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R. BASTIR

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APPARATUS FOR APPLYING PULSES TO MUSCLES AND NERVES
FOR ELECTROMEDICAL STIMULATION

Filed Aug. 16, 1952

3 Sheets-Sheet 1

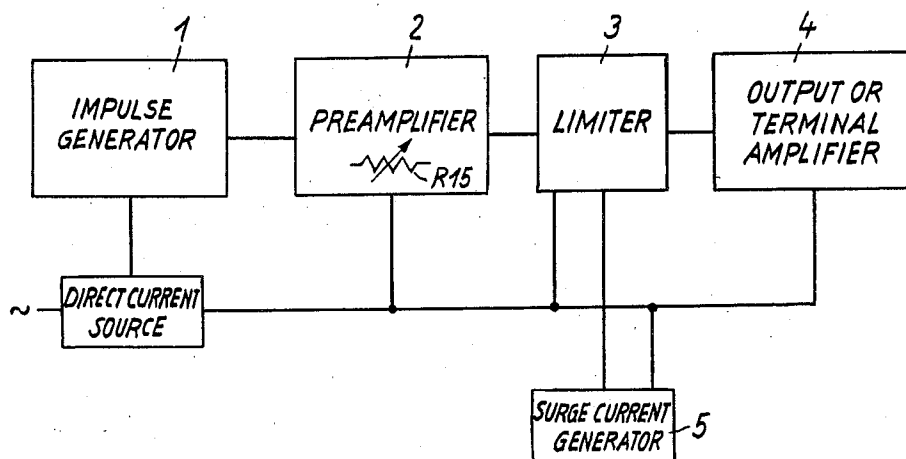


Fig. 1

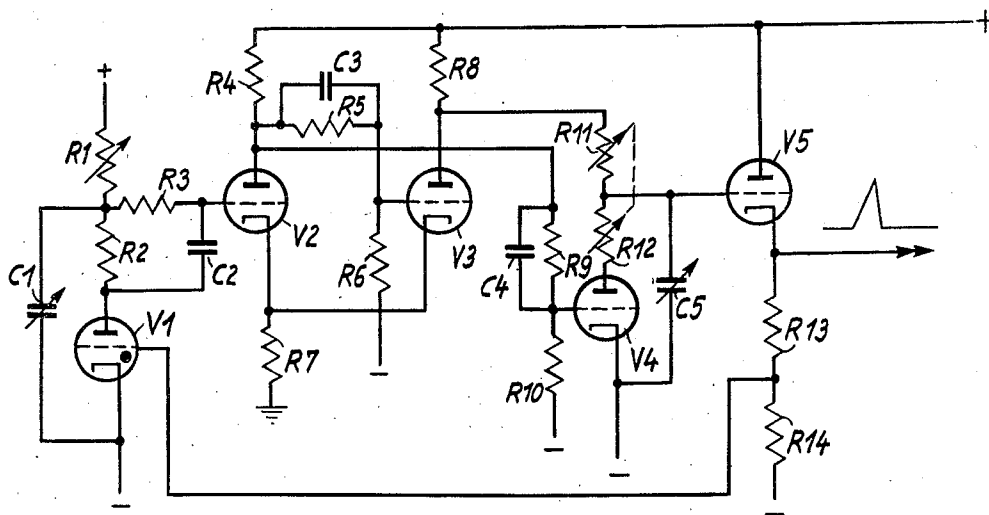


Fig. 2

Inventor:
Robert Bastir.

By *[Signature]* Atty.

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3 Sheets-Sheet 2

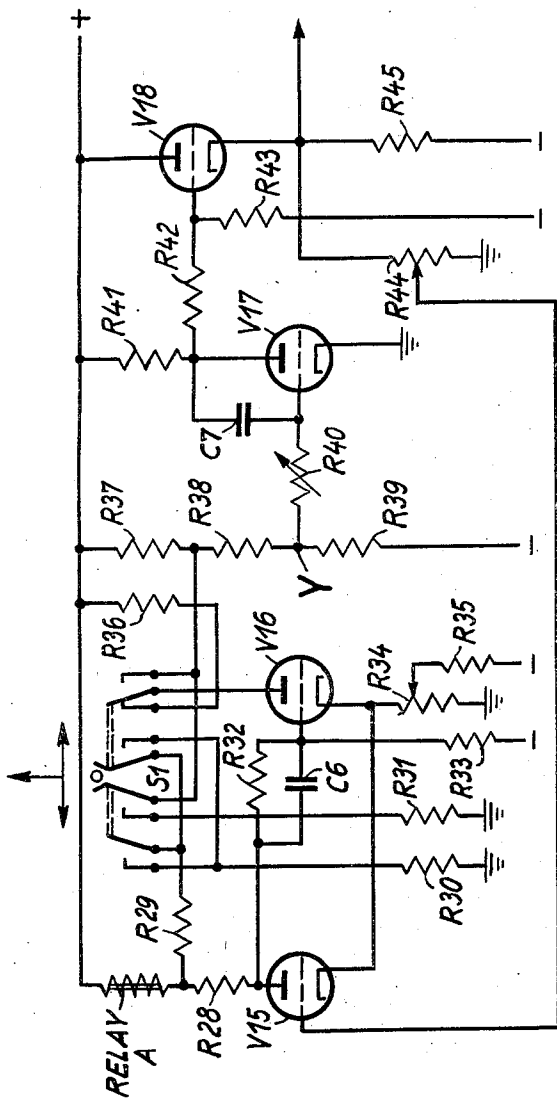


Fig. 4

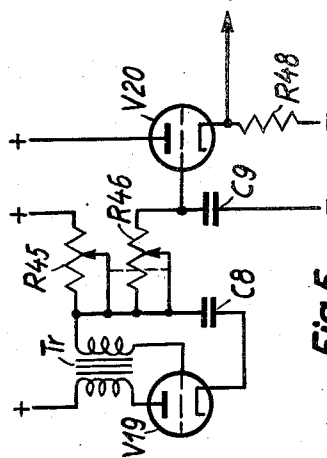


Fig. 5

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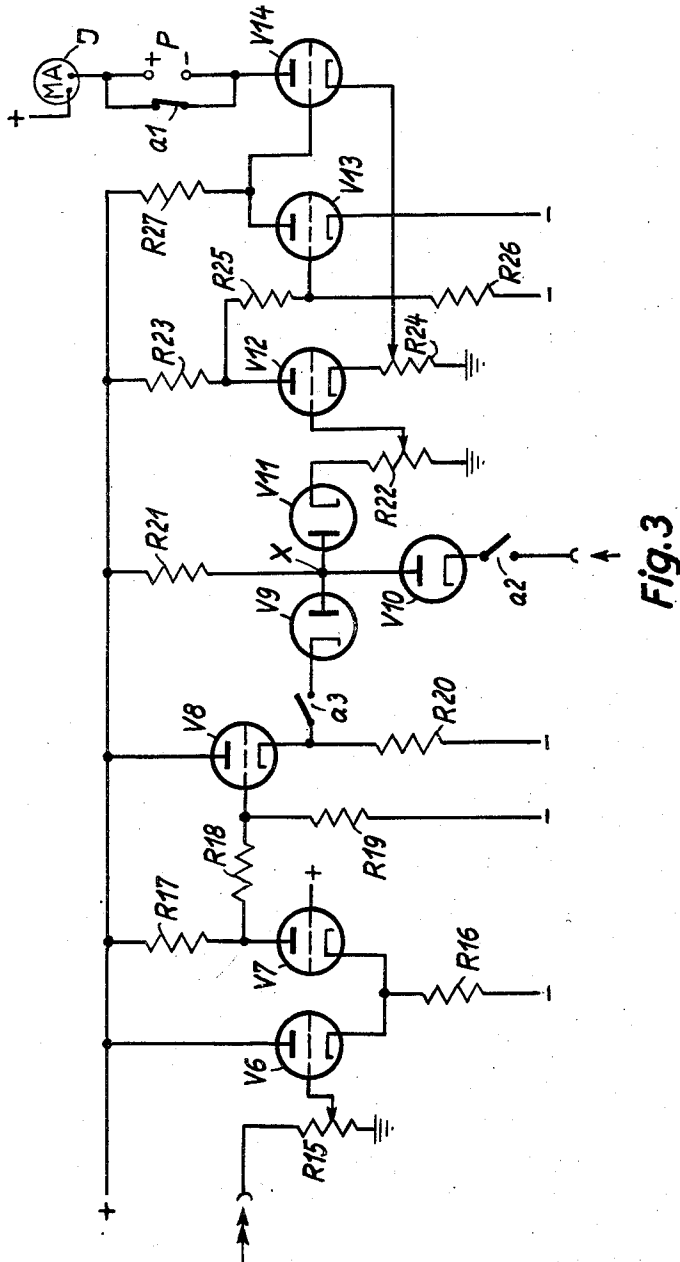


Fig. 3

Inventor.
Robert Bastir.

By.

Atty.

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APPARATUS FOR APPLYING PULSES TO MUSCLES AND NERVES FOR ELECTROMEDICAL STIMULATION

Robert Bastir, Erlangen, Germany, assignor to Siemens-Reiniger-Werke Aktiengesellschaft, Erlangen, Germany, a German corporation

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27 Claims. (Cl. 250—36)

This invention is concerned with apparatus for applying pulses to muscles and nerves for electromedical stimulation.

One of the aims of modern electrotherapy is to stimulate certain nerves or muscles or groups of nerves or muscles lying within nonhomogeneous tissue sections to act in accordance with their specific response, without affecting the neighboring tissues that should not be therapeutically treated. Apparatus which answers the corresponding requirements must generate electrical impulses of triangular or rectangular form, which are thereafter transformed into impulses of a characteristic form that will produce the desired stimuli. The originally generated triangular or rectangular impulses must for this purpose be independently adjustable with respect to the duration thereof and with respect to the duration of the pauses or spacing therebetween. In addition, the steepness of the impulses must be varied within wide limits, and the magnitude of the current at the outlet of the apparatus must be gradually adjustable from zero to a maximum value. The term "gradually," used with respect to such adjustment, is intended to distinguish as compared with sudden jumps that would result from step-by-step adjustment. Threshold or surge means is therefore preferably provided, which permits transmission of impulse groups as well as transmission of single impulses.

It should be considered in this connection that the technique of applying the treatment requires adjustment adapted to cause the impulse amplitudes of the successive impulses to increase (surge) gradually and thereafter to decrease (decay) gradually or to increase and decrease periodically, respectively. This is accomplished by modulation of the impulse amplitudes of the successive impulses delivered by an impulse generator. The corresponding modulation of the impulse amplitudes is termed "surging of the impulses" or equivalent language and the generator required for such surging is termed "surge current generator."

The object of the invention is to provide electrical stimulation apparatus which meets the above noted and other requirements.

Details of the invention will appear from the description which will presently be rendered with reference to the accompanying drawings, wherein

Fig. 1 is a block diagram showing the various apparatus elements;

Fig. 2 shows in diagrammatic circuit representation an example of the impulse generator indicated in Fig. 1 at 1;

Fig. 3 is a circuit showing a preamplifier, a limiter and a terminal or output amplifier, which are indicated in Fig. 1 at 2, 3 and 4;

Fig. 4 is a control circuit coacting with the circuit shown in Fig. 3; and

Fig. 5 indicates an impulse generator that may be used in place of a multivibrator included in other figures.

Referring now to Fig. 1, there is provided an impulse

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generator 1 (details shown in Fig. 2) for producing triangular impulses with relatively flat rise and a steeper drop. The duration of the impulses, as well as the duration of the pauses or spacing therebetween, is independently regulable in rough as well as in fine increments. The produced impulses are conducted to a preamplifier 2 (tubes V6—V7—V8 in Fig. 3) having a regulator R15 for varying the input voltage. The output of the preamplifier is conducted to a limiter 3 (tubes V9—V10—V11 in Fig. 3). If the regulator R15 of the preamplifier 2 is adjusted so that the triangular impulses pass the limiter 3, corresponding triangular impulses will appear at the output circuit of the apparatus. However, if the input voltage at the preamplifier 2 is increased, the peaks of the triangular impulses will be cut off in the limiter 3, and the result will be trapezoidal impulses. Assuming an input voltage of sufficient magnitude, the flanks of the impulses will then become so steep that rectangular impulses will appear in the output circuit of the apparatus. The adjustment of the regulator R15 of the preamplifier therefore permits continuous regulation of the steepness of the impulses.

In order to produce the required output for the desired stimulation treatment, there is provided, as shown in Fig. 1, in series with the limiter 3, an output or terminal amplifier 4. This output amplifier has a plurality of stages (tubes V12—V13—V14 in Fig. 3) and means for feed back in opposite phase, so that the output current becomes independent of the load represented by the patient undergoing treatment. The apparatus also comprises a device 5 shown in Fig. 1 which permits gradual increase or surge of the impulse current in the output circuit.

As shown in Fig. 2, the impulse generator comprises discharge tubes V2 and V3 forming a multivibrator. When the grid voltage of the tube V2 reaches a certain positive value, this tube becomes conductive while the tube V3 is at the identical instant blocked. The tubes remain in this condition until the potential on the grid of tube V2 is reduced to a certain value. The first-mentioned condition is thereafter restored; i. e., the tube V3 becomes conductive and V2 will be blocked.

The capacitor C5 will be charged over the adjustable resistor R11 at the time when the tubes V3 and V4 are blocked. The potential at the resistors R13 and R14 in the circuit of the cathode follower V5 is thereby increased, the cathode follower V5 being provided to avoid charging of the capacitor C4. When the potential between R13 and R14 reaches approximately the cathode potential of the gas-filled triode V1, the latter will become conductive. The resulting impulse at the resistor R2, which is disposed in the plate circuit of the triode V1, is conducted over the capacitor C2 to the grid of tube V2 and causes sudden blocking thereof. The tubes V3 and V4 become at the same time conductive, as described before. The capacitor C5 is now discharged by way of the regulable resistor R12. The two resistors (regulators) R11 and R12 are coupled and allow fine regulation of the impulse duration. The rough regulation is accomplished by temporarily disconnecting the capacitor C5 and switching on a capacitor of suitable and desired greater or smaller capacitance. This may be done by a simple switching operation.

The capacitor C1 is discharged responsive to firing of the gas-filled triode V1; and, when this tube extinguishes, the capacitor is charged again over the regulable resistor R1. When the potential at the capacitor C1 reaches the upper critical switching point of the circuit including the tubes V2, V3 and V4, such circuit will again switch over; i. e., the tube V4 will cease to pass current, and the capacitor C5 is again charged over the resistor R11,

and so forth. The regulable resistor R11 therefore makes it possible to finely regulate the duration of the pauses or spacing between the impulses. The rough regulation may again be accomplished by suitably switching in a capacitor of suitable capacitance to take the place temporarily of the capacitor C1.

It is often desired to produce individual impulses instead of groups of impulses. The loading resistor R1 is for this purpose placed at a voltage which lies between the two critical switching voltages of the tube V2. Accordingly, the capacitor C1 will not reach its upper critical switching voltage, and no impulses will be produced. If a single short negative impulse is now transmitted to the plate of the tube V2, e. g., by a capacitor discharge, the tube V3 will be blocked. A single impulse will consequently be transmitted, as already described. The next impulse will be transmitted only responsive to connecting another negative impulse to the plate of the tube V2.

It will be seen from the foregoing that the duration of the impulses and the duration of the pauses between the impulses are independently adjustable or regulable. The duration of the impulse pauses is determined by the resistance of the resistor R1 and the capacitance of the capacitor C1. The resistor R1 is thereby used for fine regulation and the capacitor C1 for the rough regulation. The impulse time is similarly regulated by the regulator R11 and the capacitor C5 (rise of the impulse curve) and by the resistor R12 and capacitor C5 (drop of the impulse curve). The internal resistance of the tube V4 which also affects the decay or drop of the impulse curve may be neglected because it is constant. The resistors R11 and R12 which are coupled as shown are used for the fine regulation and the capacitor C5 for the rough regulation. The mechanical coupling between the resistors R11 and R12 secures linear operation and the ratio between rise and decay of the impulse curve will be fixed and independent of the regulation of the impulse time. Each of the capacitors C1 and C5 may comprise several capacitors connected in parallel.

The impulses occurring at the cathode of the cathode follower V5 of the impulse generator are now conducted over the path indicated by arrows to the circuit shown in Fig. 3, which includes the preamplifier comprising the tubes V6—V7—V8 (numeral 2 in Fig. 1), the limiter comprising the tubes V9—V10—V11 (numeral 3 in Fig. 1) and the terminal or output amplifier comprising the tubes V12—V13—V14 (numeral 4 in Fig. 1). The circuits of Fig. 3 cooperate with the circuit shown in Fig. 4 in a manner which will presently appear. The interconnection is indicated by the conductors marked by arrows extending respectively from the cathode of tube V13 in Fig. 4 and terminating in the contact a2 leading to the cathode of the diode V10 in Fig. 3.

The input and also the output impulse of the preamplifier (tubes V6—V7—V8) must be positive. The preamplifier is therefore provided with the tubes V6 and V7 having interconnected cathodes. The tubes therefore operate in a push-pull manner. The amplified cophasal voltage is obtained at the plate of the tube V7. The tube V8 operates as a cathode follower to produce a low-ohmic preamplifier output.

The output line of the impulse generator (Fig. 2) is connected with the resistor R15 disposed in the input circuit of the preamplifier. As already explained before, this resistor makes it possible to continuously regulate the steepness of the impulses.

The polarity of the impulses at the output of the preamplifier (V8) thus remaining identical with the polarity of the impulses fed thereto over resistor R15 and the low-ohmic output at the cathode of the follower V8 great enough so that it may be conducted directly to the cathode of the diode V9 of the limiter over the contact a3. The contact a3 and also the contacts a1 and a2

in Fig. 3 are contacts operated by the relay A shown in Fig. 4 at the top left thereof. If there is a potential on the cathode of the tube V9, which is more positive than the potential of its plate, and on the plates of the diodes V10 and V11, the diode V9 will be blocked. A voltage will then occur at the resistor R22 which will correspond to the ratio of the resistors R21 and R22. The internal resistances of the diode paths may be neglected because they are small as compared with the resistances R21 and R22. If the potential at the cathode of the diode V9 of the resistors is negative, current will flow therethrough and through the resistor R22. If the potential at the plates of the diodes is at such instant negative, as compared with the cathode of the diode V11, the latter will be blocked. The voltage at the resistor R22 is in such a case zero. The slow impulses or current surges are received from the circuit shown in Fig. 4 over the diode V10 by way of the conductor indicated by the arrow. The operation of this tube (V10) corresponds to that of the diode V9.

The resistor R22 is formed as a potentiometer and therefore permits regulation of the input voltage for the tube V12 of the terminal amplifier which also comprises the tubes V13 and V14, thereby also regulating the output current at the terminals P which connect with the treatment circuit for the patient. Stating the operation more in detail, the resistor R22 regulates the maximal amplitude of the impulses from the limiter (tubes V9—V11) to the treatment circuit P, and the resistor R24 regulates the amplitude within the maximal value determined by the resistor R22.

It will be seen from the foregoing explanations that the diode V10 serves for determining the limit potential at the point which interconnects its plate with the plates of the tubes V9 and V11. The cathode potential of the diode V10 is controlled by the surge current generator (Fig. 4 or 5) in step with the cycle duration of the intended amplitude variations of the impulse series coming from the impulse generator Fig. 2. The diode V10 therefore operates as a coupling element between the limiter (V9 and V11) and the surge current generator (Fig. 4 or 5). The coupling becomes effective when the cathode potential of the diode V10 is lower than its plate potential. By shifting the zero position of the triangular impulses produced by the surge current generator Fig. 4, it is thus possible to control the impulses generated by the generator Fig. 2, i. e., to suppress them periodically completely and to permit them to variably surge (increase and decrease) temporarily, with following suppression, increase and decrease thereof, and so forth. There is thus a single electronic regulation element (diode 10) for controlling the surge impulses connected to the contact a2.

The terminal amplifier has three stages so as to provide for a sufficient feed back in opposite phase. The internal resistance of the final triode V14 is thereby very considerably increased, and the adjusted magnitude of the current becomes independent of the load represented by the patient. The current of the final tube flows for the feed back in opposite phase through part of the resistor R24 of the input stage V12. The greater the resistance of R24, the stronger will be the feed back in opposite phase. This reduces the maximal output current at identical maximal input voltage. The resistor R24 therefore is adjustable and permits, together with the adjustable resistor R22, accurate adjustment even of relatively small current values. The resistor R24 is preferably connected with a switch (not shown) for automatically switching the instrument J in the output circuit during the regulation to a higher measuring range.

Fig. 4 (which is interconnected with Fig. 3 as described before) shows an example of a circuit for the controlled generation of the impulse surges. A periodically alternating voltage is by this surge control circuit

connected over the contact *a2* to the diode V10, which causes the potential at the point X (interconnection between the plates of the diodes V9—V10—V11) to alternate between gradual increase and decrease. The lower limit of the impulses is then correspondingly at zero volt, and the upper limit at a maximal voltage which results from the voltage division at the resistors R21 and R22 in Fig. 3.

The surging of the impulses is under control of the circuit including the tubes V15 and V16 shown in Fig. 4. These tubes also form a multivibrator. In the "surge" position of the switch S1 shown at the top left of the figure (switch being operated to the right), there is produced a periodical triangular voltage having identical sides. The frequency of this voltage is adjustable down to $\frac{1}{40}$ oscillation per second. This is the lower limit with respect to the time for the recuperation of some stimulated nerves so that they will respond to another stimulus. If it is assumed that the tube V16 is at the moment blocked, the grid of the tube V17, which is connected in a so-called Miller-stage, receives over the adjustable resistor R40 a positive voltage, and the capacitor C7 is discharged. The potential at the plate of the tube V17 thereby drops linearly. V18 is again a cathode follower which is in series with the tube V17 so as to maintain a low-ohmic output. Part of the output voltage of the cathode follower V18 is conducted to the grid of the tube V15 over the adjustable resistor R44. When the potential at the grid of tube V15 drops to the lower critical switching point, the multivibrator circuit will switch to its alternate operating position. The tube V15 is now blocked, while the tube V16 is conductive. The point Y in Fig. 4 is now negative to the cathode of the tube V17. The capacitor C7 is thereby linearly charged until the grid of the tube V15 reaches its upper critical switching point. The tube V15 will then be conductive, and V16 will be blocked, and so forth. The adjustable resistor R40 thus constitutes a regulator for adjusting the cycle duration, i. e., the time of the rise of the impulse curve and the adjustable resistor R44 constitutes a regulator for adjusting the maximal amplitude of the surge impulses.

The zero-line of the triangular surge impulse curve may be adjusted or regulated by means of the adjustable resistor R34.

The circuit, Fig. 4, has outside of the generation of the surge impulses the function of avoiding sudden current fluctuations in the treatment circuit incident to the switching of the apparatus for measuring the peak current of the impulses while carrying on the treatment. When the switch S1 is in its central normal position, the circuit will be set for "measuring." The magnitude of the generated impulses will in this position of the switch be indicated on the instrument J in Fig. 3. The point Y in Fig. 4 is in this operating position of the switch S1 negative; i. e., the capacitor C7 is discharged and the grid voltage of the tube V15 has reached the lower switching charge, whereby this tube becomes blocked. The relay A in the plate circuit of the tube V15 is deenergized, and the contacts *a2* and *a3* in Fig. 3 are accordingly open, while the contact *a1* is closed. Direct current corresponding to the adjusted peak current of the impulses now flows through the terminal tube V14 in Fig. 3.

If the switch S1 is placed in the "steady" position (switch operated to the left), the relay A in Fig. 4 will energize in a circuit including the resistors R29 and R30. Contact *a1* (Fig. 3) is accordingly opened, and contacts *a2* and *a3* are closed. The closure of contact *a3* is effected before opening of the contact *a1*. Since the potential at the cathode of the tube V18 is negative, the point X in Fig. 3 will with closed contact *a2* be negative also. The output current therefore will be at zero. In such "steady" position of the switch S1 current will also flow over the resistors R37 and R31, so that the point Y is negative.

The capacitor C7 is charged and the voltage at the cathode of tube V18 gradually increases. The voltage at point X over the diode V10 in Fig. 3 increases similarly. The impulses gradually surge. The surge speed may be adjusted by means of the regulator R40 shown in Fig. 4 as explained before. The grid voltage of the tube V15 increases coincident with the increase of the voltage at the cathode of the tube V18 until the upper critical switching point is reached. The tube V15 now passes current and holds the relay A energized.

The reverse takes place when the switch S1 is operated from its left "steady" to its central "measuring" position. The potential at the point Y becomes positive, the capacitor C7 is discharged and the potential at the cathode of the tube V18 drops. The impulses gradually fade to zero. When the voltage at the grid of the tube V15 is at the lower critical switching point, the tube will stop passing current and the relay A deenergizes. The contacts *a2* and *a3* (Fig. 3) accordingly open, and contact *a1* closes and short-circuits the output circuit P. The instrument J indicates the peak current in the treatment circuit. Transmission of sudden current surges to the patient is therefore avoided incident to the actuation of the switch S1.

The surge current generator thus comprises switching means for reducing the current in the patient or treatment circuit P (Fig. 3) prior to the switching-in or disconnection, respectively, of the measuring instrument J. The current is increased again only after the measuring instrument is connected over the contact *a1*. The patient in the treatment circuit is in this manner protected against sudden variations of the current applied to the treatment circuit.

Instead of producing the impulse surges by a multivibrator, as shown, it is of course possible to use a self-excited tube generator comprising a single tube such as shown, for example, in Fig. 5. The plate and the grid of the tube V19 shown in this figure are connected to the transformer Tr. The frequency of the slow surge impulses is continuously regulable by means of the potentiometers R45 and R46 which are connected in circuit with the capacitors C8 and C9 as shown. Numeral V20 indicates an amplifier tube having its cathode connected over a resistor R48. The surge impulses are conducted from the tube V20 over the conductor Z marked by an arrow to the contact *a2* and the diode V10 of Fig. 3.

It is desirable to hold the positive as well as the negative supply voltages constant, e. g., by electronic means, so as to obtain stable conditions, especially in the transmission of impulses of relatively very long duration. It will thereby be also possible to keep the internal resistance of the current supply source relatively low.

I claim:

1. Apparatus for generating impulses and for applying said generated impulses for electromedical stimulation of muscles and nerves comprising an impulse generator for producing successive series of impulses of triangular shape, two independently adjustable time constant determining switching means in said generator for independently respectively regulating the duration of said impulses and the duration of the pauses therebetween, an amplifier connected with the output of said generator for receiving said triangular impulses therefrom and for amplifying said impulses, and an impulse limiter for receiving said amplified triangular impulses, said amplifier amplifying said triangular impulses to a magnitude such that said limiter can extract therefrom impulse components constituting impulses of practically rectangular shape.

2. The apparatus as defined in claim 1, wherein said switching means comprises means for respectively regulating said impulse and said impulse-pause duration in rough and in fine increments, and further switching means in said impulse generator for respectively regulating the duration of the rise and decay of the impulse curves of said impulses.

3. The apparatus as defined in claim 1, comprising a treatment circuit, an output amplifier for receiving the practically rectangular impulses from said impulse limiter, the output current of said output amplifier being independent of the load impedance of said treatment circuit, and switching means for transmitting said output current to said treatment circuit.

4. The apparatus defined in claim 3, wherein said output amplifier comprises a triode in the terminal stage thereof, feed back means for feeding part of the output current of said output amplifier in opposite phase to the input current therefore, the internal resistance of the output of said amplifier being relatively great as compared with the resistance represented by the load in said treatment circuit.

5. The apparatus as defined in claim 4, comprising a pair of regulators in said output amplifier for adjusting the magnitude of the output current thereof, one of said regulators determining the maximal output current, and the other regulator adjusting the magnitude of the output current lying below the maximal current determined by said first regulator.

6. The apparatus as defined in claim 5, wherein said first regulator is disposed in the input circuit of said output amplifier, and wherein said other regulator is disposed in the feed back circuit thereof.

7. The apparatus as defined in claim 5, comprising an instrument for measuring the peak current of said impulses, a switch for adjusting the measuring range of said instrument, said other regulator being mechanically coupled with said switch.

8. The apparatus as defined in claim 1, comprising a further impulse generator for varying the limit potential of said practically rectangular impulses, and means in said further generator for producing series of variably surging and periodically interrupted impulses from the series of triangular impulses produced by said first noted impulse generator.

9. The apparatus defined in claim 8, wherein said further generator generates successive triangular impulses, said generator being adjustable to vary said impulses to one-tenth oscillation per second.

10. The apparatus defined in claim 9, wherein said further generator comprises a multistage vibrator and an amplifying stage comprising a cathode follower, said amplifying stage transforming said triangular impulses into rectangular impulses, the output impedance of said cathode follower being low as compared with the load impedance in said treatment circuit.

11. The apparatus defined in claim 8, wherein said further generator comprises a frequency-controlled oscillator including a regulator for regulating the frequency thereof, a cathode follower connected serially with said oscillator, said oscillator producing oscillations of saw-tooth curve form, and an adjustable RC-circuit mechanically coupled with said regulator for modifying the shape of said saw-tooth oscillations.

12. The apparatus as defined in claim 1, comprising means forming an output circuit, a treatment circuit connected with said output circuit, an instrument for measuring the magnitude of the current impulses in said output and treatment circuits, switching means for disconnecting said treatment circuit for the purpose of measuring the current impulses in said output circuit, means for supervising the disconnection of said treatment circuit, and means for reducing the magnitude of said current impulses respectively prior to the disconnection and connection of said treatment circuit to a value which lies below the stimulation value of such impulses.

13. The apparatus as defined in claim 12, comprising an impulse surge generator for surging the current of the impulses conducted to said treatment circuit, and control means in said surge generator effective upon disconnection of said treatment circuit for automatically reducing

the magnitude of the current of said impulses and for automatically increasing the magnitude of said impulses responsive to connection of said instrument.

14. The apparatus as defined in claim 13, comprising a control relay governed by said control means, and contact means controlled by said relay for controlling the connection and disconnection of said treatment circuit and said instrument, respectively.

15. The apparatus defined in claim 13, comprising an amplifier in said surge impulse generator, and a regulable resistor in the input circuit of said amplifier for regulating the surge frequency thereof.

16. The apparatus as defined in claim 1, wherein said impulse generator includes a multistage multivibrator, one stage of said multivibrator comprising a flip-flop tube circuit, the last stage of said multivibrator comprising a cathode follower, a treatment circuit, the output impedance of said follower being small as compared with the load impedance in said treatment circuit.

17. The apparatus as defined in claim 16, comprising circuit means for said cathode follower including a regulable capacitor, circuit means including a regulable resistor for charging said capacitor, a further regulable resistor for discharging said capacitor, and means for mechanically coupling said resistors.

18. The apparatus as defined in claim 17, comprising an electron tube for controlling the discharge of said capacitor.

19. The apparatus as defined in claim 16, wherein said one stage determines the duration of the pauses between said impulses, a capacitor in such stage, a circuit including a regulable resistor for charging said capacitor, a tube for discharging said capacitor, the instant of discharge being determined by the grid potential of said tube, circuit means for connecting the grid of said tube with a resistor connected to the cathode of said cathode follower, and circuit means for said tube to cause operation of said multivibrator responsive to discharge of said capacitor.

20. The apparatus as defined in claim 19, comprising switching means for causing said impulse generator to generate selectively series of impulses and single impulses, respectively, and circuit means controlled by said switching means for making said tube ineffective and for separately causing the operation of said multivibrator.

21. The apparatus as defined in claim 1, comprising switching means in said impulse generator for interrupting the generation of successive impulses, and further switching means for causing said generator to generate single impulses instead.

22. The apparatus as defined in claim 1, wherein said amplifier is a tube amplifier comprising a plurality of stages, means for regulating the input currents at the grid of the first amplifier stage, switching means for maintaining the phase position of said amplified impulses in accordance with the phase position of the impulses delivered thereto, a treatment circuit, the output impedance of said amplifier being small as compared with the load impedance of said treatment circuit.

23. The apparatus as defined in claim 22, wherein said amplifier is a push-pull amplifier comprising a cathode follower.

24. The apparatus defined in claim 1, wherein said produced triangular impulses exhibit a rise which is steeper than the drop thereof.

25. The apparatus defined in claim 1, comprising switching means in said impulse generator for interrupting the generation and transmission of successive impulses and for producing and transmitting a single impulse instead.

26. The apparatus defined in claim 1, wherein said limiter comprises a pair of diodes, circuit means for interconnecting the plates of said diodes, and switching means for causing blocking of one diode responsive to a predetermined positive impulse voltage and for blocking the other

diode responsive to a predetermined negative impulse voltage.

27. The apparatus as defined in claim 26, together with a further diode, circuit means for interconnecting the plate of said further diode with the plates of said pair of diodes, means for transmitting to said further diode impulse surges for transmittal to said pair of diodes, the amplitude of the impulses delivered to said pair of diodes being altered in accordance with said impulse surges.

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