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W. E. SPLAIN

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DEVICE FOR DETERMINING THE CURRENT-TIME OUTPUT OF AN X-RAY TUBE

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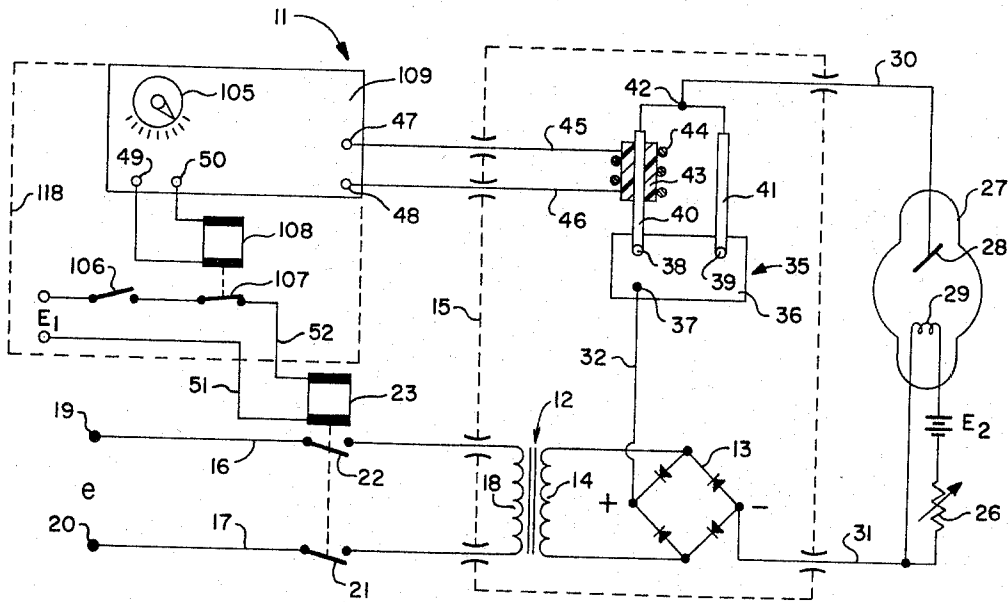


FIG.-1

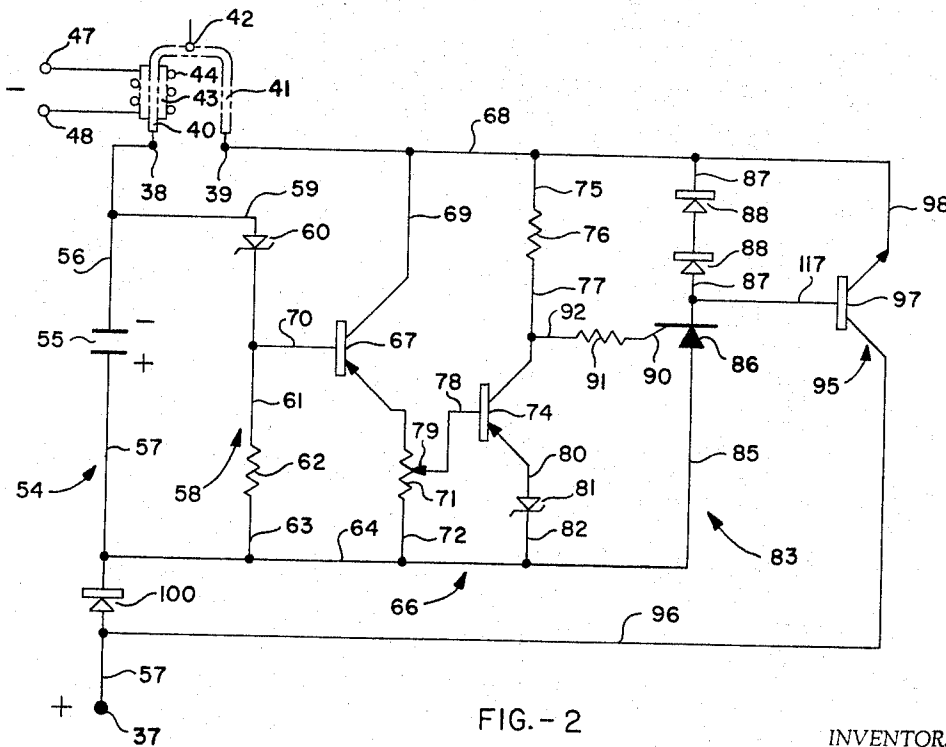


FIG.-2

INVENTOR.
WALTER E. SPLAIN
BY *Watts & Fisher*
ATTORNEYS

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DEVICE FOR DETERMINING THE CURRENT-TIME OUTPUT OF AN X-RAY TUBE

Walter E. Splain, North Olmsted, Ohio, assignor to Picker X-Ray Corporation, Waite Manufacturing Division, Inc., Cleveland, Ohio, a corporation of Ohio
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The present invention relates generally to X-ray tube systems and relates more particularly to apparatuses for accurately determining X-ray tube current and limiting an X-ray exposure to a preselected exposure.

In determining total X-ray exposure to be given to a patient or other subject, a function of total X-ray energy which in turn is controlled by a function known as MAS is used by the operator. MAS refers to the energy introduced to the X-ray tube in milliamperereconds. To make an exposure, the operator determines the milliamperereconds, hereafter referred to as MAS, required for a given exposure. With a patient, the operator takes into consideration such things as the size and color of the patient and the portion of the anatomy to be X-rayed. After the operator has determined the total MAS required, he sets either a timer or a milliamperage control on the usual X-ray apparatus and then adjusts the other control so that a multiple of the two produces the desired MAS.

Thus, prior to the present invention, the customary X-ray apparatus has required two controls, one for setting the current and the second, a timer for setting the total time required for the exposure. In the present invention, no timer is needed and the total MAS desired is set by one control.

Prior to the present invention, measurement or determination of the X-ray tube current has been an approximation as prior devices have not been capable of extremely accurate measurement. In many prior X-ray apparatuses, the X-ray tube current is determined at a center tap connection between two parts of a secondary winding of a high voltage transformer which supplies high voltage to the X-ray tube. In many applications, the high voltage supplied by the transformer is alternating current and a rectifier circuit is interposed between the transformer secondary winding and the X-ray tube.

The reason that the actual X-ray tube current cannot be determined at the center tap connection is that there is a second current in the transformer secondary in addition to the actual tube current. This second current is often referred to as a capacity current and it flows to and through the iron of the transformer. This capacity current is typically 5-10 milliamperes and may be several times the tube current at low milliamperage levels. Thus, any measurement of current at the center tap connection is only an approximation.

In the present X-ray apparatus, a current determining device is located in circuit with the X-ray tube between the X-ray tube and the rectifier. There is no capacity current or other current other than the actual tube current at this point in the X-ray tube system so that the actual tube current can be accurately determined.

In a preferred form, the present current determining device is a capacitor which is connected in series with the X-ray tube between the tube and the transformer-rectifier circuit. This capacitor is charged by the X-ray tube current when a voltage is applied across the X-ray tube from the transformer-rectifier circuit. At a predetermined level of energy charge on the capacitor, the capacitor is discharged. When the capacitor has discharged completely, it is recharged by the tube current to the predetermined level and again discharged. The capacitor

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will continue to charge and discharge as long as the current is flowing in the X-ray tube circuit. The capacitor discharges are sensed and are introduced to a suitable device which is provided to count the number of capacitor discharges. The capacitor is bypassed during each discharge so that the X-ray tube current is not interrupted.

Each time the capacitor charges to the predetermined energy level, it effectively measures a predetermined MAS. Thus, each capacitor discharge sensed and counted is indicative of a predetermined amount of X-ray energy measured in terms of milliamperereconds.

The counting device includes a selector knob control and a signal output. The signal output produces a control signal when the counter device has counted a predetermined number of capacitor discharges as set by the selector knob control. Since each discharge is indicative of a predetermined MAS, the total MAS desired for an exposure can be selected by the control knob on the counting device. In one form of the present invention, the signal output of the counting device is used to operate a suitable switching device in the primary circuit of the supply voltage transformer to de-energize the X-ray tube circuit at the termination of an exposure having the desired total MAS set by the counter control knob.

A principal advantage of the present X-ray apparatus is that a single control sets the total MAS of a desired exposure and no timer is required for terminating the exposure. The control of a total X-ray exposure is accomplished by determining the actual energy supplied to the X-ray tube. The present system further assures that the MAS of the X-ray exposure will be that set by the selector control knob because the present apparatus determines the amount of exposure directly in MAS and not by setting the tube current and the exposure time separately and relying on the multiple of these two settings to provide the proper exposure. Thus, the present X-ray exposure limiting apparatus is not affected by changes in the X-ray tube current during an X-ray exposure from an unforeseen circumstance such as a change in the characteristics of the X-ray tube circuit, or a change in the energy supplied to the X-ray tube circuit.

Expressed another way, this invention takes cognizance of the fact that within rather wide time limitations which may be considered infinite for the present consideration, the accuracy of an X-ray exposure is a function of total energy only, and not of time. If the total amount of X-ray energy passed through the object being X-rayed is accurately controlled, the length of time required is, for all practical purposes, immaterial.

Accordingly, an object of the present invention is to provide a new and improved apparatus for determining the actual X-ray tube current in an X-ray apparatus.

Another object of the present invention is to provide a new and improved apparatus for accurately determining the milliamperereconds of an X-ray exposure.

Still another object of the present invention is to provide a new and improved X-ray apparatus wherein the desired MAS exposure is set directly by a single control without having to compute the time for such MAS exposure.

Yet another object of the present invention is to provide a new and improved X-ray apparatus wherein the X-ray current is determined in the X-ray tube circuit free from other currents and circuit influences.

A principal object of the invention is to control an X-ray exposure by measuring the total energy supplied to the X-ray tube without regard for the time required for the exposure.

Other objects and a fuller understanding of the invention may be had by referring to the following description and claims taken in conjunction with the accompanying drawing in which:

FIGURE 1 is a schematic circuit drawing of the X-ray tube circuit of the present invention.

FIGURE 2 is a schematic drawing of a part of the X-ray circuit of FIGURE 1.

Referring now to the drawing, the X-ray apparatus of the present invention is indicated generally by the reference character 11 in FIGURE 1. The apparatus 11 includes a high voltage transformer 12 and a full wave rectifier bridge 13 connected across a secondary winding 14 of the high voltage transformer 12. A transformer housing indicated schematically by the broken line 15 encloses the transformer 12 and the bridge rectifier 13. The housing 15 is preferably filled with a suitable insulating oil (not designated) in which the transformer 12 and the rectifier 13 are submerged. Conductors 16, 17 connect a primary winding 18 of the transformer 12 to the terminals 19, 20 of an alternating current voltage source *e*. Normally open relay switches 21, 22 are interposed in the conductors 16, 17 respectively between the primary winding 18 and the terminals 19, 20. The switches 21, 22 are actuated by the armature of a relay 23. When the relay 23 is energized, the switches 21, 22 move from their normally open position shown to a closed position whereby they connect the primary winding 18 across the voltage source terminals 19, 20.

An X-ray tube 27, preferably of the rotating anode type, is connected in series with a MAS determining device 35 across the direct current output terminals of the rectifier bridge 13. An anode element 28 of the X-ray tube 27 is connected to a terminal 42 of the MAS determining device 35 via a conductor 30. A cathode element or filament 29 of the X-ray tube 27 is connected to a negative D.C. output terminal of the bridge rectifier 13 via a conductor 31. The cathode element is also connected in series with a filament voltage source E_2 and a variable filament voltage control resistor 26. A terminal 37 of the MAS determining device 35 is connected to the positive terminal of the bridge rectifier 13 via a conductor 32.

The MAS determining device 35 includes a printed circuit board 36 having terminals 37-39. A substantial portion of the circuit of the MAS determining device 35 is formed on the printed circuit board 36 and is connected between the terminals 37-39 by a suitable printed circuit technique. The circuit arrangement of the circuitry printed on the board 36 is shown in FIGURE 2. A pair of metallic stud-like circuit members 40, 41 are connected in series across the printed circuit board terminals 38, 39. The terminal 42 is located intermediate the metal stud-like members 40, 41. The printed circuit board 36 and the stud-like members 40, 41 are enclosed within the transformer housing 15 and preferably are also submerged in the transformer oil.

An insulator member 43 is provided around one of the stud members 40. The insulator member 43 is made of a suitable insulating material which is oil resistant. A pickup coil 44 is wound around the stud member 40 on the insulator member 43. A pair of conductors 45, 46 are connected to the pickup coil 44 and to terminals 47, 48 of a discharge signal pulse detector and indicator circuit 109 which is a part of an X-ray tube energization control device 118.

The X-ray tube energization control device 118 includes a normally open and manually closable ON-OFF switch 106, and a normally closed switch 107 operated by an exposure termination relay 108. The switches 106, 107 are connected in series with a voltage source E_1 and the coil of relay 23 via conductors 51, 52. The relay 108 is connected to the output terminals 49, 50 of the discharge signal pulse detector 109. The discharge signal pulse detector 109 includes a selector switch control 105 and suitable circuitry (not shown) for energizing the coil of the relay 108 when discharge signal pulses as selected by control 105 are received by the input terminals 47, 48. In the preferred form of the invention, the signal pulse

detector 109 is an accumulator or other counting device.

Referring to FIGURE 2, the MAS determining device 35 includes a capacitor 55 connected in series with the printed circuit board terminals 37, 38 via energy storage circuit conductors 56, 57. The capacitor 55 is thus placed in series with the X-ray tube 27 between the rectifier bridge 13 and the anode element 28 via the conductors 32, 56, 57, the stud member 40, and the conductor 30 and is charged by tube current. As shown by the voltage polarity indications on the drawing, the terminal 37 is on the positive side of the capacitor 55 and the terminals 38, 39 are on the negative side of the capacitor 55. The capacitor 55 has good temperature stability and substantially no dielectric absorption. The size of the capacitor can vary and, as an example, a 25 volt, 10 microfarad capacitor is useable in the present device.

An energy level sensing circuit 58 is provided for sensing the voltage level stored in the capacitor 55. The energy level sensing circuit 58 includes a conductor 59 which connects the anode of a Zener diode 60 to the terminal 38 on the negative side of the capacitor 55. The energy level sensing circuit 58 further includes a conductor 61, a resistor 62, and conductors 63, 64 which connect the cathode of the Zener diode 60 to the conductor 57 on the positive side of the capacitor 55. The Zener diode is thus placed across the storage capacitor 55 in a reverse biased relation. No appreciable current appears in the sensing circuit 58 until the capacitor 55 charges to a predetermined voltage level *V* at which the Zener diode 60 will undergo an avalanche breakdown. When the Zener diode 60 breaks down, its impedance to reverse current flow changes from effectively an infinite resistance to effectively little resistance so that a large current appears in the sensing circuit 58 including the resistor 62.

A transistor switching circuit 66 is connected to the energy level sensing circuit 58 and switches from one operative state to another when a current is present in the resistor 62. The switching circuit 66 includes first and second switching transistors 67, 74. The first switching transistor 67 is a PNP transistor and has its collector electrode connected to the terminal 39 via conductors 68, 69. The base electrode of the transistor 67 is connected to the conductor 61 between the Zener diode 60 and the resistor 62 via a conductor 70, and its emitter electrode is connected to the conductor 64 through a resistor 71 and a conductor 72. The second switching transistor 74 is a PNP device and is often referred to as a gate controlled switch. The transistor 74 has its collector electrode connected to the conductor 68 via a conductor 75, a resistor 76 and a conductor 77. The base electrode of transistor 74 is connected to an adjustable bias voltage tap 79 on the resistor 71 via a conductor 78, and its emitter electrode is connected to the conductor 64 via a conductor 80, a Zener diode 81, and a conductor 82. The Zener diode 81 has its anode and cathode elements connected to the conductors 80, 82 respectively and is provided to permit the use of the large base resistor 76 for the transistor 74.

A discharge circuit 83 is provided to discharge the storage capacitor 55 each time it reaches the predetermined voltage level *V*. The discharge path provided by the discharge circuit 83 includes the conductors 57, 64, a conductor 85, a silicon controlled rectifier 86, diodes 88 connected in series in a conductor 87, the conductor 68, the series connected stud members 40, 41 and the conductor 56. A gate electrode 90 of the controlled rectifier 86 is connected to the collector electrode of the transistor 74 through a low impedance resistor 91 and a conductor 92.

A tube current bypass circuit 95 is connected around the storage circuit 54 so that the X-ray tube current bypasses the storage circuit 54 during discharge of the capacitor 55. The bypass circuit 95 comprises a conductor 96 which is connected to the conductor 57 near the ter-

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minial 37, collector and emitter electrodes of a NPN transistor 97, a conductor 98, the conductor 68, the stud member 41 and the terminal 42. The base of the bypass transistor 97 is connected to the cathode of the controlled rectifier 90 via a conductor 117.

A diode 100 is interposed in the conductor 57 between the conductor 96 of the bypass circuit 95 and the conductor 64 of the discharge circuit 83. The diode 100 has its anode connected to the conductor 96 and its cathode connected to the conductor 64 so that the diode 100 effectively disconnects the low impedance path of the bypass circuit 95 from the storage and discharge circuits 54, 83 during a capacitor discharge.

The resistors 62, 71 are very high impedances on the order of 50,000 ohms and are provided in their respective circuits to prevent the circuits operating as shunt paths for the storage capacitor 55. The circuit of the transistor 74 with the resistor 76, which is on the order of 10,000 ohms, does not present a load until the controlled rectifier 86 is fired. The high impedance of the resistor 62 prevents accidental initiation of the switching transistors and firing of the controlled rectifier 86 which might otherwise result from leakage current appearing in the energy level detection circuit 58.

Operation

When the switches 21, 22 are closed by closing the switch 106 such that a current flows in the X-ray tube circuit, the storage capacitor 55 is charged until it reaches the predetermined voltage level V. At this voltage level V the Zener diode undergoes its avalanche breakdown so that a current appears in the resistor 62 and a biasing voltage appears across the resistor 62.

The voltage appearing across the resistor 62 biases the transistor 67 to a state of conduction so that its emitter-collector circuit passes current to provide a voltage across the resistor 71. The voltage appearing across the resistor 71 biases the transistor 74 to conduction which in turn triggers or fires the controlled rectifier 86. The controlled rectifier 86 thus conducts in the manner of a thyatron tube to discharge the capacitor 55 through the stud members 40, 41. The controlled rectifier 86 remains in a state of conduction until the capacitor is substantially discharged and no significant discharge current is present. When the controlled rectifier 86 fires, it causes the bypass transistor 97 to be biased to a state of conduction. The conducting bypass transistor 97 maintains the continuity of the X-ray tube circuit from the conductor 32 connected to the terminal 37 to the conductor 30 connected to the terminal 42.

At a given point near the end of the capacitor discharge, the Zener diode 60 reverts to its original state of effectively infinite impedance in the reverse current direction. This change in the conductive state of the Zener diode 60 operates the transistors 67, 74 to revert to their original non-conducting states. When the capacitor discharge is complete, the controlled rectifier 86 reverts to its original nonconductive state ready to initiate another capacitor discharge when the capacitor is again charged to the predetermined voltage level V. The capacitor 55 will continue to charge and be discharged as long as there is any X-ray tube current present in the X-ray tube circuit. The period of each capacitor charge and discharge is dependent upon the characteristics of the capacitor 55 and the other circuit components in the storage circuit 54, the voltage level V, and the impedance of the discharge circuit 83.

Each charge and discharge of the capacitor 55 indicates a predetermined MAS X-ray exposure. In other words, the capacitor 55 is essentially an integrating device which, as it is charged by the current in the X-ray tube circuit, takes into consideration the time required for charging it to the predetermined voltage level V. The charge on the capacitor 55 is thus a function of the selected X-ray tube current and of the time required to

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reach a predetermined charge level with that selected tube current. For example, if a capacitor at the predetermined voltage level V has a MAS charge of say 10, this charge can be developed either with 10 milliamperes in one second, 1 milliampere in 10 seconds, or an infinite number of other combinations of tube current and time. In the present circuit, each charge and discharge of the 25 volt, 10 microfarad capacitor used as an example would indicate .25 MAS.

The actual X-ray tube MAS during each period of capacitor charge and discharge is the MAS represented by the actual charge of the capacitor plus a small MAS factor occurring during the discharge of the capacitor 55. Normally, the MAS during discharge can be disregarded since the time required for the capacitor discharge is small and on the order of 10 microseconds as compared to approximately 1000 microseconds for the shortest charging period at the high end of the X-ray tube current range. Thus, the MAS of the X-ray tube circuit during discharge is very small compared to the total MAS and represents less than one percent of the total MAS during each period of capacitor charge and discharge. At the middle and lower end of the X-ray tube current range the longer capacitor charging times make the MAS during capacitor discharge even less significant.

The current discharges of the capacitor 55 pass through the stud member 40 and induce corresponding discharge signal pulses in the coil 44. The discharge signal pulses are introduced into the input terminals 45, 46 of the discharge signal pulse indicator or accumulator 109.

In the preferred form of the present X-ray apparatus 11, the selector control 105 of the discharge signal pulse indicator or accumulator 109 is selectively positionable at any one of a plurality of MAS settings between, for example, 5 and 500 MAS. The pulse accumulator counts the discharge signal pulses received at its input terminals 47, 48 until the selected MAS setting is reached and then energizes the exposure termination relay 108 to open the switch 107 and end the X-ray exposure. A suitable accumulator device is currently sold by Picker X-Ray Corporation, Waite Mfg. Division, Inc., as Cat. 2810 and is entitled "Digital Scaler."

In another form of the present invention a rate meter may be substituted for the signal pulse accumulator 109. A rate meter is effectively a differentiating device and by differentiating the discharge signal pulse rate with respect to time will provide an indication of magnitude of current in the X-ray tube circuit. A suitable rate meter is currently sold by Picker X-Ray Corp., Waite Manufacturing Division, Inc., as Cat. 2805.

The present invention may be briefly described as comprising essentially an apparatus for determining actual tube current in the X-ray tube circuit and for giving an indication of the MAS of an X-ray exposure by the X-ray tube which apparatus comprises an energy storage device connected in circuit with the X-ray tube and charged by the current in the X-ray tube circuit during an X-ray exposure, a discharge circuit connected in series with the storage circuit, an energy level detection circuit connected to the storage circuit and to the discharge circuit and causing the discharge circuit to discharge the storage circuit each time the storage circuit is charged to the predetermined energy level and a discharge detector device associated with one of the circuits to provide an indication of each discharge. The invention further contemplates that the storage device be of a capacitive nature and that each charge represents both the time and current factors involved in achieving that charge. Finally, the invention contemplates that the detector device should include an accumulating device for accumulating or counting the number of discharges and a control for controlling the energization of the X-ray tube circuit in relation to the discharge information collected by the accumulator device.

Although the invention has been described in its preferred form with a certain degree of particularity, it is understood that the present disclosure of the preferred form has been made only by way of example and that numerous changes in the details of construction and the combination and arrangement of parts may be resorted to without departing from the spirit and the scope of the invention as hereinafter claimed.

What is claimed is:

1. An X-ray apparatus comprising:

- (a) an X-ray tube having an anode element and a cathode element;
- (b) circuit means for connecting said anode and cathode elements to a power supply;
- (c) capacitive storage means connected in said circuit means between the power supply and one of said elements;
- (d) discharge circuit means connected to said capacitive storage means and including a switching means, said discharge circuit means discharging said capacitive storage means when said switching means is activated to close said discharge circuit means;
- (e) energy level detection means connected to said capacitive storage means and to said switching means, said energy level detection means activating said switching means to close said discharge circuit means when the energy stored in said capacitive storage means reaches a first predetermined level and to keep it closed until the stored energy is at a second, lower predetermined level;
- (f) bypass circuit means connected between said one element and the power supply and being responsive to the discharge of energy from said storage means to bypass said storage means during a discharge; and,
- (g) indicator means electrically associated with said discharge circuit means and providing a signal indication of an energy discharge.

2. The apparatus of claim 1 wherein said indicator means includes an accumulator, and provides a signal indication after a predetermined number of energy discharges by the storage means.

3. The apparatus of claim 2 wherein said accumulator includes an adjustment control for adjusting the number of energy discharges to be accumulated before a single indication is provided.

4. The apparatus of claim 3 wherein the capacitive storage means includes a capacitor.

5. The apparatus of claim 4 including, in combination:

- (h) a high voltage transformer including primary and secondary windings, and first circuit means connecting the primary winding to the power supply; and,
- (i) a rectifier, and second circuit means connecting the rectifier to the secondary winding and to the X-ray tube with said capacitor of said capacitive storage circuit means connected between the rectifier and said one element.

6. A device to be connected in an X-ray tube circuit between the X-ray tube and an energy source for determining the current-time exposure provided by the X-ray tube, said device comprising:

- (a) an energy storage circuit means including a storage capacitor connected in series with the X-ray tube;
- (b) a sensing circuit means connected to said storage circuit for sensing the energy level of the energy stored in the capacitor;
- (c) a discharge circuit means connected to said storage circuit means and being responsive to said sensing circuit means for discharging said capacitor each time the sensing circuit means determines that the energy stored in the capacitor has reached a predetermined level as sensed by the sensing circuit means; and,
- (d) indicator means operatively associated with at least one of said circuit means for giving an indication of the total capacitor discharge after a series of discharges during an X-ray exposure.

7. The device of claim 6 including, in combination: (e) by-pass circuit means connected in parallel with said storage circuit means and being operatively associated with at least one of the other circuit means to by-pass the tube current around the storage circuit means during the capacitor discharge.

8. The device of claim 7 wherein the sensing circuit means includes a voltage breakdown device connected in parallel with the capacitor, said voltage breakdown device breaking down at a predetermined voltage level each time the capacitor charges to that level, and the discharge circuit being responsive to the voltage breakdown to discharge said capacitor.

9. The device of claim 8 wherein said voltage breakdown device is a Zener diode.

10. The device of claim 9 wherein said discharge circuit means includes a controlled rectifier having its anode and cathode electrodes connected in series with the capacitor and its gate electrode connected to the sensing circuit means so that each time the Zener diode undergoes a voltage breakdown the gate electrode is biased to render the anode-cathode circuit of the control rectifier conductive for discharging said capacitor.

11. The device of claim 10 wherein said sensing circuit includes:

- (i) a high impedance connected in series with the Zener diode across the capacitor.
- (ii) a transistor switch having two of its electrodes in series with a second high impedance and in parallel with said Zener diode and the first high impedance, said transistor switching means having a third electrode connected between the Zener diode and said first high impedance, and said third electrode causing the circuit formed by said first and second electrodes to switch from a non-conductive state to a conductive state when the Zener diode breaks down at said predetermined voltage level,
- (iii) said high impedances being sized sufficiently to prevent their respective circuits from shunting the capacitor, and,
- (iv) the gate electrode of said controlled rectifier being connected to the circuit of the first and second electrodes so that a voltage appearing across the high impedance when the electrode circuit is conductive causes said gate electrode to render said controlled rectifier conductive.

12. The device of claim 11 wherein said discharge circuit includes a series connected metal stud member, and said indicator means includes a coil wound around the metal stud member so that a discharge signal pulse is induced in the coil each time the capacitor discharges.

13. An X-ray apparatus comprising:

- (a) an X-ray tube;
- (b) a high voltage transformer having a primary winding for connection to an energy supply, a secondary winding for connection to the X-ray tube, and a housing surrounding the primary and secondary windings;
- (c) conductors being connected to said secondary winding, extending out through said housing, and being connected to said X-ray tube; and,
- (d) a printed circuit board disposed within said housing, a current determining circuit being supported on said printed circuit board, said circuit comprising:
 - (i) a capacitive storage branch connected in the circuit of one of said conductors between said transformer and said X-ray tube;
 - (ii) a discharge branch connected in series with said storage circuit, said discharge branch including a switching means for opening and closing said discharge circuit,
 - (iii) a stored energy detection branch connected to said storage branch and to said switching means, said detection branch operating said switching means to close said discharge branch when the energy stored

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- in said storage branch reaches a predetermined level;
- (iv) a by-pass branch connected in parallel with said storage branch and shunting the tube current around said storage branch each time the storage branch is discharged; and,
- (v) indicator means operatively associated with one of said branches and extending outside the said housing to provide an indication of each discharge of said storage branch.
14. The apparatus of claim 13 wherein the energy source is of an alternating nature and a rectifier is disposed in the transformer housing and is connected to the conductors in an electrically interposed relation between the X-ray tube and the transformer and between the transformer and the current determining circuit.
15. The apparatus of claim 13 including a counter connected to said indicator means for counting the number of discharges of the storage branch.
16. The apparatus of claim 13 wherein the indicator means includes a differentiation means for differentiating the discharges with respect to time to provide an indication of tube current.
17. In an X-ray exposure circuit, including an X-ray tube, an exposure control comprising:
- (a) capacitor means in said circuit for storing predetermined portions of electrical energy supplied to said tube;
- (b) discharge means electrically connected to the capacitor means and responsive to the stored energy in the capacitor means for discharging the capacitor means each time the stored energy reaches a predetermined energy level; and,
- (c) circuit control means in said circuit and responsive to the discharge means for opening the circuit to stop an exposure after the capacitor means has been discharged a predetermined plurality of times during an exposure.
18. A method of determining the current-time output of an X-ray tube comprising the steps of:

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- (a) storing electrical current that is proportional to the current flowing through said X-ray tube;
- (b) measuring the amount of said stored current;
- (c) discharging said current when said stored current reaches a predetermined level; and,
- (d) counting the number of times said stored energy is discharged.
19. A method of controlling the current-time exposure of an X-ray tube comprising the steps of:
- (a) setting a predetermined-count counter to a number indicative of the desired exposure time;
- (b) applying an energizing voltage across said X-ray tube;
- (c) storing energy proportional to the current flowing through said X-ray tube;
- (d) measuring the level of said stored energy;
- (e) discharging said stored energy whenever said stored energy reaches a predetermined level;
- (f) applying a count to said predetermined-count counter each time said energy is discharged whereby said predetermined-count counter generates an output pulse after said energy has been discharged a number of times corresponding to that said on said predetermined-count counter; and,
- (g) removing said energizing voltage from said X-ray tube upon generation of said output pulse from said predetermined-count counter.

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RALPH G. NILSON, *Primary Examiner.*A. L. BIRCH, *Assistant Examiner.*