April 21, 1964 J. R. CRAIG 3,130,312

X-RAY TIMER SYSTEM TO PRODUCE SHORT DURATION RADIATION PULSES

Filed July 26, 1961 2 Sheets-Sheet 1

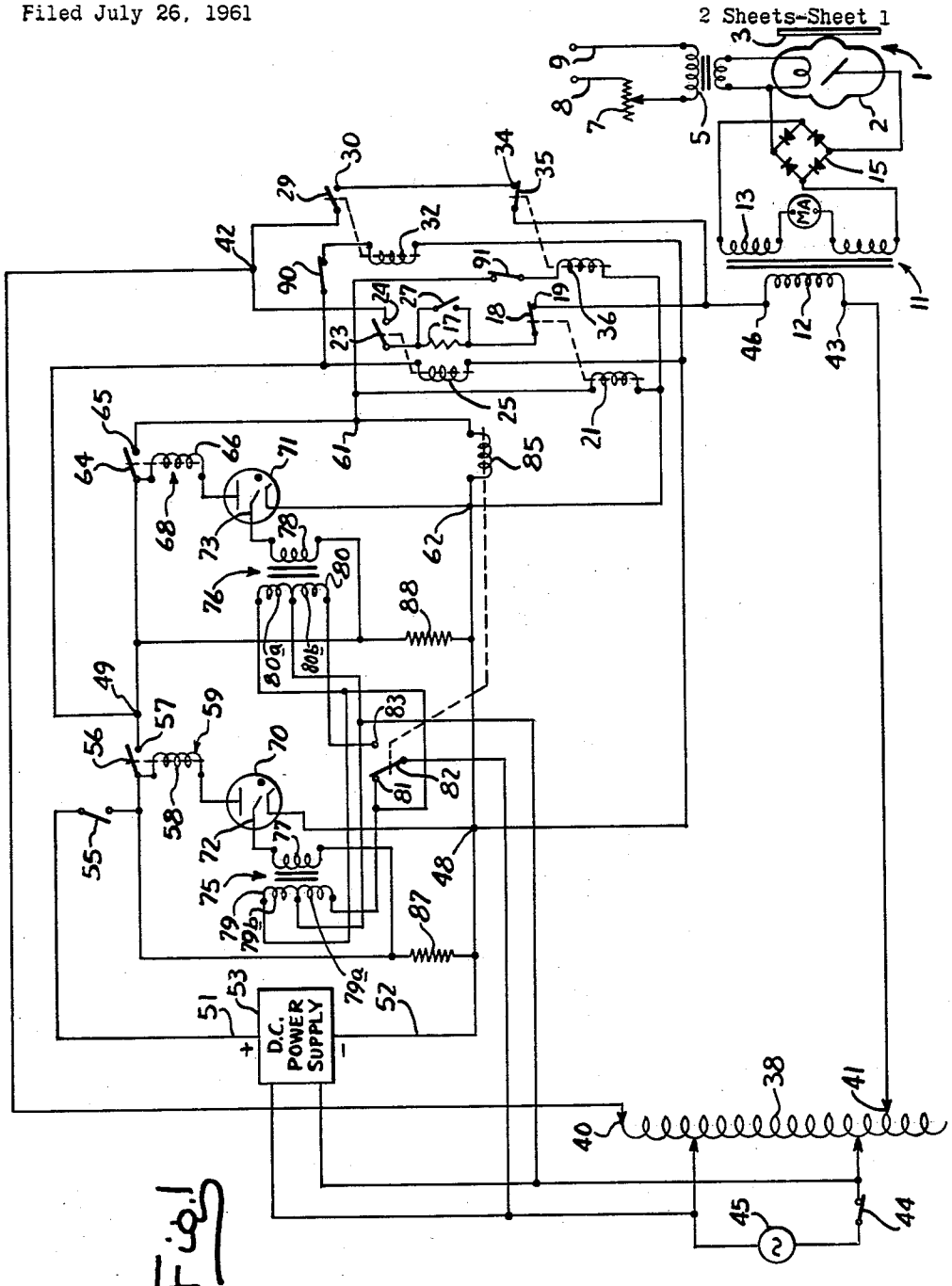


Fig. 1

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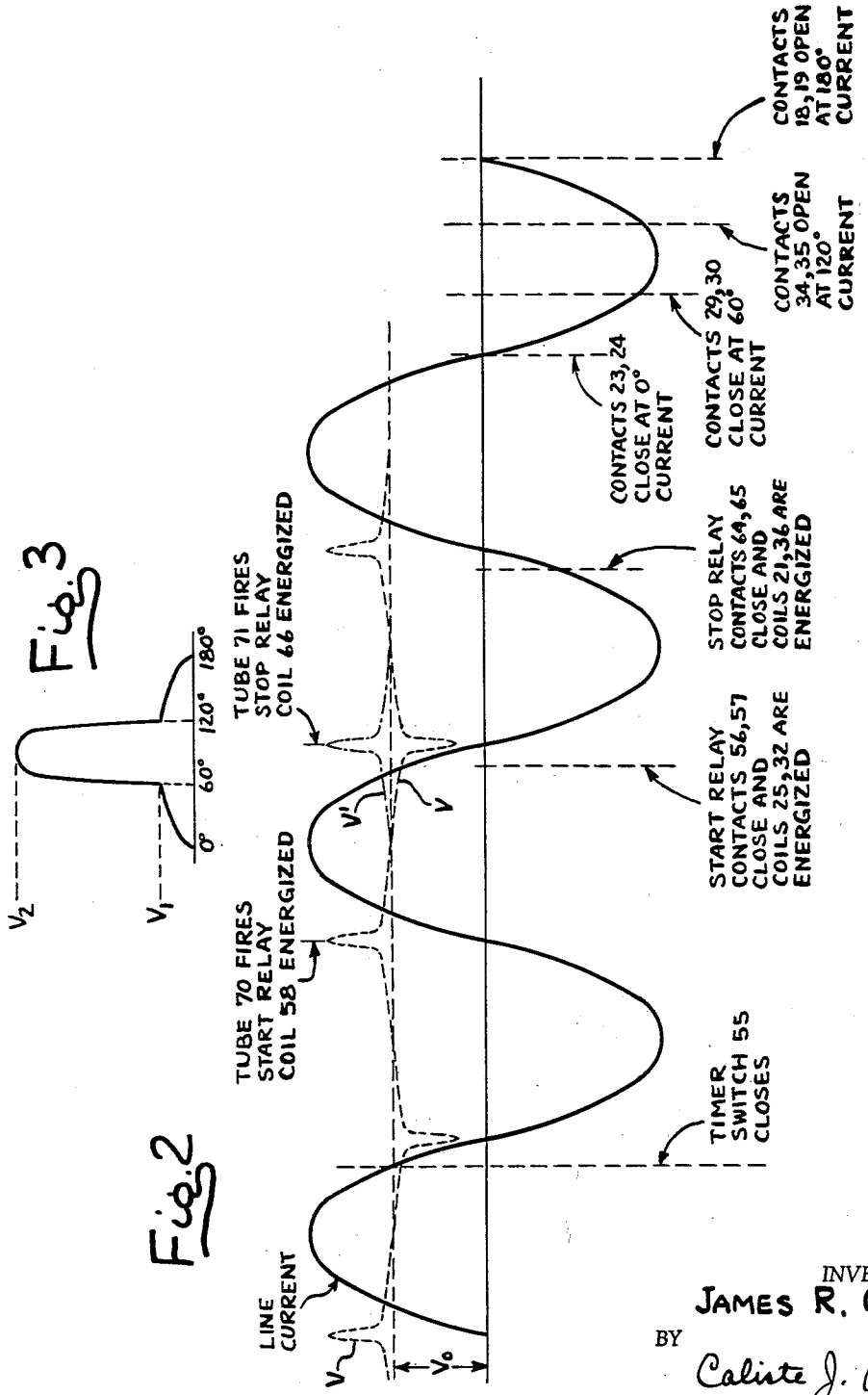


Fig. 3

Fig. 2

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3,130,312

X-RAY TIMER SYSTEM TO PRODUCE SHORT DURATION RADIATION PULSES

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This invention relates generally to X-ray apparatus and, more particularly, to improvements in timing the operation of an X-ray tube.

Most high capacity diagnostic X-ray apparatus currently made in this country is designed to be operated from a 60 cycle single phase power line. The power line is connected through an autotransformer to the primary of the X-ray or high tension transformer and the primary circuit voltage may be varied in order to vary the output voltage of the secondary, and hence the output of the X-ray tube. The timing of the operation of the X-ray tube is usually accomplished by providing switches in the primary circuit of the high tension transformer and appropriate circuitry to control accurately the operation of the switches.

When X-ray apparatus of the foregonig type is operated at full capacity (frequently 150 kvp. and up to 500 ma.), the shortest exposure time ordinarily used when switching in the primary circuit, is $\frac{1}{120}$ second, namely, one-half cycle. When switching the primary circuit at $\frac{1}{120}$ second at full power, the switching phase angle must be precisely controlled, preferably such that the primary circuit is closed and opened at 0° (or 180°) current for one exposure and then closed at 180° current (or 360° if closed at 180°) for the next exposure. This controlled switching causes a D.C. pulse to be applied to transformer for each exposure. By alternately switching at positive and negative half cycles, the hysteresis loop of the transformer is completed at the end of every other exposure, thereby assuring a full output of the transformer each time the tube operates, producing repetitive film exposures which are consistent. Failure to control the switching phase angle may result in dangerous high voltage switching transients in the secondary of the transformer and may also impair the output of the transformer. Also, it will be apparent that opening the primary circuit at variable phase angles will cause the input impedance of the transformer to vary at the instant of next closing of the primary circuit which will, in turn, vary the X-ray output each time the tube operates, resulting in inconsistent successive exposures.

The need for accurate control of the switching phase angle in order to maintain consistency of output of the high tension transformer, as aforesaid, has usually precluded exposure times of less than $\frac{1}{120}$ second for full or near full output despite the fact that for certain diagnostic procedures shorter exposure times are desirable in order to provide greater detail and/or quality of image.

It is an object of the present invention to provide X-ray apparatus in which a preselected voltage may be applied to the X-ray tube at successive exposures for time intervals which are considerably shorter than $\frac{1}{120}$ second without impairing the output consistency of the high voltage transformer during repetitive exposures, particularly when the transformer is operated at or near full output.

It is a further object of the present invention to provide apparatus of the type stated in which the transformer primary circuit includes a series resistance to limit the primary voltage to that sufficient to provide exciting current in the transformer primary for beginning and end fractions of a half cycle, but insufficient to provide enough anode voltage across the X-ray tube from the secondary of the transformer to cause radiation output from the tube assembly. The primary circuit also includes switching to short circuit the resistance and permit the preselected voltage to be applied to the primary for the remaining fraction of the half cycle to produce X-rays for only that remaining fraction of the half cycle.

It is also an object of the present invention to provide apparatus of the type stated in which exposures of $\frac{1}{360}$ second are possible while at the same time providing a pulse across the X-ray tube which results in more than half the X-ray energy than would be present for the same apparatus operated at $\frac{1}{120}$ second exposure.

The attainment of the above and further objects of the present invention will be apparent from the following specification taken in conjunction with the accompanying drawing forming a part thereof.

In the drawing:

FIG. 1 is a circuit diagram of a portion of an X-ray apparatus which embodies the present invention;

FIG. 2 illustrates diagrammatically the operation of certain components of the circuit of FIG. 1; and

FIG. 3 illustrates diagrammatically the D.C. kilovoltage across the X-ray tube.

Referring now in more detail to the drawing which illustrates a preferred embodiment of the present invention, 1 designates a conventional X-ray tube assembly which includes an X-ray tube 2 and radiation filters diagrammatically indicated 3, and located at the X-ray tube port of the machine. The radiation filters 3 prevent radiation output from the tube assembly 1 below a predetermined anode kilovoltage. The filament of the X-ray tube 2 is connected to a filament transformer 5 which is connected through a variable resistance 7 and leads 8, 9 to a source of constant voltage. The resistance 7 may form part of an X-ray tube current selector switch which is preset prior to excitation of the tube 2. A high tension or X-ray transformer 11 has a primary winding 12 and a secondary winding 13, the latter being connected to the X-ray tube 2 through a rectifier bridge 15 and serving to apply anode kilovoltage across the X-ray tube 2. Conventionally, a milliammeter may be provided in the circuit of the secondary winding 13.

In circuit of the primary 12 is a series resistance 17, normally closed relay contacts 18, 19 which are operated by a relay coil 21, and normally open relay contacts 23, 24 which are operated by relay coil 25. A manually operable switch 27 may be shunted across the resistance 17. Short circuited across the resistance 17 and contacts 18, 19, 23, 24 are normally open contacts 29, 30 which are operated by a relay coil 32, and normally closed relay contacts 34, 35 which are operated by a relay coil 36. An autotransformer 38 is suitably provided with taps 40, 41 in conventional manner to provide a preselected voltage across the primary circuit, namely, across 42—43. This preselected voltage may vary, for example, from 75 to 275 volts and is used to adjust or select the desired anode kilovoltage across the X-ray tube 2.

When the contacts 18, 19 and 23, 24 are closed and one or more of the contacts 29, 30 and 34, 35 are open, the preselected voltage, determined from the autotransformer tap settings, is applied across 42—43. The voltage across the primary 12 (i.e., across 43—46) will be less than the voltage across 42—43, being reduced in accordance with the value of the series resistance 17. The ohmic value of the resistance 17 will depend upon the characteristics of the transformer 11. However, as a minimum this ohmic value should be high enough to limit the voltage across the primary 12 (when operating the transformer 11 at full power) to less than that required for that minimum kilovoltage across the secondary which will cause radiation output from the tube assembly 1. In accordance with the dictates of present radiation safety standards, the filters 3 preclude radiation output from

the tube assembly **1** at anode voltages less than 30 kvp.; therefore, under these conditions the resistance **17** must be such as to limit the voltage across the secondary **13** to a value below 30 kvp. As a maximum, the ohmic value of resistance **17** should be such that the voltage across the primary **12** is sufficient to provide exciting current for the transformer **11** to assure the normal sinusoidal flux in the transformer **11**, thereby completing that part of the hysteresis loop for each half cycle.

When the contacts **29**, **30** and **34**, **35** are closed, the resistantce **17** is short circuited whereby the preselected voltage across **42**—**43** is the same as that across the primary **12**. The several pairs of relay contacts forming the switches in the primary circuit are operated in a preset timed sequence by their respective relay coils which are, in turn, controlled by circuit hereinafter described.

The relay coils **25**, **32** are connected in parallel and as indicated at **48**, **49** for simultaneous energization from the output **51**, **52** of a rectifier or other suitable D.C. power supply **53** upon closing of a timer switch **55** and the contacts **56**, **57**, the latter being operated by the coil **58** of a start relay **59**. The timer switch **55** may be a hand switch or the contacts of a relay energized upon closing of the hand or starting switch on the apparatus. Similarly, the relay coils **21**, **36** are connected in parallel and as indicated at **61**, **62** so both coils **21**, **36** may be simultaneously energized from the D.C. power supply **53** when the timer switch **55**, contacts **56**, **57**, and contacts **64**, **65** are closed. The contacts **64**, **65** are operated by the coil **66** of a stop relay **68**. The relays of which the contacts **18**, **19**, **23**, **24**, **29**, **30**, **34**, **35** form a part are of a type capable of precision adjustment over a limited range so that for each relay, the contacts open or close, as the case may be, at a preset time interval after voltage is applied to its relay coil. Such relays are known in the art and are, therefore, not described in detail herein.

The start and stop relay coils **58**, **66** are, respectively, in the anode-cathode circuits of switch tubes **70**, **71** (for example type 5823 tubes) that switch on causing the tubes to conduct when the voltages at their starter anodes **72**, **73** reach the critical value. Consequently, when each tube **70**, **71** fires, the current in the anode-cathode circuits of the tubes **70**, **71** will energize the relay coils **58**, **66** and close their respective contacts **56**, **57**, **64**, **65**.

For applying the critical starter anode voltage to each tube **70**, **71**, a pair of similar peaking transformers **75**, **76** are provided. The secondary windings **77**, **78** of these transformers are connected respectively to the starter anodes **72**, **73**. These transformers **75**, **76** are saturable core transformers of a known type in which the voltage across the secondary peaks once each half cycle triggering the tubes **70**, **71** when the voltages peak positive. In the transformers **75**, **76** the primary windings **79**, **80** are center tapped to provide primary halves **79***a*, **79***b*, **80***a*, **80***b*, and the several leads from these primary windings are connected as shown across the A.C. source **45** through the contacts **81**, **82**, **83** of a double acting impulse or memory relay, the latter having a coil **85** in parallel with the coils **21**, **36**. These connections of the primary windings to the A.C. source **45** are such that the line voltage is applied across the primary halves **79***a*, **80***a* but with the line connections reversed at those two primary halves. Therefore, the voltage across the primary half **80***a* will be 180 degrees out of phase with the voltage across the primary half **79***a*. As a result the voltages across the secondaries **77**, **78** will be 180 degrees out of phase. The broken line curve V in FIG. 2 illustrates approximately the voltage across secondary **77** while the dot-dash curve V′ illustrates the voltage across the secondary **78**. Since the voltages are the same except for the difference in phase, only a fraction of a cycle for the curve V′ is shown. Resistors **87**, **88** in the circuits of the secondaries **77**, **78** provide a D.C. voltage V_0 (FIG. 2) which is superimposed or added onto each secondary voltage so that the peak positive voltage at the starter anodes of the switching tubes is sufficient to trigger the tubes.

In operation, the switch **44** is closed whereby to apply line voltage across the autotransfromer **38** and the primary halves **79***a*, **80***a* of the peaking transformers **75**, **76**. The voltage across the secondaries **77**, **78** will rise and fall in accordance with the wave forms V, V′ but since switch **55** is open, no anode voltage is applied to the tubes **70**, **71** and, therefore, the tubes **70**, **71** will not conduct. Upon closing of the switch **55** at some random time with respect to line current (FIG. 2), a voltage from the D.C. power supply **53** will be applied from anode-to-cathode in the tube **70** but this voltage is insufficient to cause the tube **70** to conduct. However when the voltage V, which is applied to the starter anode **72**, reaches the next positive peak, the tube **70** will fire, whereupon current will flow in the anode-cathode circuit thereof and energize the start relay coil **58**. After a time delay of somewhat less than a half cycle, start relay contacts **56**, **57** will close and energize relay coils **25**, **32**, and voltage from the D.C. power supply **53** will then be applied from anode to cathode in the tube **71**. The tube **71** does not immediately conduct, but thereafter when the voltage V′, applied to starter anode **73**, peaks positive (which occurs exactly a half cycle after tube **70** fires), the tube **71** will fire, causing current to flow in the anode-cathode circuit and energize the stop relay coil **66**. After a delay of somewhat less than a half cycle, the contacts **64**, **65** close. This energizes the relay coils **21**, **36**, **85**.

In the present invention the time delay for closing of the contacts **56**, **57** must be precisely the same each time the coil **58** is energized. This is likewise necessary with respect to the contacts **64**, **65** and coil **66**.

The four coils **21**, **25**, **32**, **36** will be energized, but the time delays for opening or closing, as is the case, of the contacts **18**, **19**, **23**, **24**, **29**, **30**, **34**, **35** are adjusted so that the preselected primary voltage is applied directly across the primary winding **12** for a fraction of a half cycle only, while a lower voltage across the primary **12** (as limited by the resistance **17**) is applied for fractions of the half cycle before and after the fraction of the cycle during which the preselected voltage is applied. Preferably, the time delays are accurately set so that contacts **23**, **24** close at 0° line current, contacts **29**, **30** close at 60° current, contacts **34**, **35** open at 120° current and contacts **18**, **19** open at 180° current. Thus, from 0° to 60°, and from 120° to 180° the voltage across the primary will be limited by the the resistance **17** so that during those fractions of the half cycle there will be no X-rays from the tube assembly **1**; however, during those times there will be sufficient exciting current for the transformer. During the 60° to 120° portion of the half cycle, the resistance **17** will be short circuited so that the preselected primary voltage will be applied directly across the primary **12** and radiation from the tube assembly will take place. As a result, the radiation from the tube assembly or "exposure" takes place only ⅓ of a half cycle or $\frac{1}{360}$ second.

FIG. 3 shows the approximate D.C. voltage across the X-ray tube over the half cycle. No X-rays are emitted from the tube assembly **1** below V_1. However, from 60° to 120° there is a fast rise to peak voltage V_2 and as fast decay thereafter. A D.C. pulse of this type has been found to contain over 50% more X-ray energies than would be present for the same apparatus set to operate at the same selected output for $\frac{1}{120}$ second.

The impulse relay coil **85**, having been energized upon closing of contacts **64**, **65**, operates a short time after contacts **18**, **19** open to shift the contact **82** away from contact **81** and into engagement with contact **83**. Thereafter the switch **55** is opened, dropping the anode voltages of the tubes **70**, **71** to zero whereupon the tubes **70**, **71** cease to conduct, the coils **58**, **66** deenergize and the contacts **56**, **57**, **64**, **65** open.

The shifting of the contact **82** into engagement with the

contact 83 means that line voltage is now applied across the primary halves 79*b*, 80*b*. As shown in FIG. 1, the power line connections are such that the voltage across the primary half 79*b* will be 180° out of phase with the voltage across the primary half 79*a*, and, similarly, the voltage across the primary half 80*b* is 180° out of phase with the voltage across the primary half 80*a*. As a result, the voltages V, V′ will be shifted 180° with respect to line current the next time the tube 1 is to be excited and, consequently the operation of the primary circuit relay contancts 18, 19, 23, 24, 29, 30, 34, 35 will be shifted 180°. Therefore, if the transformer 11 is switched on and off over the negative half cycle with respect to line current, the next time the transformer 11 will be operated over the positive half cycle. The contact 82 shifts to its alternate position upon completion of each exposure. In this way the hysteresis loop of the transformer 11 is completed at every other exposure to insure full output and consistency of operation of the transformer 11.

For operation of the tube 1 at 1/120 second or a half cycle, the manually operated switches 90, 91 in series with the coils 32, 36 respectively, may be opened and the switch 27 may be closed to short circuit the resistance 17. Therefore, when the switch 55 is closed the control circuit will cause the contacts 23, 24 to close at 0° current and the contacts 18, 19 open at 180° current.

In compliance with the requirements of the patent statutes I have herein shown and described a preferred embodiment of the invention. It is, however, to be understood that the invention is not limited to the precise construction and circuitry herein shown, the same being merely illustrative of the principles of the invention. What is considered new and sought to be secured by Letters Patent is:

1. In an X-ray apparatus including an X-ray tube assembly having an X-ray tube, a transformer having a secondary for supplying current to the X-ray tube, a primary for the transformer, a circuit by which a predetermined A.C. voltage of sufficient magnitude may be applied to the primary to cause radiation output from the X-ray tube assembly, a circuit by which an A.C. voltage of lesser magnitude may be applied to the primary, the lesser magnitude voltage being insufficient to cause radiation output from the X-ray tube assembly but sufficient to provide exciting current for the transformer, switching means in the two circuits, and means for operating the switching means in predetermined timed relationship to apply the predetermined voltage to the primary for a fraction of a half cycle only and for applying the lesser magnitude voltage to the primary for fractions of the half cycle before and after the predetermined voltage is applied thereto.

2. In an X-ray apparatus including an X-ray tube assembly having an X-ray tube, a transformer having a secondary for supplying current to the X-ray tube, a primary for the transformer, a circuit by which a predetermined A.C. voltage of sufficient magnitude may be applied to the primary to cause radiation output from the X-ray tube assembly, a circuit including a resistance in series with the primary by which an A.C. voltage of lesser magnitude may be applied to the primary, the lesser magnitude voltage being insufficient to cause radiation output from the X-ray tube assembly but sufficient to provide exciting current for the transformer, switching means in the two circuits, and means for operating the switching means in predetermined timed relationship to apply the predetermined voltage to the primary for a fraction of a half cycle only and for applying the lesser magnitude voltage to the primary for fractions of the half cycle before and after the predetermined voltage is applied thereto.

3. In an X-ray apparatus including an X-ray tube assembly having an X-ray tube, a transformer having a secondary for supplying current to the X-ray tube, a primary circuit including a primary for the transformer, resistance means in series therewith, first switching means in the series circuit, a short circuit across the resistance means, and second switching means in the short circuit, means for imposing an A.C. voltage across the primary circuit, timer means including timer switch means, said timer means operating the first and second switching means at predetermined times and in a predetermined order and including means permitting the application of A.C. voltage across the transformer primary for alternate single positive and negative half cycles upon repeated closing of the timer switch means, the resistance means and said predetermined order being such that the voltage across the primary for a fraction of the half cycle is sufficient to cause radiation output from the X-ray tube assembly, but for fractions of the half cycle before and after the first mentioned fraction is insufficient to provide enough secondary voltage to cause radiation output from the X-ray tube assembly but is sufficient to provide exciting current for the transformer.

4. In an X-ray apparatus including an X-ray tube assembly having an X-ray tube, a transformer having a secondary for supplying current to the X-ray tube, a primary for the transformer, a resistance in series with the primary, means for imposing an A.C. voltage across the series circuit formed by the primary and resistance, a short circuit across the resistance, first switching means in the series circuit, second switching means in the short circuit, the first switching means closing the series circuit and the second switching means opening the short circuit at the beginning of a half cycle, the second switching means thereafter closing the short circuit and then opening the short circuit before completion of the half cycle, the first switching means then opening the series circuit at the end of the half cycle, thereby to supply current to the primary through the resistance for beginning and end fractions of the half cycle and through the short circuit for the remaining fraction of the half cycle, the magnitude of the resistance being such as to limit the voltage across the primary to an amount insufficient to provide enough voltage across the secondary to cause radiation from the X-ray tube assembly during the beginning and end fractions of the half cycle but sufficient to provide exciting current for the transformer, thereby to provide radiation from the X-ray tube assembly only during said remaining fraction of the half cycle, and timer means for actuating the first and second switching means in the sequence and for the times specified.

5. In an X-ray apparatus including an X-ray tube assembly having an X-ray tube, a transformer having a secondary for supplying current to the X-ray tube, a primary for the transformer, a resistance in series with the primary, means for imposing an A.C. voltage across the series circuit formed by the primary and resistance, a short circuit across the resistance, first switching means in the series circuit, second switching means in the short circuit, the first switching means closing the series circuit and the second switching means opening the short circuit at the beginning of a half cycle, the second switching means thereafter closing the short circuit and then opening the short circuit before completion of the half cycle, the first switching means then opening the series circuit at the end of the half cycle, thereby to supply current to the primary through the resistance for beginning and end fractions of the half cycle and through the short circuit for the remaining fraction of the half cycle, the magnitude of the resistance being such as to limit the voltage across the primary to an amount insufficient to provide enough voltage across the secondary to cause radiation from the X-ray tube assembly during the beginning and end fractions of the half cycle but sufficient to provide exciting current for the transformer, thereby to provide radiation from the X-ray assembly tube only during said remaining fraction of the half cycle, said beginning and end fractions each being substantially one-third of the half cycle, and timer means for actuating the first and second switching means in the sequence and for the times specified.

6. In an X-ray apparatus comprising an X-ray tube assembly having an X-ray tube, a transformer having a secondary for supplying current to the X-ray tube, a primary for the transformer, an A.C. voltage source, means including switching means by which a preselected A.C. voltage from said source may be applied across the primary for a fraction of a single half cycle, which fraction commences after the beginning of that half cycle and includes that portion of the half cycle wherein the current in the primary reaches a maximum, said preselected voltage being sufficient to provide enough secondary voltage to cause radiation output from the tube assembly, said means further including a circuit by which a lesser magnitude voltage is applied across the primary prior to said fraction of the half cycle, said lesser magnitude voltage being insufficient to cause radiation output from the tube assembly but sufficient to provide exciting current for the transformer.

7. In an X-ray apparatus comprising an X-ray tube assembly having an X-ray tube, a transformer having a secondary for applying voltage across the X-ray tube, a primary for the transformer, an A.C. voltage source, circuit means across which voltage from said A.C. source is applied, said circuit means including switching means by which a preselected A.C. voltage from said A.C. source may be applied across said primary for a fraction of a single half cycle, which fraction commences after the beginning of that half cycle and terminates before the end of that half cycle, said preselected voltage being sufficient to provide enough secondary voltage to cause radiation output from the tube assembly,, said circuit means further including impedance means, and additional switching means in said circuit means and cooperating with the first-mentioned switching means and impedance means for providing, during the remaining fractions of the half cycle, respectively, such changes in the flux in said transformer as to insure completion of one-half the hysteresis loop of the transformer over the half cycle, but preventing sufficient transformer secondary voltage to cause radiation output from the tube assembly during said remaining fractions of the half cycle.

8. In an X-ray apparatus comprising an X-ray tube assembly having an X-ray tube, a transformer having a secondary for applying voltage across the X-ray tube, a primary for the transformer, an A.C. voltage source, circuit means across which voltage from said A.C. source is applied, said circuit means including switching means by which a preselected A.C. voltage from said A.C. source may be applied across said primary for a fraction of a single half cycle, said preselected voltage being sufficient to provide enough secondary voltage to cause radiation output from the tube assembly, said circuit means further including impedance means, additional switching means cooperating with the first mentioned switching means and impedance means for providing, during the remaining portion of the half cycle, such flux conditions in the transformer as to insure completion of one-half the hysteresis loop of the transformer over the half cycle but preventing sufficient transformer secondary voltage to cause radiation output from the tube assembly during said remaining portion of the half cycle, and timer means having timer switch means and memory means, said timer means operating the first and second-mentioned switching means in a predetermined manner during alternate single positive and negative half cycles upon repeated operation of the timer switch means, thereby to complete the hysteresis loop of the transformer at the end of every other half cycle of operation.

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