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X-RAY APPARATUS

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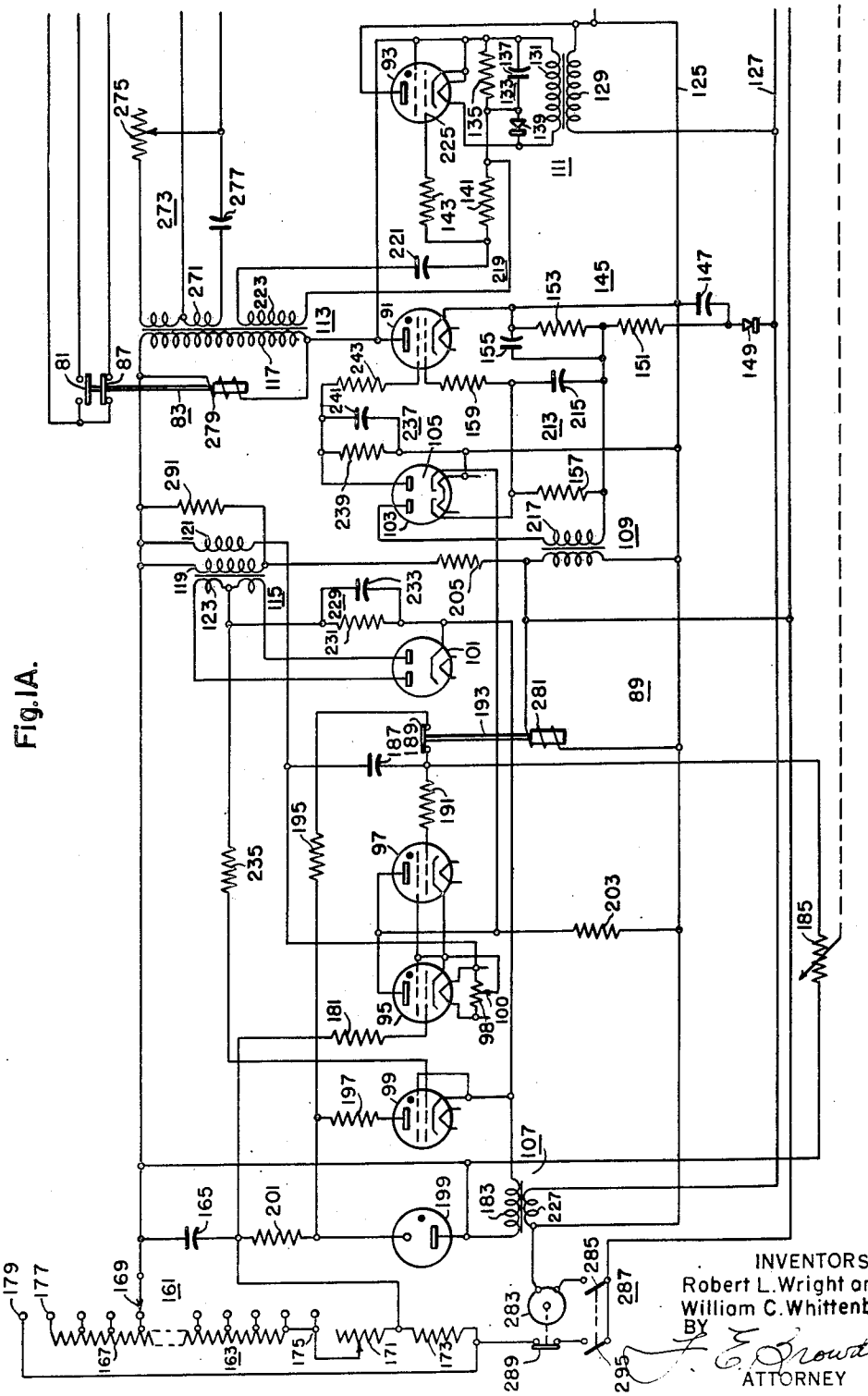


Fig. 1A.

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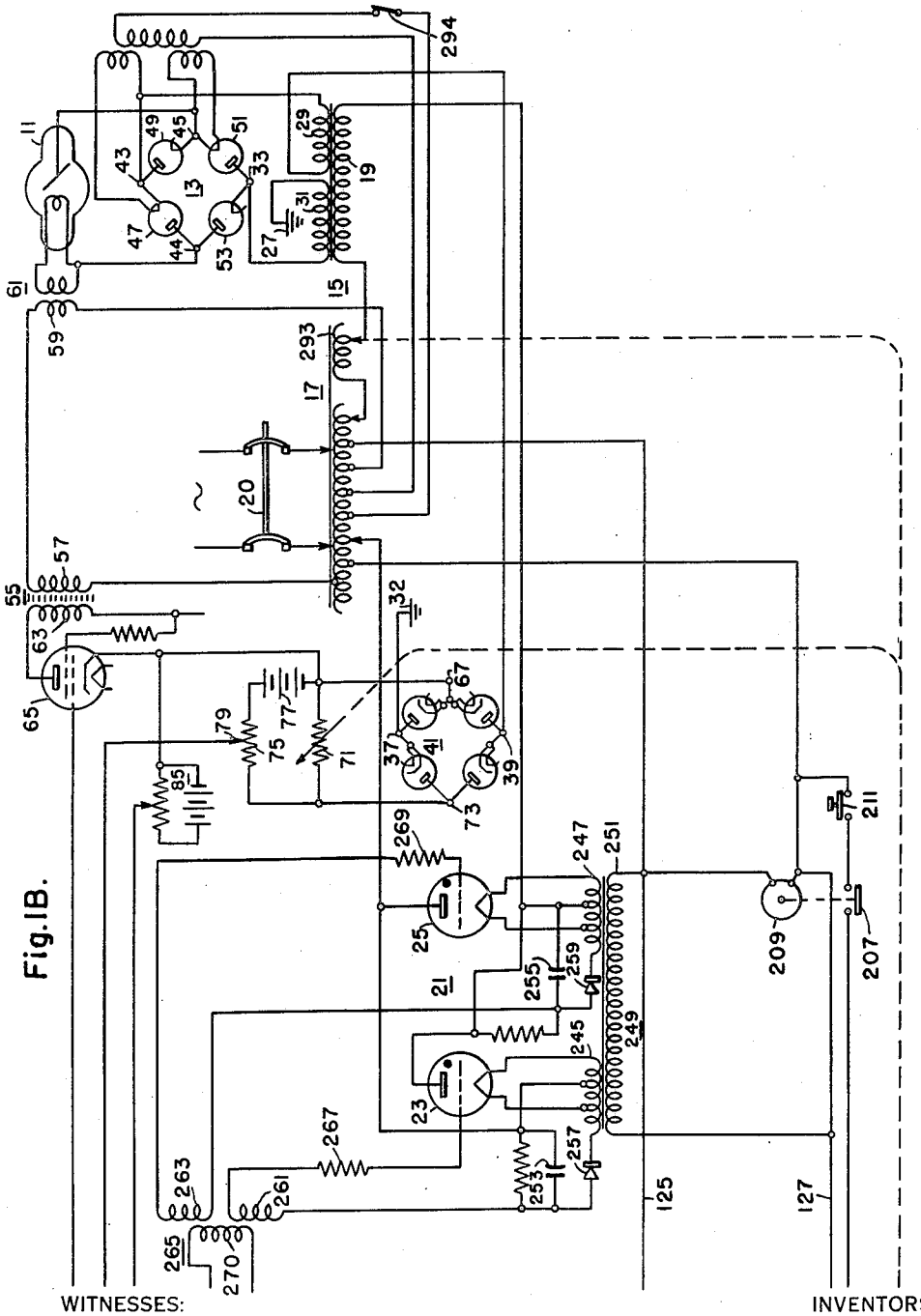


Fig. 1B.

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X-RAY APPARATUS

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Our invention relates to X-ray apparatus, and more particularly to electronic control circuits for such apparatus.

Most modern X-ray techniques require that the X-ray tube be energized for brief precise periods of time which are of selectable duration. The device for closing the power supply circuit to energize the X-ray tube in X-ray apparatus, is generally called a contactor. Heavy duty X-ray apparatus in the prior art of which we are aware has utilized ignitron tubes as contactors, the ignitron tubes being controlled by a mechanical timing device. Ignitron tubes do not work well as contactors for medium duty X-ray apparatus because of the low load currents involved. Existing medium duty X-ray apparatus utilizes mechanical contactors actuated by mechanical timing devices. These mechanical contactors do not operate well for X-ray exposure times which are less than 1/30 of a second, nor can they make rapid successive exposures.

It is an object of our invention to provide an X-ray apparatus which utilizes an electronic contactor which is controlled by an electronic timing mechanism.

It is another object of our invention to provide an X-ray apparatus utilizing an electronic contactor which is controlled by an electronic timing device having a plurality of selectable timing ranges.

It is another object of our invention to provide an X-ray apparatus which utilizes an electronic contactor which is controlled by an electronic timing device incorporating means to insure closing of the electronic contactor at the beginning of a half period of the alternating current supply voltage.

It is another object of our invention to provide an X-ray apparatus utilizing an electronic contactor controlled by an electronic timing device which is capable of producing X-ray exposures having a time duration of less than 1/60 of a second.

It is a further object of our invention to provide an X-ray apparatus utilizing an electronic contactor controlled by an electronic timing device, in which there is included safety means to insure an X-ray exposure of not more than a predetermined maximum time duration.

It is a further object of our invention to provide an X-ray apparatus having automatic load current control means, and utilizing an electronic contactor controlled by an electronic timing device wherein said timing device includes means for initiating operation of the automatic load current control means.

Our invention will be best understood from the following description when read with reference to the accompanying drawings in which Figures 1A and 1B constitute a schematic circuit diagram of a preferred embodiment of our invention.

Referring now to Fig. 1B, there is shown an X-ray generator comprising an X-ray tube **11**, an X-ray tube anode supply bridge circuit **13**, a high tension transformer **15** and a power supply transformer. The power supply transformer may be an autotransformer **17** having its

input terminals connected through a circuit breaker **20** to a suitable alternating current power supply (not shown). The autotransformer **17** is provided with a plurality of output terminals. The primary winding **19** of the high tension transformer **15** is connected in series with an electronic contactor **21**, which may comprise a pair of thyratrons 23, 25 connected inversely in parallel, across suitable output terminals of the autotransformer **17**. A first secondary winding **31** of the high tension transformer **15** has one end terminal grounded at **27**, and the other end terminal connected to one input terminal **33** of the X-ray tube anode supply bridge circuit **13**, hereinafter called the main bridge. A second secondary winding **29** of the high tension transformer **15** having one end terminal connected through input terminals **37, 39** of a stabilizer bridge circuit **41**, hereinafter called the stabilizer bridge is connected to ground at **32**. The other end terminal of the second secondary winding **29** of the high tension transformer is connected to the other input terminal of the main bridge **13**. The output terminals **44, 45** of the main bridge **13** are connected across the X-ray tube **11**. The main bridge **13** consists of four rectifiers **47, 49, 51, 53** which are connected in a well known manner to supply full-wave rectified output potential.

Shown also in Fig. 1B is an X-ray tube stabilizer circuit comprising a saturable reactor **55**, the secondary winding **57** of which is connected in series with the primary winding **59** of the X-ray tube filament transformer **61** across suitable output terminals of the autotransformer **17**. The primary winding **63** of the saturable reactor **55** is connected in the anode circuit of an electric discharge device, which may be a tetrode, hereinafter called the stabilizer tube **65**, the cathode of which is connected to one output terminal **67** of the stabilizer bridge **41**. A variable resistor **71** is shunted across the output terminals **67, 73** of the stabilizer bridge **41**. A potentiometer **75** is connected in series with a source of direct current potential shown as a battery **77** across the variable resistor **71**. The movable contact **79** of the potentiometer **75** is connected in series with normally open contacts **81** of the stabilizer relay **83** to the grid of the stabilizer tube **65**. A direct current bias source **85** is connected in series with normally closed contacts **87** of the stabilizer relay **83** between the grid and cathode of the stabilizer tube **85**.

Turning now to Fig. 1A, there is shown an electronic timer circuit **89** comprising five gaseous electric discharge devices, which may be tetrodes. These discharge devices may be identified for convenience as the first and second contactor control tubes **91, 93**, the timer stop tube **95**, the safety time stop tube **97**, and the timer start tube **99**. Also included in the timer circuit are two double diode rectifier tubes, one of which may be termed the timer start full-wave rectifier tube **101**. The left section of the other is designated as the first contactor control tube start rectifier **103**, and the right section as the first contactor control tube cutoff rectifier **105**. Further, in Fig. 1A there are shown five transformers. These are designated as the timer start tube anode supply transformer **107**, the first contactor control tube start rectifier anode supply transformer **109**, the second contactor control tube filament and bias supply transformer **111**, the first control transformer **113** and the second control transformer **115**. The first control transformer **113** has a single primary winding **117** and two secondary windings, one of which is midtapped. The second control transformer **115** has first and second primary windings **119, 121** and a single midtapped secondary winding **123**. Filament heater power supplies for all tubes in Figs. 1A and 1B with the exception of the contactor tubes **23, 25**, the second contactor control tube **93** and the X-ray tube **11** and two rectifiers **47, 51** of the main bridge **13**, are conventional and are not shown.

First and second timer power supply buses 125, 127 may be connected across suitable output terminals of the autotransformer 17. The contactor control tubes 91, 93 are connected inversely in parallel. The primary winding 129 of the second contactor control tube filament transformer 111 is connected across the timer power supply buses 125, 127, and its secondary winding 131 is connected in series with the heater of the tube 93. The second contactor control tube 93 is held initially non-conductive by a bias network 133 which comprises a biasing resistor 135 and capacitor 137 connected in multiple and in series with a rectifier 139 across the secondary winding 131 of the second contactor control tube filament transformer 111. One terminal of the biasing resistor 135 is connected to the cathode of the second contactor control tube 93 and the other terminal is connected in series with a time constant resistor 141 and a current limiting resistor 143 to its grid. The first contactor control tube 91 is held initially non-conductive by a bias network 145 which comprises a capacitor 147 connected in series with a rectifier 149 across the timer power supply buses 125, 127, a voltage dropping resistor 151 connected in series with a biasing resistor 153 across the capacitor 147, and a capacitor 155 shunting the bias resistor 153. One terminal of the bias resistor 153 is connected to the cathode of the first contactor control tube 91 and the other terminal is connected in series with another time constant resistor 157 and a current limiting resistor 159 to its grid. The timer stop tube 95 is held initially non-conductive by a time constant network 161 comprising the main timing resistance network 163 in parallel with the main timing capacitor 165. The main timing resistance network 163 includes three resistance elements. The first of these resistance elements is a resistor 167 provided with a plurality of taps and a tap selector 169. The second resistance element is a potentiometer 171, and the third resistance element is a fixed resistor 173. One end terminal 175 of the tapped resistor 167 is connected to the movable contact of the potentiometer 171. The other end terminal 177 of the tapped resistor 167 is floating. The tap selector 169 is arranged to move past the floating terminal 177 to another terminal 179 which is connected in series with the fixed resistor 173 to an end terminal of the potentiometer 171. One terminal of the main timing capacitor 165 is connected to the junction of the potentiometer 171 and the fixed resistor 173 and through a current limiting resistor 181 to the grid of the timer stop tube 95. The other terminal of this capacitor 165 is connected to the tap selector 169. The tap selector 169 is also connected in series with the secondary winding 183 of the timer start tube anode supply transformer 107 to the cathode of the timer start tube 99. The safety time stop tube 97 is held initially non-conductive by a time constant network which comprises the safety timer variable resistor 185 connected in series with the second primary winding 121 of the second control transformer 115 across the safety timing capacitor 187. One terminal of the safety timing capacitor 187 is connected through a current limiting resistor 191 to the grid of the safety time stop tube 97, and through the normally closed contacts 189 of the safety time start relay 193 in series with a current limiting resistor 195 and a voltage dropping resistor 197 to the anode of the timer start tube 99. The other terminal of the safety timing capacitor 187 is connected to one terminal of a potentiometer 98, which is connected in shunt with the heater element of the timer stop tube 95. The movable contact 100 of this potentiometer 98, is connected to the cathode of the timer stop tube 95. The junction of the safety time resistor 185 and the second primary winding 121 of the second control transformer 115 is connected through the secondary winding 183 of the timer start tube anode supply transformer 107 to the cathode of the timer start tube 99. A voltage regulator tube 199 has its anode connected to the junction of the main timing capacitor 165 and the second primary winding 121 of the second control transformer 115 and has its cathode connected in series with a dropping resistor 201 to the other terminal of the main timing capacitor 165, and through a dropping resistor 197 to the anode of the timer start tube 99. The timer stop tube 95 and the safety stop tube 97 have their anodes connected together and their cathodes connected together. The anodes of these tubes 95, 97 are connected through a dropping resistor 203 to the first timer power supply bus 125, and their cathodse are connected in series with a potentiometer 98, the second primary winding 121 of the second control transformer 115, the first primary winding 119 of the second control transformer 115, and a short circuit preventing resistor 205, the contacts 207 of a time delay relay 209 and the timer start switch 211 to the second timer power supply bus 127. The potentiometer 98 has its end terminals connected across a low voltage alternating current source which may be the filament supply for the timer stop tube 95. The function of this potentiometer will be explained hereinafter.

The first contactor control tube is rendered conductive at the proper time by a time constant network 213 which comprises a time constant resistor 157 and a capacitor 215 connected in parallel. One terminal of this time constant network 213 is connected through a current limiting resistor 159 to the control grid of the first contactor control tube 91, and also to the cathode of the first contactor control tube start rectifier 103, the anode of which is connected through the secondary winding 217 of its anode potential supply transformer 109 to the other terminal of the time constant network 213. The first contactor control tube 91 receives anode potential through the connection from its anode in series with the primary winding 117 of the first control transformer 113, the first primary winding 119 of the second control transformer 115, the short circuit preventing resistor 205, the contacts 207 of the time delay relay 209, and the timer start switch 211, to the second timer power supply bus 127. The cathode of the first contactor control tube 91 is connected to the first timer power supply bus 125. The second contactor control tube 93 is rendered conductive at the proper time by a time constant network 219 which comprises a capacitor 221 connected in series with a time constant resistor 141 and one secondary winding 223 of the first control transformer 113. The junction of the time constant resistor 141 and the capacitor 221 is connected through a current limiting resistor 143 to the control grid 225 of the second contactor control tube 93. The other terminal of the time constant resistor 141 is connected through a bias resistor 135 to the cathode of the second contactor control tube 93. The timer start tube 99 is initially conductive, and receives its anode potential through a connection from its anode through a voltage dropping resistor 197, another voltage dropping resistor 201, a potentiometer 171, the tapped resistance 167, the selector 169 and the secondary winding 183 of its anode supply transformer 107 to its cathode. The primary winding 227 of this anode supply transformer 107 is connected across the timer power supply buses 125, 127. The timer start tube 99 is rendered non-conductive by a time constant network 229 which comprises a time constant resistor 231 and a capacitor 233 connected in multiple. One terminal of this time constant network 229 is connected to the cathode of the timer start full-wave rectifier tube 101, and to the cathode of the timer start tube 99. The other terminal of this time constant network 229 is connected through the current limiting resistor 235 to the control electrode of the timer start tube 99, and also to the mid-tap of the secondary winding 123 of the second control transformer 115. Each of the end terminals of the secondary winding 123 of the second control transformer 115 is connected to an anode of the timer start full-wave rectifier tube 101.

The first contactor control tube 91 is rendered non-

conductive by a time constant network 237 comprising a resistor 239 and capacitor 241 connected in parallel. One terminal of this time constant network 237 is connected to the first timer power supply bus 125. The other terminal of this time constant network 237 is connected through a current limiting resistor 243 to the second control grid of the first contactor control tube 91, and also to the anode of the first contactor control tube cutoff rectifier 105, the cathode of which is connected to the anodes of the timer stop and safety time stop tubes 95, 97.

The contactor thyratrons 23, 25 receive their heater potential from taps on the respective secondary windings 245, 247 of their filament supply transformer 249. The primary winding 251 of this transformer is connected across the timer power supply buses 125, 127. The contactor thyratrons 23, 25 are held initially non-conductive by means of similar bias network 253, 255. Each of these networks comprises a bias resistor and a capacitor connected in parallel and connected in series with a rectifier 257, 259 across suitable taps of its respective filament transformer secondary winding 245, 257. The junction of the network 253, 255 and the rectifier 257, 259 is in each case connected through a respective secondary winding 261, 263 of a third control transformer 265 and a current limiting resistor 267, 269 to the control grid of the respective thyratron 23, 25. One terminal of the primary winding 270 of the third control transformer 265 is connected to the mid-tap of the mid-tapped secondary winding 271 of the first control transformer 113. A phase shift network 273 comprising a variable resistor 275 in series with a capacitor 277 is connected across the end terminals of the mid-tapped secondary 271 of the first control transformer 113. The other terminal of the primary winding 270 of the third control transformer 265 is connected to the junction of the resistor 275 and capacitor 277 of the phase shift network 273.

The energizing winding 279 of the stabilizer relay 83 is connected across the primary winding 117 of the first control transformer 113. One terminal of the energizing winding 281 of the safety time start relay 193 is connected to the first time power supply bus 125, while the other terminal is connected through the contacts 207 of the time delay relay 209 and the timer start switch 211 to the second timer power supply bus 127. The time delay relay 209 may be of any suitable type, and has its energizing terminals connected across the timer power supply buses 125, 127. The long range section of the main timer comprises a synchronous motor driven timer 283. One energizing terminal of this timer 283 is connected to the first power supply bus 125, while the other terminal is connected through an initially open contact 285 of a long range timer switch 287, the contacts 207 of the time delay relay 209, and the timer start switch 211 to the second timer power supply bus 127. One terminal of the relay contact 289 of this motor driven timer 283 is connected to the open terminal 179 which may be selected by the tap selector of the main timing resistance network 163. The other terminal of this relay contact 289 is connected through another normally open contact 295 of the long range timer switch 287, the contacts 207 of the time delay relay 209, and the timer start switch 211 to the second timer power supply bus 127. A by-pass resistor 291 is connected across the first primary winding 119 of the second control transformer 115. The operating controls for the variable resistor 185 of the safety time constant network, the variable resistor 71 which is shunted across the stabilizer rectifier bridge 41 and a variable voltage section 293 on the auto-transformer 17 may be ganged.

The apparatus shown in Figs. 1A and 1B may be set to give X-ray exposure times of from less than $\frac{1}{60}$ of a second up to 15 seconds. To obtain exposure times in the range from $\frac{1}{60}$ of a second to 1¾ seconds, the contacts 285, 295 of the long range timer switch 287 are set to the open position; the filament supply switch 294 is closed, and the selector 169 is moved to the desired tap of the tapped resistance 167. An exposure time of approximately $\frac{1}{120}$ of a second may be otbained by setting the selector 169 on the lowest tap of its associated resistance 167, and opening the filament supply switch 294 which is in the filament circuits of a pair of rectifiers 47, 51 in opposite legs of the X-ray tube anode supply bridge 13. To obtain exposure times in the range from 2 seconds to 15 seconds, the selector 169 is moved to the terminal 179 which is connected to the relay contact 289 of the motor driven timer 283, and the contacts of the long range timer switch 287 are closed. It will be clear to those skilled in the art that the motor driven timer 283 for long range timing could be replaced with resistance added to the main timing resistance network 183. Also, the above-mentioned values for the timing ranges are by way of example only, and not in any sense limiting.

For convenience in explaining the operation of the apparatus, assume that the timer 89 has been set to give an exposure time in the range from $\frac{1}{60}$ to 1¾ seconds. In this case the selector 169 is set on the appropriate tap of the tapped resistance 167. The variable resistor 171 which is a calibrating resistor in the main timing resistance network 163 has been properly adjusted. The long range timer switch 287 is open, and the filament supply switch 294 is closed. The circuit breaker 20 is closed to energize the autotransformer 17. Filament heating power is now available to all tubes. The timer start tube 99 is immediately rendered conductive to charge the main timing capacitor 165 and the safety timing capacitor 187. The time delay relay 209 is also energized. After the time delay relay 209 has closed its contacts 207, it is possible to complete a circuit by closing the timer start switch 211. When the timer start switch 211 is closed, two things happen. First, the operating coil 281 of the safety time start relay 193 is energized to open its contacts 189 and stop the charging of the safety timing capacitor 187. This capacitor 187 then begins to discharge through the safety time resistor 185. Second, anode potential is supplied to the first contactor control tube start rectifier 103 and to the first contactor control tube 91. Assume, for example, that at the instant the timer start switch 211 is closed, the voltage wave of the power supply is at the peak of a positive half period. The first contactor control tube 91 will not then become conductive because its control grid is still biased negative. During the remainder of this half period of the power supply, the anode of the first contactor control tube start rectifier 103 is negative and it is therefore non-conductive. During the next half period of the power supply, which is negative, the anode of the first contactor control tube 91 is also negative, so that tube is non-conductive. However, during this negative half period of the power supply voltage wave, the anode of the first contactor control tube start rectifier 103 is positive so it conducts to charge its associated time constant network capacitor 215 to render the control grid of the first contactor control tube 91 positive. Then, when the power supply voltage wave swings positive on the next half period, the first contactor control tube 91 is rendered conductive. It is thus assured, that the first contactor control tube 91 will start conducting at the beginning of a positive half period of the power supply voltage wave regardless of when the timer start switch 211 is closed. When the first contactor control tube 91 conducts, it does four things. First, it energizes the stabilizer relay 83 to open the connection between the grid of the stabilizer tube 65, and its standby bias supply 85, and closes the connection between the grid of the stabilizer tube 65 and its operating bias supply 75, 77. Second, it energizes the first primary winding 119 of the second control transformer 115 to place anode voltage on the timer start full-wave rectifier tube 101. This rectifier tube 101 is then rendered conductive to

charge its associated time constant network capacitor 233 to place a negative potential on the control grid of the timer start tube 99. The timer start tube 99 is then rendered non-conductive, stopping the charging current to the main timer capacitor 165. This capacitor 165 now begins to discharge through that portion of the main timer resistance network 163 which is connected across it. Third, the time constant network capacitor 221 which is in series with one of the secondary windings 223 of the first control transformer 113 is charged to render the control grid of the second contactor control tube 93 positive. Fourth, the mid-tapped secondary 271 of the first control transformer 113 is energized to send a pulse which is delayed by the phase delay network 273 to the primary winding 270 of the third control transformer 265. This pulse appears as a positive pulse in the grid circuit of the first contactor tube 23 to overcome the negative bias in that circuit. The anode of the first contactor tube 23 is positive at this instant and the tube 23 is consequently rendered conductive. The primary winding 19 of the high tension transformer 15 is now energized, and the X-ray tube 11 conducts to start an exposure. On the next half period of the power supply voltage wave, the anodes of the first contactor and the first contactor control tubes 23, 91 are negative so they are rendered non-conductive. The anodes of the second contactor tube 25 and the second contcator control tube 93 are, however, now positive. Since the control grid of the second contactor control tube 93 was made positive during the preceding half period of the power supply voltage wave, and is still positive, that tube 93 is now rendered conductive to place a second delayed pulse on the primary 270 of the third control transformer 265. This second pulse appears in the grid circuit of the second contactor tube 25 as a positive pulse to overcome the negative bias and render the grid of that tube positive. The second contactor tube 25 then conducts to energize the primary 19 of the high tension transformer 15 and again supply anode potential to the X-ray tube 11. The first contactor control tube 91, the first contactor tube 23, and the second contactor control tube 93 and the second contactor tube 25 then continue to conduct on alternate half periods of the power supply voltage wave. Thus, through the X-ray tube anode supply bridge 13, the X-ray tube 11 is continuously supplied with full-wave rectified anode potential. When the main timing capacitor 165 has discharged sufficiently, signalling the end of the exposure, the negative potential is removed from the grid of the timer stop tube 95 and that tube is rendered conductive. When the timer stop tube 95 conducts it does two things. First, it places a voltage on the dropping resistor 203 in its anode circuit to render the first contactor control tube cutoff rectifier 105 conductive. The time constant network capacitor 241 in the anode circuit of this rectifier 105 is then charged to place a negative potential on the second control grid of the first contactor control tube 91 of sufficient magnitude to render that tube 91 non-conductive. The first contactor tube 23 is then also rendered non-conductive. Since the time constant network capacitor 221 in the control grid circuit of the second contactor control tube 93 does not thereafter receive a positive charge, the second contactor control tube 93 is rendered non-conductive and also the second contactor tube 25. Conduction of the timer stop tube 95, secondly, energizes the first primary winding 119 of the second control transformer 115 in order to hold the negative potential on the grid of the timer start tube 99 to maintain it in the non-conductive state. When the timer start switch 211 is opened, anode voltage is removed from the timer stop tube 95 and that tube ceases to conduct. As a result, the negative potential is removed from the timer start tube 99, and it becomes again conductive to charge the main timing capacitor 165. The apparatus is now ready for another X-ray exposure.

To explain the operation of the safety circuit, let us assume that for some reason the timer stop tube 95 was not rendered conductive to stop the X-ray exposure. The variable resistor 185 in the safety time constant circuit has, of course, been previously set for the maximum desired safe X-ray exposure time. It will be remembered that the capacitor 187 in the safety time constant circuit started timing out upon operation of the safety time start relay 193, at the same time the main timing capacitor 165 was started timing out by cutting off the timer start tube 99. When the safety time capacitor 187 has timed out, it has discharged sufficiently to remove the negative potential from the grid of the safety time stop tube 97. The safety time stop tube 97 is then immediately rendered conductive to perform identically the same functions as have been described above for the timer stop tube 95.

It should be noted here that the cathodes of the timer stop and safety time stop tubes 95, 97 have a small alternating current voltage placed on them, which voltage is variable by means of the potentiometer 98. Thus, the decay characteristics of the time constant networks in the control grid circuits of these tubes 95, 97 are made to intersect their cathode voltage wave sharply. A sharp, positive, finely adjustable cutoff of the timer stop and safety time stop tubes 95, 97 is thereby provided.

Now, if it is desired to take an X-ray exposure having a duration of less than a period of the power supply, or approximately $\frac{1}{120}$ of a second for a 60 cycle power supply, the filament supply switch 294 in the filament circuits of two of the rectifier tubes 47, 51 in the X-ray tube anode supply bridge is opened. The selector 169 is placed on the lowest tap 175 of the tapped timing resistor 167. The long range time switch 287 is in open position. Then, when the timer start switch is closed, the apparatus moves through its cycle of operation in exactly the same manner as was described above. However, the high tension transformer is energized for only one cycle of the power supply voltage wave. Since the filament circuits of the two rectifiers 47, 51 in opposite legs of the X-ray tube anode supply bridge 13 are open, only a single half wave of rectified voltage is supplied to the anode of the X-ray tube 11. The length of the X-ray exposure, then, has a duration of only a half period of the power supply voltage, or approximately $\frac{1}{120}$ of a second, for a 60 cycle power supply.

If it is desired to take an exposure of duration longer than 1¾ seconds, the motor driven timer 283 is used. This timer is a synchronous driven motor having a range of 2 seconds to 15 seconds in ½ second steps. To use the motor driven timer, the selector 169 is moved to the terminal 179 which is connected to the contacts of the motor driven timer relay switch 289. The long range timer switch 287 is closed, and the filament supply switch 294 is closed. Now, when the timer start switch 211 is closed, the motor driven timer 283 is energized. The operation of the apparatus proceeds in the same manner as described above, except that a short circuit is placed on the first primary winding 119 of the second control transformer 115 by the closed relay contacts 289 of the motor driven timer. This short circuit may be traced from the upper terminal of the first primary winding 119 of the second control transformer 115 through the selector 169, the closed contacts of the motor driven timer relay switch 289, a closed contact 295 of the long range timer switch 287, and through the short circuit preventing resistor 205 to the other terminal of the first primary winding 119 of the second control transformer 115. When the motor driven timer 283 has timed out and opened its relay switch 289, the short circuit is removed, and the short range timer section operates as heretofore described.

The load current of the X-ray tube 11 is stabilized by means of the saturable reactor 55 and its associated circuits. The filament potential of the X-ray tube 11 is controlled by the saturable reactor 55, which is in turn

controlled by a stabilizer tube **65**. In standby position, the grid of the stabilizer tube **65** is connected through a pair of contacts **87** of the stabilizer relay **83** to a direct current bias source **85**. This bias source is set to allow the stabilizer tube **65** to conduct sufficiently to cause the X-ray tube filament to be heated to the proper temperature for the desired X-ray tube load current. At the beginning of an X-ray exposure, the stabilizer relay **83** is energized to disconnect the grid of the stabilizer tube **65** from the standby position to connect it to the movable contact **79** of sensing potentiometer **75** in operating bias circuit. It will be noted that the stabiliber bridge **41** is connected in series with one secondary winding **29** of the high tension transformer **15**, and thus carries X-ray tube load current. A voltage is then produced across the sensing potentiometer **75** in the stabilizer bridge circuit **41**, which is proportional to X-ray tube load current. This voltage is applied in shunt with the stabilizer operating bias supply **75**, **77**. The voltage across the sensing potentiometer **71** is in a sense opposite to that produced by the stabilizer operating bias supply **75**, **77**. Unbalance in these voltages resulting from variations in X-ray tube **11** current will produce a regulating potential on the grid of the stabilizer tube **65**. The magnitude of current drawn through the primary winding **57** of the saturable reactor **55** will then vary in the sense to make the proper correction to the X-ray tube filament potential.

We are aware that many modifications of the preferred embodiment shown and described are possible without departing from the scope of our invention. We desire, therefore, to be limited only insofar as is necessitated by the prior art and the spirit of the appended claims.

We claim as our invention:

1. The combination comprising first and second gaseous electric discharge devices, each having an anode, a cathode, and a control electrode, and being connected inversely in parallel, first and second transformers, said first transformer having a primary winding and a secondary winding, said second transformer having a secondary winding, the primary winding of said first transformer being connected in series with the anode of said first discharge device, biasing means for maintaining said discharge devices initially non-conductive, a time constant network in the control electrode circuit of said second discharge device, a secondary winding of said first transformer being connected in series with said network to render the control electrode of said second discharge device positive upon conduction of said first discharge device, a time constant network connected in the control electrode circuit of said first discharge device, a rectifier having an anode, the secondary winding of said second transformer being connected in series with said rectifier and said last-mentioned network in such manner as to render the anode of said rectifier positive when the anode of said first discharge device is negative.

2. The combination comprising first, second, and third electric discharge devices each having an anode, a cathode, and a control electrode, a transformer having first and second primary windings and a secondary winding, a time constant network connected in the control electrode circuit of said first discharge device, a rectifier connected in series with said time constant network and said secondary winding, said first primary winding being connected in the anode circuit of said second discharge device, and said second primary winding being connected in the anode circuit of said third electric discharge device.

3. The combination comprising a plurality of electric discharge devices each having an anode, a cathode, and a control electrode, said devices being connected in parallel, an impedance connected in the anode circuits of said discharge devices, a rectifier connected in series with a time constant network to shunt said impedance, an additional electric discharge device having a control electrode, connections between the control electrode of said additional discharge device and said time constant network, whereby a signal applied to the control electrode of any one of said plurality of discharge devices will render said one discharge device conductive and charge said time constant network to render said additional discharge device non-conductive.

4. The combination comprising an electric discharge device having an anode, a cathode, and a control grid, a time constant network in circuit with said control grid, terminals adapted for connection to a source of low voltage alternating current, a potentiometer having input terminals connected across said first-mentioned terminals and having output terminals connected in series with the control grid and cathode of said discharge device, and said time constant network.

5. In X-ray apparatus wherein an X-ray tube is energized from an alternating current source through a bridge rectifier circuit comprising a plurality of pairs of legs and including rectifier tubes having filament heating circuits, and an electronic timer controls operation of a contactor which in turn controls the flow of energy to the bridge circuit, the timer being capable of closing the contactor for one cycle only of the alternating current supply, the combination with said bridge rectifier of switch means operable to de-energize the filament heating circuits of rectifiers in one of said pairs of legs of said bridge circuit.

6. In combination, first and second gaseous electric discharge devices, each having an anode, a cathode and a control electrode and being connected inversely in parallel, a time constant network connected in the control electrode circuit of each of said devices, means for applying alternating current potential to the anodes of said devices, means for charging the time constant network connected to said first device when the anode of said first device is negative to render the control electrode of said first device positive, and means responsive to conduction of said first device to charge the time constant network of said second device when the anode of said second device is negative to render its control electrode positive.

7. The combination comprising an electric discharge device, means for rendering said discharge device non-conductive in response to current flow in a certain path, a plurality of electric discharge devices connected to cause current flow in said path when any one of said plurality of discharge devices is rendered conductive, and a time constant network connected to each of said plurality of discharge devices in a manner such that its respective discharge device will be rendered conductive upon expiration of a time interval dependent upon the parameters of the said network.

8. The combination comprising a first electric discharge device having an anode, a cathode and a control electrode, a time constant network connected to said device to render it non-conductive when said network is charged, second and third electric discharge devices each having an anode, a cathode, and a control electrode, and each of said second and third discharge devices being connected to charge said network when conductive, and means for rendering said third discharge device non-conductive responsive to conduction of said second discharge device.

9. In X-ray apparatus including an X-ray tube and a power supply for said tube, the combination of a contactor connected between said tube and said power supply to control the energization of said tube by the power supply, control means connected to said contactor for controlling said energization, said control means including timer means for controlling the time duration period of said energization, said control means further including timer stop means and safety stop means respectively connected to said timer, with said timer stop means and said safety stop means being respectively operable to determine said time duration period.

10. In X-ray apparatus including an X-ray tube and a power supply for said tube, said power supply including an X-ray tube current control member and an X-ray tube voltage control member, the combination of a con-

tactor connected between said tube and said power supply for controlling the energization of said tube by said power supply, timer means connected to said contactor for controlling the energization of said X-ray tube and for determining the time period of said energization, timer stop means connected to said timer for terminating said time period and safety stop means connected to said timer for terminating said time period, said safety stop means being gang connected to said X-ray tube current control member and said X-ray tube voltage control member respectively for operation in conjunction with the latter control members.

11. In X-ray apparatus including an X-ray tube and a power supply for said tube, the combination of a control connected between said tube and power supply for controlling the energization of said tube from said power supply, timer means connected to said control for determining the time duration period of said energization, timer start means connected to said timer means for preparing said timer means to provide a predetermined time period, and timer stop means connected to said timer means for terminating the time period of said energization.

12. The apparatus of claim 11, with said X-ray apparatus including an X-ray tube current control member and an X-ray tube voltage control member, with said combination including a safety stop member which is gang connected with said current control member and said voltage control member, said safety stop means being connected to said timer means and operable to terminate said time period of energization of the X-ray tube.

13. In X-ray apparatus including an X-ray tube and a power supply for said tube, the combination of control apparatus connected between said tube and said power supply for controlling the energization of said X-ray tube, first bias means connected to said control apparatus and operable to prevent the undesired operation of said control apparatus, second bias means connected to said control apparatus and operable to overcome the effect of said first bias means and to thereby cause said control apparatus to operate and energize said X-ray tube, and timer means connected to said control apparatus and operable to determine the time duration period of said energization.

14. The apparatus of claim 13, including an X-ray tube current control member and an X-ray tube voltage control member with a safety means connected to said timer and gang operated with said current control member and said voltage control member, said safety stop means being operable to terminate the energization of said X-ray tube should the timer means be set for more than the maximum desired safe X-ray exposure time.

15. In X-ray apparatus including an X-ray tube and a power supply for said tube, the combination of a contactor connected between the X-ray tube and the power supply, control means connected to said contactor for controlling the energization of said X-ray tube by said contactor, said control means including a timer which controls the time duration period of said energization, timer start means connected to said timer for preparing the timer to provide the desired time duration period of energization for said X-ray tube, timer stop means connected to said timer for terminating the energization of the X-ray tube at the end of said time period, and an operating switch connected to said timer start means to terminate the operation of said timer start means and to initiate the operation of said timer.

16. The apparatus of claim 15 including an X-ray tube current control and an X-ray tube voltage control, and a safety stop means gang connected with said current control and voltage control to operate thereby in conjunction with said current control and voltage control, said safety stop means being operable to terminate the operation of said timer should the latter timer be set for a time period greater than the maximum desired safe X-ray exposure time for said X-ray tube.

17. In X-ray apparatus including an X-ray tube and a power supply for said tube, said power supply including a bridge rectifier circuit having a plurality of pairs of legs, the combination of a contactor connected between said X-ray tube and said power supply for controlling the energization of said X-ray tube from said power supply, a timer connected to said contactor for controlling the time duration period of said energization, and a switch member connected to one pair of said legs to make said one pair of legs inoperable.

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