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Lombardo et al.

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[54] **PROTECTIVE CIRCUIT FOR X-RAY TUBE AND METHOD OF OPERATION**

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(Under Rule 47)

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[52] **U.S. Cl.** **250/409**, 250/416

[51] **Int. Cl.** **H05g 1/26**

[58] **Field of Search** 250/93, 103, 95

[56] **References Cited**

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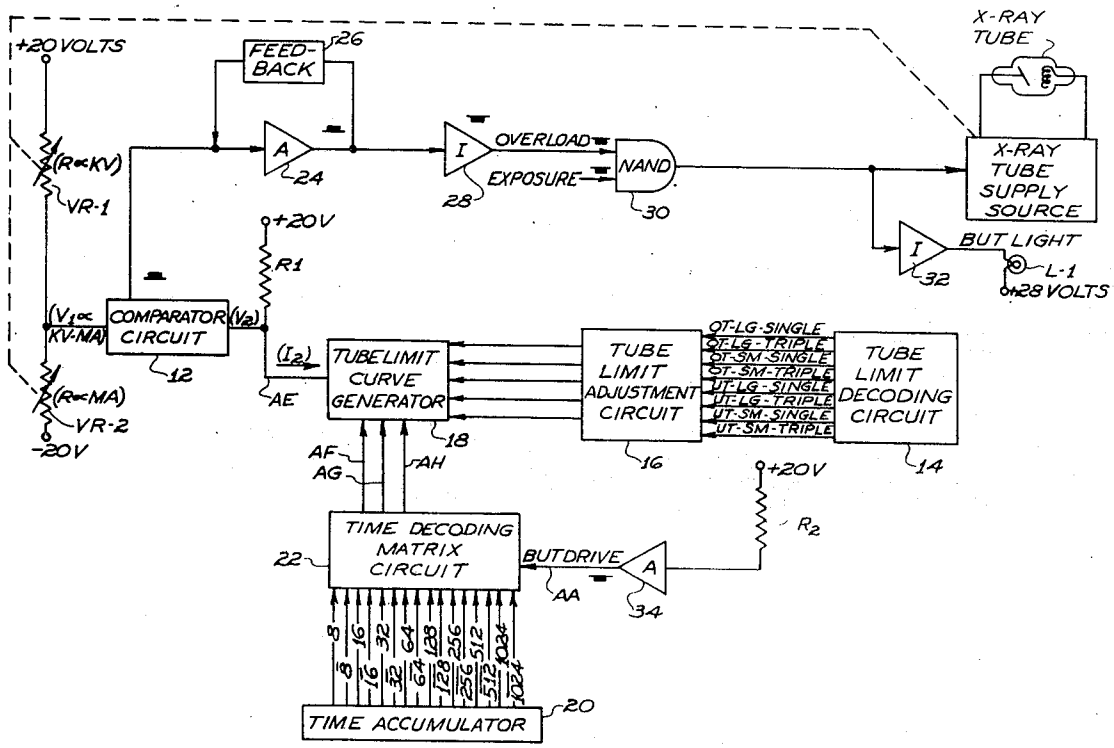
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[57] **ABSTRACT**

A protective circuit and method of operation for interrupting a signal which is applied to an X-ray tube when the signal attains a value which exceeds a maximum rating for the tube. The protective circuit includes a signal generating circuit for developing a limit signal which varies in value with respect to time in accordance with a maximum tube rating signal, a programming circuit for developing a program signal having a value representative of a preselected signal to be applied to the X-ray tube, and a comparator circuit for developing an interrupt signal if the program signal exceeds the value of the limit signal.

31 Claims, 6 Drawing Figures



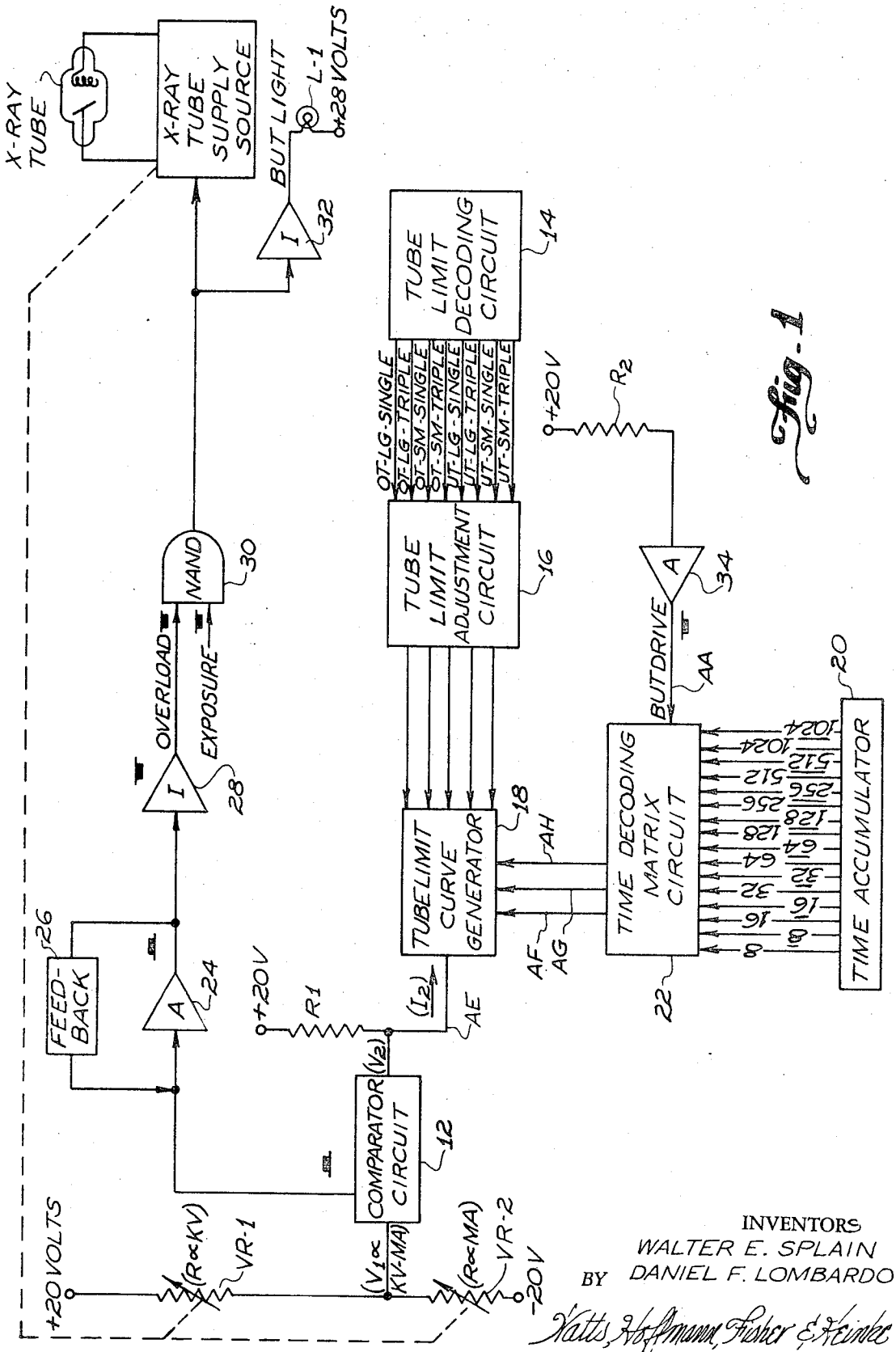


Fig. 1

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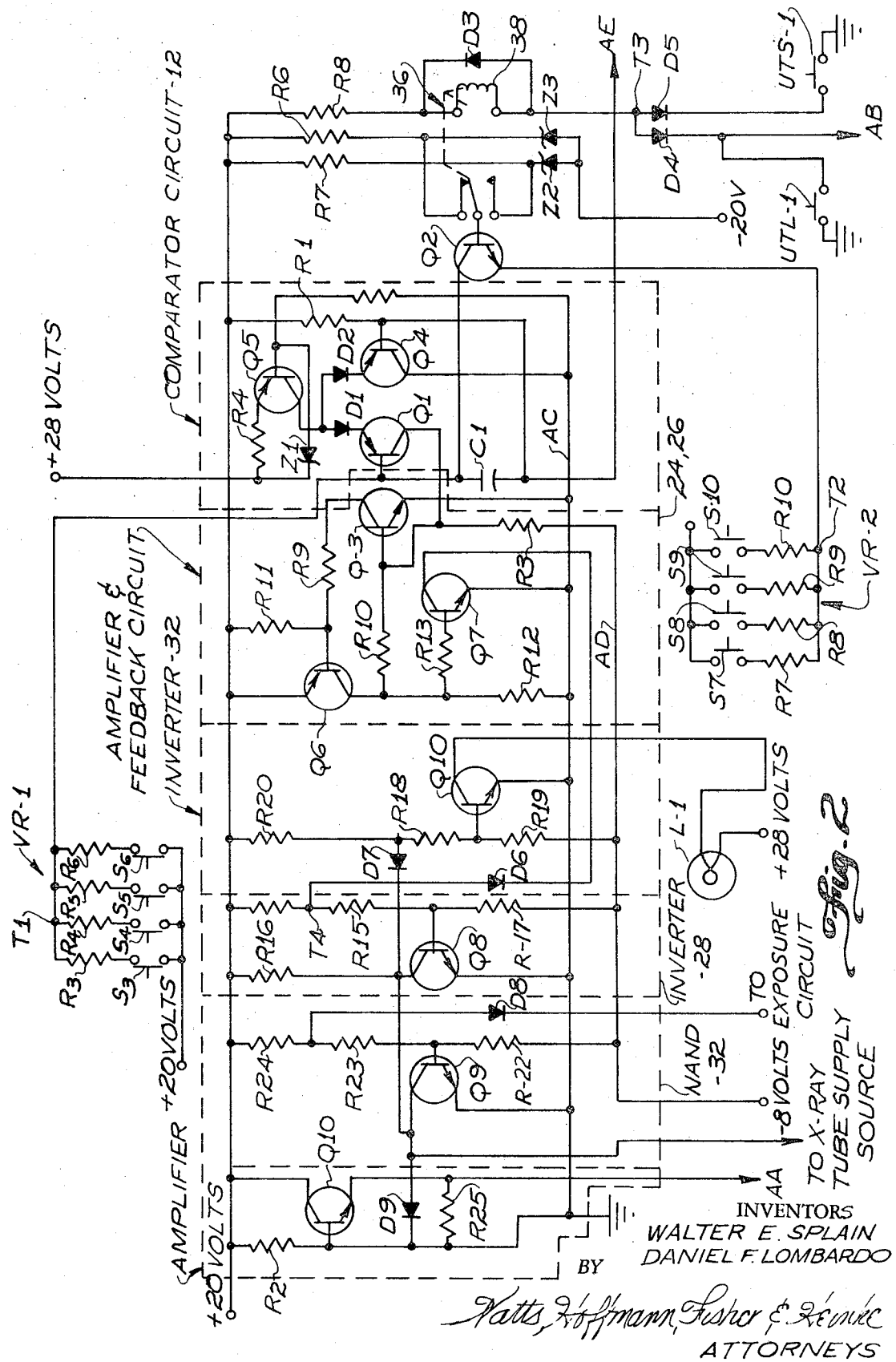


Fig-2

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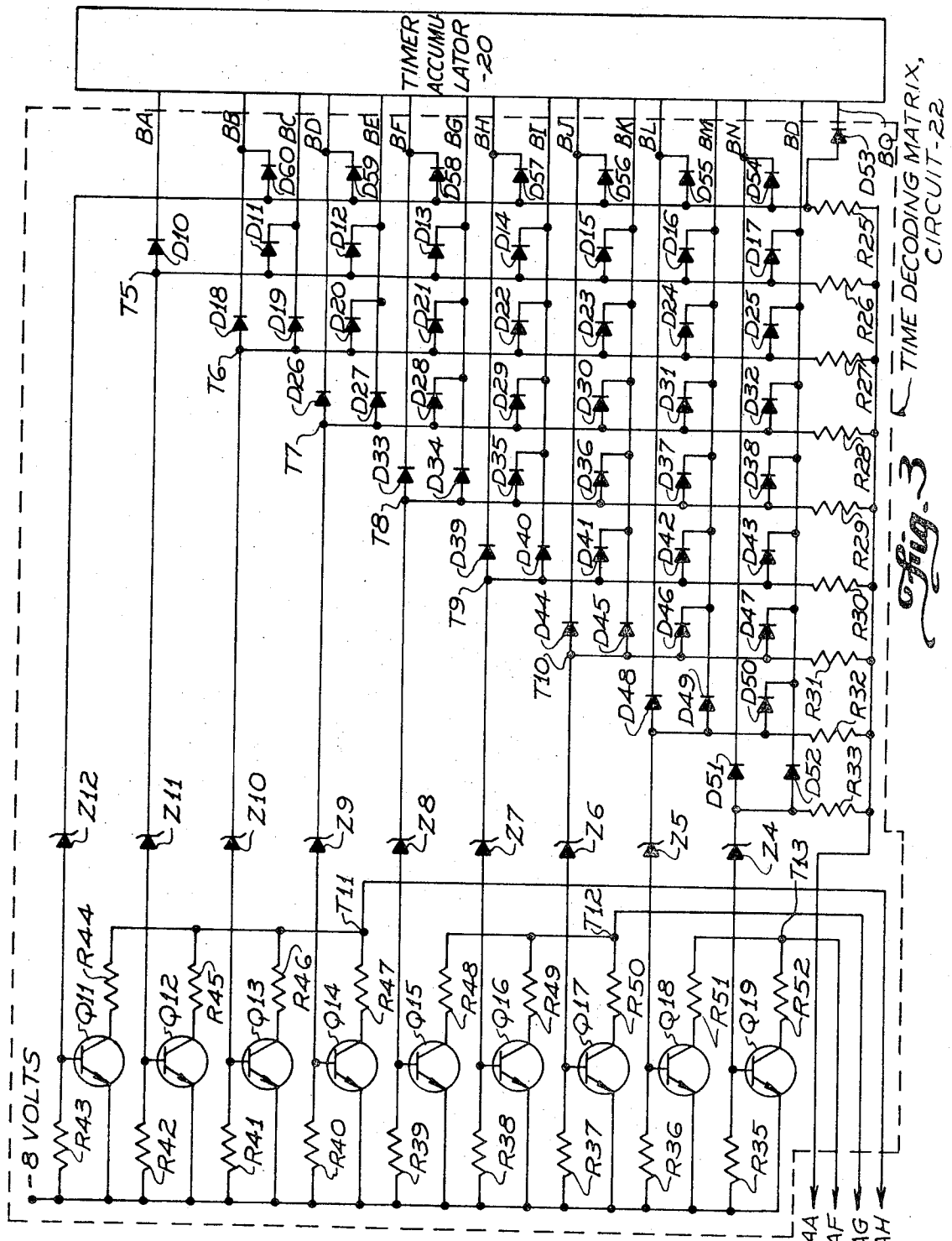


Fig. 3

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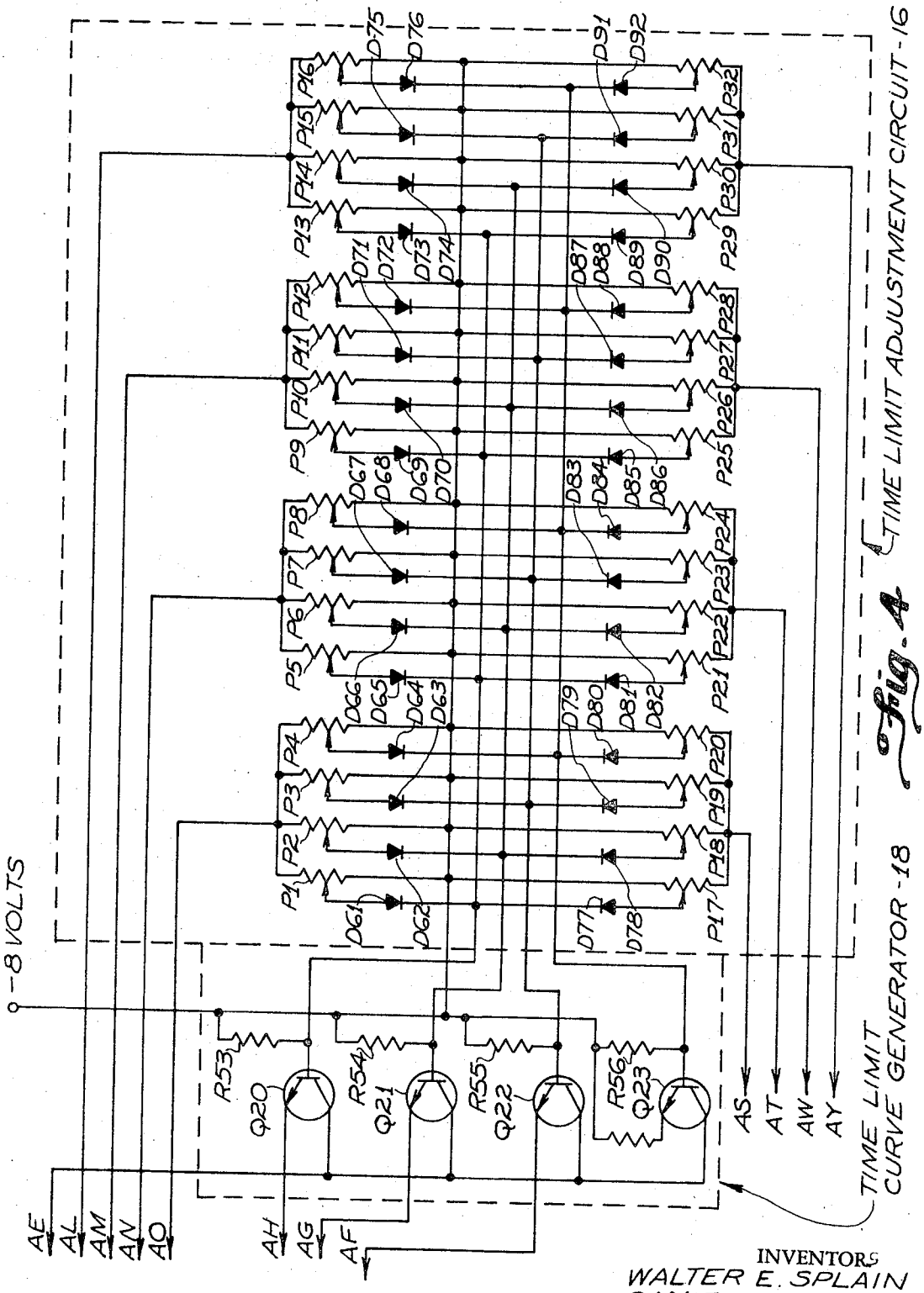


Fig. 4

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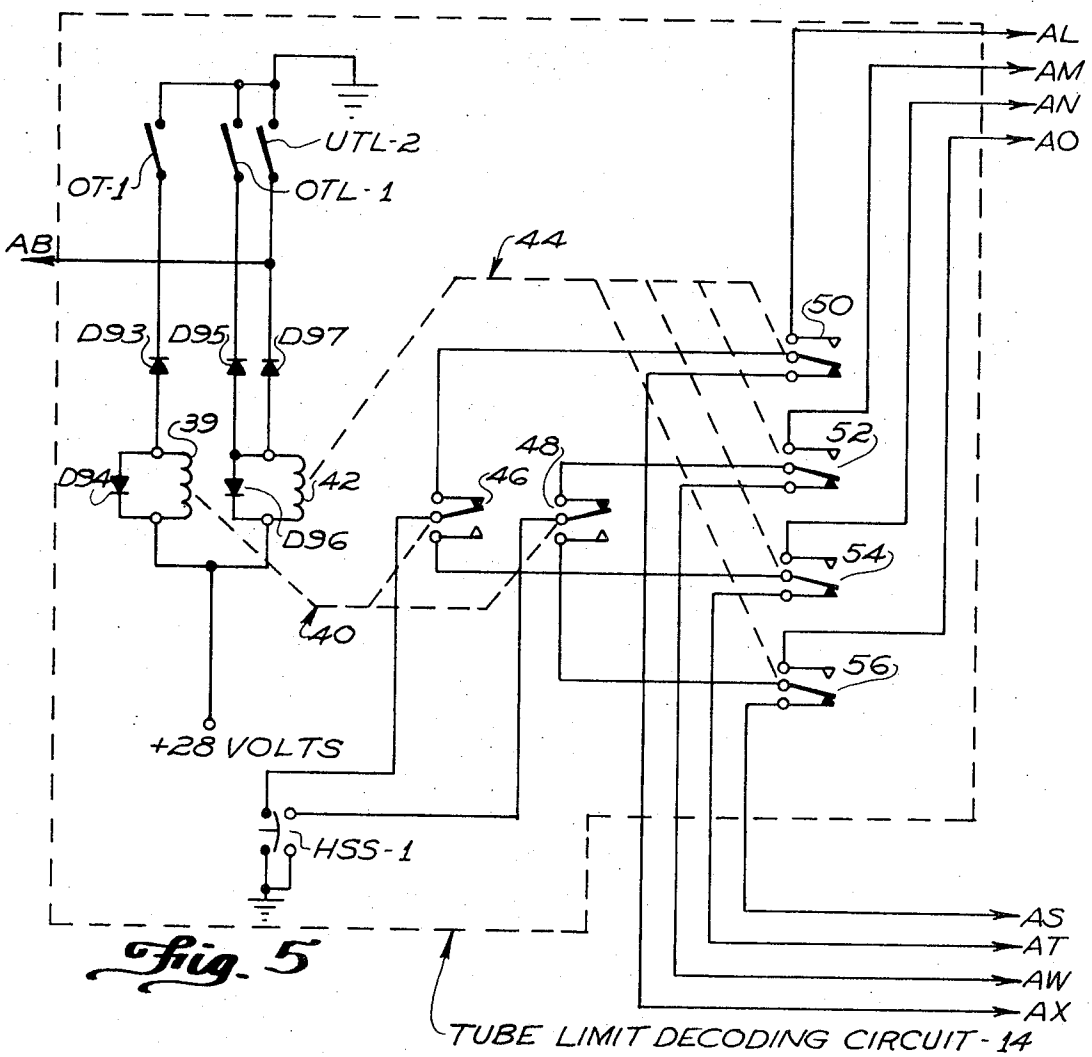


Fig. 5

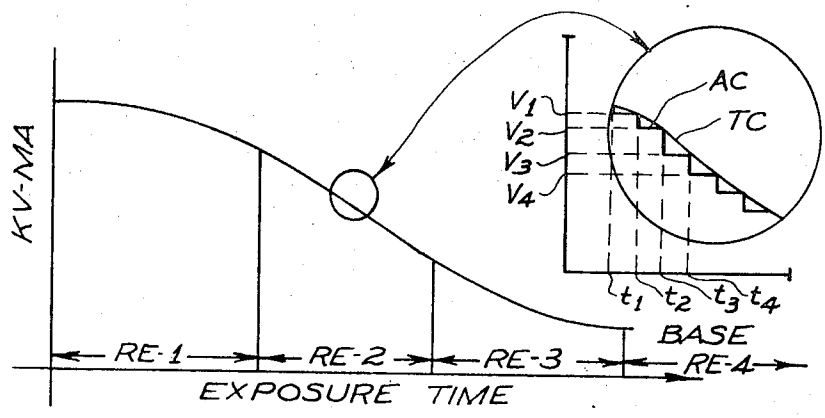


Fig. 6

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PROTECTIVE CIRCUIT FOR X-RAY TUBE AND METHOD OF OPERATION

CROSS REFERENCES TO RELATED PATENT APPLICATIONS AND PATENTS

U.S. Patent application Ser. No. 743,421, to Walter E. Splain, entitled "X-Ray Tube Kilovoltage Control System", filed July 9, 1968, and assigned to the same assignee as the present invention.

U.S. Pat. No. 3,284,631 to Walter E. Splain, entitled "Device for Determining the Current-Time Output of an X-Ray Tube", issued on Nov. 8, 1966, and assigned to the same assignee as the present invention.

U.S. Pat. No. 3,502,877 to Walter E. Splain, entitled "Grid-Controlled X-Ray Tube Control System", issued Mar. 24, 1970 and assigned to the same assignee as the present invention.

U.S. Pat. No. 3,521,067, to Walter E. Splain, entitled "X-Ray Tube Current Stabilization", issued July 21, 1970 and assigned to the same assignee as the present invention.

BACKGROUND OF THE INVENTION

This invention pertains to the art of electrical circuits for limiting the value of a signal applied to an electronic device, and more particularly, to a protection circuit for interrupting a signal which is applied to an X-ray tube if the value of the signal exceeds a predetermined value.

In the operation of X-ray equipment, a very high voltage potential signal, for example 125 kilovolts, is applied to the anode of the X-ray tube. When operated at this voltage potential, a current of 250 milliamperes may flow through the X-ray tube. The resultant input power applied to the tube will then be in excess of 30,000 watts. While this input power level may be maintained for a relatively short time duration exposure, i.e., on the order of 0.05 seconds, a longer exposure time will result in permanent damage to the X-ray tube.

X-ray tube protection circuits for use in most radiographic modes of operation have heretofore included circuitry for monitoring the value of the voltage potential signal which is applied to the X-ray tube, and if this signal exceeds a predetermined constant level, the signal is removed from the tube. These protective circuits have been satisfactory to a large extent; however, these circuits do not take into account the fact that the maximum input power which may be applied to an X-ray tube decreases as the elapsed exposure time increases.

Also, in the operation of X-ray equipment, the high potential signal applied to the anode of the tube is adjusted to vary the intensity of X-rays which are produced by the tube. With different X-ray procedures, i.e., high speed, low speed, large focal spot, small focal spot, overtable operation and undertable operation, there are different requirements as to X-ray intensity and exposure time.

In certain X-ray procedures it is desirable to apply a very high intensity level of X-rays for an extremely short period of time. With the above-described tube protection circuits, it was not possible to apply a signal to the tube having a value great enough to produce the desired X-ray intensity level because the protection circuit would remove the signal from the tube since the signal exceeded the predetermined level.

Also, if the exposure time of the tube is increased beyond a given period of time, the tube will be permanently damaged, even when operated at a conservative potential level, in view of the fact that the maximum input power which may be applied to an X-ray tube decreases rapidly with respect to time. This type of tube damage will occur in the phototimed mode of operation if an X-ray technician merely inadvertently leaves a lead apron on the X-ray table at a position in the path of the X-rays so as to prevent the phototiming circuit from deenergizing the X-ray tube.

It has been found to be highly desirable to compare the value of the signal applied to the X-ray tube not merely with a constant tube limit signal, but to instead compare the value of the signal applied to the X-ray tube to a limit signal which varies in value in accordance with a limiting parameter of the X-ray tube, such as the maximum input power which may be applied to the tube.

SUMMARY OF THE INVENTION

The present invention is directed toward a protective circuit and method of operation for interrupting the operation of an X-ray tube whenever a signal applied to the tube exceeds a maximum time-varying rating for the tube, thereby overcoming the noted disadvantages, and others, of such previous systems.

In accordance with one aspect of the present invention, there is provided in an X-ray apparatus a protective circuit for limiting the value of a signal applied to an X-ray tube. The protective circuit includes a signal generating circuit for generating a limit signal which varies in value with respect to time in accordance with the value of a maximum tube rating signal, a programming circuit for developing a program signal having a value representative of the value of a preselected signal to be applied to the X-ray tube, and a comparator circuit for monitoring the limit and program signals for developing an output signal whenever the value of the limit signal attains a predetermined value with respect to the value of the program signal.

In accordance with another aspect of the present invention, the signal generating circuit includes a circuit for generating a limit signal which decreases in value with respect to time in accordance with the value of a decreasing maximum power rating with respect to exposure time of the X-ray tube.

In accordance with another aspect of the present invention, the signal generating circuit includes a variable control for varying the rate at which the limit signal decreases with respect to time.

In accordance with another aspect of the present invention, the signal generating circuit includes a circuit for generating a limit signal which decreases in amplitude by a predetermined amount at each interval for N intervals of time where N is equal to or greater than five.

In accordance with still another aspect of the present invention, the signal generating circuit includes a circuit for generating a limit signal having a plurality of timed portions each being of a different amplitude.

In accordance with another aspect of the present invention, the signal generating circuit includes an actuatable switching circuit for selectively developing a pattern of control signals representative of a desired one of a plurality of predetermined tube rating signals, and a second actuatable circuit coupled to the actuatable

switching circuit for, upon receipt of a pattern of control signals, actuating the signal generating circuit corresponding to the received pattern of control signals to thereby generate a limit signal which varies in accordance with a selected one of the plurality of predetermined tube rating signals.

In accordance with still another aspect of the present invention, the programming circuit includes a variable circuit for altering the value of the programmed signal in accordance with the value of a voltage to be applied to the X-ray tube.

In accordance with still another aspect of the present invention, the programming circuit includes a variable circuit for altering the value of the program signal in accordance with the value of a current and/or a voltage to be applied to the X-ray tube.

In accordance with another aspect of the present invention, there is provided a method of protecting an X-ray tube in an X-ray apparatus. The method includes the steps of generating a limit signal which decreases in value with respect to time in accordance with a decrease in the value of the amplitude with respect to exposure time of a maximum signal which may be applied to the X-ray tube, developing a program signal having a value representative of the value of a preselected signal to be applied to the X-ray tube, and comparing the values of the limit signal and the program signal and developing an output signal if the value of the program signal exceeds the value of the limit signal.

In accordance with another aspect of the present invention, the method includes the step of interrupting the signal applied to the X-ray tube in response to the receipt of an output signal.

It is therefore an object of the present invention to provide a protective circuit for an X-ray tube for interrupting the operation of the X-ray tube when the signal applied to the tube exceeds a maximum rating for the tube.

Another object of the present invention is to provide a protective circuit for an X-ray tube which monitors the value of a signal to be applied to the tube and also monitors a time-varying signal representative of a maximum rating for the tube.

Another object of the present invention is to provide in an X-ray system a control circuit for interrupting the signal which is applied to an X-ray tube whenever the value of that signal exceeds the value of a maximum input power rating for the tube.

A further object of the present invention is to provide a protective circuit for interrupting the operation of an X-ray tube whenever the input power applied to the tube exceeds a predetermined time-varying maximum power rating for the tube.

A further object of the present invention is to provide a protective circuit for developing an output indication whenever the value of a signal applied to the X-ray tube exceeds the value of a maximum rating for the tube.

Another object of the present invention is to provide a method of operation of a protective circuit for interrupting a signal applied to an X-ray tube whenever that signal attains a value in excess of a maximum rating for the tube.

These and other objects and advantages of the invention will become apparent from the following description of the preferred embodiment of the invention as read in conjunction with the accompanying drawings and in which:

BRIEF DESCRIPTION OF DRAWINGS

FIG. **1** is an electrical block diagram illustrating in basic form the X-ray tube protective system of the present invention;

FIGS. **2** through **5** are electrical schematic diagrams illustrating in more detail the circuitry of the protective system shown in FIG. **1**; and,

FIG. **6** is a graphical representation of a typical curve representative of the maximum input power to be applied to an X-ray tube as a function of exposure time.

DESCRIPTION OF A PREFERRED EMBODIMENT

FIG. **1** illustrates an X-ray tube protective system **10** which is generally comprised of circuitry for developing a tube limit signal, circuitry for developing another signal having a value representative of the signal to be applied to the X-ray tube, and a comparator circuit **12** for developing an interrupt signal whenever the X-ray tube representative signal exceeds the value of the tube limit signal.

More particularly, the tube limit signal generating circuitry includes a tube limit decoding circuit **14** for developing a pattern of signals representative of the desired mode of operation, i.e., large focal spot, small focal spot, single speed, triple speed, overtable operation, and undertable operation. The pattern of signals developed by the tube limit decoding circuit **14** is applied to a tube limit adjustment circuit **16,** which is in turn coupled to a tube limit curve generator **18.** Also, a time accumulator circuit **20** having a plurality of output circuits for developing a pattern of binary coded decimal signals representative of elapsed time is coupled to a time decoding matrix circuit **22.** The decoding matrix circuit **22** is in turn coupled to the tube limit curve generator **18.**

Thus, the tube limit curve generator **18** generates a signal which varies in value with respect to time in accordance with the value of a maximum tube power rating. This signal is applied to one of the input terminals of the comparator circuit **12.**

The circuitry for developing a signal having a value representative of the signal to be applied to the X-ray tube generally includes a first variable resistor arrangement VR–1 in which the resistance may be varied in accordance with the selected voltage potential to be applied to the X-ray tube, and a second variable resistance arrangement VR–2 in which the resistance may be varied in accordance with the value of the current to be applied to the X-ray tube. The resistive arrangements VR–1, VR–2 are connected in series between a positive 20 volt voltage potential source and a negative 20 volt voltage potential source. The junction point between the resistance arrangement VR–1 and the resistance arrangement VR–2 is connected directly to the other input terminal of the comparator circuit **12.**

The output terminal of the comparator circuit **12** is connected through an amplifier **24** including a feedback path **26** to the input terminal of an inverter **28.** The output terminal of the inverter **28** is connected to one of the input terminals of a NAND gate **30.** The other input terminal of the NAND gate **30** is connected to circuitry for developing a signal representative of an exposure, and the output terminal of the NAND gate **30** is connected to the X-ray tube supply source. Thus, when a signal is developed by the comparator circuit **12** indicative of a tube overload condition, an output sig-

nal is developed by the NAND gate **30** to interrupt the X-ray tube supply source thereby removing the high potential signal from the X-ray tube.

The output terminal of the NAND gate **30** is also coupled through an inverter **32** to one terminal of a monitoring lamp L–1. The other terminal of lamp L–1 is connected directly to a positive 28 volt supply source. Thus, the monitoring lamp L–1 is energized whenever an interrupt signal is applied to the X-ray tube supply source.

The output terminal of the tube limit generator **18** is connected through a resistor R1 to the positive 20 volt supply source in order to maintain this terminal at a fixed operating potential prior to the current drain applied to this terminal by the tube limit curve generator **18** as the tube limit signal is developed. Also, a backup time drive signal is applied to the time decoding matrix circuit **22** by a conductor AA which is coupled to the output terminal of an amplifier **34.** The input terminal of the amplifier **34** is connected through a resistor R2 to the positive 20 volt supply source.

Reference is now made to FIG. 2 which illustrates in more detail the comparator circuit **12,** the amplifier and feedback circuits **24, 26,** the inverter circuits **28, 32,** the NAND gate **30,** and the amplifier **34,** as well as the resistance arrangements VR–1, VR–2. More particularly, the resistance arrangement VR–1 generally comprises a plurality of resistors R3, R4, R5, R6 each having one terminal connected to a common junction point T1. The other terminals of the resistors R3, R4, R5, R6 are respectively connected to one of the terminals of a plurality of single-pole, single-throw switches S3, S4, S5, S6. The other terminals of the switches S3, S4, S5, S6 are connected in common to the positive 20 volt supply source.

Similarly, the resistance arrangement VR–2 includes a plurality of resistors R7, R8. R9, R10 each having one terminal connected in common to a junction point T2. The other terminals of the resistors R7, R8, R9, R10 are respectively connected to one of the terminals of a corresponding number of single-pole, single-throw switches S7, S8, S9, S10. The other terminals of the switches S7, S8, S9, S10 are connected in common to the negative 20 volt supply source.

The junction point T1 of the resistance arrangement VR–1 is connected directly to the base of a PNP transistor Q1 in the comparator circuit **12.** The base of the transistor Q1 is also connected directly to the collector of an NPN transistor Q2, and through a capacitor C1 to an output terminal AE.

The collector of transistor Q1 is connected through a resistor R3 to an output terminal AD, and is also connected directly to the base of a transistor Q3 in the amplifier and feedback circuits **24, 26.** The emitter of transistor Q1 is connected to the cathode of a diode D1 having its anode connected in common with the anode of a diode D2. The cathode of the diode D2 is connected directly to the emitter of a PNP transistor Q4

The collector of transistor Q4 is connected directly to an output terminal AC, and the base of this transistor is connected through the resistor R1 to the positive 20 volt supply source and is also connected directly to the output terminal AE. The commonly connected anodes of the diodes D1, D2 are connected to the collector of a PNP transistor Q5 having its base connected through a resistor R4 to the positive 28 volt supply source. The base of the transistor Q5 is connected to the anode of a Zener diode Z1 having its cathode connected directly to the positive 28 volt supply source. Also, the base of transistor Q5 is connected through a resistor R5 to the output terminal AC.

The emitter of the transistor Q2 is connected directly to the junction point T2 of the resistance arrangement VR–2 and the base of this transistor is connected directly to the common contact of a single-pole, double-throw relay **36.** The normally-closed contact of the relay **36** is connected through a resistor R6 to the positive 20 volt supply source and the normally-open contact of the relay **36** is connected through a resistor R7 to the positive 20 volt supply source. Also connected to the normally-open contact of the relay **36** is the cathode of a Zener diode Z2 having its anode connected directly to the negative 20 volt supply source. Similarly, the cathode of a Zener diode Z3 is connected to the normally-closed contact of relay **36** and its anode is connected directly to the negative 20 volt supply source. One terminal of the relay coil **38** of the relay **36** is connected through a resistor R8 to the positive 20 volt supply source and the other terminal is connected to a common junction point T3. Also, a diode D3, polarized as shown in FIG. 2, is connected across the terminals of the coil **38** of relay **36.**

The common junction point T3 is connected through a diode D4, polarized as shown in FIG. 2, to an output terminal AB. The output terminal is also connected through a single-pole, single-throw switch UTL–1 to ground. The switch UTL–1, upon being closed, actuates circuitry in the tube limiting decoding circuit **14** for undertable and large focal spot operation.

The junction point T3 is also connected through a diode D5, polarized as shown in FIG. 2, and a single-pole, single-throw switch UTS–1 to ground. The switch UTS–1, upon being closed, actuates circuitry in the tube limit decoding circuit **14** for undertable and small focal spot operation.

The collector of transistor Q3 in the amplifier and feedback circuits **24, 26** is connected through a resistor R9 to the base of a PNP transistor Q6, and the emitter of transistor Q3 is connected directly to ground. The base of transistor Q3 is also connected through a resistor R10 to the collector of the transistor Q6.

The emitter of transistor Q6 is connected directly to the positive 20 volt supply source, the base of this transistor is connected through a resistor R11 to the positive 20 volt supply source, and the collector of this transistor is connected through a resistor R12 to ground. Also, the collector of transistor Q6 is connected through a resistor R13 to the base of an NPN transistor Q7 having its emitter connected directly to ground. The collector of the transistor Q7 is connected through a diode D6, polarized as shown in FIG. 2, to a junction point T4 in the inverter **28.**

The junction point T4 in the inverter **28** is connected through a resistor R14 to the positive 20 volt supply source and through a resistor R15 to the base of an NPN transistor Q8. The collector of the transistor Q8 is connected through a resistor R16 to the positive 20 volt supply source, the emitter of this transistor is connected directly to ground, and the base of this transistor is also connected through a resistor R17 to the output terminal AD. Finally, the collector of the transistor Q8 provides a common junction point T5 which is connected to the collector of an NPN transistor Q9 in the

NAND gate 30 and to the cathode of a diode D7 in the inverter 32.

The anode of the diode D7 is connected through a resistor R18 to the base of an NPN transistor Q10 having its emitter connected directly to ground and its collector connected to one terminal of the monitor lamp L-1. The other terminal of the lamp L-1 is connected directly to the positive 28 volt supply source. The base of transistor Q10 is also connected through a resistor R19 to the output terminal AD, and the anode of the diode D7 is also connected through a resistor R20 to the positive 20 volt supply source.

The base of the transistor Q9 in the NAND gate 30 is connected through a resistor R22 to the output terminal AD and is also connected through a pair of series-connected resistors R23, R24 to the positive 20 volt supply source. The junction point between the series-connected resistors R23, R24 is connected to the anode of a diode D8 having its cathode connected to circuitry within the X-ray apparatus for developing an exposure signal. The base of transistor Q9 is connected directly to ground and the collector of this transistor is also connected to the X-ray tube supply source and to the anode of a diode D9. The cathode of diode D9 is connected directly to ground. In addition, the output terminal AD is connected directly to a negative 8 volt supply source.

The cathode of diode D9 is connected to an NPN transistor Q10 in the amplifier circuit 34. The base of this transistor is connected through the resistor R2 to the positive 20 volt supply source, the collector of this transistor is connected directly to the positive 20 volt supply source, and the emitter of this transistor is connected to an output terminal AA. Finally, a resistor R25 is connected between the output terminal AA of the amplifier circuit 34 and ground.

Reference is now made to FIG. 3 which illustrates in more detail the circuitry within the time decoding matrix circuit 22 and the circuit connections between the matrix circuit 22 and the timer accumulator circuit 20. More particularly, the timer accumulator circuit 20, upon being actuated, generates a pattern of binary coded decimal signals representative of the elapsed time. In other words, once an exposure cycle is commenced, the timer accumulator circuit 20 begins a counting sequence with the pattern of binary signals applied to the output terminals being changed at preselected intervals of time. The pattern of signals which appears on the output terminals of the timer accumulator circuit 20 for each time interval is set forth in Table I below.

The output terminals of the timer accumulator circuit 20 are connected to the input terminals DA through DQ of the time decoding matrix circuit 22. As illustrated in FIG. 3, the decoding matrix circuit 22 generally comprises a digital-to-analog matrix for actuating selected ones of the nine NPN transistors Q11 through Q19.

More particularly, the input terminal BA of the decoding matrix circuit 22 is connected to the cathode of a diode D10 having its anode connected to a junction point T5. Seven diodes D11 through D17 have their anodes connected to the junction point T5 and their cathodes respectively connected to the input terminals BC, BE, BG, BI, BK, BM, BO. The junction point T5 is connected to the cathode of a Zener diode Z11 and is also connected through a resistor R26 to the output terminal AA.

Similarly, the input terminal BB of matrix circuit 22 is connected to the cathode of a diode D18 having its anode connected to a junction point T6. The junction point T6 is connected to the cathodes of seven diodes D19 through D25 having their anodes respectively connected to input terminals BC, BE, BG, BI, BK, BM, BO. The junction point T6 is connected to the cathode of a Zener diode Z10 and is also connected through a resistor R27 to the terminal AA.

In a like manner, the input terminal BD of matrix circuit 22 is connected to the cathode of a diode 26 having its anode connected to a junction point T7. The junction point T7 is in turn connected to the anodes of six diodes D27 through D32 having their cathodes respectively connected to the input terminals BE, BG, BI, BK, BM, BO. Also, the junction point T7 is connected directly to the cathode of a Zener diode D9 and through a resistor R28 to the terminal AA.

The input terminal BF is connected to the cathode of a diode D33 having its anode connected to a junction point T8, which is in turn connected to the cathode of a Zener diode Z8. The junction point T8 is also connected to the anode of five diodes D34 through D38 having their cathodes respectively connected to the input terminals BG, BI, BK, BM, BO. In addition, the junction point T8 is connected through a resistor R29 to the terminal AA.

Similarly, the input terminal BH is connected to the cathode of a diode D39 having its anode connected to a junction point T9 which is in turn connected to the cathode of a Zener diode Z7. The junction point T9 is also connected to the anode of four diodes D40 through D43 having their cathodes respectively connected to the terminals BI, BK, BM, BO. In addition, the junction point T9 is connected through a resistor R30 to the common terminal AA.

In a like manner, the input terminal BJ is connected to the cathode of a diode D44 having its anode connected to a junction point T10 which is in turn connected to the cathode of a Zener diode Z6. The junction point T10 is connected to the anode of three diodes D45, D46, D47, and is also connected through a resistor R31 to the common terminal AA. The cathodes of diodes D45, D46, D47 are respectively connected to the input terminals BK, BM, BO.

The input terminal BL of the matrix circuit 22 is connected to the cathode of a diode D48 having its anode connected to the cathode of a Zener diode Z5 and to the anodes of a pair of diodes D49, D50. The cathodes of diodes D49, D50, are respectively connected to the input terminals BM, BO. In addition, the anode of diode B48 is connected through a resistor R32 to the common terminal AA.

The input terminals BM, BO are respectively connected to the cathodes of a pair of diodes D51, D52 having their anodes connected in common to the cathode of a Zener diode Z4. The anodes of the diodes D51, D52 are connected through a resistor R33 to the common terminal AA.

Finally, the common terminal AA is connected through a resistor R34 to the anodes of eight diodes D53 through D60 having their cathodes respectively connected to the input terminals BQ, BN, BL, BJ, BH, BF, bd, BB. The anodes of these diodes are also connected to the cathode of a Zener diode Z12.

The anodes of the Zener diodes Z4, Z5, Z6, Z7, Z8, Z9, Z10, Z11, Z12 are respectively connected to the base terminals of transistors Q19, Q18, Q17, Q16, Q15, Q14, Q13, Q12, Q11. In addition, the base terminals of these transistors are respectively connected through the resistors R35 through R43 to a negative 8 volt supply source. The emitters of the transistors Q11 through Q19 are connected directly to the negative 8 volt supply source. The collectors of transistors Q11 through Q14 are respectively connected through resistors R44 through R47 to a common terminal T11 which provides an output terminal AH. Similarly, the collectors of transistor Q15, Q16, Q17, are respectively connected through resistors R48, R49, R50 to a common terminal T12 which provides an output terminal AG. Finally, the collectors of transistors Q18, Q19 are respectively connected through resistors R51, R52 to a common terminal T13 which provides an output terminal AF.

Reference is now made to FIG. 4 which illustrates in more detail the circuitry of the time limit adjustment circuit 16 and the time limit curve generator 18. More particularly, the time limit adjustment circuit 16 includes eight input terminals AL, AM, AN, AO, AS, AT, AW, AY which are each connected to the stationary contacts of a set of four potentiometers.

Thus, input terminal AO is connected to the commonlyconnected stationary contact of a set of four potentiometers P1, P2, P3, P4; the input terminal AN is connected to the stationary contact of a set of potentiometers P5, P6, P7, P8; the input terminal AM is connected to the stationary contacts of a set of four potentiometers P9, P10, P11, P12; and the input terminal AL is connected to the commonly-connected stationary contacts of a set of four potentiometers P13, P14, P15, P16.

Similarly, the input terminal AF is connected to the commonly-connected stationary contact of a set of four potentiometers P17, P18, P19, P20; the input terminal AT is connected to the commonly-connected stationary contact of a set of four potentiometers P21, P22, P23, P24; the input terminal AW is connected to the commonly-connected stationary contact of a set of four potentiometers P25, P26, P27, P28; and the input terminal AY is connected to the commonly-connected stationary contact of a set of four potentiometers P29, P30, P31, P32. The other stationary contacts of the potentiometers P1, P2, P3, P4 are respectively connected to the other stationary contacts of the pontentiometers P17, P18, P19, P20. Similarly, the other stationary contacts of the potentiometers P5, P6, P7, P8 are respectively connected to the other stationary contacts of the potentiometers P21, P22, P23, P24. In a like manner, the other stationary contacts of the potentiometers P9, P10, P11, P12 are respectively connected to the other stationary contacts of the potentiometers P25, P26, P27, P28. Finally, the other stationary contacts of the potentiometers P13, P14, P15, P16 are respectively connected to the other stationary contacts of the potentiometers P29, P30, P31, P32.

The movable contacts of the potentiometers P1 through P32 are respectively connected to the anodes of a corresponding member of diodes D61 through D92. Also, the cathodes of the diodes D61 through D76 are respectively connected to the cathode of the diodes D77 through D92.

As illustrated, the tube limit curve generator 18 includes four NPN transistors Q20, Q21, Q22, Q23 having their collectors connected in common to an output terminal AE. The base terminal of transistor Q20 is connected through a resistor R53 to the negative 8 volt supply source and is also connected to the cathodes of diodes D61, D65, D69, D73. Similarly, the base of transistor Q21 is connected through a resistor R54 to the negative 8 volt supply source and is also connected to the cathodes of the diodes D62, D66, D70, D74. In a like manner, the base of transistor Q22 is connected through a resistor R55 to the negative 8 volt supply source and is also connected to the cathodes of the diodes D63, D67, D71, D75. Finally, the base of transistor Q3 is connected through a resistor R56 to the negative 8 volt supply source and is also connected to the cathodes of the diodes D64, D68, D72, D76.

The negative 8 volt supply source is coupled directly to all of the junction points between the series connected potentiometers P1 through P32. The emitters of the transistors Q20, Q21, Q22, provide the output terminals AH, AG, AF, respectively, of the time limit curve generator 18.

Reference is now made to FIG. 5 which illustrates in more detail the tube limit decoding circuit 14. This circuit generally comprises four mode of operation switches, i.e., an overtable switch, OT–1, and overtable low speed switch OTL–1, an undertable low speed switch UTL–2, and a high and low speed switch HSS–1. These switches are connected through appropriate relays in order to cause the tube limit curve generator 18 to generate a maximum tube input power curve appropriate to the mode of operation.

More particularly, the switches OT–1, OTL–1 are single-pole, single-throw switches with each switch having one terminal connected directly to ground. The other terminal of the switch OT–1 is connected through a diode D93 polarized as shown in FIG. 5 to one of the terminals of a coil 39 of a relay 40. The other terminal of the coil 39 is connected directly to the positive 28 volt supply source and a diode D94, polarized as shown in FIG. 5, is coupled across the terminals of the relay coil 39.

The other terminal of switch OTL–1 is connected through a diode D95, polarized as shown in FIG. 5, to one of the terminals of a coil 42 of a relay 44. The other terminal of coil 42 is connected directly to the positive 28 volt supply source. A diode D96 polarized as shown in FIG. 5, is coupled across the terminals of the relay coil 42.

The other terminal of the switch UTL–2 is connected through a diode D97, polarized as shown in FIG. 5, to the same terminal of relay coil 42 which is connected to diode D95.

The relay contacts of relay 40 take the form of double-pole, double-throw contacts 46, 48. The common contact of the sets of contacts 46, 48 are respectively connected to a pair of terminals of the high and low speed switch HSS–1. The switch HSS–1 takes the form of a double-pole, double-throw switch. The other contacts of the switch HSS–1 are connected directly to ground.

The relay contacts of relay 44 take the form of four sets of single-pole, double-throw contacts 50, 52, 54, 56. The common terminal of contact set 50 is connected directly to the normally-closed terminal of contact 46 of relay 40, the common terminal of contact set

52 is connected directly to the normally-closed terminal of contact 48 of relay 40, the common terminal of contact set 54 is connected to the normally-open terminal of contact 46 of relay 40, and the common terminal of contact set 56 is connected to the normally-open terminal of contact 48 of relay 40.

As illustrated, the normally-open terminals of contact sets 50, 52, 54, 56 provide the output terminals AL, AM, AN, AO, respectively, of the tube limit decoding circuit 14. Similarly, the normally-closed terminals of the contact sets 50, 52, 54, 56 provide the output terminals AS, AT, AW, AX of the decoding circuit 14.

Reference is now made to FIG. 6 which is a graphical representation of a typical maximum input tube power curve PC having the time-varying limit curve which is generated by the tube limit curve generator 18 superimposed thereon. More particularly, the maximum input tube power curve TC represents the maximum voltage times current (KV × MA) as a function of exposure time which may be applied to the X-ray tube without damaging the X-ray tube. This curve which may be obtained from the tube manufacturer, will vary according to the mode of operation, i.e., high speed, low speed, overtable, etc.

The limit curve AC which is generated by the tube limit curve generator 18 generally takes the form of a decreasing staircase type signal which may be adjusted in amplitude for each time interval to closely approximate the value over each time interval of the maximum input tube power curve PC. In other words, the intervals of time, T1, T2, T3, T4 are predetermined fixed intervals of time of equal time duration, and the voltage, i.e., V1, V2, V3, V4, generated by the tube limit curve generator 18 for each interval of time may be adjusted to satisfy the approximation of the input tube power curve TC.

OPERATION OF THE PROTECTIVE CIRCUIT

Prior to the actual operation of the X-ray tube protection circuit, the potentiometers P1 through P32 are adjusted so that the eight sets of curves which are generated by the tube limit curve limit generator 18 closely approximate the maximum input tube power curves recommended by the tube manufacturer. The eight curves generally represent different combinations of: types of tubes, size of focal spot, and anode rotation. In other words, there are eight possible combinations of these parameters which require a different maximum input tube power curve. As discussed before, the maximum input tube power curve PC as illustrated in FIG. 6 is a typical curve for input power versus exposure time; however, it is to be appreciated that eight different curves each having different amplitudes with respect to exposure times would be required for the eight possible modes of operation.

Thus, in order to generate a signal for overtable, large focal spot, triple-speed operation, the four potentiometers P1, P2, P3, P4, are adjusted to set the voltage amplitude of the curve for the regions RE–1, RE–2, RE–3, RE–4 respectively. Similarly, in another mode of operation, i.e., in the overtable, large focal spot, single-speed operation, the potentiometers P5, P6, P7, P8 would be adjusted to obtain the desired signal amplitudes over the exposure regions RE–1, RE–2, RE–3, RE–4, respectively.

Accordingly, the potentiometers P1 through P32 correspond to the following modes of operation:

Mode of Operation	Potentiometers
Overtable, large focal spot, triple-speed	P1, P2, P3, P4
Overtable, large focal spot, single-speed	P5, P6, P7, P8
Undertable, large focal spot, triple-speed	P9, P10, P11, P12
Undertable, large focal spot, single-speed	P13, P14, 15, P16
Overtable, small focal spot, triple-speed	P17, P18, P19, P20
Overtable, small focal spot, single-speed	P21, P22, P23, P24
Undertable, small focal spot, triple-speed	P25, P26, P27, P28
Undertable, small focal spot, single-speed	P29, P30, P31, P32

Upon commencement of an exposure cycle, the timer accumulator circuit 20 begins a counting cycle in binary-coded-decimal logic which is applied to the time decoding matrix circuit 22. The diode matrix in the decoding matrix circuit 22 performs the function of converting the binary-coded-decimal logic signals to analog signals which are then applied to the transistors Q11 through Q19 to actuate these transistors to either forward or reverse biased states. The patterns of binary signals, and the states of the transistors Q11 through Q19 are set forth in Table I below:

TABLE I

Bits from Time Accumulator — 20								Time Range	Transistor Turned on
8	16	32	64	128	256	512	1024		
0	0	0	0	0	0	0	0	0–2.77ms	Q11
1	1	1	1	1	1	1	0	2.77–22ms	Q12
0	1	1	1	1	1	1	0	22ms–44ms	Q13
0	0	1	1	1	1	1	0	44ms–88ms	Q14
0	0	0	1	1	1	1	0	88ms–176ms	Q15
0	0	0	0	1	1	1	0	176ms–352ms	Q16
0	0	0	0	0	1	1	0	352ms–704ms	Q17
0	0	0	0	0	0	1	0	0.704ms–1.4sec.	Q18
0	0	0	0	0	0	0	1	1.4sec–2.8sec.	Q19

Upon the actuation of each of the transistors Q11 through Q19, a different resistance value of a corresponding resistor R44 through R52 is coupled into the circuit to thereby cause the generated limit signal AC to decrease in value with elapsed exposure time. Thus, as the transistors Q11 through Q19 are sequentially forward biased, the resistors R44 through R52 are sequentially coupled into the circuit to thereby cause the limit curve AC to take the form of a decreasing stairstep type function with respect to time.

With reference to FIG. 5, the switches OT–1, UTL–1, UTL–2, HSS–1, and their associated relays 40, 44, provide circuitry for switching the desired set of four potentiometers of the potentiometers P1 through P32 into the circuit. In other words, upon closure of the switch OTL–1, assuming the switch HSS–1 is in the position as indicated, the overtable, large focal spot, triple-speed potentiometers P1 through P4 are placed into the circuit to generate a limit curve AC representative of the maximum input tube power which may be applied to

the X-ray tube when operated in that mode of operation.

The output current I2 from the tube limit curve generator 18 is applied across the resistor R1 to develop a voltage V2 which is proportional to the maximum allowed input power at the particular time interval of the exposure time. This voltage signal is applied to one of the input terminals of the comparator circuit 12.

When the X-ray tube supply source is set by the X-ray technician for a desired voltage potential and current signal to be applied to the X-ray tube, the resistive arrangements VR–1, VR–2 are simultaneously set to develop a signal V1 representative of the voltage potential (KV) and current (MA) to be applied to the X-ray tube during an actual exposure. The voltage signal V1 is applied to the other input terminal of the comparator circuit 12.

Thus, if the voltage V1 remains less than the voltage V2, the signal developed by the comparator circuit remains at a binary 0 thereby causing the X-ray tube supply source to continue to supply a voltage potential signal to the X-ray tube.

If the signal V1 representative of the value of the signal which is applied to the X-ray tube exceeds the value of the time-varying signal V2, the signal developed by the comparator circuit 12 changes to a binary 1 signal which is applied through the amplifier 24, inverter 28, NAND gate 30 to thereby interrupt the voltage signal which is applied to the X-ray tube by the tube supply source.

Accordingly, as long as the value of the programmed signal V1 remains less than the value of the tube limit signal V2, the exposure will continue until it is terminated by either a phototimer or a preset timer. If the value of the programmed signal V1 exceeds the value of the limit signal V2, the exposure is immediately terminated. Also, the monitoring lamp L–1 simultaneously provides a visual indication that the exposure has been terminated.

Although the invention has been shown in connection with a preferred embodiment, it will be readily apparent to those skilled in the art that various changes in form and arrangement of parts may be made to suit requirements without departing from the spirit and scope of the invention as defined by the appended claims.

Having thus described my invention, I claim:

1. In an X-ray apparatus a protective circuit for limiting the value of a signal applied to an X-ray tube and comprising:

signal generating means for generating a limit signal which varies in value as a function of elapsed exposure time in accordance with the value of a maximum tube rating signal;

programming circuit means for developing a program signal having a value representative of the value of a preselected signal to be applied to said X-ray tube;

comparator means for monitoring the limit and program signals for developing an output signal when the value of a said limit signal attains a predetermined value with respect to the value of a said program signal; and,

actuatable circuit means coupled to a said comparator circuit means for, upon receipt of a said output signal, interrupting a signal which is applied to said X-ray tube.

2. An apparatus as defined in claim 1 wherein said programming means includes variable circuit means for altering the value of a said program signal in accordance with the value of the voltage to be applied to said X-ray tube.

3. An apparatus as defined in claim 1 wherein said signal generating means includes circuit means for generating a said limit signal which decreases in value with respect to time in accordance with the value of a decreasing maximum power rating with respect to exposure time of said X-ray tube.

4. An apparatus as defined in claim 3 wherein said signal generating circuit means includes variable control means for varying the rate at which a said limit signal decreases with respect to time.

5. An apparatus as defined in claim 4 wherein said programming means includes variable circuit means for altering the value of a said program signal in accordance with the value of the voltage to be applied to said X-ray tube.

6. An apparatus as defined in claim 4 wherein said programming means includes variable circuit means for altering the value of a said program signal in accordance with the value of the current to be applied to said X-ray tube.

7. An apparatus as defined in claim 4 wherein said programming means includes first variable circuit means for altering the value of a said program signal in accordance with the value of the voltage to be applied to said X-ray tube; and,

second variable means for altering the value of a said program signal in accordance with the value of the current to be applied to said X-ray tube.

8. An apparatus as defined in claim 1 wherein said signal generating means includes circuit means for generating a said limit signal which decreases in value with respect to time and which varies in the rate of decrease in value with respect to time.

9. An apparatus as defined in claim 8 wherein said programming means includes first variable circuit means for altering the value of a said program signal in accordance with the value of the voltage to be applied to said X-ray tube; and,

second variable means for altering the value of a said program signal in accordance with the value of the current to be applied to said X-ray tube.

10. An apparatus as defined in claim 1 wherein said signal generating means includes circuit means for generating a said limit signal which decreases in amplitude by a predetermined amount for N intervals of time where N is equal or greater than five.

11. An apparatus as defined in claim 1 wherein said signal generating means includes circuit means for generating a said limit signal having a plurality of timed portions each being of a different amplitude.

12. An apparatus as defined in claim 11 wherein said programming means includes variable circuit means for altering the value of a said program signal in accordance with the value of the current to be applied to said X-ray tube.

13. An apparatus as defined in claim 11 wherein said programming means includes first variable circuit means for altering the value of a said program signal in accordance with the value of the voltage to be applied to said X-ray tube; and,

second variable means for altering the value of a said program signal in accordance with the value of the current to be applied to said X-ray tube.

14. An apparatus as defined in claim **1** wherein said signal generating means includes a plurality of circuit means each for generating a said limit signal which varies in value with respect to time in accordance with one of a plurality of different predetermined tube rating signals;

actuatable switch means for selectively developing a pattern of control signals representative of a desired one of said plurality of predetermined tube rating signals; and,

second actuatable circuit means coupled to said actuatable switch means for, upon receipt of a pattern of control signals, actuating a signal generating circuit means corresponding to said received pattern of control signals to thereby generate a said limit signal which varies in accordance with a selected one of said plurality of predetermined tube rating signals.

15. An apparatus as defined in claim **14** wherein said programming means includes variable circuit means for altering the value of a said program signal in accordance with the value of the current to be applied to said X-ray tube.

16. An apparatus as defined in claim **14** wherein said programming means includes first variable circuit means for altering the value of a said program signal in accordance with the value of the voltage to be applied to said X-ray tube; and,

second variable means for altering the value of a said program signal in accordance with the value of the current to be applied to said X-ray tube.

17. An apparatus as defined in claim **1** wherein said signal generating means includes a timer means for developing a plurality of patterns of signals each representative of the elapsed time;

a plurality of circuit means each for generating a limit signal which varies in accordance with one of a plurality of predetermined time functions; and,

second actuatable circuit means coupled to said timer means for, upon receipt of one of a said plurality of patterns of signals, actuating a signal generating circuit means corresponding to a said received pattern of signals to thereby generate a limit signal which varies in accordance with a selected one of said plurality of time functions.

18. An apparatus as defined in claim **17** wherein said programming means includes variable circuit means for altering the value of a said program signal in accordance with the value of the current to be applied to said X-ray tube.

19. An apparatus as defined in claim **18** wherein said programming means includes first variable circuit means for altering the value of a said program signal in accordance with the value of the voltage to be applied to said X-ray tube; and,

second variable means for altering the value of a said program signal in accordance with the value of the current to be applied to said X-ray tube.

20. A control system for indicating that the input power which is applied to an X-ray tube has exceeded a level defined by a maximum tube power rating which varies in value with respect to time and comprising;

tube limit signal generating means for developing a limit signal which varies in value as a function of elapsed exposure time in accordance with variations in a said maximum power rating of the tube with respect to time;

variable programming circuit means for developing a program signal having a value representative of the value of voltage and current signals applied to said X-ray tube;

comparator means for monitoring the limit and program signals for developing an output signal when the value of a said limit signal attains a predetermined value with respect to the value of a said program signal; and

indicator circuit means coupled to a said comparator circuit means for, upon receipt of a said output signal, developing an output indication that the tube input power has exceeded the maximum power rating.

21. An apparatus as defined in claim **20** wherein said variable program circuit means includes first variable circuit means for developing a first signal having a value representative of the value of a voltage potential to be applied to said X-ray tube;

second variable circuit means for developing a second signal having a value representative of the value of a current to be applied to said X-ray tube; and,

resolving circuit means coupled to said first and second circuit means for developing a said program signal having a value representative of the values of said voltage potential and said current to be applied to said X-ray tube.

22. An apparatus as defined in claim **20** wherein said variable program circuit means includes first variable circuit means for developing a first signal having a value representative of the value of a current to be applied to said X-ray tube;

second variable circuit means for developing a second signal having a value representative of the value of a current to be applied to said X-ray tube; and,

resolving circuit means coupled to said first and second circuit means for developing a said program signal having a value representative of the values of said current to be applied to said X-ray tube.

23. An apparatus as defined in claim **20** wherein said tube limit signal generating means includes timer means for developing a plurality of patterns of control signals each representative of the elapsed exposure time;

a plurality of signal generating circuits each for developing a limit signal which decreases in value at a different predetermined rate;

actuator circuit means coupled to said timer means for, upon receipt of said plurality of predetermined patterns of signals, actuating a corresponding one of said plurality of signal generating circuits to thereby develop a limit signal which decreases in value at a corresponding predetermined rate.

24. An apparatus as defined in claim **23** wherein said timer means includes time accumulator means for developing a plurality of patterns of signals each of which take the form of binary coded decimal signals; and matrix circuit means for converting said binary coded decimal signals to a plurality of patterns of signals each of which takes the form of analog signals.

25. In an X-ray apparatus a protective circuit for indicating that the value of a signal applied to an X-ray

tube has reached a time-varying maximum tube limit rating and comprising:

an X-ray tube;

a voltage supply source coupled to said X-ray tube for applying an operating signal to said X-ray tube;

means for varying the value of a said operating signal applied to said X-ray tube;

waveform generating means for developing a limit signal having a value which decreases as a predetermined function with respect to elapsed exposure time for a preselected period of time;

monitor circuit means for developing a signal having a value representative of a said operating signal applied to said X-ray tube;

comparator means coupled to said waveform generating means and said circuit means for developing an output signal when the value of the limit signal decreases to a predetermined level relative to the monitor signal; and,

indicator circuit means coupled to said comparator circuit means for, upon receipt of a said output signal, developing an output indication that the operating signal has reached a maximum limit value.

26. An apparatus as defined in claim **25** wherein said waveform generating means includes circuit means for generating a said limit signal which decreases in value with respect to time and which varies in the rate of decrease in value with respect to time.

27. An apparatus as defined in claim **25** wherein said waveform generating means includes a plurality of circuit means each for generating a said limit signal which varies in value with respect to time in accordance with one of a plurality of different predetermined tube rating signals;

actuatable switch means for selectively developing a pattern of control signals representative of a desired one of said plurality of predetermined tube rating signals; and,

second actuatable circuit means coupled to said actuatable switch means for, upon receipt of a pattern of control signals, actuating a signal generating circuit means corresponding to said received pattern of control signals to thereby generate a said limit signal which varies in accordance with a selected one of said plurality of predetermined tube rating signals.

28. In an X-ray apparatus a protective circuit for monitoring the value of a signal applied to an X-ray tube from exceeding a time-varying maximum tube limit rating and comprising:

signal generating means for generating a limit signal which decreases in value as a predetermined, nonlinear function with respect to elapsed exposure time in accordance with the value of a time-varying maximum tube rating;

programming circuit means for developing a program signal having a value representative of the value of a preselected signal applied to a said X-ray tube;

comparator means for monitoring the limit and program signals for developing an output signal when the value of a said limit signal decreases to a predetermined value relative to the value of a said program signal; and,

indicator circuit means coupled to said comparator circuit means for, upon receipt of a said output signal, developing an output indication that the operating signal has reached a maximum limit value.

29. An apparatus as defined in claim **28** wherein said signal generating means includes a timer means for developing a plurality of patterns of signals each representative of the elapsed time;

a plurality of circuit means each for generating a limit signal which varies in accordance with one of a plurality of predetermined time functions; and,

second actuatable circuit means coupled to said timer means for, upon receipt of one of a said plurality of patterns of signals, actuating a signal generating circuit means corresponding to a said received pattern of signals to thereby generate a limit signal which varies in accordance with a selected one of said plurality of time functions.

30. An apparatus as defined in claim **28** wherein said signal generating means includes a plurality of circuit means each for generating a said limit signal which varies in value with respect to time in accordance with one of a plurality of different predetermined tube rating signals;

actuatable switch means for selectively developing a pattern of control signals representative of a desired one of said plurality of predetermined tube rating signals; and,

second actuatable circuit means coupled to said actuatable switch means for, upon receipt of a pattern of control signals, actuating a signal generating circuit means corresponding to said received pattern of control signals to thereby generate a said limit signal which varies in accordance with a selected one of said plurality of predetermined tube rating signals.

31. A method of protecting an X-ray tube in an X-ray apparatus comprising the steps of:

generating a limit signal which decreases in value with respect to elapsed exposure time in accordance with a decrease in the value of the amplitude with respect to exposure time of a maximum signal which may be applied to the X-ray tube;

developing a program signal having a value representative of the value of a preselected signal to be applied to said X-ray tube;

comparing the values of the limit signal and program signal;

developing an output signal if the value of said program signal exceeds the value of said limit signal; and,

interrupting a signal applied to said X-ray tube in response to the receipt of an output signal.

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