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Siedband et al.

[11] **3,838,285**

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[54] **X-RAY TUBE ANODE PROTECTIVE CIRCUIT**

[75] Inventors: **Melvin P. Siedband,** Madison, Wis.; **Jack L. James,** Westminister; **Ambalal T. Patel,** Baltimore, both of Md.

[73] Assignee: **CGR Medical Corporation,** Baltimore, Md.

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[52] **U.S. Cl.** **250/413,** 250/416

[51] **Int. Cl.** **H05g 1/28**

[58] **Field of Search** 250/416, 401, 402, 413, 250/414; 315/74

[56] **References Cited**

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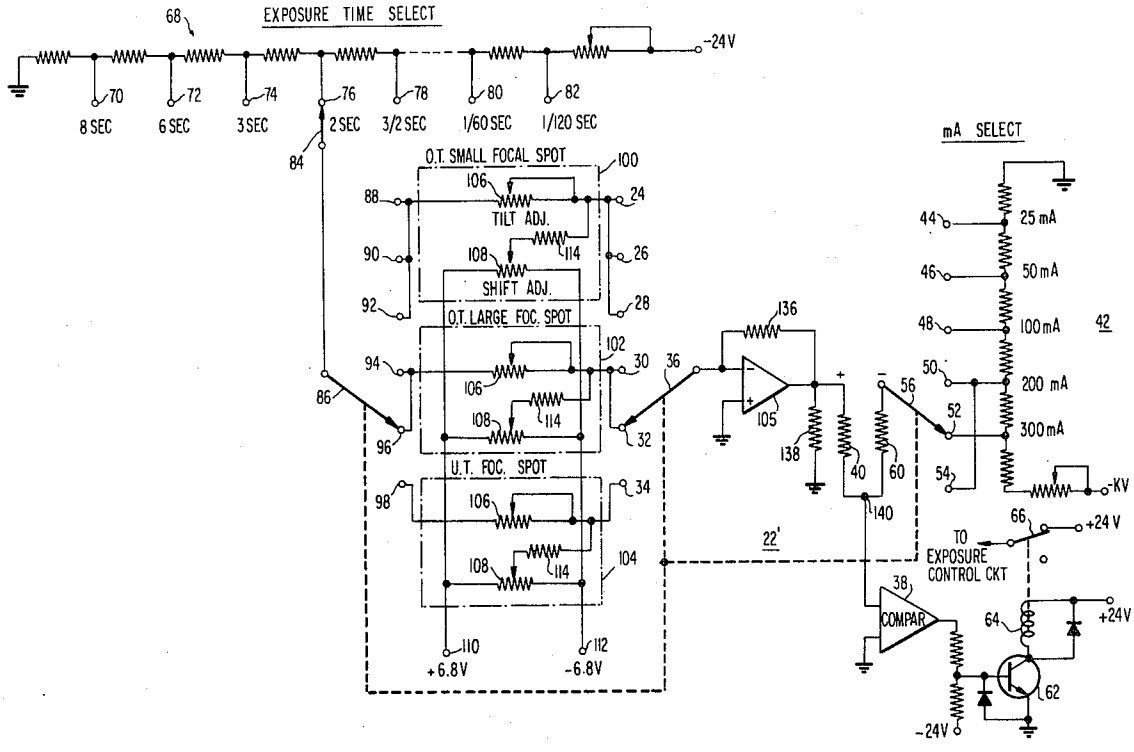
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Primary Examiner—James W. Lawrence
Assistant Examiner—D. C. Nelms
Attorney, Agent, or Firm—Brady, O'Boyle & Gates

[57] **ABSTRACT**

An X-ray tube protective circuit wherein the selected exposure time and X-ray tube power are compared prior to operation to determine whether or not a condition exists which exceeds the anode rating of the tube and thereafter prevents operation in the event that such condition does exists while permitting an X-ray exposure for a safe condition. The protective circuit utilizes a single empirically derived anode "rating chart" curve which is representative of a generalized or standard X-ray tube rating chart curve. This empirical curve is generated by a series connected string of resistors connected to the exposure time select switch. This curve is then tilted and/or offset for selected operating modes in order to substantially conform to the acual rating curve for the respective various focal spot sizes and anode speeds of the particular X-ray tube in use.

10 Claims, 5 Drawing Figures



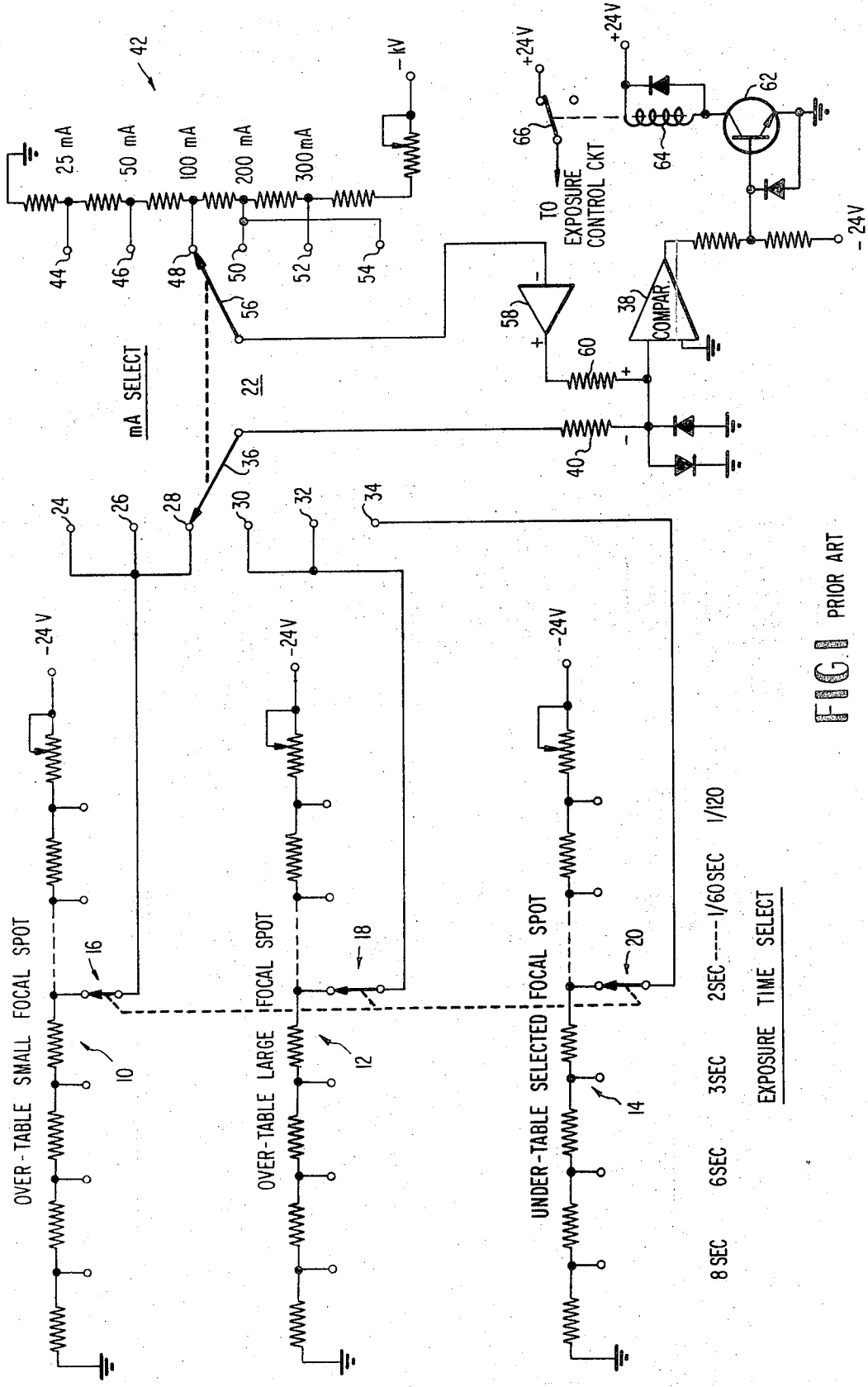


FIG. 1 PRIOR ART

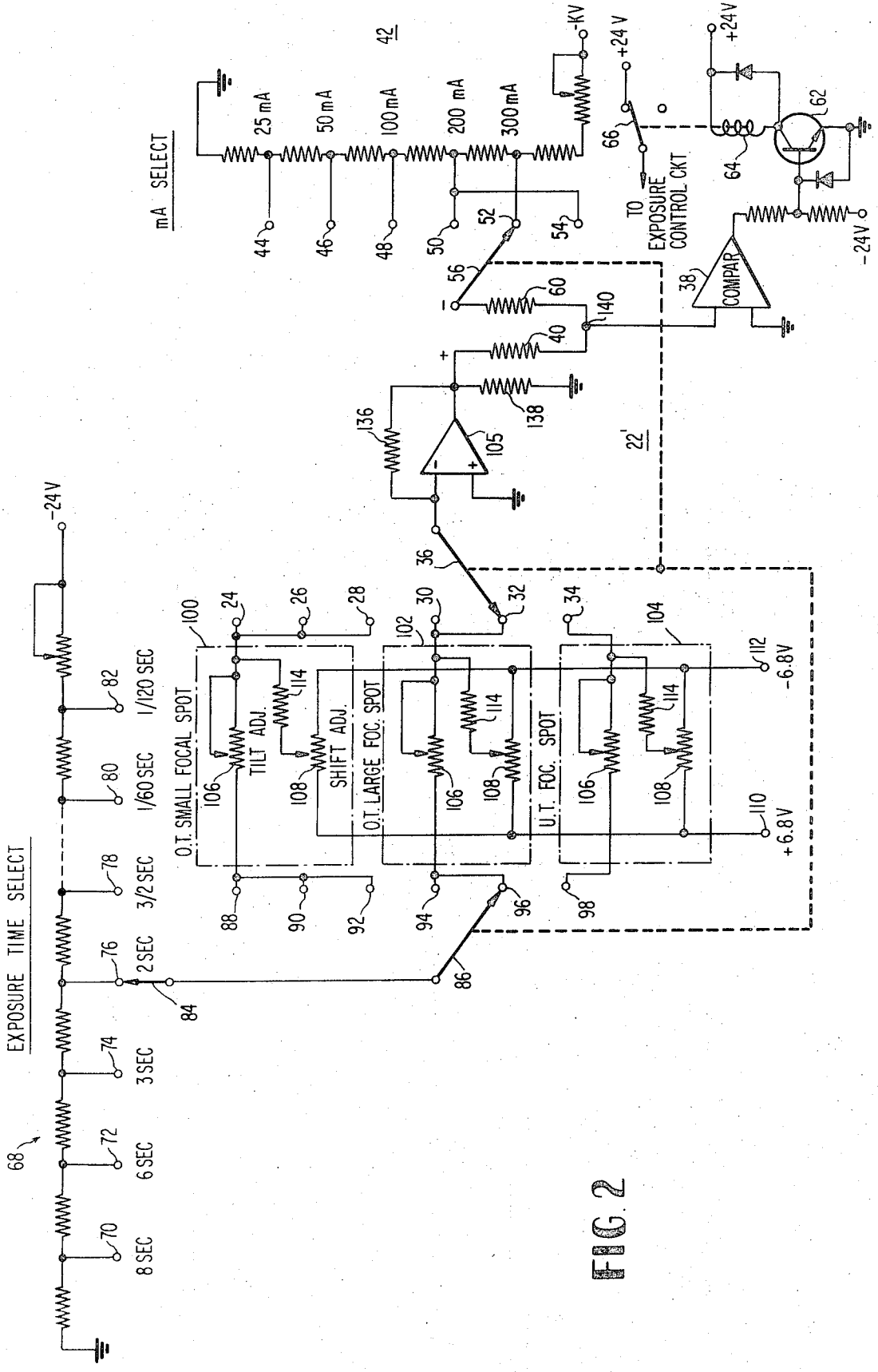

mA SELECT
25 mA
50 mA
100 mA
200 mA
300 mA
42
-KV
+24 V
66
TO EXPOSURE CONTROL CKT
+24 V
62
64
-24 V
COMPAR
38
44
46
48
50
52
54
56
60
140
40
138
136
105
22'
36
32
O.T. SMALL FOCAL SPOT
TILT ADJ.
SHIFT ADJ.
O.T. LARGE FOC. SPOT
U.T. FOC. SPOT
24
26
28
30
34
100
102
104
106
108
114
112
-6.8V
110
+6.8V
88
90
92
94
96
98
86
84
EXPOSURE TIME SELECT
-24 V
68
70
72
74
76
78
80
82
8 SEC
6 SEC
3 SEC
2 SEC
3/2 SEC
1/60 SEC
1/120 SEC

FIG. 2

FIG. 3

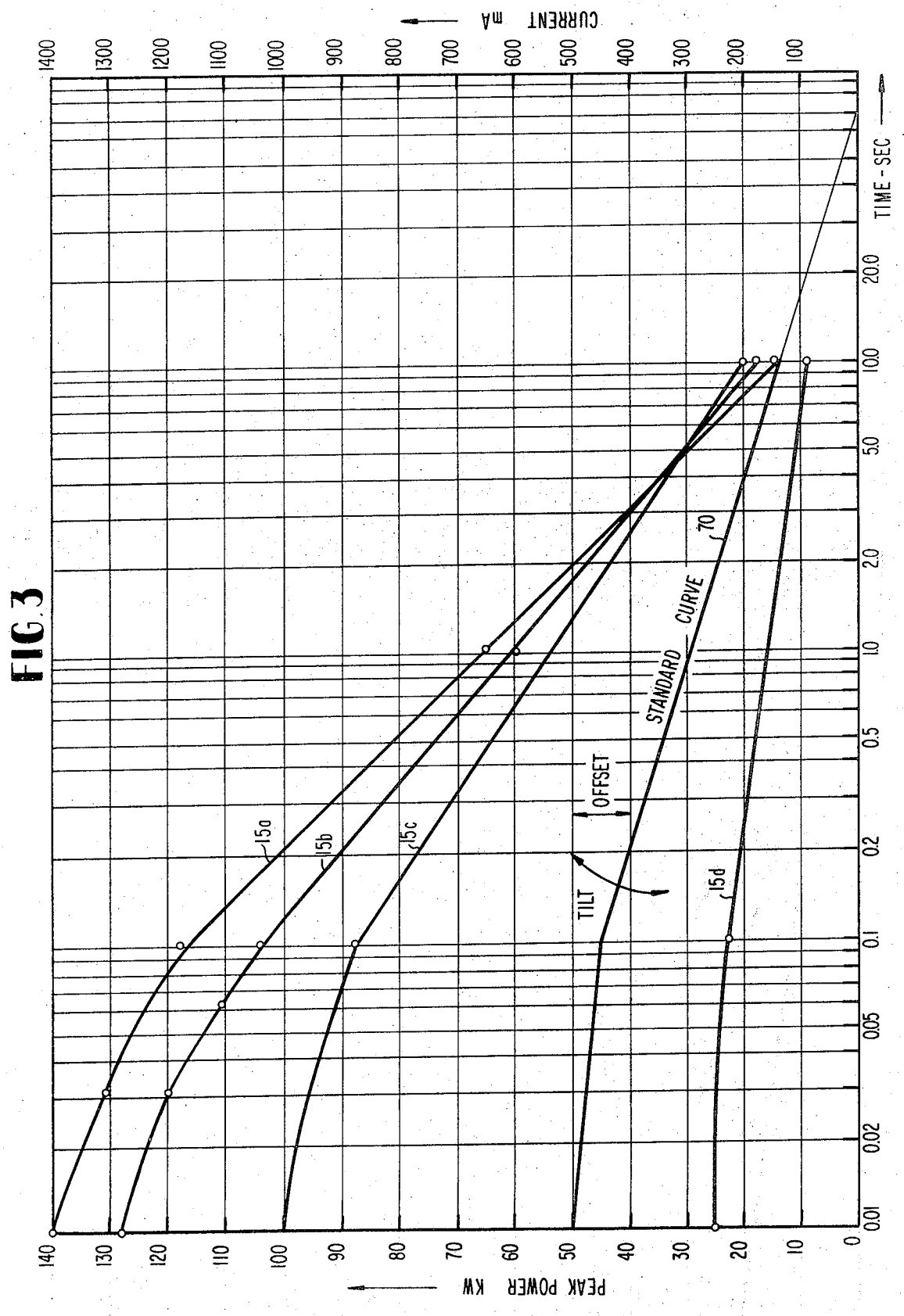

CURRENT mA
1400
1300
1200
1100
1000
900
800
700
600
500
400
300
200
100
TIME - SEC
20.0
10.0
5.0
2.0
1.0
0.5
0.2
0.1
0.05
0.02
0.01
0
PEAK POWER KW
140
130
120
110
100
90
80
70
60
50
40
30
20
10
15a
15b
15c
15d
70
STANDARD CURVE
OFFSET
TILT

FIG. 4

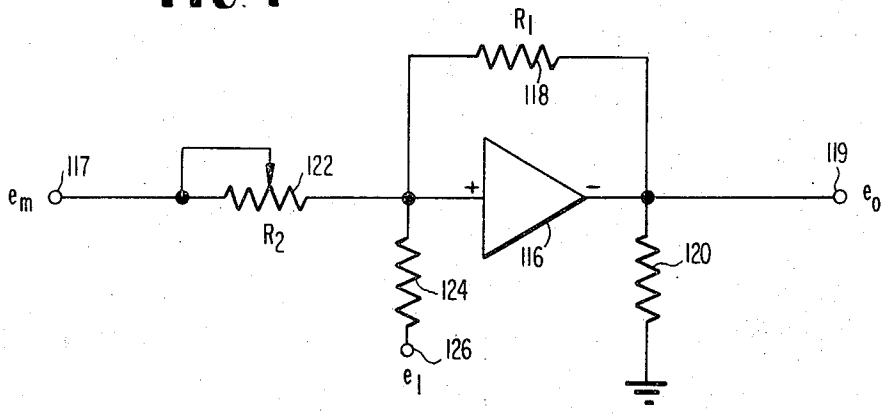
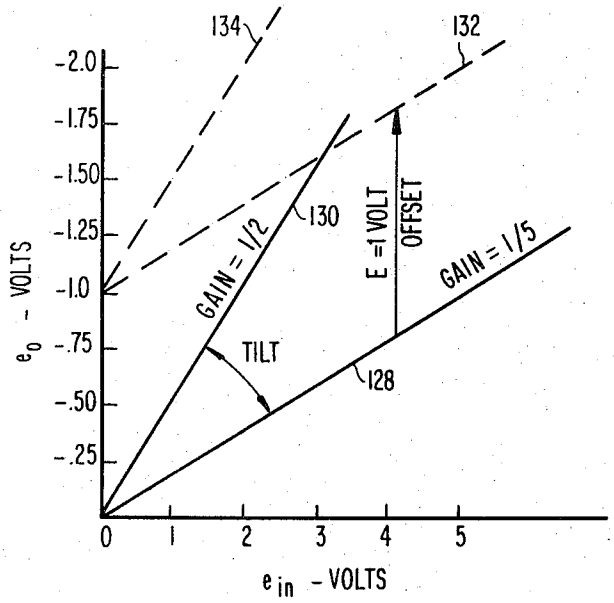

R1
118
117
em
122
R2
119
eo
+
-
116
120
124
126
e1

FIG. 5


134
132
-2.0
-1.75
-1.50
-1.25
-1.0
-.75
-.50
-.25
eo - VOLTS
GAIN = 1/2
130
E = 1 VOLT
OFFSET
GAIN = 1/5
TILT
128
0
1
2
3
4
5
ein - VOLTS

X-RAY TUBE ANODE PROTECTIVE CIRCUIT

BACKGROUND OF THE INVENTION

1. Field of the Invention

This invention relates to X-ray apparatus and more particularly to an electrical system for automatically preventing X-ray exposures under overload conditions.

2. Description of the Prior Art

Modern, high power, X-ray tubes normally include a tungsten filament encased in a cathode cup which is mounted a short distance away from a rotating tungsten anode. The anode, in turn, is connected to a motor armature and bearing assembly with the entire structure mounted within the glass envelope of the X-ray tube. The tube is placed such that the motor armature and that portion of the glass envelope surrounding it are within the motor stator winding. When the stator winding is energized, the anode rotates so that during the X-ray exposure, new areas of the anode are brought within the electron beam cross section. The thermal capacity of the tube, i.e., the maximum X-ray exposure possible without damage to the anode, is determined by the energy level per exposure which is a function of the peak power expressed in terms of voltage (kV) and current (mA) and the exposure time in seconds (sec.), the area on the anode subtended by the electron beam as well as the shape, and finally the speed of rotation of the anode.

In an effort to obtain the maximum output per exposure of a particular X-ray tube, the manufacturer attempts to rate the respective tube at the maximum possible value per exposure such that the anode is brought almost to the point of melting during each X-ray exposure. In order to do this, the manufacturer publishes curves called "rating charts" which describes the maximum exposure for a particular X-ray tube under the various conditions of operation. Such a curve is plotted as a function of time versus the anode current (mA) for different high voltage potentials (kV) applied to the anode of the X-ray tube. For a given anode potential the same curve can represent time versus peak power by simply multiplying the mA coordinate by the potential.

Prior art protective circuits provide a control circuit which is responsive to analog voltages which, in turn, are functions of the desired power level and the exposure time duration, respectively, being then operative to compare the manual settings with predetermined and known maximum safe values allowed by the tube "rating chart" curve for the particular X-ray tube employed. These analog voltages are developed by means of suitable power supply voltages feeding two separate voltage dividers, one of which corresponds to X-ray tube power while the other corresponds to exposure time. If the X-ray generator operates with two X-ray tubes and if each X-ray tube has two different focal spot sizes, and further if the X-ray tube anodes are permitted to rotate at two different speeds, separate voltage dividers or switch decks for exposure time (eight in number) would be required to be mounted on the X-ray exposure time switch in order to simulate each "rating chart" curve for the particular mode of operation.

In U.S. Pat. No. 3,290,596 issued to J. Bougle, it was recognized that in the case of several X-ray tubes, rating charts relating to each focus may be resolvable in logarithmic coordinates into a number of straight lines and may be deduced from one another by simple translation according to the axis of the coordinates.

The present invention also recognizes the similarity in shape of the various "rating charts" for X-ray tubes but also recognizes the fact that a simple translation i.e., shifting of one simulated curve will not duplicate substantially all of the required curves, due to the fact that in some cases the slopes as well as the offset of the various curves differ widely.

SUMMARY

Accordingly, it is an object of the present invention to provide an improved anode protective circuit, which eliminates the need for multiple voltage divider switch decks, ganged on the shaft of the exposure time switch, requiring replacement when one type of X-ray tube is substituted for another. Briefly, the invention comprises a single resistive voltage divider, simulating an empirically derived standard or generalized "rating chart" curve, fabricated as a single switch deck coupled to the exposure timing switch. An operational amplifier and a plurality of like circuits for both varying the gain and an input offset bias potential of the operational amplifier for each selected operating mode are individually coupled to the voltage divider switch deck for tilting and shifting the generalized curve in order to correspond to the actual curve required for the selected mode of operation. The output of the operational amplifier is then fed into a comparator circuit which additionally receives an input corresponding to the selected power level. The comparator determines whether or not a harmful condition exists and in the event such occurs, due to the operator selection of power and time of exposure, it energizes a relay to prevent an X-ray tube exposure. Each of the circuits for varying the gain of the operational amplifier comprises a variable resistance connected in series between the voltage divider and the inverting input of the operational amplifier and a potentiometer coupled across a source of constant potential providing a selected bias to the inverting input of the operational amplifier. Thus the characteristic of a single voltage divider is electrically tilted and/or offset thereby replacing the multiple switch decks heretofore required not only aiding installation but future maintenance procedures as well.

BRIEF DESCRIPTION OF THE DRAWINGS

FIG. **1** is an electrical schematic diagram illustrative of a typical prior art anode protective circuit;

FIG. **2** is an electrical schematic diagram illustrative of the preferred embodiment of the subject invention;

FIG. **3** is a graph illustrative of several selected X-ray tube "rating charts" helpful in understanding the operation of the subject invention;

FIG. **4** is an electrical schematic diagram illustrative of a portion of the circuitry shown in FIG. **2**, being helpful in understanding the operation of the subject invention; and

FIG. **5** is a graph illustrative of the operation of the circuit shown in FIG. **4**.

DESCRIPTION OF THE PREFERRED EMBODIMENT

Referring now to the drawings wherein like reference

characters refer to like parts throughout, attention is directed to FIG. 1 which is illustrative of a prior art X-ray tube anode protective circuit of which the present invention is an improvement thereon. The circuitry disclosed in FIG. 1 includes means for manually selecting a plurality of X-ray exposure times expressed in seconds and peak power expressed in terms of anode current (mA). The exposure time select means couple to a plurality of resistive voltage dividers **10, 12,** and **14** which are electrical analogs of the respective "rating charts" for each operational mode for the one or more X-ray tubes, not shown. Such curves are shown for purposes of illustration in FIG. 3 by reference numerals 15_a, 15_b, 15_c and 15_d. For example, where two separate tubes are utilized, one for over-table use and having both a small and a large focal spot operating modes and another tube for under-table use having a selected focal spot size, the three resistive voltage divider networks **10, 12,** and **14** are coupled across a fixed voltage supply (−24 volts) and each has a plurality of voltage taps connected to fixed switch contacts of respective rotary switches **16, 18** and **20** with the taps mechanically corresponding to selectable exposure times of 8 seconds, 6 seconds ... one-sixtieth second, one-twentieth second, etc. The voltage at each tap, however, is representative of the corresponding allowable peak power of the appropriate rating chart curve. The switch **16** permits selection of the exposure time and the corresponding allowed peak power as indicated from the respective rating chart curve for the over-table small focal spot mode of the first tube, while switch **18** is operable for the over-table large focal spot mode of the first tube. The switch **20,** on the other hand, is adaptable to select allowed peak power voltage signals corresponding to the plurality of exposure times for the under-table focal spot mode of the second tube. The movable contact of the switches **16, 18** and **20** are selectively connected to fixed contacts of one section of a two section ganged manually operable X-ray tube current (mA) select switch **22.** More particularly, the movable contact of time select switch **16** is commonly connected to fixed switch contacts **24, 26** and **28** while the movable contact of switch **18** is connected to fixed contacts **30** and **32.** The movable contact of switch **20,** on the other hand, is connected to the single fixed contact **34.** The movable contact **36** of switch **22** is coupled to the non-inverting input of a voltage comparator circuit **38** by means of a fixed resistor **40.** The other input of the comparator **38** is grounded. Thus the three upper positions of the switch **22** are adapted to couple analog voltages of the selected exposure time and the corresponding allowed peak power from the voltage divider **10** to the comparator **38** while two positions of the switch **22** are adapted to select voltages from voltage divider **12.** The remaining position is adapted to provide selected voltages from voltage divider **14.** As noted, each of the voltage dividers **10, 12** and **14** provide an electrical analog of the operating characteristic of a particular X-ray tube and operating mode. This characteristic, as provided from the tube manufacturer's rating charts can be graphed, for example as shown by FIG. **3,** and calculations made therefrom to provide the necessary resistance values for the required exposure times for each voltage divider network. Moreover, the movable contact of switches **16, 18** and **20** are ganged together on the same shaft of the X-ray exposure time switch, not shown, and as such the voltage dividers are arranged as switch decks which must be changed when changing from one tube type to another.

The tube rating charts also take into account peak power. An analog circuit for this variable is provided by the single resistive voltage divider network **42** coupled across the X-ray tube high voltage potential (kV) which is held constant. A plurality of voltage taps corresponding to selectable values of anode current (mA) terminate in the fixed contacts **44, 46, 48, 50, 52** and **54** of the other section of the switch **22** which is defined as the mA select switch. The movable contact **56** thereof is mechanically coupled to movable contact **36** such that when movable contact makes electrical connection with fixed contact **44,** movable contact **36** makes electrical contact with fixed contact **24.** It can be seen, therefore, that as the mA select switch **22** is moved between the upper three positions, corresponding to 25mA, 50mA and 100mA, voltages corresponding to selected exposure time and peak power can only be taken from resistance voltage divider **10** corresponding to the over-table focal spot mode. In the same manner, mA switch positions for 200mA and 300mA select voltage divider network **12,** while voltage divider network **14** operates in conjunction with the last position of the switch providing 200mA. It should be pointed out that the voltages appearing at the mA switch contacts **44, 46,** etc. correspond to power inasmuch as the kV potential is applied across the resistive voltage divider is constant, taking note of the fact that power is equal to the product of the anode current (mA) and anode voltage (kV).

The movable contact **56** of the mA select switch **22** is coupled to an inverter amplifier **58** whose output is connected to the common connection with resistor **40** by means of fixed resistor **60** which has the same ohmic value as resistor **40.** The purpose of the inverter amplifier **58** is to provide a positive (+) polarity voltage to the input of the comparator **38** inasmuch as a negative polarity high voltage (kV) is applied to the voltage divider **42** and since the fixed supply potential coupled across the voltage dividers **10, 12** and **14** is of a negative polarity thereby providing a negative potential to the resistor **40.**

In operation, the circuit values are selected so that the voltages corresponding to the selected exposure time and the anode current or peak power are compared, the one voltage being of a negative polarity, and the other being of positive polarity. Since they are commonly applied through resistors **40** and **60** to the comparator **38** an algebraic summation takes place yielding a resultant voltage. If this voltage is at some positive value, an output will be provided which would be of proper polarity to cause transistor **62** to become conductive and energize a relay coil **64** which in turn operates a set of relay contacts **66** for opening or deactivating an X-ray exposure control circuit, not shown. In the event that the resultant input to the comparator **38** is of a negative polarity, an output is provided which will not cause transistor **62** to conduct and not energize relay coil **64** to open the relay contact **66.**

Thus when the operator selects the tube in the mode of operation desired, the appropriate switch deck including the required voltage divider **10, 12** or **14** is selected by a relay arrangement, not shown. When the exposure time is set, a voltage is selected from that deck and compared to the voltage associated with the

selected electron beam current of the X-ray tube. The voltages are then compared and an X-ray exposure is either permitted or forbidden as a function of whether the selected power exceeds the anode rating of the tube or whether it is within bounds.

As noted above, the switching decks including the voltage dividers must be selected for each X-ray tube focal spot and operating characteristics. In the field, if it is necessary to change from one tube type to another, the appropriate switching decks must also be changed. Now turning attention to the subject invention and more particularly to FIG. **3**, there is shown semilog plots of several rating chart curves from which it is observed that most tube characteristics have a substantially straight line characteristic extending from the region of 0.2 seconds to 10 seconds with a bend in the curve in the region of 0.1 seconds. While the Bougle patent U.S. Pat. No. 3,290,596 recognized that in the case of several different tubes rating charts relating to each focus may be deduced from one another by simple translation; however, FIG. **3** further indicates that the slope of various rating chart curves differ as well as being offset from one another. The present invention recognizes this latter fact and provides a single empirically derived resistive voltage divider network or switch deck **68** activated by the exposure time select mechanism to provide substantially a log function voltage characteristic with respect to time in order to provide an electrical analog of a standard or generalized curve such as shown in FIG. **3** and denoted by reference numeral **70.** The electrical voltage divider characteristic of the switch deck **68** is effectively tilted and/or shifted (offset) for each X-ray tube and focal spot as well as any other operating parameter which calls for a separate tube rating chart curve in order to substantially match a curve for the instant operating condition. More particularly, the voltages selected from the fixed switch contacts **70, 72, 74, 76, 78, ... 80** and **90** and corresponding to desired exposure time, are fed by means of the movable switch contact **84** to the movable contact **86** of one section of a three section mA select switch **22'**. The switch section additionally includes fixed switch contacts **88, 90, 92, 94, 96** and **98,** while the other two sections correspond to the mA select switch configuration shown by reference numeral **22** in FIG. **1.** Whereas FIG. **1** disclosed three voltage divider switch decks **10, 12** and **14** for the three separate modes of operation, the circuit configuration shown in FIG. **2** includes three sets of resistive circuit means **100, 102** and **104** which are individually connected to the input of a feedback voltage amplifier **105** between the comparator circuit **38** and the single standardized voltage divider switch deck **68.** Each of the circuit means **100, 102** and **104** is identical and is comprised of a variable resistance or rheostat **106** coupled in series to one (−) input of the amplifier **105** through the switch contact **36** as well as a resistor potentiometer **108.** The potentiometer is coupled across a fixed supply potential (+6.8^v and −6.8^v) applied to circuit terminals **110** and **112** with the slider of the potentiometer **108** being coupled to the same (negative) input of the operational amplifier by means of a fixed resistor **114** through the second section of the mA select switch **22'** including the movable contact **36.** The circuit **100** is used for the over-table small focal spot mode and is adapted to be selected by the upper three switch positions of switch **22'** which also select voltages corresponding to 25mA, 50mA and 100mA of the voltage divider network **42** while circuit **102** is utilized for the over-table large focal spot mode associated with the 200mA and 300mA switch positions. And finally, the single under-table focal spot mode operable with the 200mA select position of switch **22'** utilizes circuit **104.**

Since circuits **100, 102** and **104** are identical in circuit configuration, the operation of one of the circuits in relation to the feedback amplifier **105** will suffice for the other two. The variable resistor **106** varies the operating characteristic (gain) of the amplifier **106** to effectively tilt the voltage divider characteristic of the switch deck **68** whereas the potentiometer **108** acts to provide a shift or offset of the analog function of the rating chart curve by providing a DC input bias voltage to the amplifier. This can best be understood by referring now to FIG. **4** wherein a hypothetical electrical operational amplifier **116** is disclosed coupled between input and output terminals **117** and **119,** respectively. The operational amplifier **116** includes a feedback resistor **118,** an output resistor **120,** a variable resistor **122** in series between the input terminal **117** and the amplifier **116** and a resistor **124** connected between the input of amplifier **116** and a terminal **126** which is adapted to receive a bias voltage e_1. Assuming that the operational amplifier is of the inverting type, reference to FIG. **5** illustrates the transfer characteristic of such a circuit as shown in FIG. **4.** The voltage gain which comprises the ratio of e_0/e_{in}, assuming an infinity gain amplifier **116,** is determined by the ohmic values of the fixed resistor **118** and **122,** i.e., R_1/R_2. If for example the ratio of R_1/R_2 is 1/5, a transfer characteristic such as shown with respect to the linear portion of the curve **128** of FIG. **5** will be provided. If the value of the resistance **122,** however, is reduced wherein R_1/R_2 is equal to 1/2, the characteristic becomes steeper such as shown by the curve portion **130** thereby effecting a tilt of the transfer characteristic. If the bias voltage applied to terminal **126** of FIG. **4** is at zero or ground potential, the curves **128** and **130** shown in FIG. **5** will pass through the origin as shown; however, if a + 1.0 volt bias potential is applied to terminal **126,** the output voltage e_0 will be shifted or offset accordingly, such as shown with respect to lines **132** and **134.** Thus, by varying the ohmic value of resistance **122,** a tilt of the transfer characteristic of the amplifier **116** can be effected whereas the application of a suitable bias potential applied to terminal **126** can effect an offset of the transfer characteristic.

Referring now back to FIG. **2,** the variable resistance **106** corresponds to the variable resistance **122** of FIG. **4** while resistor **144** corresponds to the resistor **124.** In a like manner, a feedback resistor **136** in FIG. **2,** corresponds to resistor **118** in FIG. **4** and resistor **138** corresponds to the output resistor **138.** In operation, when an X-ray tube is changed or its mode of operation altered such as changing focal spot sizes, it is not now necessary to change the resistive voltage divider switch deck as required by the prior art but rather it is only necessary to suitably adjust the resistances **106** and/or **108** of circuits **100, 102** or **104** to effectively change the slope and/or offset of the characteristic of the voltage divider **68** for each new rating chart curve as required. Thus the analog of a single standard rating chart curve is selectively adjusted for each operating mode by means of respective adjustment of the rheo-

stat **106** and potentiometer **108.** By a manual preselection of desired anode current, a particular negative potential will appear at the movable contact **56** which is coupled to a summing point **140** by means of resistor **60.** The setting of the mA select switch **22'** will also cause movable switch contact **86** and **36** to make a corresponding connection with associated fixed switch contacts. Now a preselection of a desired exposure time will couple a negative voltage from a fixed contact **70 ... 82** to the input of the operational amplifier **105** and modified by the action of the elements **106** and **108** to provide a positive output potential which is coupled to the summing point **140** by means of fixed resistor **40.** The comparator **38** is now operable such that if summation of the voltages at summing point **140** is some negative value, the output thereof will cause transistor **62** to conduct and open relay contact **66.** On the other hand, if the voltage at summing point **140** comprises a positive potential greater than zero, the comparator output will not cause transistor **62** to conduct. Relay contacts **66** therefore remain closed.

In summation, therefore, the subject invention is directed to the improvement of providing a voltage amplifier with selective gain and bias adjust means coupled between selective voltage taps of an exposure time select voltage divider deck and a comparator to which is also applied voltage corresponding to the desired anode current. The analog voltage corresponding to the selected exposure time and the anode current are respectively of opposite polarity which are summed and the resultant voltage therefrom being adapted to operate circuit means which either allow or disallow an X-ray exposure.

Having disclosed what is at present considered to be the preferred embodiment of the subject invention,

We claim:

1. X-ray tube anode protective circuitry including circuit means being operated by the output of a comparator circuit which compares selected values of analog voltages representative of X-ray tube rating chart curves for preventing energization of the X-ray tube in the event preselected operating parameters are outside of the ratings of the X-ray tube, comprising the combination of:

a supply voltage;

a single voltage divider network, for multiple operational modes having respective different rating chart curves for at least one X-ray tube, coupled across said supply voltage and having a current-voltage characteristic adapted to simulate a generalized rating chart curve which is a function of a plurality of exposure times and providing a plurality of voltage points corresponding to allowable peak power for said exposure times;

first switch means having a movable contact and a plurality of fixed contacts respectively connected to said plurality of voltage points on said voltage divider;

a voltage amplifier having an input and output and including circuit means coupling the output of said amplifier to the input of said comparator circuit;

a plurality of first circuit means, each respectively adapted to vary the signal transfer characteristic of said voltage amplifier, selectively coupled between the input of said amplifier and the movable contact of said first switch means for each of said multiple operational modes whereby the output of said amplifier provides an output simulating the actual rating chart curve for the selected multiple operational mode;

an X-ray anode supply voltage;

a second voltage divider network coupled across said anode supply voltage and providing a plurality of voltage points proportional to the product of X-ray anode voltage and beam current of the X-ray tube; and

second switch means having a movable switch contact and a plurality of fixed contacts selectively connected to said plurality of voltage points of said second voltage divider network and additionally including second circuit means coupling the movable contact of said second switch means to the input of said comparator circuit whereby the resultant voltage at said input of said comparator comprises a signal input which is a function of the preselected operating parameters.

2. The protective circuitry as defined by claim **1** and additionally including switch means operable in conjunction with said second switch means, selectively coupling said plurality of first circuit means to the input of said amplifier.

3. The protective circuit as defined by claim **1** wherein each of said first circuit means includes means for selectively varying at least the gain of said amplifier.

4. The protective circuit as defined by claim **3** wherein said voltage amplifier comprises a feedback amplifier including an impedance coupled between its input and output, and said means for selectively varying the gain of said amplifier comprises a variable impedance coupled in series between the input of said amplifier and said movable switch contact of said first switch means.

5. The protective circuitry as defined by claim **4** and additionally including circuit means in each said first circuit means for providing a bias voltage to the input of said amplifier for further varying the signal transfer characteristic of said amplifier.

6. The protective circuitry as defined by claim **5** wherein said circuit means for providing a bias potential to the input of said amplifier comprises a second supply voltage and a potentiometer coupled across said second supply voltage, said potentiometer including a movable voltage tap coupled to the input of said amplifier.

7. The protective circuitry as defined by claim **5** and additionally including third switch means ganged with said second switch means, having a movable switch contact and a plurality of fixed contacts selectively connected to said plurality of first circuit means for varying the signal transfer characteristic of said amplifier, said movable switch contact of said third switch means being connected to the movable switch contact of said first switch means.

8. The protective circuitry as defined by claim **7** and additionally including fourth switch means ganged with said second and third circuit means, having a movable switch contact and a plurality of fixed contacts selectively coupled to the opposite end of said first circuit means for varying the signal transfer characteristic of said amplifier, said movable switch contact of said fourth switch means being coupled to the input of said amplifier.

9. The protective circuitry as defined by claim 1 and additionally including first resistor means coupling the output of said amplifier to the input of said comparator and second resistor means coupling the movable switch contact of said second switch means to said input of said comparator, said first and second resistor means being coupled at a common junction thereat.

10. The protective circuitry as defined by claim 1 wherein said first and second voltage divider networks are comprised of resistor divider networks.

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