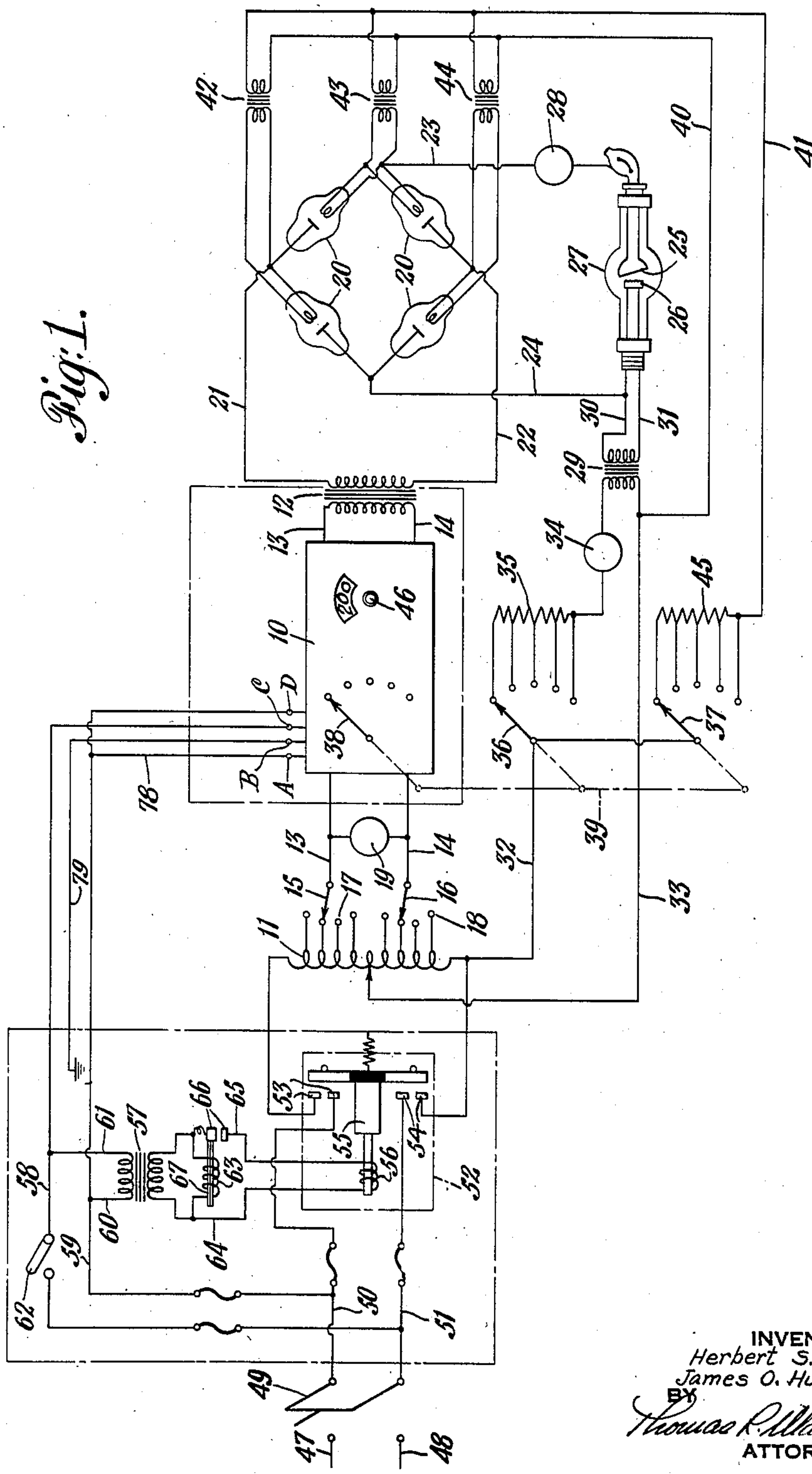
Jan. 25, 1944. H. S. AKERS ET AL 2,339,902

X-RAY APPARATUS

Filed March 18, 1942 3 Sheets-Sheet 1

Fig. 1.



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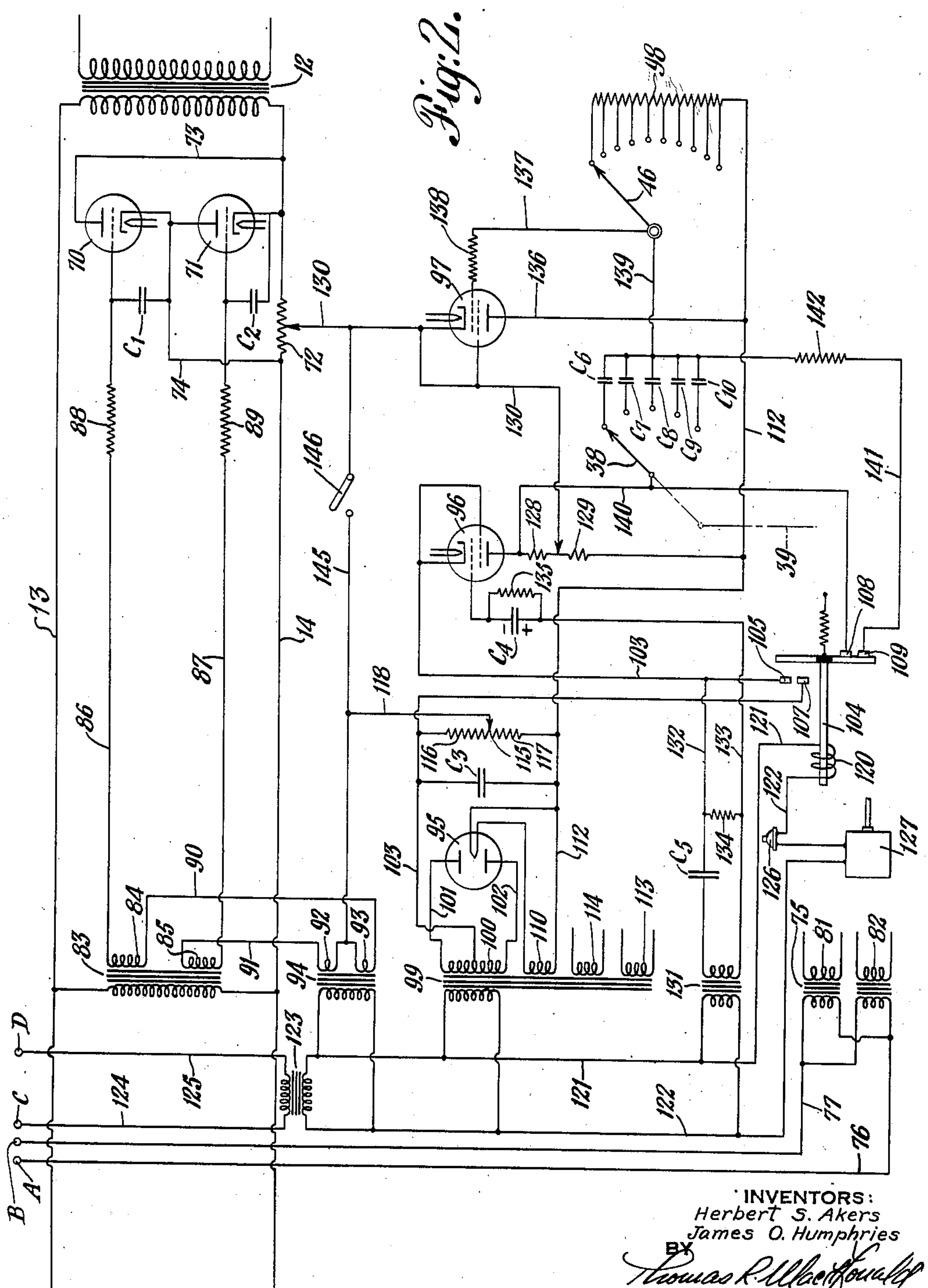

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Filed March 18, 1942 3 Sheets-Sheet 3

Fig: 3.

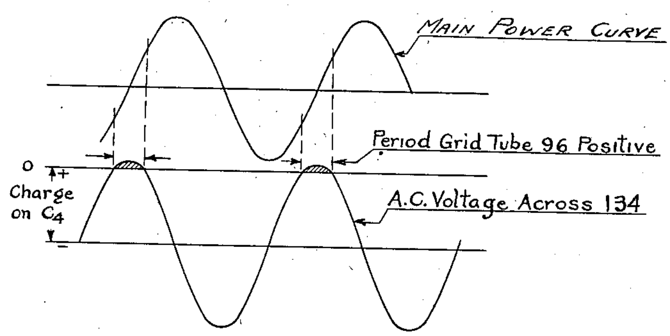
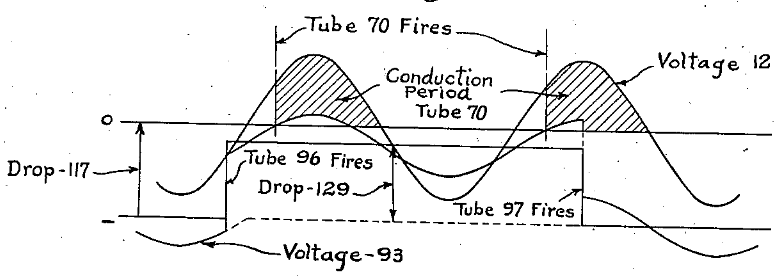


Fig: 4.



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X-RAY APPARATUS

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Application March 18, 1942, Serial No. 435,176

12 Claims. (Cl. 250—95)

This invention relates to improvements in X-ray apparatus.

The quantity of energy, in the form of X-rays, radiated per unit of time from the anode of an X-ray tube, i. e. the intensity of radiation, is a function of, among other things, the current which flows through the tube. This current is usually measured in milliamperes so that the product of milliamperage and time in seconds gives an energy factor which is a measure of the total energy radiated and may be expressed as milliampere-seconds. This energy factor, for convenience, is sometimes hereinafter referred to as Ma. S.

In the practical application of this principle, it has already been proposed to employ a Ma. S. timing device in conjunction with X-ray apparatus such as device being disclosed, for example, in Patent No. 2,136,116 granted November 8, 1938, on an invention of W. W. Mowry. As there embodied, the timing device permits the utilization, at a given milliamperage, of any one of a group of timing elements allocated for use with that particular milliamperage.

If the milliamperage is changed, as an accompaniment, for example, to a change in radiographic technique, a concurrent shift is automatically made to a different group of timing elements respectively more suited to the new milliamperage employed.

There are obvious advantages to be realized in the use of X-ray apparatus which would permit the obtainment, automatically and with exactitude, of equal total amounts of X-ray energy at milliamperages which differ widely or narrowly from each other and it is an object of this invention to provide such apparatus.

Another object of this invention is to provide improved X-ray apparatus.

Another object of this invention is to provide X-ray apparatus with which changes in the current flowing through the X-ray tube can be made without an accompanying change in the Ma. S. factor to which the apparatus may be set.

Another object of this invention is to provide X-ray apparatus with which a change in the current flowing through the X-ray tube can be effected independently of the Ma. S. energy factor selected.

Another object of this invention is to provide an improved timing device for X-ray apparatus.

Other and further objects of this invention will appear from the accompanying drawings, the following description and the appended claims.

In the accompanying drawings which form part of the instant specification and are to be read in conjunction therewith; and in which like numbers refer to like parts throughout the several views;

Fig. 1 is a schematic and diagrammatic representation of the electric circuits and controls of X-ray apparatus constituting a preferred embodiment of this invention; and,

Fig. 2 is a schematic representation of the portion of Fig. 1 within the area enclosed by the dotted lines particularly showing in detail the electric circuits and controls of an electronic Ma. S. timer of the embodiment represented by Fig. 1.

Figs. 3 and 4 are views diagrammatically illustrating certain time-voltage relationships in the timer circuits.

The objects and advantages of this invention are attained in part by the provision in the circuits for controlling the flow and magnitude of the current through an X-ray tube, of a manually variable timing device which operates to initiate the flow of current through the X-ray tube and to terminate the current flow after a predetermined time interval. This time interval in turn is adapted to be automatically inversely varied in direct proportion to any manually effected change in the magnitude of the current which flows through the tube whereby a preselected Ma. S. factor may be maintained constant regardless of the current employed.

As embodied, the timing device is electrically coupled in the circuits of the X-ray apparatus so as to initiate and interrupt the current flow in the primary circuit of the transformer which supplies high voltage current to the X-ray tube.

As here embodied, an electronic Ma. S. timer generally designated by the numeral 10, Fig. 1, is electrically coupled in the low voltage A. C. circuit formed by the auto-transformer 11, the primary coil of the X-ray transformer 12 and the leads 13 and 14, all as best shown in Fig. 2. Voltage control in this circuit is effected by means of a pair of switch arms 15 and 16 which connect the leads 13 and 14, respectively, to respective banks of taps 17 and 18 on the auto-transformer 11. Major and minor control of the voltage is effected by the banks 17 and 18, respectively, through establishment of a predetermined ratio of turns in the auto-transformer. The peak kilo voltage (PKV) in this circuit is measured by the voltmeter 19 shunted across the leads 13 and 14.

The output of the X-ray transformer 12 is supplied, after rectification, to the X-ray tube. As embodied, full-wave rectification of the transformer output is provided for. As here embodied, the secondary of the transformer 12 is connected to a bank of rectifier valve tubes, four in number, by leads 21 and 22. The valve tubes 20 are connected in the known manner so as to effect full-wave rectification of the input voltage, the output of the valve tubes being delivered through the leads 23 and 24 to the anode 25 and the cathode 26 of the X-ray tube 27. The direct current magnitude in the X-ray tube circuit is measured by a milliammeter 28 in the lead 23.

The magnitude of the current in the X-ray tube circuit, for a given PKV, is controlled by the temperature of the X-ray tube filament (or filaments) and of the valve tube filaments. As embodied, these filaments are heated by power supplied thereto from suitable filament transformers, the power input to each of which is varied simultaneously to effect the desired milliamperage change in the X-ray tube circuit. As here embodied, the filament of the X-ray tube 27 is supplied with power in the known manner by a filament transformer 29 whose output is delivered to the X-ray tube filament (cathode) by the leads 30 and 31, the former being also connected to the high voltage lead 24. The power input to the filament transformer 29 is obtained from the auto-transformer 11 through leads 32 and 33, the former having in series therewith an ammeter 34 a resistor 35 and a switch arm 36. As embodied, the resistor 35 may be continuously or progressively variable. As here embodied, the resistor 35 is provided with a series of taps, five in number, adapted to be engaged successively by the switch arm 36 so that clockwise movement of the switch arm from the position shown will increase the filament current.

The switch arm 36 forms part of one deck of a multi-deck, multi-position switch which, as here embodied, is provided with two additional decks having the switch arms 37 and 38, respectively, mechanically coupled with the switch arm 36 by link mechanism diagrammatically indicated at 39. Equal simultaneous angular movements of the switch arms is effected by rotation of the common switch arm shaft.

The switch arm 37 functions to control the filament current in the valve tubes 20. To the accomplishment of this end the leads 33 and 32 are connected by the leads 40 and 41, respectively, to filament transformers 42, 43 and 44, as shown. The switch arm 37, lead 41, and resistor 45 form a circuit. As embodied, the resistor 45 may be continuously, or progressively, variable, the particular form being chosen to conform to that of the companion resistor 35. As here embodied, the resistor 45 is provided with a series of taps, five in number, adapted to be engaged successively by the switch arm 37 so that clockwise movement from the position shown will cut out resistance so as to effect an increase in the valve tube filament temperature simultaneously with an increase in the X-ray tube filament temperature. Thus, the switch arms 36 and 37 together operate to regulate the milliamperage in the X-ray tube high voltage circuit.

The switch arm 38 of the multi-deck switch functions to insert in the circuit of the timer 10, as is more fully described hereinafter, a value of timing capacitance which, at each position of the switch arm, is so correlated to the milliamperage determined by the position of the switch arms 36 and 37 as to maintain the same basic Ma. S. factor at all times. As here embodied, the switch arm 38 is adapted to engage successively a series of contacts, five in number, respectively connected to one side of respective condenser units C_6 to C_{10} inclusive. Variation of the basic Ma. S. factor at each position of the switch arms 36 to 38 inclusive may be effected, however, by rotation of the numbered dial 46, Fig. 1, which represents a correspondingly numbered switch arm as best appears in Fig. 2 and is more fully described hereinafter.

Power is supplied to the auto-transformer 11 and to the Ma. S. timer 10 from an A. C. source, by the leads 47 and 48. As here embodied, a main wall switch 49 couples the leads 47 and 48 with the auto-transformer 11 through leads 50 and 51 containing switch points 53 and 54, respectively, of a main control switch 52, having a switch arm 55 constituting a solenoid plunger. The switch points 53 and 54 are closed by movement of the solenoid plunger 55 when actuated by the flow of current through the solenoid coil 56. Power for the operation of the solenoid is obtained from a suitable transformer 57 to the primary coil of which power is supplied from the leads 58 and 59 through the leads 60 and 61 when the switch 62 is closed. Leads 58 and 59 connect the leads 51 and 50 with terminals C and A—D, respectively, of the timer 10.

The transformer 57 has its secondary winding in parallel circuit arrangement with a pair of circuits of which the first is constituted by a heating coil 63, the second being a delayed action circuit constituted by the solenoid coil 56 and leads 64 and 65. The circuit through the lead 65 is adapted to be completed by closing of a pair of contacts 66 therein when actuated by a thermo-bar 67 energized by the heating coil 63. Thus, closing of the main switch 49 and of the switch 62 is not followed by closing of the solenoid switch 52 until delayed closure of the contacts 66 permits current to flow in the solenoid circuit.

The timer 10 when set in operation functions to initiate the flow of current through the primary coil of the X-ray transformer 12 and to terminate this flow after the elapse of a predetermined interval of time which is automatically varied inversely in direct proportion to a change in the magnitude of the milliamperage in the X-ray tube 27 effected by the switches 36 and 37. As embodied, the timer comprises essentially an electronic relay tube circuit energizable to permit the flow of alternating current in the primary coil of the X-ray transformer 12, and, an electronic timing circuit by means of which the relay tube circuit is energized for a predetermined time interval.

As here embodied, the relay circuit comprises a pair of grid controlled gas tubes 70 and 71 whose grids are normally negatively biased so that on current flows in the plate-cathode circuit of either. Situated in the lead 14 to the primary of the X-ray transformer 12 is a center tapped resistor 72. The plates of the tubes 70 and 71 are connected to the lead 14 at either side of this resistor, the plate of tube 70 by the lead 73, and the plate of tube 71 by the lead 74. This negative bias on the tubes 70 and 71 is obtained from the D.-C. voltage drop across a section of a continuously variable resistor 115 in the timing circuit as is described more fully hereinafter. When the tube 70 is positively biased and fires, current flows, during the positive half cycle of voltage thereon from its plate to its cathode and thence via lead 74, to which its cathode is connected, to lead 14. When tube 71 fires, during the other half cycle, current flows from the lead 14 via lead 74 to the plate of tube 71 and thence via the tube cathode to lead 14. Thus, an alternating current may be made to flow in the primary of the transformer 12 so long as the grids of the tubes 70 and 71 are alternately positively biased.

The cathode heaters of the tubes 70 and 71 are supplied with power from a filament transformer 75 having a split primary winding connected by leads 76 and 77 to terminals A and B, respectively, of the timer 10. The terminal A is connected by a lead 78 to the power lead 59 while the terminal B is connected by a lead 79 to a ground. Thus, it will be observed that by closing the main wall switch 49 current will flow in the primary coil of the filament transformer 75 whose split secondary has a section 81 connected to the filament of tube 70 and a section 82 connected to the filament of the tube 71.

The resistor 72 has substantially A. C. line voltage impressed across it when the tubes 70 and 71 are non-conducting, so that the midpoint of the resistor differs from the cathode potential of aech tube by one half the A. C. line voltage. This A. C. voltage must be neutralized so that any D. C. potential impressed by the timing circuit upon the grids of tubes 70 and 71 in one direction will make both grids positive, and will make both grids negative if impressed in the other direction. As here embodied a neutralizing transformer 83 has its primary winding shunted across the leads 13 and 14. The secondary of the transformer consists of two windings 84 and 85, the former being connected at one terminus by a lead 86 containing a resistor 88 of high value to the grid of the tube 70 and the latter being connected at one terminus by a lead 87 containing a resistor 89 of high value to the grid of the tube 71. The remaining terminals are connected by leads 90 and 91 to the secondary windings 92 and 93 of a grid-biasing transformer 94 to be more fully described hereinafter. It is essential that the secondary windings 84 and 85 be properly phased to obtain the desired neutralization.

The grids of tubes 70 and 71 are normally negatively biased relative to the cathodes by a negative D. C. potential of a fixed value. This potential is supplied by the timing circuit. These grids are alternately carried positive by the positive half of the A. C. potential supplied by the respective secondary windings 92 and 93 of the grid-biasing transformer 94 in conjunction with a positive D. C. potential supplied by the timing circuit. The windings 92 and 93 are therefore suitably phased to accomplish this object. Condenser units C_1 and C_2 of suitable capacity are shunted across the grid-cathode leads of the tubes 70 and 71, respectively, to prevent switching surges from momentarily changing the grid to cathode potential of these tubes and allowing them to fire.

The timing circuit, as here embodied, comprises a rectifier tube 95; grid controlled gas tubes 96 and 97 which function to initiate and terminate, respectively, the timing cycle; a bank or fixed capacity condenser units C_6 to C_{10} inclusive, for inversely varying the timing interval in direct proportion to the magnitude of a change in the milliamperage of the X-ray tube 27; a variable resistor 98 for selectively varying the charging rate of the condensers C_6 to C_{10} inclusive; together with the necessary resistors, leads, switches and other devices necessary for coordinating the foregoing elements into an operative and useful timing circuit.

The rectifier tube 95 is energized in the known manner by a transformer 99 having a center tapped secondary winding 100 whose termini are connected by leads 101 and 102, respectively, to either plate of the tube 95 and whose center tap is adapted to be connected to the cathode of the tube 96 through a lead 103 containing switch points 105 and 107 connectable to each other by a solenoid-operated relay switch arm 104 which simultaneously disconnects other switch points 108 and 109 from each other.

The filament of the tube 95 is heated by the transformer 99 through a secondary winding 110 connected in series with the filament in the usual fashion. The filaments of the heater type gas-filled tubes 96 and 97 are powered by the transformer 99 through secondary windings 113 and 114, respectively, the filament leads in each case being omitted from the drawings for simplification.

The low and high potential output leads 103 and 112, respectively, of the rectifier unit have shunted thereacross, a variable resistance unit 115 and a filter condenser C_3.

The resistor 115 is electrically divided into sections 116 and 117 by a lead 118 which connects the resistor to the common center tap of the secondary windings 92 and 93. A potential drop exists across the section 116 so that the grids of the tubes 70 and 71 are, in consequence, impressed with a D. C. potential which is negative relative to the lead 112 and, as will appear more fully hereinafter, relative to the cathodes of the tubes 70 and 71. This negative D. C. potential on the grids is supplemented by the A. C. output potential of the transformer 94. The grids become more and less negative in a uniformly varying fashion but the tubes 70 and 71 remain in a non-conducting state until the tube 96 fires and the grids of these tubes alternately swing positive.

The tube 96 is adapted to be placed in circuit with the negative and positive output leads 103 and 112, respectively, of the rectifier 95 so as to initiate the timing cycle and cause the relay tubes 70 and 71 to become conductive, by means of the solenoid operated switch 104.

The switch 104 is energized by a solenoid winding 120 connected by the leads 121 and 122 in series with the secondary winding of the transformer 123 whose primary winding is connected by the leads 124 and 125 to the terminals C and D, respectively, which are connected in turn by the leads 58 and 59, respectively, to the main A. C. source through the wall switch 49.

A push button 126 and auxiliary safety timer 127 are placed in series with the lead 122 for closing the circuit through winding 120 so as to move the switch arm 104 into engagement with the switch points 105—107, the switch points 108 and 109 being disengaged from each other at the same time for a purpose described more fully hereinafter.

Upon closure of the contacts 105 and 107, the output voltage of the rectifier unit is applied to the gas tube 96 through the negative lead 103, connected to its cathode and its suppressor grid, and through the positive lead 112. The latter is connected to the plate of the tube through a pair of series connected plate load resistors 128 and 129 whose common terminal is connected by a lead 130 to the electrically neutral center tap of the resistor 72. Thus, until the tube 96 fires, the cathodes of tubes 70 and 71 will be at the potential of lead 112, with reference to which the grids are negative, by the voltage drop across 116.

The resistor 129 functions when the tube 96 is firing to provide a D. C. voltage drop which is utilized partially to cancel the voltage drop across the resistor section 116. The biasing transformer windings 92 and 93 supply the required additional A. C. voltage necessary to carry the grids of tubes 70 and 71, respectively, positive when the plate of each of the tubes 70 and 71 is positive.

Firing of the gas tube 96 is instituted by swinging its control grid positive relative to its cathode through the medium of a suitable grid biasing circuit. Preferably, the tube 96 is caused to fire within a range of, for example, about thirty degrees (30°) to either side of the start of each cycle of the main voltage wave and continues to fire throughout the cycle in each instance.

As here embodied, the biasing circuit consists of a transformer 131 whose primary winding is connected to the power leads 121 and 122. The secondary winding of the transformer 131 is connected to the tube cathode through a condenser unit C_5 by leads 132 and 103, as shown, and is connected to the control grid of the tube 96 by means of a lead 133. A resistor 134 is shunted across the leads 132 and 133. The voltage wave across the resistor 134 is, in consequence, substantially 90° leading in phase with relation to the main A. C. voltage wave. A grid condenser C_4 which is shunted by a resistor 135 is provided in the lead 133.

The voltage drop across the resistor 134 is utilized to charge the condenser C_4 by grid rectification in the direction indicated. The capacity of the condenser C_4 is preferably such that the grid of tube 96 will become positive for a small part only of the positive half cycle of the voltage wave across the resistor 134, as is shown in Fig. 3. Since the resistor voltage wave leads the main A. C. voltage wave by approximately 90°, the control grid will be positive and fire the tube 96 at a point on the main A. C. voltage wave within a range of preferably plus or minus 30° from the start of each cycle of the main wave as is shown in Fig. 3.

The resistor 135 may or may not be required. If it is, its value should be as high as possible and should not be reduced below that at which the tube 96 will fire consistently.

The current flow in tube 96 produces a voltage drop across resistor 129 which partially cancels the voltage drop across resistor 116 by which the grids of tubes 70 and 71 are normally negatively biased. This condition is shown in Fig. 4. The additional voltage for cancelling the remainder of the drop across resistor 116 and for positively alternately biasing these grids is provided by the respective secondary winding of the transformer 94 whose alternating E. M. F. supplements the drop across 129 in amount and phase relationship so as to cancel the negative bias on the respective grids at the proper moment and thereafter to swing each grid alternately positive so as to initiate firing of these tubes. This condition is diagrammatically illustrated in Fig. 4.

If the grids of the relay tubes were made positive solely by D. C. voltage, any unbalance in current conduction between them would cause a D. C. component to flow through the primary of the X-ray transformer 12 tending to saturate it and aggravate the unbalance. This tendency is overcome in the instant embodiment by retarding the firing with the main grids to a point at least 2° or 3° later than the natural zero of the alternating current. Thus, as appears from Fig. 4, firing of the relay tubes 70 and 71 must be restrained throughout an initial portion of each half cycle of the main voltage wave. The extent of this restraint will be determined by the power factor of the alternating current. Thus, by way of example, if the power factor of this current is 90%, firing must be restrained for the first 28° of each half cycle of the main voltage wave. This condition is depicted in Fig. 4 wherein it will be observed that transformer 94 adds an alternating E. M. F. in the grid circuit of each tube 70 and 71 in such a way as to carry the grids alternately positive at about the 28° point of each half cycle when the timing circuit is on. The circuit is easily adjusted for any reasonable power factor which may be encountered, by adjusting the slider on resistor 115 to the proper position for the particular condition.

When the tube 96 fires to initiate the timing cycle, the output voltage of the rectifier is applied to the series connected resistors 128 and 129 and to one of the condensers C_6 to C_{10} inclusive which charges up at a rate fixed by the setting of the continuously or progressively variable resistor 98.

The timing cycle is adapted to be terminated after the elapse of a predetermined time interval the magnitude of which is variable simultaneously with and in inverse relation to the magnitude of any change in the milliamperage in the X-ray tube current. As embodied, termination of the timing cycle is effected by means of the gas tube 97 and any one of condensers C_6 to C_{10}. The gas tube 97 is caused to function at the proper moment by means of the respective condenser units C_6 to C_{10} so as to neutralize the positive potential being supplied to the main grids in consequence of the potential drop across the plate load resistor 129.

As here embodied, the plate of the tube 97 is connected by the lead 136 to the positive lead 112 of the rectifier while the cathode and suppressor grid of the tube are connected to the lead 130. Thus, the plate of the tube 97 is positive relative to its cathode, while the tube 96 is firing, by the voltage drop across the resistor 129

The tube 97 is maintained in a non-conducting state until the selected time interval has elapsed and, as embodied, this is accomplished by maintaining the control grid of the tube negative with relation to its cathode during this interval. As here embodied, the control grid is connected by a lead 137, containing a grid leak 138, to the switch arm 46 which is adapted to be manually rotated in a clockwise direction so as to engage successively a series of taps on the variable resistance 98 which latter is inserted in the high potential lead 112.

The variable resistance 98, as here embodied, may consist of a series of timing resistors each preferably of a fixed value. As resistance is cut into the condenser charging circuit, by counterclockwise movement of switch arm 46, the basic charging rate of the selected condenser unit of the condenser units C_6 to C_{10} inclusive will be decreased.

The switch arm 46 is in turn connected by a lead 139 to one side of each of the condenser units C_6 to C_{10} inclusive, the opposite side of each of which is connected to one of a series of taps respectively adapted to be engaged successively by a switch arm 38 upon rotation in a clockwise direction of the multi-position, multiple-deck milliampere selector switch previously described. The switch arm 38 is in turn connected by the lead 140 to the plate end of the resistor 128 and also to the condenser discharge contact 107 of the solenoid switch 104 whose opposed contact 109 is connected by a lead 141, containing a condenser discharge resistor 142, to the common side of the condensers C_6 to C_{10} inclusive.

Thus, it will be observed that before the condensers have received any charge the potential drop across the resistor 128 will render the control grid of tube 97 negative relative to its cathode. As current flows in the condenser circuit, the condenser C_6, for example, whose tap is engaged by the switch arm 38, will charge up at a rate fixed by the value of resistance selected by the setting of the switch arm 46 until the charge on the condenser C_6 equals the drop across the resistor 128. At that time the control grid of tube 97 will cease to be negative and will allow tube 97 to conduct. This amounts to shortcircuiting the resistor 129, the voltage drop across 129 disappears and tubes 70 and 71 cease to conduct.

The condenser units C_6 to C_{10} inclusive, as embodied, are preferably of a type which will ensure that the capacity of the respective units will remain substantially constant throughout an appreciable range of operating temperatures and over a long period of time. Units of the mica or paper type are therefore to be preferred over units of the electrolytic type since the latter have less constant time-temperature characteristics.

The capacitance of the respective condenser units C_6 to C_{10} inclusive is chosen so as to reduce progressively the timing interval as the X-ray tube current is increased so as to preserve a constant current-time relationship. As embodied, the relationship is such that the increase in milliamperage resulting from clockwise movement of the coupled switch arms 36 and 37 from the position shown in Fig. 1 to the next tap on the variable resistor banks 35 and 45, respectively, will be accompanied automatically by a decrease in capacitance resulting from a corresponding movement of the coupled switch arm 38 from the condenser unit C_6, for example, to the condenser unit C_7 of lower capacitance. As here embodied, the resistor units 35 and 45 are respectively provided with taps, five in number, each of which will effect a doubling of the milliamperage obtainable from the next preceding tap. For example, techniques of 25, 50, 100, 200 and 400 milliamperes may be provided for. In conformance with the operating principle here involved, the condenser units C_6 to C_{10} inclusive, are respectively of a capacity which is one half that of the next preceding condenser unit. For example, values of capacitance of 16, 8, 4, 2 and 1 mfds., respectively, for the condenser units C_6, C_7, C_8, C_9 and C_{10}, respectively, would provide in conjunction with techniques of 25, 50, 100, 200 and 400 milliamperes, a Ma. S. factor which would be the same in each case. Thus, for example, if a setting of the switch arms 36, 37, 38 as in Fig. 1 provided for 8 seconds operation at 25 ma., i. e. an Ma. S. factor of 200, positioning of the switch arms on the last tap of each deck would provide for ½ of a second operation at 400 ma., i. e. the same Ma. S. factor of 200. This base Ma. S. factor may be decreased by clockwise movement of the switch arm 46 to the minimum obtainable through decreasing the effective value of the resistance 98.

Once the tube 97 starts to conduct and the timing cycle terminates, it can be repeated only by discharging the condenser unit which is operative in the circuit. This is effected by releasing the push button 126. In consequence, the solenoid 104 moves to the position shown in Fig. 2 and the condenser charge is dissipated through the resistor 142.

The auxiliary safety timer 127 is intended to limit automatically the possible exposure time should the main electronic timer be set to provide a time current condition exceeding the normal safety rating of the X-ray tube. As embodied, the timer 127 comprises a motor driven synchronous timing device or other suitable mechanical timing device which will open the circuit through the lead 122 should the main electronic timer be set for an Ma. S. factor in excess of the rating, or safety limits of the X-ray tube. As here embodied, setting of the auxiliary timer 127 is accomplished by utilizing the shaft, or an extension of the shaft, of the multi-deck, multi-position, milliampere selector switch to pre-set the timer so that as the milliamperes are increased from the lowest rating to the highest rating the shaft will automatically set the motor driven synchronous safety timing device to limits which will be within the ratings of the X-ray tube.

Provision for extended operation of the relay tubes 70 and 71, such as is required in fluoroscopy, is made by connecting the leads 118 and 130 by a lead 145 in which is positioned a switch 146, preferably foot operated. The switch 146 in its open position, as shown in Fig. 2, permits the timer to control the duration of operation of the relay tubes. Closing of the switch results in the same negative D. C. potential occasioned by the drop across the resistor section 116 being impressed on the grid and cathode of each of the relay tubes 70 and 71. In consequence, the alternating E. M. F. supplied by the secondary windings 92 and 93 is effective to bias the grids of these tubes alternately positively in proper sequence to obtain continuous operation until the switch 146 is opened.

The system shown in Fig. 1 is placed in operation by closing the main wall switch 49 as a first step. This energizes the filament transformer 75 which lights the filaments of the relay tubes 70 and 71. These filaments should be lit an appreciable time, e. g. forty or more seconds, before the rest of the machine is turned on. The relay tubes 70 and 71, as here embodied, are preferably gas filled tubes of suitable capacity, such as, for example, type C-6-J tubes and may be lit continuously with no loss in filament emission.

The switch 62, which controls voltage to the timer section 10, is closed as a next step so as to light the filaments of the tubes 95, 96 and 97. The tubes 96 and 97 are gas filled tubes, such as, for example, type 2050 while the rectifier tube is preferably type 5Z3.

Closure of the switch 62 is followed in a short time, e. g. around 10 seconds, by automatic closure of the solenoid operated main control switch 52 consequent upon delayed closure of the contacts 66. The system is now ready for operation either for radiography or for fluoroscopy.

If radiography is to be carried out, the PKV decided upon is set by adjustment of the autotransformer controls 15 and 18. The timer is then set for the Ma. S. factor deemed proper for the particular operation to be undertaken, by moving the switch arm to the selected Ma. S. factor, such as, for example, 200 Ma. S., as shown in the dial window in Fig. 1. Any one of the techniques obtainable by a setting of the milliamperage selector switch, such as, for example, 25, 50, 100, 200 or 400 milliamperes technique, may then be employed by simultaneous movement of the switch arms 36, 37, 38 to the desired setting. Regardless of the technique selected, however, the same milliampere-second relationship will obtain upon pressing the push button 126 to initiate the timing cycle. If the Ma. S. factor employed would exceed the rated capacity of the X-ray tube, the auxiliary timing device will operate to open the timing circuit before the preset timing cycle has been completed.

If fluoroscopy is to be carried out, the footswitch 146 is closed and the X-ray tube will operate without interruption until the switch is again opened.

The invention in its broader aspects is not limited to the specific mechanisms shown and described but departures may be made therefrom within the scope of the accompanying claims without departing from the principles of the invention and without sacrificing its chief advantages.

We claim:

1. Apparatus for timing X-ray exposures comprising means for varying the magnitude of the X-ray tube current; and, means for automatically interrupting said current upon the elapse of a selected time interval, said interrupting means including means set by said current varying means for proportioning the timing interval with relation to the magnitude of said tube current so as to provide the same time-current relationship at each value of the tube current.

2. Apparatus for timing X-ray exposures comprising means for varying the magnitude of the X-ray tube current; and, means for automatically interrupting said current upon the elapse of a selected time interval, said interrupting means including means set by said current varying means for proportioning the timing interval with relation to the magnitude of said tube current so as to provide the same time-current relationship at each value of the tube current; and, means for independently varying said relationship at each value of the tube current.

3. Apparatus for timing X-ray exposures comprising means for varying in a step-wise fashion the magnitude of the X-ray tube current; and, means for automatically interrupting said current upon the elapse of a selected time interval, said interrupting means including a bank of condenser units for proportioning the timing interval with relation to the magnitude of the tube current so as to provide the same time-current relationship at each value of the tube current, and means actuated by said first mentioned means for selecting a condenser unit of the required capacity from said bank with each stepwise variation in the magnitude of said current.

4. A timing device comprising a multi-deck, multi-position switch of which one deck controls the magnitude of the current in a current conducting circuit; a condenser circuit in which the value of the capacitance is controlled by another deck of said switch, said value being inversely varied upon a change in the setting of said switch in direct proportion to the magnitude of the accompanying change in said current; and, a control tube having a voltage sensitive element connected to said condenser circuit so as to respond to changes in the voltage across the capacitance unit in said circuit and cause interruption of said current when said capacitance unit has attained a predetermined charge.

5. A timing device comprising a multi-deck, multi-position switch of which one deck controls the magnitude of the current in a current conducting circuit; a condenser circuit in which the value of the capacitance is controlled by another deck of said switch, said value being inversely varied upon a change in the setting of said switch in direct proportion to the magnitude of the accompanying change in said current; and, a control tube having a voltage sensitive element connected to said condenser circuit so as to respond to changes in the voltage across the capacitance unit in said circuit; and, relay means in circuit with said control tube and said current conducting circuit for interrupting said current when said capacitance unit has attained a predetermined charge.

6. A timing device comprising a multi-deck, multi-position switch of which one deck controls the magnitude of the current in a current conducting circuit; a condenser circuit in which the value of the capacitance is controlled by another deck of said switch, said value being inversely varied upon a change in the setting of said switch in direct proportion to the magnitude of the accompanying change in said current; and, a control tube having a voltage sensitive element connected to said condenser circuit so as to respond to changes in the voltage across the capacitance unit in said circuit; and, relay means in circuit with said control tube and said current conducting circuit for interrupting said current when said capacitance unit has attained a predetermined charge, said relay means comprising a voltage controlled thermionic valve tube.

7. Apparatus for timing X-ray exposures comprising a multi-deck, multi-position switch of which one deck controls the magnitude of the X-ray tube current; relay means in the primary circuit of the X-ray transformer for interrupting the flow of current in said circuit upon the elapse of a selected time interval; and, means for actuating said relay means comprising a control tube having a voltage-sensitive element, and a bank of timing condenser units respectively, selectively connectable to said element by another deck of said switch, said condenser units respectively having a capacity which will provide the same time-current relationship for each value of the X-ray tube current selected by said switch.

8. Apparatus for timing X-ray exposures comprising means for varying the magnitude of the X-ray tube current; relay means for interrupting the flow of said current upon the elapse of a predetermined time interval; and, means for actuating said relay means upon the elapse of said predetermined interval, said actuating means comprising a timing circuit including a bank of timing condenser units of different capacities, means for selectively connecting the respective condenser units in said circuit so as to obtain the same time-current relationship for each value of the tube-current, and a control tube connected to said relay means, said control tube having a voltage-sensitive element connected to said condensers so as to respond to changes in the voltage across the condenser in circuit whereby said relay means will be actuated when said condenser has acquired a predetermined charge.

9. Apparatus for timing X-ray exposures comprising means for varying the magnitude of the X-ray tube current; relay means for interrupting the flow of said current upon the elapse of a pre-

determined time interval; and, means for actuating said relay means upon the elapse of said predetermined interval, said actuating means comprising a timing circuit including a bank of timing condenser units of different capacities, means for selectively connecting the respective condenser units in said circuit so as to obtain the same time-current relationship for each value of the tube-current, and a control tube connected to said relay means, said control tube having a voltage-sensitive element connected to said condensers so as to respond to changes in the voltage across the condenser in circuit whereby said relay means will be actuated when said condenser has acquired a predetermined charge, and means for independently varying the charging rate of said condensers.

10. A milliampere-second timing device for timing X-ray exposures comprising a multiple-deck, multi-position switch of which one deck controls the magnitude of the X-ray tube current; a condenser circuit in which the value of the capicitance is controlled by another of said decks so as to provide the same time-current relationship for each value of the X-ray tube current selected by said switch; condenser charging means; relay means; and, a control tube for actuating the relay means, said control tube having a voltage-sensitive element connected to said condenser circuit so as to respond to voltage changes therein, whereby said control tube will become operative and actuate said relay means when said condenser circuit has acquired a predetermined charge.

11. Apparatus for timing X-ray exposures comprising thermionic valve tube relay means in the primary circuit of the X-ray transformer; means for negatively biasing said valve tubes so as to render them normally non-conductive; means for neutralizing said negative bias to initiate the timing cycle comprising separate sources of direct current and alternating current bias potential connected to said valve tubes; and, means for neutralizing the positive biasing potential after a predetermined time interval so as to terminate the timing cycle.

12. Apparatus for timing X-ray exposures comprising thermionic valve tube relay means in the primary circuit of the X-ray transformer; means for negatively biasing said valve tubes so as to render them normally non-conductive; means for neutralizing said negative bias to initiate the timing cycle comprising separate sources of direct current and alternating current bias potential connected to said valve tubes; and, means for neutralizing the positive biasing potential after a predetermined time interval so as to terminate the timing cycle, said means comprising a timing condenser and a control tube in parallel circuit arrangement with said source of D. C. biasing potential, said control tube having a voltage sensitive element connected to said condenser so as to respond to changes in voltage across said condenser whereby said control tube may be caused to fire when said condenser acquires a predetermined charge and thereby neutralize said positive biasing potential.

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