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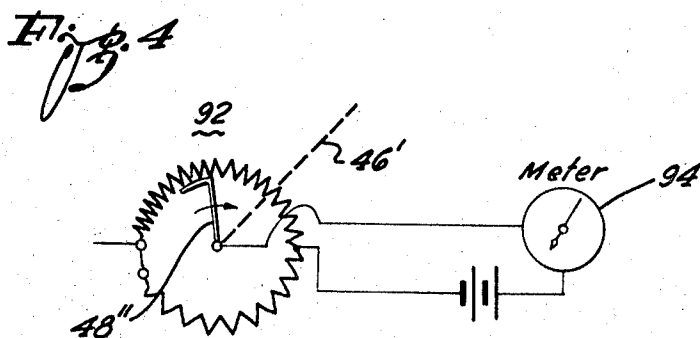
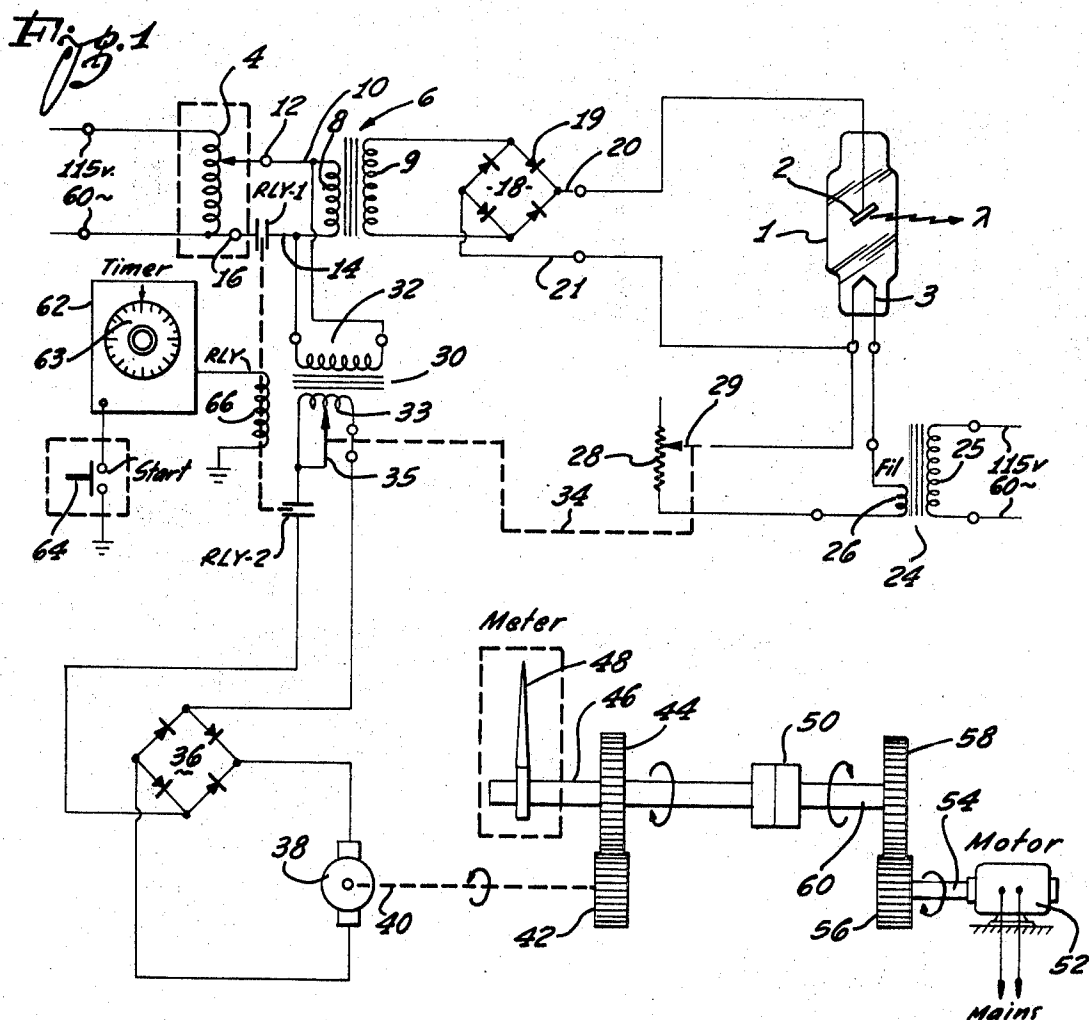
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ANODE HEAT CONTENT CALCULATOR FOR X-RAY TUBE

Filed July 16, 1968

2 Sheets-Sheet 1



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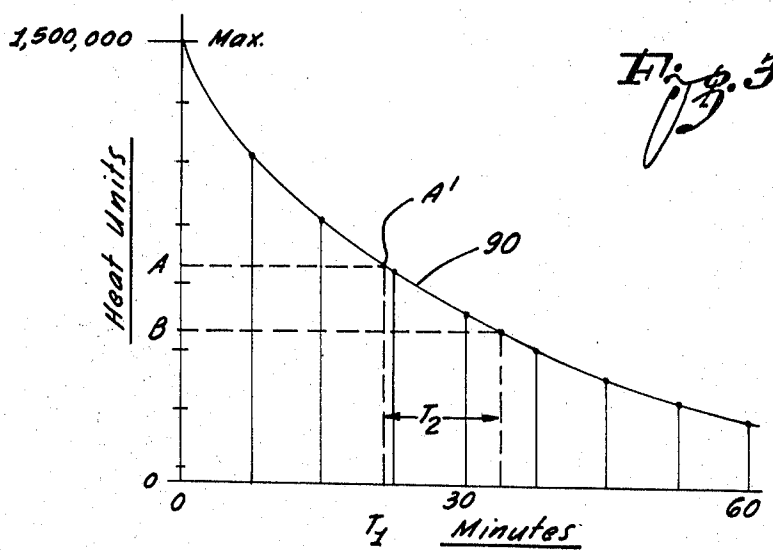
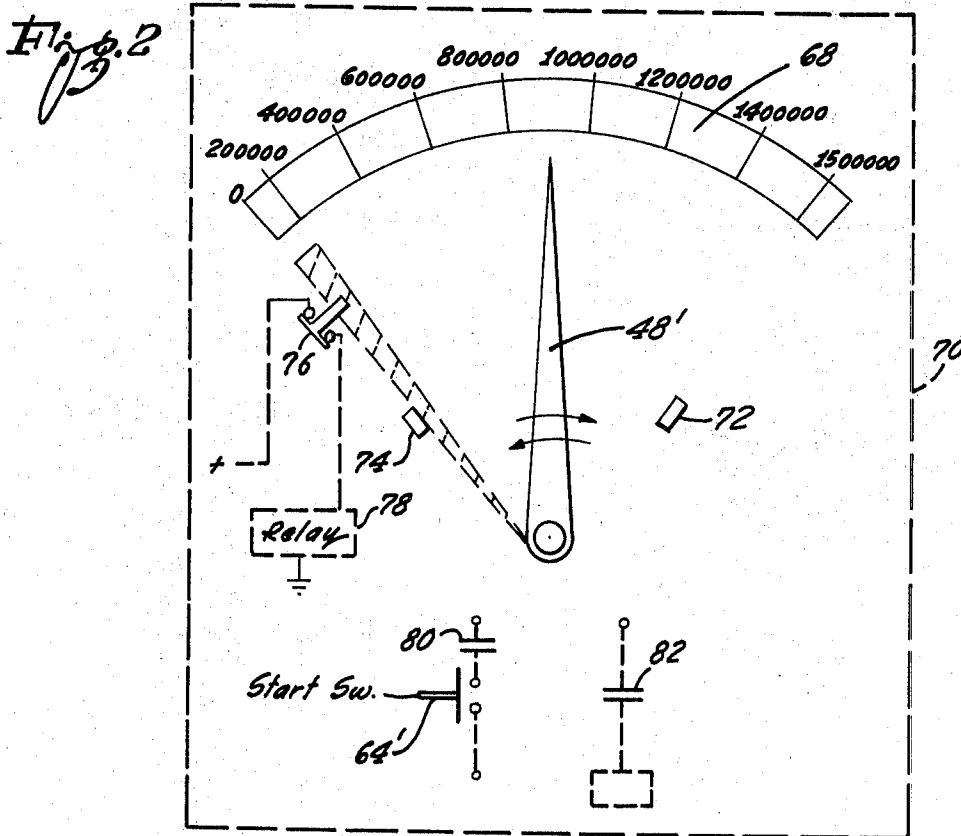
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ANODE HEAT CONTENT CALCULATOR
FOR X-RAY TUBE

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3 Claims

ABSTRACT OF THE DISCLOSURE

An X-ray apparatus heat content calculator for preventing thermal runaway. A calibrated meter is provided to indicate the remaining heat content in the X-ray tube. The meter indicator is suitably controlled to indicate the decreasing amount of thermal heat units which can be safely generated within the X-ray apparatus by a first means that responds substantially to the product of anode voltage, tube current, and the duration of energization of the X-ray tube. At other times, the meter pointer is slowly driven in an opposed direction at a speed proportional to the thermal discharge of the X-ray tube which suitably represents the increase in thermal capacity.

This invention relates to X-ray apparatus, and, more particularly to an X-ray apparatus which incorporates a calculator for automatically informing the operator of the instantaneous heat content of the X-ray tube, based on power applied to the tube, and the amount of heat that can safely be dissipated by the X-ray tube at any given time thereby preventing overheating of the X-ray tube.

To produce a beam of X-radiation with a vacuum tube, high energy electron beams are emitted from the tube cathode and strike a tapered or tilted tube anode. In ordinary X-ray equipment the electrons fall through a potential difference between the anode and cathode of up to 150,000 volts and at currents of between one to two hundred milliamps for predetermined periods of time. As desired, such electron bombardment of the anode produces the desired magnitude of X-radiation for the desired duration. Undesirably, such operation, however, is accompanied by the production of large quantities of heat at the tube anode.

In order to dissipate the heat generated at the anode of the X-ray tube, it is conventional to place the tube in an oil filled housing. The heat produced at the tube anode is radiated through the tube vacuum and glass envelope into the oil. The oil in turn acts as a large heat sink. As the heat is dissipated in the oil, the temperature of the oil naturally rises.

During normal intermittent use of the X-ray apparatus, the protection afforded by the oil is sufficient. A factor limiting that operation is the amount of heat which can be dissipated by the oil in the housing. For protection temperature sensors may effectively be used to monitor the temperature of the oil. However, there is another factor which limits the suitability of that method of protection. There is inherent a time lag between the time that the anode is heated and the time that such generated heat is dissipated in or to the oil bath. Thus, for example, it is possible to over-heat the X-ray tube by operating it in one operation or in quick succession of operations. The tube is destroyed by the excess heat generated even though the oil bath may not appear hot, because there was insufficient time for the heat to be transferred to the oil bath.

Each year many X-ray tubes are inadvertently destroyed in this manner. Because the operator's attention and concern is, as it should be, focused entirely on the

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patient, the limitations of the X-ray apparatus are often overlooked. Thus, if the operator makes a series of X-rays in quick succession, it is quite possible that a sufficient amount of heat will be created at the anode in an amount which exceeds the heat dissipation capability of the X-ray tube in that short time. When this occurs, the heat although insufficient to melt the tube envelope or elements, is sufficient to cause increased electron emission from the cathode which in turn generates more heat. Suitably this phenomenon is descriptively termed a thermal runaway. This process continues until substantially all of the electron emissive coating, normally tungsten, is stripped away from the cathode and deposited over the glass envelope. As a consequence, the tube is no longer useful.

While a single operator may be alert to the limitations of the X-ray equipment and may properly space out his exposures, the problem is still present in a different form. In modern hospitals much emphasis is placed on the full utilization of the facilities such as the X-ray equipment. Modern sophisticated X-ray apparatus is an expensive piece of equipment which is centrally located and accessible to many radiologists who must schedule their time with the equipment. Thus, one operator may complete a large exposure during which the tube anode is heated to a high temperature. As he leaves, the next operator scheduled to use the equipment and his patient enter. The second operator may not know or be informed of the recent thermal history, so to speak, of the X-ray tube. This leaves the operator two alternatives: One, to assume that the tube has been operated to its limit by the preceding operator and wait the requisite number of minutes until the heat generated by the anode should have been dissipated in the oil; or, two, to assume the opposite or possibly overlook the matter altogether. In modern X-ray fluorocinematography a series of exposures are taken on motion picture film, thus, both increasing the number of exposures and aggravating the problem. The thermal destruction of many X-ray tubes suggests that the second alternative is often taken.

Heretofore, both the X-ray tube manufacturer and equipment manufacturer attempted to eliminate the problem of thermal runaway by imposing additional and unnecessary burdens upon the operator. The tube manufacturer provides a heat chart for a particular X-ray tube used in the X-ray apparatus. The ordinate of this chart is given in terms of "heat units" and the abscissa is given in terms of time, usually minutes. A heat unit is defined as the product of a voltage of 1000 volts multiplied by a current of one milliamp which is in turn multiplied by a time of one second. This chart plots the decrease in the number of heat units remaining in the anode after operation of the tube to its maximum heat capability, typically 100,000 heat units, versus time in minutes. This plot is a continuously decreasing curve.

Thus, for instance, the operator desires to make ten successive exposures while operating the tube at 100,000 volts, 600 mils for a twentieth of a second each. The operator must multiply the magnitude of these quantities together and multiply by ten to obtain the total heat units generated in the tube. In this example, the total number of heat units is 30,000 heat units. With reference to his chart the operator knows that he can take more exposures since there are many heat units remaining. By referencing the generated heat units at the ordinate to the intersection with the thermal decay curve and thence to the abscissa, the time required for the anode to dissipate the generated heat and the time which must elapse until the full heat unit capacity of the tube is again available is indicated.

This arithmetical and graphical procedure is obviously time consuming and an extreme inconvenience. Quite

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often a small desk calculator is provided to assist the operator in making these calculations. Thus, it is apparent both how and why this procedure is sometimes overlooked or disregarded. Obviously even though one operator has faithfully attended to these calculations, a subsequent operator may have no knowledge of the thermal history of the X-ray tube during its operation by the preceding operator. The same destruction accordingly results, unless to be on the safe side the second operator assumes the X-ray tube to have been operated to its full heat capacity and waits out the long minutes until such an amount of heat should have been transferred or dissipated in the oil bath. Quite often a busy radiologist will neither wait or think about the problem at all, since his sole concern is, as it should be, his patient.

Therefore, it is an object of the invention to avoid thermal runaway in X-ray tube operation;

It is another object of the invention to render manually performed heat capacity calculations unnecessary; and

It is a further object of the invention to permit a continuous display of the thermal condition of the X-ray tube.

Briefly stated, the invention is characterized by a meter with a pointer and a scale calibrated in heat units particular to the X-ray tube installed in the apparatus. The pointer is driven in a first direction showing increasing remaining heat capacity on the scale as a function of elapsed time, and the pointer is driven in the opposite direction in an amount proportional to the exposure applied to the X-ray tube upon each such exposure or operation. In accordance with another aspect of the invention, a meter relay element is incorporated which shuts off the X-ray apparatus, where the heat capacity is about to exceed the rated capacity of the X-ray tube.

The foregoing and other objects and advantages of the invention, together with its arrangement and form, are better understood by reference to the following detailed description taken together with the drawings in which:

FIG. 1 shows, schematically, one embodiment of the invention in an X-ray apparatus;

FIG. 2 shows a pointer and scale and a shut off device embodied in the embodiment of FIG. 1;

FIG. 3 shows an exemplary heat capacity chart used to calibrate the scale illustrated in FIG. 2; and

FIG. 4 illustrates a potentiometer arrangement which may be used in a different embodiment of the invention.

FIG. 1 schematically illustrates an X-ray apparatus containing a continuous heat content calculator. As is conventional, the apparatus contains an X-ray tube 1 for generating a beam of X-radiation. Tube 1 contains an anode 2 and a heater or filament 3 which additionally functions as the electron emitting cathode. A power supply is provided. This conventionally includes an adjustable or tapped autotransformer 4 which is connected at its input to a source of 115 v. A.C. 60 cycle line current. A second transformer 6 is provided to step up the line voltage to suitable high voltages of 150 kv. necessary to properly operate the X-ray tube 1. Transformer 6 contains a primary winding 8 and an output or secondary winding 9. Input or primary winding 8 is connected to the output of autotransformer 4. One lead 10 of primary winding 8 is connected to the output terminal 12 of autotransformer 4 and a second primary winding lead 14 is connected to the ground side terminal 16 of the autotransformer in series with the normally open contacts of a make relay contact RLY-1 under control of a timer 62. The high voltage output or secondary winding 9 of transformer 6 is connected across one diagonal of a full wave rectifier bridge 18 which consists of the conventional arrangement of diodes 19.

The D.C. output voltages are obtained across the remaining diagonal of the rectifier bridge 18 at leads 20 and 21 and applied to anode 2 and the cathode filament 3. Filter capacitors may be connected in series across leads

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20 and 21 and their midpoint connected to ground if such filtering is desired.

A second step-down transformer 24 is provided which contains a primary 25 and secondary winding 26. The input winding is connected to a source of A.C. line voltage which is stepped down and appears across the output or secondary winding 26 as a low voltage for providing the low filament voltages required by X-ray tube 1. The output winding 26 is connected across the filament 3 of tube 1 in series with an adjustable resistor or rheostat 28. Rheostat 28 provides an adjustment of the filament current and hence by changing the electron emission of the filament 3 indirectly control the anode current which flows in tube 1.

A third voltage step-down transformer 30 is provided which contains an input or primary winding 32 connected across primary winding 8 of transformer 6 and an adjustable tapped output or secondary winding 33 has a movable switch or contact 35 which permits a selection of the desired one of taps on winding 33. This movable contact is mechanically connected by a link 34 to the manually adjustable selector 29 on the rheostat. Secondary winding 33 is connected through contact 35 across one diagonal of a full wave bridge rectifier 36 in series with a normally open set of relay contacts RLY-2 controlled by the timer 62. The output of rectifier bridge 36 is connected to the input of an electric motor 38. Motor 38 is of the conventional type which rotates its shaft 40 at a speed proportional to the voltages applied to its input, commonly termed a synchro. Motor shaft 40 is coupled to a gear 42. Gear 42 meshes with and drives a second gear 44. The second gear is connected to and revolves a shaft 46. Shaft 46 has a mechanical arm or pointer 48 coupled to it at one location and a slip clutch 50 connected at its end. A motor 52 is provided which drives a shaft 54 containing gear 56 which in turn meshes with and drives gear 58. Gear 58 is coupled to a shaft 60 which in turn is coupled to shaft 46 through slip clutch 50. As is schematically illustrated, the input of motor 52 is connected to a source of current. Such connection causes motor 52 to continuously revolve shaft 46 in one direction. The first motor 38 is connected so as, when energized to revolve shaft 46 in an opposite direction. The conventional supports and bearings for the mounting of the miscellaneous shafts and gears are not necessary to an understanding of the invention and are not illustrated.

A conventional X-ray timer 62 schematically illustrated, is provided to control the operation of the power supply and, hence, the duration of an X-ray exposure. Timer 62 includes a start switch 64 and an output relay RLY-66. Relay RLY-66 when energized closes the normally open make contacts RLY-1 and RLY-2, previously referred to. A dial 63 is provided to permit the setting of the exposure time.

The mechanical arm or pointer 48 is arranged in a housing to cooperate with a scale as illustrated in FIG. 2 or with a potentiometer as illustrated in FIG. 4.

FIG. 2 illustrates a scale 68 that has been calibrated in "remaining heat units" and is arranged to convert the linear rotation or movement of pointer arm 48' to mechanically and visually indicate the remaining heat units of a particular X-ray tube which quantity changes in a nonlinear manner with respect to time. The scale 68 and pointer 48' are contained in a windowed housing schematically represented by dashed lines 70. The scale 68 may be calibrated in terms of related quantities such as in percentages of remaining heat content or in terms of heat content already used. A pair of stops, 72 and 74, are provided to prevent pointer 48' from rotating outside the scale range. As is illustrated, pointer 48' may cooperate with a switch 76, illustrated for convenience as a mechanical switch but which may suitably be any conventional noncontacting meter-relay operating device. Switch 76 is connected in series with a source of current and a relay 78. The contacts of relay 78, schematically

illustrated as 80 and 82, may be connected in the power supply circuit of FIG. 1 so as to interrupt the supply of current to the X-ray tube 1 when relay 78 is deenergized to prevent overheating the X-ray tube and to prevent premature operation of timer start switch 64 in FIG. 1.

The units for scale 68 are calculated with the aid of a heat capacitor chart such as that shown in FIG. 3. Each particular type of X-ray tube in the housing has a particular heat capacity characteristic. The dissipation of a full charge of heat units (ordinate) relative to time (abscissa) is represented by curve 90. Hence, with charge such as A, any series of charges less than a full charge in heat units, the time necessary to dissipate such a charge is found by the interval between the time at the intersection of the ordinate and the curve 90, A', and the time zero. This time difference between the two points on the abscissa is the desired time. Further, if the heat content expressed in heat units A dissipated in operation of the tube is known and the time delay or interval T_2 to the next energization is known reference to the chart reveals the remaining heat content (MAX-B) at the end of that interval which can safely be dissipated in the next operation by the X-ray tube. By converting the units of time in the plot of FIG. 3 into degrees of angular rotation on the scale of FIG. 2, the same calculations are obtained. While the curve of FIG. 3 possesses a slight "bulge," it can be approximated by a straight line. In that instance, the meter scale can be linear.

In operation of the apparatus, timer 62 is set to provide the desired exposure time, rheostat arm 29 is set to limit tube current to a desired level, which, because of the mechanical link 34, concurrently sets adjustable arm 35 to a corresponding tap on output winding 33 of transformer 30. The autotransformer 4 is adjusted to provide the anode on X-ray tube 1 voltage. The quantities of time, voltage, and current determine the exposure generated by X-ray tube 1 and the product of such seconds, milliamperes, and kilovolts determine the heating of X-ray tube 1 in terms of heat units.

If the X-ray apparatus of FIG. 1 has been in recent use, the pointer 48' will be at some point along scale 68 as shown in FIG. 3. Motor 52 connected to a suitable source continuously rotates its shaft 54 at a constant predetermined speed. Consequently, through the illustrated gears and shafts, the pointer arm 48 slowly rotates clockwise in FIG. 2. Since any pause or interval of non-use in the operation of the X-ray tube permits the tube to dissipate heat, the slowly rotating arm 48' represents the dissipation of heat during such pause, and, as noted on the scale 68, the amount of heat content which can be generated by the operation of tube 1. Hence, as time elapses, exposure time or heat capacity available with the X-ray tube increases.

Operation of the start switch 64 in FIG. 2 actuates timer 63 which in turn actuates relay 66 for the predetermined proper duration set upon dial 63. Relay contacts RLY-1 close and connect current from the autotransformer 4 to transformer 6 for the interval. The output of transformer 6 is rectified by rectifier 18 and applied between the anode 2 and cathode-filament 3 of X-ray tube 1. X-ray tube 1 is energized and generates X-radiation during the interval in which the anode voltage is applied.

Simultaneously relay contacts RLY-2 close and connect the output of transformer 30 to rectifier 36. Rectifier 36 connects the A.C. voltage into a D.C. voltage and applies it to motor 38 for that same interval. Since the input voltage to primary winding 32 of transformer 30 is proportional to the high voltage applied to X-ray tube 1 and the output voltage from secondary winding 33 is adjusted by tap selector 35 and its linkage to rheostat 29 to be proportional to the current applied to the X-ray tube 1, the resultant voltage applied to rectifier 36 and hence motor 38 is proportional in magnitude to the product of voltage and current applied to tube 1. Addi-

tionally, since the time intervals in which both rectifiers 18 and 36 produce D.C. voltage are identical, the total energy applied to bridge rectifier 36 and the input of motor 38 is proportional to the product of voltage, current, and time of exposure. The motor 38 rotates shaft 40 counterclockwise at a speed proportional to the voltage applied to its input for the set time interval. Motor 38 thus rotates shaft 40, gears 42 and 44, shaft 46, and pointer 48' counterclockwise in FIG. 2. Counterclockwise rotation of pointer 48' indicates a decrease in heat content available to be generated within the X-ray tube which is reflected by reference to scale 68. The slip clutch 50 decouples shaft 60, and hence, motor 52, and permits only motor 38 to rotate pointer arm counterclockwise during the interval. Since exposure time is measured in fractions of a second and heat dissipation time is measured in minutes, any errors due to such decoupling are negligible.

By referring to the scale 68 and position of pointer 48' in the meter embodiment of FIG. 3, the operator is immediately apprised and can continuously monitor the remaining heat content within X-ray tube 1.

With the optional circuits indicated by the dashed lines, if during a series of exposures, the heat content used should exceed the total available for the particular X-ray tube, pointer 48' in FIG. 3 is moved fully left where it actuates shut-off switch 76. Operation of switch 76 opens the circuit to relay 78 which then deenergizes and restores contacts 80 and 81. This opens the electrical circuit to the X-ray power supply and to start switch 64. Since the source of current is thus removed, the X-ray tube cannot be overloaded and since the start switch circuit is opened, the circuit cannot be restarted. The operator's attention is then drawn to the meter. The operator then waits until sufficient heat has been dissipated by the X-ray tube before he can complete his series of exposures.

FIG. 4 shows an alternative arrangement of presenting the scale readings. Arm 48 instead of being placed in the meter housing, as in FIG. 2, is the mechanical arm 48' of a potentiometer 92. Potentiometer 92 is in a series electrical circuit with an electrical meter 94. Meter 94 is calibrated in the same manner as the meter of FIG. 2. It is noted that due to the slight nonlinearity in the curve of FIG. 3, the potentiometer resistance is not quite linear. To make the unit universal for any X-ray tube, cams and eccentrics can be incorporated into the potentiometer driving arm mechanism. This permits the potentiometer resistance to be made linear. Obviously if the curve of FIG. 3 is approximated by a straight line, all associated elements can be made linear. Additionally, meter 94 may contain any conventional meter-relay elements to shut-off the X-ray apparatus when the exposures have exceeded the thermal capacity of the X-ray tube as in FIG. 2. The operation is otherwise identical with the operation of the elements in FIGS. 1 and 2.

The foregoing illustrations and embodiments are presented to aid the understanding of applicant's invention and not by way of limitation. As is apparent, other equivalent means for practicing the invention present themselves to those skilled in the art. For example, instead of simple motors and the slips clutch arrangement used in the preferred embodiment, more exotic electromechanical movements and transistorized electronic timers are available which in light of the teachings of this application can be adapted by one skilled in the art to practice invention.

Accordingly, it is understood that applicant's invention is not limited to the details disclosed and is to be broadly construed commensurate with the breadth and scope of the appended claims.

What is claimed is:

1. In an X-ray apparatus containing an X-ray tube having a predetermined thermal capacity and a predetermined thermal discharge rate, a time settable electric timer for controlling the duration of operation of said

X-ray tube during each X-ray exposure, a power supply means for energizing said X-ray tube, said power supply containing adjustable voltage control means for adjusting the anode voltage applied to said tube, the improvement comprising:

- (a) an independently adjustable current control means for adjusting the current flowing in said X-ray tube;
- (b) meter means containing a scale calibrated in units representative of the heat content of said X-ray tube and a pointer for pointing to locations on said scale;
- (c) transformer means having a primary winding and a secondary winding, said primary winding connected to the output of said adjustable voltage control means, said secondary winding having a plurality of taps;
- (d) tap selection means for selecting one of said plurality of taps, said tap selection means being mechanically linked to said adjustable current control means;
- (e) a first motor having a first shaft and a first mechanical means for coupling said first shaft to the pointer of said meter, said first motor being electrically connected to said tapped secondary winding by a rectifier means such that said first shaft is rotated in accordance with the product of the voltage and current applied to the X-ray tube and the duration of the X-ray tube energization; and
- (f) a second motor powered by an independent power supply means and including a second shaft and slip-clutch means coupling said second shaft to said

pointer whereby said second shaft is rotated at a constant rate in accordance with said predetermined thermal discharge rate of the X-ray tube, said slip-clutch being engaged when said X-ray tube is de-energized and disengaged when said X-ray tube is energized, said second motor driving said pointer in a direction opposite the direction said pointer is driven by said first motor only during the period that said slip-clutch is engaged.

2. The invention as defined in claim 1 wherein said adjustable current control means includes a means for adjusting the current to the filament of said X-ray tube, thereby controlling the current flowing through said tube.

3. The invention of claim 2 further including a potentiometer and electrically driven meter movement connected to the output of said potentiometer, said potentiometer being mechanically coupled to said first and second shafts.

References Cited

UNITED STATES PATENTS

2,571,013	10/1951	Cobean et al.	250—93
2,579,255	12/1951	Graves	250—95
3,163,757	12/1964	Fransen	250—95

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U.S. Cl. X.R.

250—95