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G. A. KIRK ETAL

3,249,801

METHOD AND SYSTEM FOR SWITCHING HIGH CURRENTS USING
POOL TYPE TUBES WITH EXTERNAL FIRING BANDS

Filed Jan. 19, 1962

2 Sheets-Sheet 1

FIG. 3

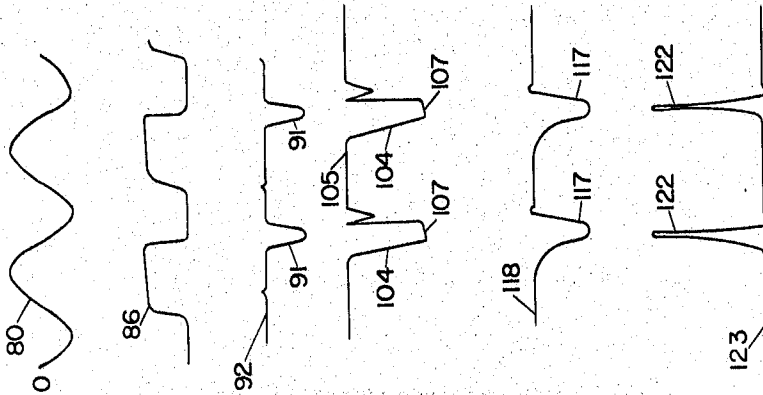
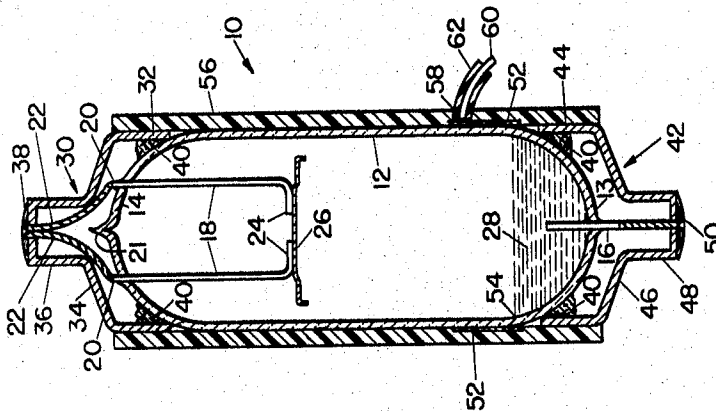


FIG. 1



INVENTORS.

G. KIRK AND E. K. SMITH

BY

Forest N. Hitchcock

THEIR ATTORNEY

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G. A. KIRK ETAL

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FIG. 2

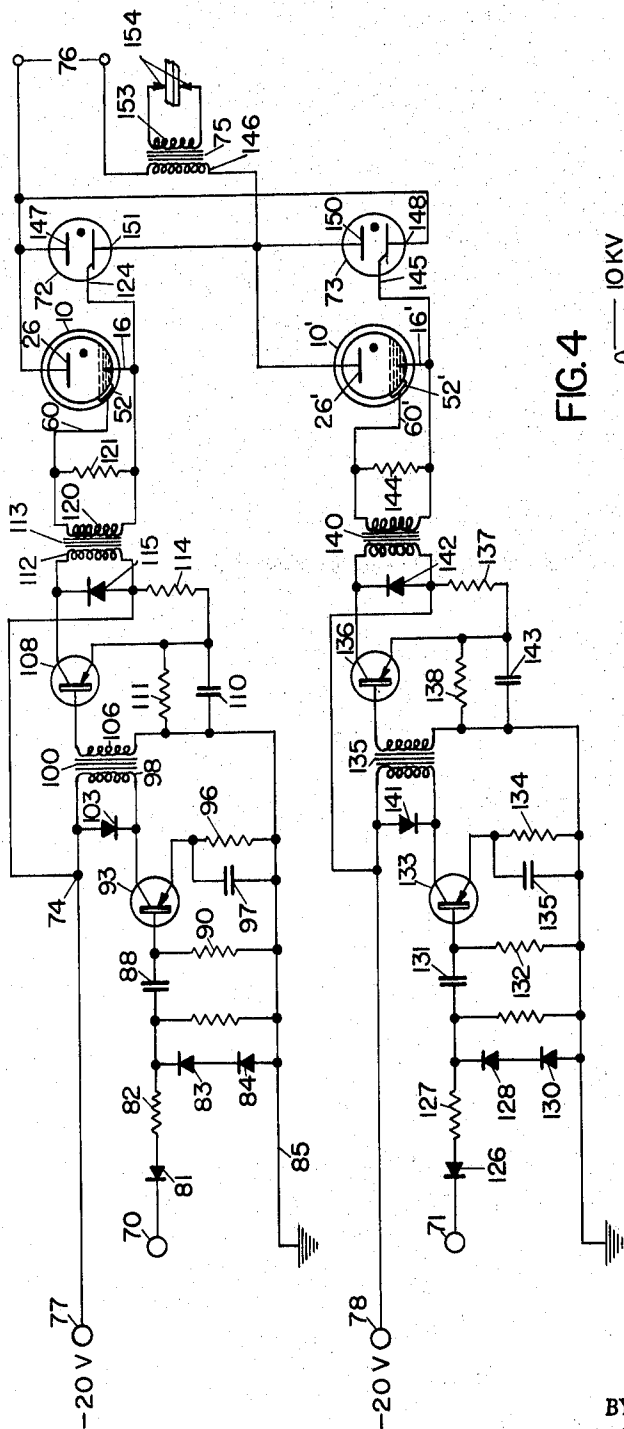
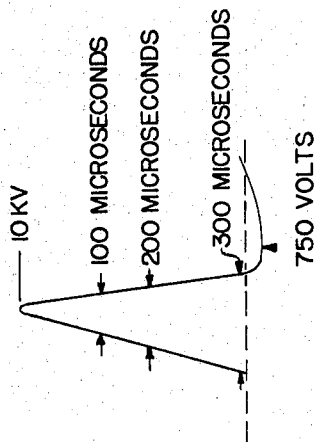


FIG. 4



INVENTORS.
G.KIRK AND E.K.SMITH

BY

Forrest B. Withenack

THEIR ATTORNEY

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METHOD AND SYSTEM FOR SWITCHING HIGH CURRENTS USING POOL TYPE TUBES WITH EXTERNAL FIRING BANDS**George A. Kirk, Teaneck, and Earle K. Smith, West Orange, N.J., assignors to General Signal Corporation, a corporation of New York****Filed Jan. 19, 1962, Ser. No. 167,304
13 Claims. (Cl. 315-166)**

The present invention relates to a method, apparatus, and system for controlling the switching times of high currents, and more particularly to a system for precisely controlling the conduction time of high amperage currents during one or more half cycles of line voltage. In one specific example, the present invention relates to an improved method and system for firing a mercury pool discharge tube of the capacitron type.

Heretofore, conventional thyatron tubes were commonly used to control precisely the time and duration of the firing of high current switching devices during each half cycle of power line voltage. For example, in electronic control circuits for resistance welding, the welding transformer is connected to its source through two pool type mercury vapor tubes, commonly known as ignitrons. These ignitrons are connected in a well-known circuit to fire during alternate half cycles of line voltage and controlled to fire anywhere from a small fraction of a half cycle up to sixty half cycles depending upon the desired duration and intensity of the weld. The thyatrons, in this type of circuit, start conducting when a positive voltage is applied to their grids and they continue to fire during the respective half cycle until the plate voltage reaches extinction, which is usually in the neighborhood of ten volts. The thyatrons are connected to start ignition of the ignitrons when the thyatrons are fired. This ignition current, though normally of short duration and low average current, has a peak current value of tens of amperes.

However, there are certain disadvantages in using thyatrons for switching high currents. For example, the life of the cathode of a thyatron tube is finite and it has limited peak current availability. It is also necessary to wait a predetermined period of time for the filament to heat up before an anode voltage may be applied. Moreover, it is impractical to install thyatron tubes in the same mounting cabinet with solid state devices because the heat of the thyatron conducts throughout the cabinet causing the destruction or malfunction of the solid state devices therein.

In an attempt to overcome the disadvantage in the use of thyatron tubes, a circuit substituting silicon controlled transistor rectifiers therefore is sometimes employed. However, silicon controlled rectifiers are vulnerable in that if the voltage or current is exceeded momentarily, they fail in a catastrophic manner. This requires the installation of expensive protective devices to prevent such an occurrence. Also, in order to obtain the peak power requirement, it may be necessary to connect a plurality of these rectifiers in parallel in the circuit.

Heretofore, it has also been proposed to use gated field emission rectifier tubes of the mercury pool type, commonly known as capacitrons, to control the switching of the high currents. These gated field emission rectifiers, or so-called capacitrons, are comprised of a mercury pool

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cathode and an anode spaced in an evacuated envelope. The mercury pool forms a meniscus between its circumferential edge and the tube envelope because of the surface tension of the mercury and the non-amalgamating property of the mercury with the innersurface of the envelope. A relatively high firing voltage is applied to a firing band, which is mounted on the external surface of the tube envelope opposite the surface of the meniscus of the mercury pool. This firing voltage initiates an arc at the mercury meniscus and causes conduction between the anode and cathode when the anode is more positive than the cathode. Tubes of this type offer definite advantages over previous devices for the switching of high currents in that there is no vulnerable cathode to be destroyed and they have unlimited peak current capability.

Heretofore, however, the use of this capacitron type tube was impractical in that after being in service a relatively short period of time, they would fire inconsistently, or not at all, and in many instances the glass would craze and/or collapse. The inherent disadvantages of the capacitron type tube were caused by glass electrolysis and by the "wetting" of the innersurface of the tube envelope with mercury. This "wetting" would destroy the meniscus and prevent the reliable initiation of the arc for firing the tube. Previous attempts were made to prevent rapid deterioration of the tube, which involved subjecting the tubes to a painstaking and elaborate treatment during their construction.

The United States patent application bearing Ser. No. 122,546 filed July 7, 1961, and assigned to the common assignee herein, discloses a method and system for firing a gated field emission rectifier of the capacitron type which renders the tube practical for controlling the switching of high currents. The method and system disclosed therein includes generally the teaching that a high voltage firing pulse of sufficient amplitude to fire the tube consistently, and in the order of one hundred microseconds in duration, may be applied to the envelope of the tube without the resulting failure common to this type of tube, and without the necessity of painstaking and elaborate treatment in its construction. In accordance with the above teaching, the duration of each firing pulse is preferably one hundred microseconds, and if it is appreciably longer than this, the tube becomes "wet" with mercury after a relatively short period of time and failure ensues. In this regard two one hundred microsecond pulses were applied to insure consistent firing in each half-cycle.

The present invention is an improvement over the system and method disclosed in the aforementioned patent application bearing Ser. No. 122,546 with regard to the system and method for firing a gated field emission rectifier of the capacitron type.

One of the objects of the present invention is to provide an improved system for controlling the switching time of high power requirements.

Another object of this invention is to provide an improved system and method for operating mercury pool cathode tubes to prevent "wetting" of the tube envelope with mercury, thereby retaining the meniscus of the mercury pool.

Another object of the present invention is to provide an improved method and system for firing a gated field emission rectifier of the capacitron type, which permits

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the practical use of the tube over a long period of time without failure or malfunction.

Another object of this invention is to provide an improved high current switching system employing a gated field emission rectifier of the capacitron type wherein the rectifier tube is reliable in its operation over long periods of time, may be simplified in its fabrication, and relatively inexpensive to manufacture.

A still further object of this invention is to provide an improved method and system for firing an ignitron tube using a gated field emission rectifier of the capacitron type, which eliminates the inherent disadvantages of systems heretofore known.

Other objects, of this invention will become apparent from the specification, the drawings, and the appended claims.

In the drawings:

FIG. 1 is a longitudinally sectional view of a tube of the type adapted to be fired in accordance with the present invention;

FIG. 2 is a schematic diagram of the circuitry according to one embodiment of the invention using tubes of the type shown in FIG. 1 to control the firing of ignitrons in a resistance welding circuit;

FIG. 3 illustrates voltage wave forms in various parts of the circuits of FIG. 2 during operation thereof; and

FIG. 4 is a magnified illustration of the pulse waveform for firing a tube of the type shown in FIG. 1 according to the present invention.

Generally speaking, and without intending to limit the scope of the present invention, tubes of the capacitron type are reentered reliable and practical by applying to the firing band of the tube a positive voltage firing pulse having an attenuated negative swing. The positive portion of the firing pulse must be of sufficient amplitude to fire the tube. The applied positive high voltage pulse according to the present embodiment may be anywhere from five kilovolts to fifteen kilovolts, for example, depending upon the thickness of the glass envelope. The duration of the firing pulse must be at least one hundred microseconds and preferably in the neighborhood of two to three hundred microseconds to insure ionization and reliable firing. Although the duration of the firing pulse is not critical in the stated maximum voltage range, the extension of this time only increases proportionately the average driving or firing power requirements for the tube. The negative swing of the firing pulse should be attenuated so that it is below three kilovolts because it appears that the life of the tube decreases rapidly when the swing is above this amount. Although the complete elimination of the negative swing of the pulse is ideal, in actual practice it has been found that an attenuated swing up to three kilovolts does not cause as rapid a decrease in tube life. A negative swing of one half a kilovolt or below does not age the tube appreciably. A negative swing above one-half kilovolt will eventually deteriorate the glass after a time which depends upon the amplitude of the negative swing. For example, test showed that a one and one-half kilovolt negative swing caused discoloration and puncturing after seventeen hundred fifty hours of operation at sixty firings per second. In one practical application of the invention, a positive voltage firing pulse having a duration in the stated maximum range of two to three hundred microseconds, an amplitude in the order of ten kilovolts and a negative voltage swing of substantially seven hundred fifty volts operated the capacitron tube reliably and without any signs of "wetting" or approaching its end of life after three thousand hours of operation.

The firing of capacitron type tubes in accordance with the method and system of the present invention produces the unexpected and unobvious result of minimizing harmful gloss electrolysis, eliminating destructive "wetting," and the tubes operate reliably without malfunction, glass crazing, discoloration or glass rupture over a long

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period of time. In an attempt to explain this unexpected result in part, it appears that the negative swing of the firing pulse, which contributes nothing in causing conduction between the mercury pool cathode and the anode, promotes harmful glass electrolysis and the liberation of oxygen in the tube envelope. The liberated oxygen promotes the mercury "wetting." The positive portion of the applied pulse liberates sodium in the tube envelope which does not appear to have an adverse effect on the operation or life of the tube. Thus, in accordance with the present invention we have minimized the harmful electrolysis currents that occur during the negative swing of the applied pulse.

One example of a tube of the type adapted to be fired in accordance with the present invention is shown in FIG. 1 and referred to at 10. The illustrated tube 10, comprises a cylindrical glass envelope 12 having generally hemispherical opposite ends 13 and 14. A cathode conductor 16 extends into the glass envelope 12 through the end portion 13 and the glass at this end portion is fused around the conductor 16 to effectively support it therein and seal off the envelope. A pair of spaced conducting rods 18 are supported by the envelope 12 at the end portion 14 and extend into the envelope 12 for a portion of their length. The rods 18 are sealed in the portion 14 of the glass envelope 12 as by fusing, and have upper ends 20 which extend from the envelope 12. The glass envelope 12 has a tubular sealed-off extension 21 through which the envelope is evacuated. The rods 18 have a bent portion 24 inside the envelope 12 to which an anode 26 is attached. The anode 26 is preferably tantalum but may be any metal such as iron or nickel, and where heat is a factor may be made of carbon. A pool of mercury 28 is contained in the envelope 12 in sufficient quantity so when the tube is in its upright position the mercury immerses completely that portion of the rod 16 inside the glass envelope 12.

A sheet metal end cap 30 is affixed over the end portion 14, and has a cylindrical portion 32, the outside diameter of which is substantially equal to the outside diameter of envelope 12. Cap 30 has a portion 34 which extends inwardly from the cylindrical portion 32 and is bent outwardly to provide a central projecting portion 36 of small diameter. The anode conductors 22 are electrically secured to a top portion 38 of the cap 30. A metallic cap 42 is also positioned over the portion 13 of the glass envelope 12 and is similar to the cap 30. The cap 42 has a cylindrical portion 44 and an inwardly converging portion 46 and a small cylindrical projection 48. The cathode connection 16 is affixed to an end portion 50 of the cap 42. The caps 30 and 42 are securely attached to the glass envelope 12 by an adhesive substance 40, which may be epoxy for example. In operation, the tube 10 is mounted so that the cap 42 is the lower end of the tube and the cap 30 is the upper end. An external anode connection is made by connection to the central projecting portion 36 of the cap 30 and an external cathode connection is made by attachment to the projection 48 of the cap 42. A firing band 52, which may be a compound or a colloidal suspension that includes carbon particles, such as aquadag for example, is painted around the glass envelope 12 to form a ring of material of only moderately good conductivity. This firing band on the outside of the glass envelope 12 is in registry with the top surface or meniscus of the mercury pool 28 which is referred to at 54. The glass envelope 12 and the firing band 52 is coated with a silicon grease to prevent the surface resistance of the envelope 12 from decreasing to a point where the tube misfires when atmospheric conditions are such that the relative humidity is over 85%, and then enclosed by a plastic sleeve 56 which slidably fits over the coated exterior surface of the envelope 12. The sleeve 56 prevents misfiring of the tube 10 due to dust and moisture condensation or other foreign matter which might collect on the exterior surface of the envelope 12. The collection of

this foreign matter tends to provide a leakage path between the band and the cathode, thus loading down the circuit with the result that firing ceases.

The sleeve 56 has an opening 58 into which is inserted a conductor 60 that is covered by suitable installation 62. The conductor 60 is securely attached to be in electrical contact with the firing band 52.

A circuit according to the present invention employing capactron tubes of the type herein described to fire ignitron tubes for controlling the switching of high currents is shown schematically in FIG. 2; and is adapted for use as shown therein in resistance welding. In resistance welding circuits the need for accurate control of the average current and duration of the weld is of paramount importance. The average current in this type of control circuit is determined by varying the phase of the firing signal with respect to the line voltage. The duration of the weld may be controlled by supplying the timed signal for a predetermined number of half cycles of line voltage in accordance with the requirements of practice. The circuits for controlling the times of starting during the half cycles of line voltage and the duration of the firing through a predetermined number of half cycles are not shown as they are well known in the art and form no part of the present invention.

Referring to FIG. 2, by numerals of reference, the output from a conventional timing circuit is operatively connected to terminal 70 and 71 to provide the input control signal for firing ignitron 72 and 73 at the proper time during each respective half cycle of the line voltage. The input terminal 70 is connected to that portion of the circuitry which is used to fire the ignitron 72; and the input terminal 71 is connected to that portion of the circuitry for firing the ignitron 73. The input signals to 70 and 71 are sine waves which are 180° out of phase so that the ignitrons 72 and 73 fire during alternate half cycles. The input signals are in a predetermined phase relation with the line voltage in accordance with the regulation of the conventional timing circuits to control the average current in a welding transformer 75. The line voltage, which may be anywhere from 220 to 560 volts at sixty cycles, for example, is adapted to be connected across the terminals 76. A power source which may be twenty volts negative and in the order of five watts, for example, is connected to a terminal 77 for the circuitry associated with the ignitron 72 and to terminal 78 for the circuitry associated with the ignitron 73.

The input signal applied to the terminal 70, which is illustrated by the sine wave 80 of FIG. 3, is rectified by a diode 81 to eliminate positive going portions of the waveform 80. The rectified negative half wave appears across a resistor 82 and series connected diodes 83 and 84 to a ground bus 85. The diodes 83 and 84 are normal rectifying diodes whose zener characteristics are utilized to produce clipping. This clipped waveform is illustrated at 86 in FIG. 3 and has a peak-to-peak amplitude in the illustrated embodiment of the invention in the order of 1¼ volts.

A capacitor 88 and a resistor 90 form a differentiation circuit so that differentiated pulses which are referred to at 91 of waveform 92 in FIG. 3 are applied to the base terminal of a transistor 93 during alternate half cycles of the sine wave 80. The transistor 93, which is a PNP transistor has its base connected to the junction of the capacitor 88 and the resistor 90. Its emitter terminal is connected through a resistor 96 to the ground bus 85. A capacitor 97 is connected in parallel with the resistor 96 and forms therewith a temperature compensation circuit for the transistor 93 up to one hundred degrees centigrade. The collector terminal of the transistor 93 is connected to one side of a primary winding 98 of a coupling transformer 100. The other side of the primary winding 98 is connected to the terminal 74 that has the negative source of D.C. voltage applied thereto. A diode 103 is connected across the primary

101 to absorb the negative going inductive energy in the primary winding 98 when the transistor 93 turns off.

When the differentiated pulse 91 is applied to the base terminal of the transistor 93, the transistor 93 conducts to complete a circuit from the negative potential at the terminal 77 through the primary winding 98 of the transformer 100, the collector terminal and the emitter terminal of the transistor 93, and the resistor 96 to the ground bus 85. The positive induced pulse is effected in the primary winding 98 and a negative induced pulse is bypassed by the diode 103. The induced voltage pulse in the primary winding 98 is amplified and is referred to at 104 of waveform 105 in FIG. 3. Thus, each time the transistor 93 conducts the lower end of the primary winding 98 as viewed in FIG. 2 is positive and the upper end is negative.

The pulses 104 which also appear across secondary winding 106 of the transformer 100 when the transistor 93 is turned on have a flat top, which is referred to at 107 in FIG. 3, which indicates saturation of the transistor 93. The secondary winding 106 has its upper end, as viewed in FIG. 2, connected to the base terminal of a PNP transistor 108 and its lower end connected to the ground bus 85. The emitter terminal of the transistor 108 is connected to one side of a capacitor 110, the other side of which is connected to the ground bus 85. A resistor 111 is connected between the emitter terminal of the transistor 108 and the lower end of the secondary winding 106 across the capacitor 110. The collector terminal of the transistor 108 is connected to the upper end of a primary winding 112 of a transformer 113 as viewed in FIG. 2. The lower end of the primary winding 112 is connected to the terminal 74. A resistor 114 is also connected to the lower end of the primary winding 112 and the emitter terminal of the transistor 108. The resistors 111 and 114 provide the temperature compensation for the transistor 108 by developing a back bias which is in the neighborhood of one tenth of a volt. The capacitor 110 serves to bypass the emitter terminal of the transistor 108. A diode 115 is connected across the primary winding 112 of the transformer 113 and serves to absorb the inductive energy when the transistor 108 turns off in a manner similar to the diode 103 previously described.

When the transistor 108 turns on in response to the application of the pulse induced in the secondary winding 106 of the transformer 100 a circuit is completed from the ground bus 85 through the resistor 111, the emitter and collector terminals of the transistor 108, the primary winding 112 of the transformer 113 and the negative D.C. potential that is applied to the terminal 77. The voltage pulse which appears across the primary winding 112 when the transistor 108 is conducting is referred to at 117 of the waveform 118 in FIG. 3.

The transformer 113 has a secondary winding 120 which steps up the voltage in the primary winding 112 to approximately ten kilovolts at its peak; and a resistor 121 connected across the secondary winding 120, which loads up the transformer 113 so that the negative swing of the ten kilovolt pulse is attenuated to approximately 750 volts, which minimizes the harmful electrolysis currents in the tube 10. The pulses which are applied to the firing band of the capacitor tube are referred to at 122 of the waveform 123 of FIG. 3, and in a magnified form by the waveform of FIG. 4. The upper end of the secondary winding 120 of the transformer 113 is connected to the wire 60 that is connected to the firing band 52 of the tube 10. The lower end of the secondary winding 120 is connected to the cathode connector 16 and igniter 124 of the ignitron 72.

The circuitry for operating the ignitron 73 in subsequent half cycles is identical to the circuitry for operating the ignitron 72, previously described, and is comprised of a diode 126 to eliminate the positive portions of the incoming sine wave at the terminal 71, a resistor

127 and diodes 128 and 130 which clip the rectified sine wave. It also comprises a capacitor 131 and a resistor 132 for differentiating the signal that is applied to the base terminal of a transistor 133. The temperature compensation circuit for the transistor 133 is comprised of a resistor 134 and a capacitor 135 that are connected in parallel to the emitter terminal. A coupling transformer 135 is connected in a manner similar to the transformer 100 previously described to provide voltage pulses for driving a transistor 136. Resistors 137 and 138 provide the back bias for the transistor 136 which protects the transistor up to one hundred degrees centigrade. A transformer 140, which is similar to the transformer 113 previously described, steps up the output from the collector terminal of the transistor 136 to provide a firing pulse having a ten kilovolt peak. Diodes 141 and 142 are connected across the primary windings of the transformers 135 and 140 respectively to absorb the inductive energy when the transistors 133 and 136 turn off. Capacitor 143 is a bypass for the emitter terminal of the transistor 136. A resistor 144 is connected across the secondary winding of the transformer 140 to load up the transformer so that the negative swing of the ten kilovolt position pulse is attenuated to approximately seven hundred fifty volts to minimize the harmful electrolysis currents during the negative swing.

Tube 10' is identical to the tube 10 in construction with the various parts of the tube bearing similar reference characters of the tube 10. The upper end of the secondary winding of the transformer 140 is connected to conductor 60' which is connected to firing band 52' of the capacitron 10'. The lower end of the secondary winding of the transformer 140 is connected to the cathode 16' of the capacitron tube 10' and igniter 145 of the ignitron 73. Thus, the application of the high voltage bursts to the wires 60 and 60' that are connected to the firing bands 52 and 52' of the tubes 10 and 10' respectively occur in adjacent half cycles of the line voltage as controlled by the timing signal connected to the terminals 70 and 71 so that the tubes 10 and 10' are alternately fired during each cycle of line voltage. The ignitrons 72 and 73 are fired during alternate half cycles of line voltage that is applied across the terminals 76 only during those times when the tubes 10 and 10' are conducting.

The anode 26 of the tube 10 is connected to one terminal 76 connected to the line voltage and anode 26' of the tube 10' is connected to the other terminal 76 through primary winding 146 of the welding transformer 75. The ignitron 72 has an anode 147 which is connected to one of the terminals 76 in common with cathode 148 of the ignitron 73. The ignitron 73 has an anode 150 which is connected to the other terminal 76 of the line source through the primary winding 146 of the welding transformer 75 and is also connected directly to cathode 151 of the ignitron 72. Because the tubes 10 and 10' fire only by the application of positive pulses applied to the wire 60 and 60', and the tubes 10 and 10' will fire only when their anode is positive with respect to their cathode, it is apparent that in alternate half cycles they will complete a circuit to fire the ignitrons 72 and 73 respectively. When the tube 10 fires, a circuit is completed which extends from one terminal 76 of the line voltage through the anode 26, the cathode connection 16, and the firing electrode 124 of the ignitron tube 72. Similarly, when the tube 10' fires, a circuit is completed from the other terminal 76 through the winding 146 of the transformer 75, the anode 26' and the cathode connection 16' to the firing electrode 145 of the ignitron 73.

When the ignitron 72 fires during one half cycle a circuit is completed for the line voltage 76 through the primary winding 146 of the transformer 75 to cause current to flow through the primary winding for the remainder of the half cycle in which the ignitron 72 is fired. When the ignitron 73 fires a circuit is completed for the line voltage through the primary winding 146

during the next half cycle of the line voltage. Secondary winding 153 of the transformer 75 is connected to the resistance welding apparatus in a well known manner as represented diagrammatically by points 154.

An improved circuit has been shown and described in accordance with one embodiment of the invention which employs capacitron type tubes for firing ignitrons, however, it is understood that other circuits and systems may be employed for the application and the firing of tubes of the capacitron type. For example, a special type pulse transformer may be used which is comprised of a low voltage primary winding that is keyed by a transistor, a high voltage step-up winding, and a tertiary D.C. core setting winding. Another system might be employed utilizing the principle of applying a mechanical stress to certain crystals and ceramics to obtain the high voltage pulse. Control of these pulses may be accomplished by a synchronous motor-cam arrangement whereby timed pressure is applied to the crystal and the negative voltage excursion is limited by the cam configuration. Also, an arrangement similar to an automobile distributor may be utilized whereby the rotor has a positive high voltage applied to it and the stator contacts are paralleled and attached to the firing band. The rotor may be driven by a synchronous motor. Moreover, low cost high voltage triode tubes may be used as series switches to gate high voltage D.C. or high voltage radio frequency to the annular firing band of the capacitron. The positive high voltage D.C. or A.C. is connected to the anode of the triode, and the cathode is connected to the firing band. The grid of the triode is biased so as to keep the triode tube cut off. When a positive pulse is applied to the grid of the triode tube it conducts and applies a high voltage potential to the capacitron firing band. In the case where alternating current is applied to the anode of the triode, rectification occurs and only positive going pulses are effective at the firing band of the capacitron. Also, other circuits may be employed using the transformer damping principle and a three-winding transformer.

With reference to FIG. 4, the base of the applied positive ten kilovolt pulses according to the present embodiment of the invention are in the order of three hundred microseconds and present a wavefront so that the width of the pulse is approximately two hundred microseconds at the five kilovolt range and one hundred microseconds at the seven kilovolt range, which provides consistent firing. The negative swing is in the order of seven hundred fifty volts, which value is well within the range for effectively minimizing the harmful effects of electrolysis currents caused by a negative voltage.

Although, one type of capacitron tube is shown and described herein as being adapted to be fired in accordance with the present invention, it is understood that tubes of this type having various other constructions and configurations may be used.

The tubes which were fired in accordance with this embodiment of the convention had a conventional standard glass envelope anywhere from thirty thousandths of an inch to seventy thousandths of an inch thick which required from five to ten kilovolts to fire. A thicker glass envelope would require a greater positive potential and a thin glass envelope a lesser positive potential. The negative swing of the pulse, however, which produces the harmful glass electrolysis currents, must be below three kilovolts in any event because the glass electrolysis rises exponentially above this point which causes the tube to fail in a few hours. Although ordinary glass may be used, it is understood that other types of glasses, such as ceramic, low sodium oxide, or quartz may also be employed as the tube envelope.

Although the circuitry illustrated and described employs the capacitron type tubes for firing ignitrons, it is intended that they may be used to replace the ignitrons

as the main current switch as long as the mercury vapor pressure is maintained below the critical value for the desired anode-cathode voltage, by limiting the maximum condensed mercury temperature. The capacitron tube when used in the circuitry illustrated and described operates a few degrees higher than the temperature of its environment. However, if the tube is to be operated in excess of ninety degrees centigrade, external cooling should be provided.

The illustrated embodiment of the invention provides a novel and workable control circuit for resistance welding that overcomes those disadvantages of previous control circuits, however, it is understood that the present invention may be utilized wherever high peak current applications are involved. For example, such as in the controlled releasing of stored energy, i.e., firing capacitors, or as X-ray contactors.

Having described a method of firing the capacitron type tubes and a circuit for firing capacitron type tubes wherein the capacitron type tubes are utilized to fire ignitron type tubes, it is understood that various modifications, adaptations and alternations may be used without departing from the spirit or scope of the present invention.

What we claim is:

1. A system for controlling the conduction of capacitron type tubes having an anode and a mercury pool cathode and a firing band on an outer surface of said tube envelope, comprising means for connecting an A.C. voltage to said anode and cathode during one portion of each cycle of said A.C. voltage, means effective to receive an A.C. voltage firing signal in predetermined phase relation to said A.C. voltage connected to the anode and cathode, means effective to amplify said A.C. firing signal to have an amplitude sufficient to cause conduction between said anode and cathode when said anode is positive with respect to said cathode, means effective to limit said firing signal during a respective half cycle to have only a duration in the order sufficient to cause reliable conduction, means effective to attenuate the negative portion of said firing signal to an amplitude substantially less than the positive portion to minimize harmful effects in the tube when the tube is conducting, and means electrically connecting operatively said amplifying and limiting and attenuating means to said firing band to apply the firing signal to said firing band to fire said tube at that portion of said half cycle as governed by the phase of said A.C. firing signal.

2. A system according to claim 1 wherein said amplifying means is effective to amplify said firing signal to have a positive portion in excess of five kilovolts.

3. A system according to claim 1 wherein said limiting means is effective to limit the amplified signal to have a duration in the order of not greater than three hundred microseconds at its base.

4. A system according to claim 1 wherein said attenuating means is effective to attenuate the negative portion of said signal to less than three kilovolts.

5. A system for controlling the switching times of currents during each half cycle of an A.C. voltage, comprising a pair of capacitron type tubes each having an anode and a mercury pool cathode in a respective tube envelope and a firing band on an outer surface of the tube envelope, means for connecting the cathodes and anodes of each of said tubes to said A.C. voltage to cause the anode of each tube to be positive with respect to its cathode during alternate half cycles of said A.C. voltage, circuit means effective to receive a pair of A.C. input signals in predetermined phase relation to said A.C. voltage and phased 180° from each other, means effective to rectify one polarity of each of said input signals to have an input signal of the same polarity during each half cycle, means connected to said rectifying means effective to differentiate each of said rectified signals, means operatively connected to said differentiating means effective to amplify said signal to have a voltage of suf-

ficient amplitude to cause conduction of each of said tubes, means including said amplifying and differentiating means effective to limit the duration of each input signal to an amount sufficient to ionize the mercury in each of said tubes, means operatively connected electrically to said amplifying means to control said amplified signal in the negative direction so that the negative portion of each signal is of an amplitude less than a predetermined value to prevent wetting of the inner surface of the tube envelope, and means effective to connect each of said amplified signals to a respective firing band of each tube to cause each tube to fire during alternate half cycles at a predetermined time during said half cycles as governed by the phase relationship between said input signals and said A.C. voltage.

6. A system for controlling the switching times of currents during each half cycle of an A.C. voltage, comprising a pair of ignitrons operatively connected electrically to said A.C. voltage to cause conduction there through when each of said ignitrons is fired, a pair of capacitron type tubes each having an anode and a mercury pool cathode and a firing band, means connecting the anode and cathode of each of said capacitron tubes to a respective ignitron and said A.C. voltage to fire its respective ignitron when said capacitron tube is conducting, circuit means adapted to receive a pair of A.C. input signals in predetermined phase relation to said A.C. voltage and phased 180° from each other, means effective to amplify each of said input signals to have an amplitude sufficient to fire a respective one of said capacitron tubes during alternate half cycles of said A.C. voltage, means effective to limit the duration of each of said input signals to have a width in excess of one hundred microseconds at the firing range, means effective to attenuate the negative portion of each of said signals to have an amplitude of less than three kilovolts, and means effective to connect said amplifying and limiting and attenuating means to the firing band of each of said capacitron tubes to cause said capacitron tubes to fire during alternate half cycles of A.C. voltage at a time during each said half cycle as governed by the phase relation of said pair of input signals to said A.C. voltage.

7. A method of operating a discharge tube during alternate half cycles of an alternating voltage, said discharge tube having elements including an anode and a mercury pool cathode contained in an envelope and a firing band positioned so that the wall of the envelope is between the meniscus of the mercury pool and the band, said alternating voltage being applied to the anode and cathode so that the anode is positive with respect to the cathode during alternate half cycles, comprising generating firing voltage pulses each having a duration substantially less than each of said alternate half cycles but of sufficient duration and positive amplitude to cause conduction between the anode and cathode during said alternate half cycles when applied to the firing band, reducing the amplitude of any negative portion of said firing voltage to less than three kilovolts, and applying one of said firing voltage pulses to the band at selected times during each said alternate half cycles so that the positive portion of each firing pulse causes conduction during the remainder of each said alternate half cycle, said negative portion of each pulse being of insufficient amplitude to harm the tube elements during conduction of the tube.

8. A method according to claim 7 wherein the envelope of the tube is glass.

9. A method according to claim 7 wherein the negative portion of each firing voltage pulse is reduced in amplitude to less than 1,000 volts.

10. A method according to claim 7 wherein the negative portion of each firing voltage pulse is substantially eliminated.

11. A method according to claim 7 wherein the positive portion of each firing pulse is in excess of five kilovolts in amplitude.

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12. A method according to claim 11 wherein the duration of the positive portion of each voltage pulse is greater than 100 microseconds.

13. A method of causing conduction between the anode and the mercury pool cathode contained in a glass envelope wherein the anode is spaced above the surface of the mercury pool in the envelope, comprising applying a coating of carbon particles around the outside of the envelope adjacent the meniscus of the mercury pool, applying an alternating voltage to the anode and the cathode so that the anode is made positive with respect to the cathode during alternate half cycles thereof, generating firing voltage pulses each having sufficient amplitude to cause conduction between the cathode and the anode during said alternate half cycles when applied to the coating, reducing said negative portion of each firing voltage to less than three kilovolts, and applying each of said voltage pulses

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to the carbon coating at selected times during each said alternate half cycles.

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GEORGE N. WESTBY, *Primary Examiner.*

C. R. CAMPBELL, *Assistant Examiner.*