherein a non-linear resistor is connected in parallel with an exciter tube.

4. An impulse generator for high-frequency electric-impulse metal finishing according to claim **1**, wherein voltage, feeding amplifier tubes, amounts to 0.7 to 0.8 of the rated value.

5. An impulse generator for high-frequency electric-impulse metal finishing according to claim **1**, wherein the windings of the output transformer are filled with epoxy resin which prevents a possible breakdown when transient processes occur.

6. An impulse generator for high-frequency electric-impulse metal finishing according to claim **1**, wherein the output transformer is manufactured with an air gap in the magnetic core.

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