

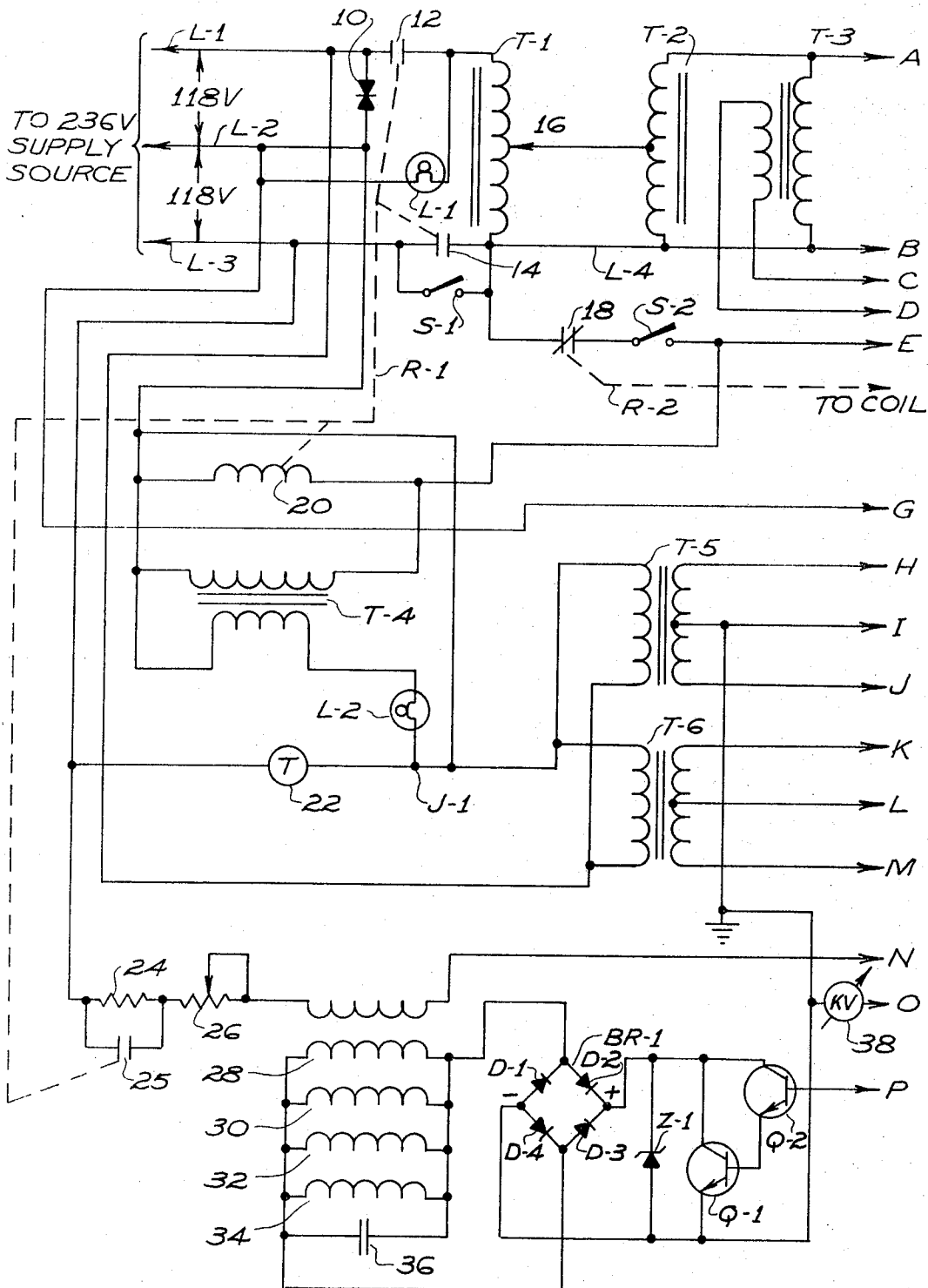


Fig. 1

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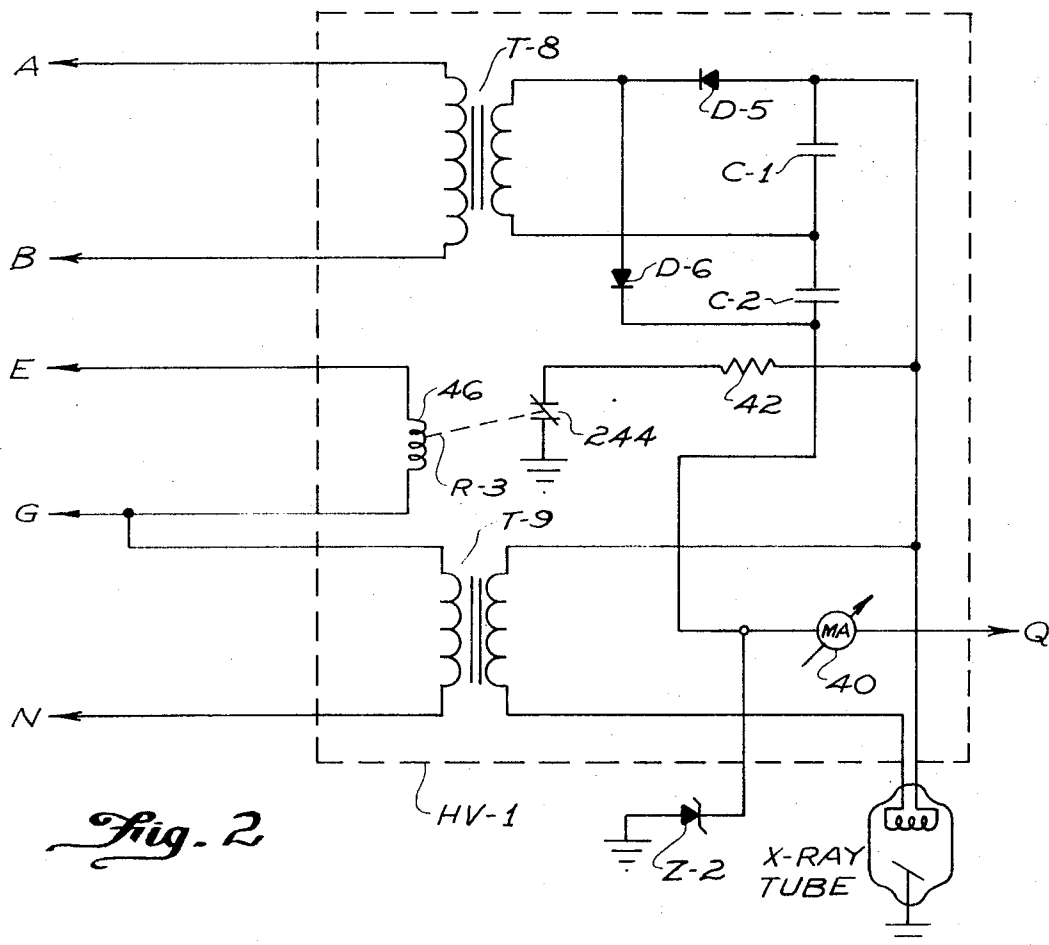


Fig. 2

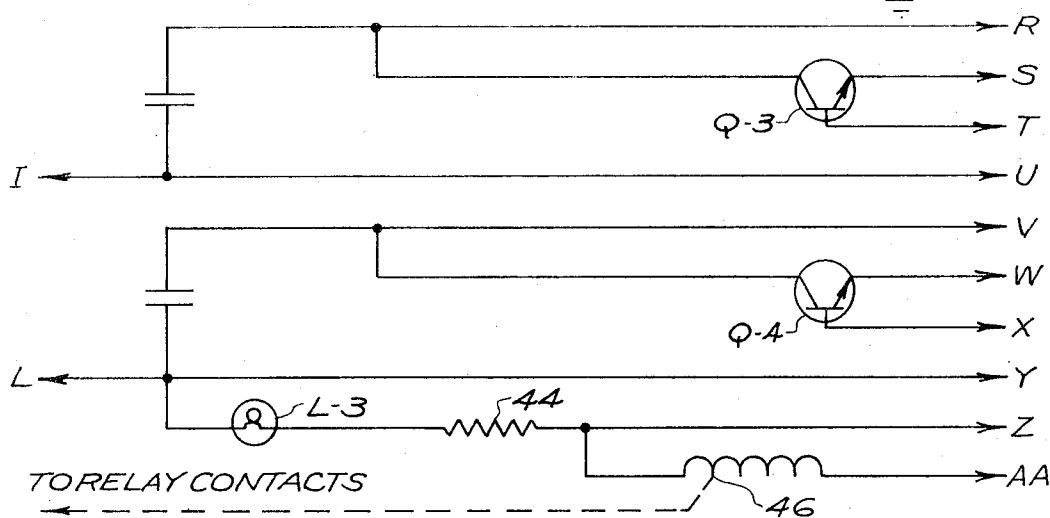


Fig. 2A

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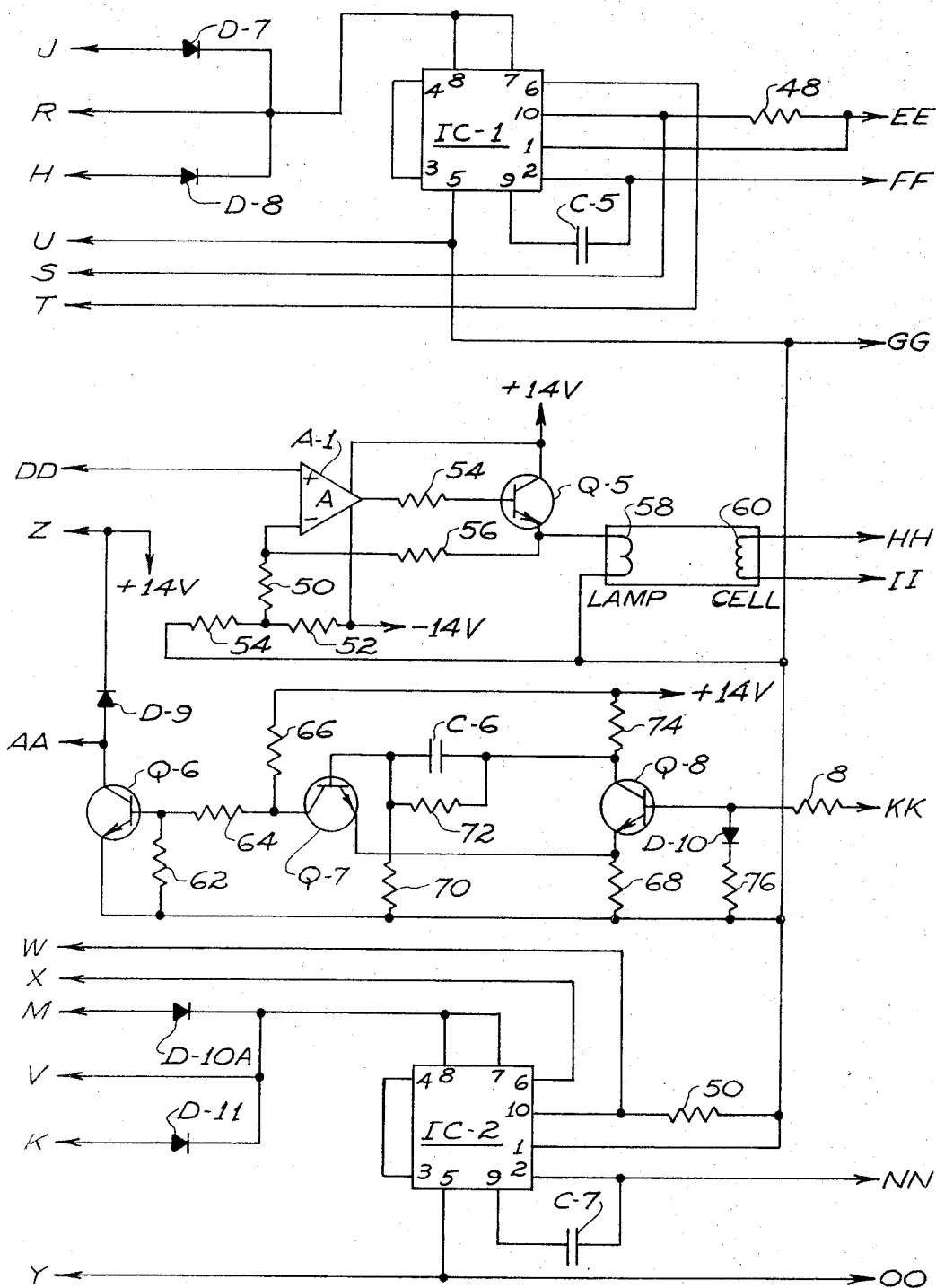


Fig. 3

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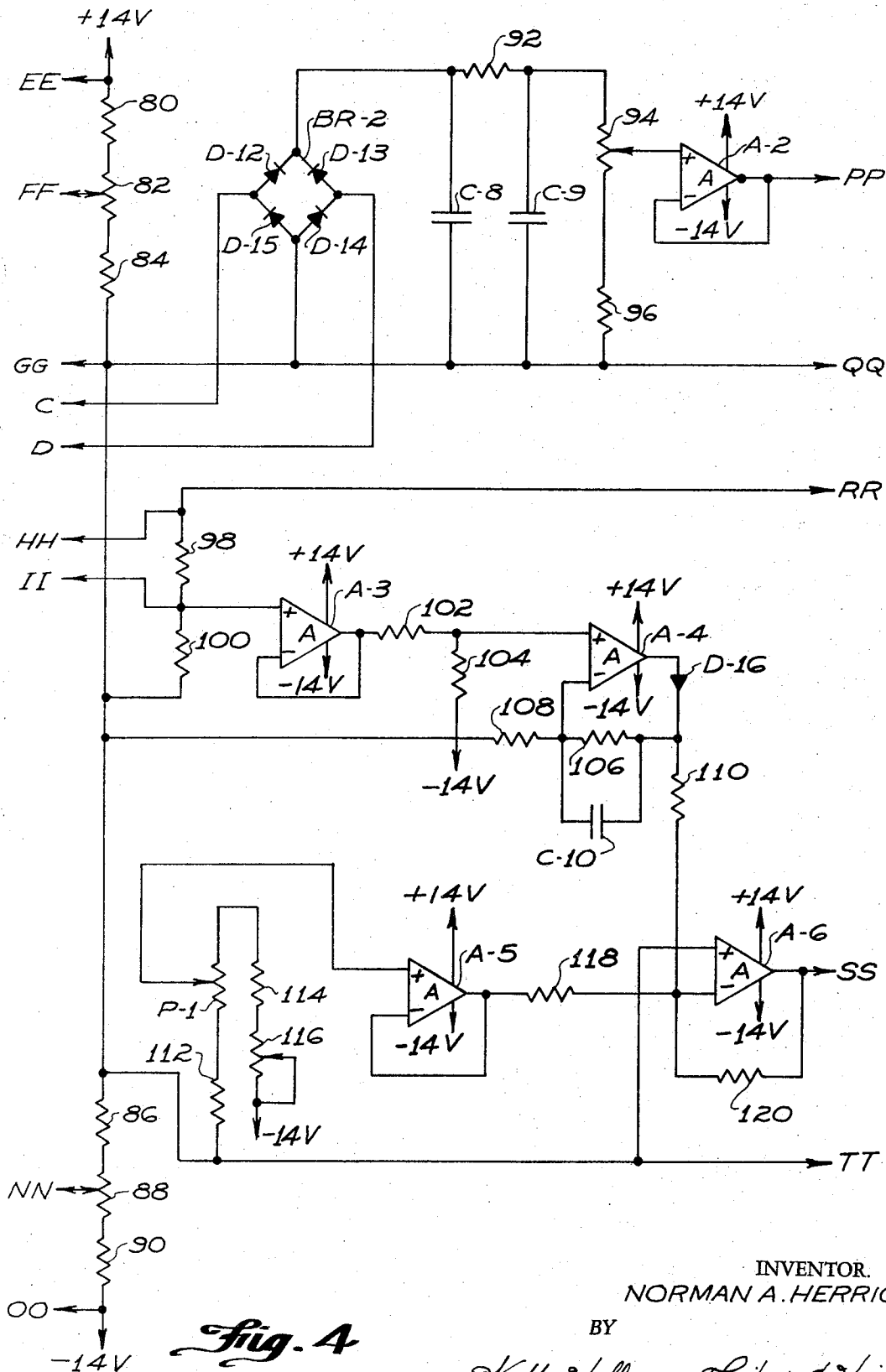


Fig. 4

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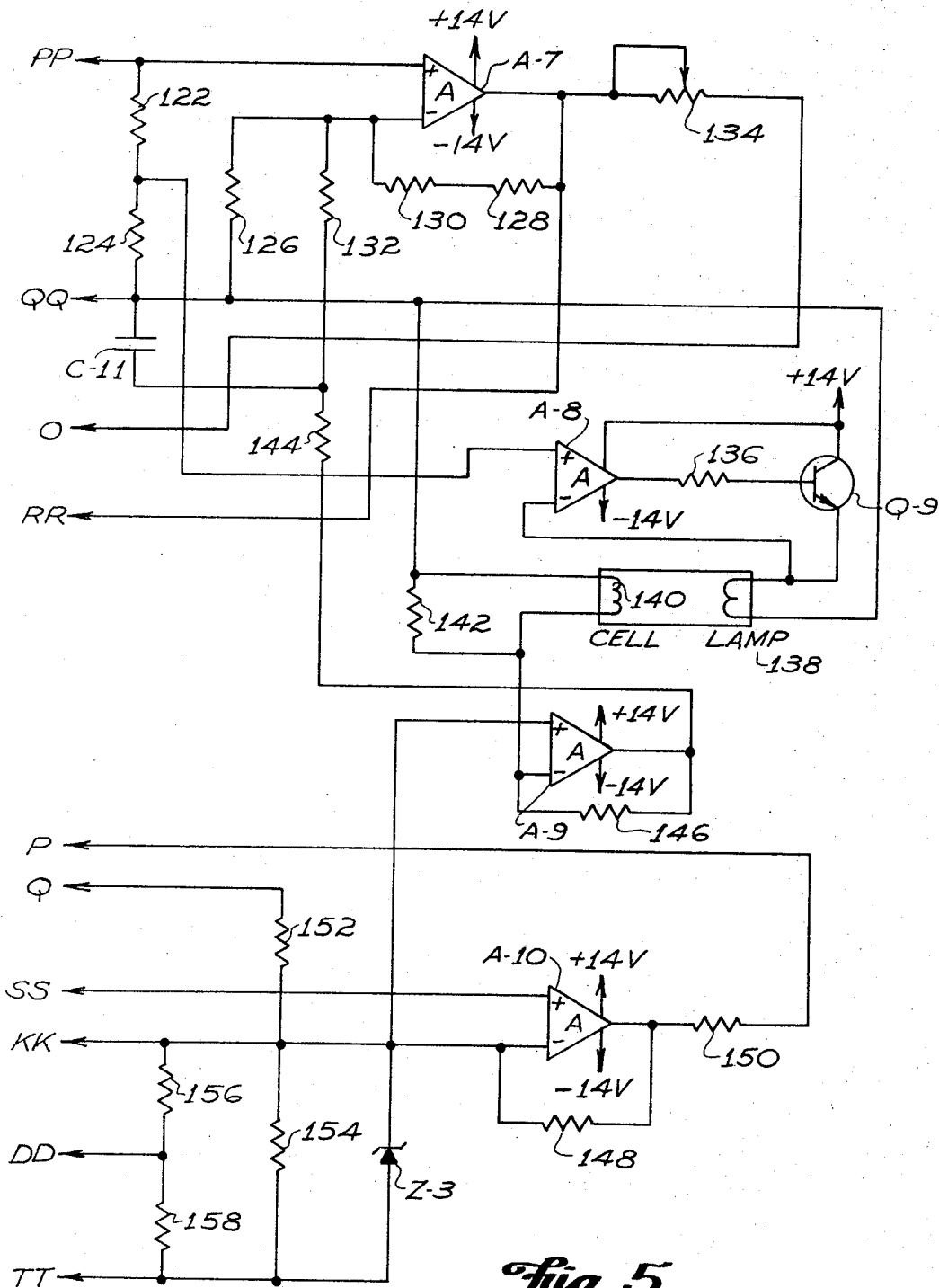


Fig. 5

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PROTECTIVE CIRCUIT FOR LIMITING THE INPUT POWER APPLIED TO AN X-RAY TUBE AND METHOD OF OPERATION

This is a continuation, of application Ser. No. 101,127, filed Dec. 23, 1970, now abandoned.

CROSS REFERENCES TO RELATED PATENT APPLICATIONS AND PATENTS

U. S. Pat. No. 3,631,527, issued Dec. 28, 1971 to Walter E. Splain, entitled "X-Ray Tube Kilovoltage Control System," and assigned to the same assignee as the present invention.

U.S. Pat. No. 3,746,862, issued July 17, 1973 to Walter E. Splain and Daniel F. Lombardo, entitled "Protective Circuit for X-Ray Tube and Method of Operation," 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 relates to the art of electrical circuits for limiting the value of the input power applied to an electronic device, and more particularly, to a protective circuit for preventing the input power applied to an X-ray tube from exceeding a predetermined level.

In the operation of X-ray equipment, if the input power applied to the X-ray tube exceeds a maximum tube rating, it is possible to damage the X-ray tube by localized melting of the target of the tube at the focal spot on the target.

The electrical energy dissipated at the focal spot of the X-ray tube target during an X-ray exposure depends upon three primary tube factors, to wit, anode peak kilovoltage, tube current in milliamperes, and the duration of the exposure. In the operation of certain types of X-ray equipment, it is necessary that the operator make certain mathematical computations to determine whether the values of the selected variables exceed a maximum tube rating.

In the operation of certain other types of X-ray equipment, protective circuits have been included to prevent the input power applied to the X-ray tube from exceeding a predetermined maximum power rating. In these latter types of X-ray systems, only a predetermined number of voltage, current, and exposure duration settings are available to the operator. Thus, even though the X-ray tube maximum input power characteristic curves take the form of stepless or smooth curves, exact settings may not be obtained because the variables must be adjusted in incremental steps. Obviously, as the number of incremental steps increases, there will be a correspondingly better match with the maximum input power characteristic curves, as well as more precise control over exposure and radiographic film density. To provide a system with a large number

of incremental steps in order to achieve better control, it has been necessary to resort to numerous rotary switches and relays, as well as complicated circuitry, to prevent the input power applied to the tube at each incremental step from exceeding a predetermined value.

Accordingly, in the operation of X-ray equipment, it is desirable that the operator have precise control over both the voltage and current applied to the X-ray tube.

It is also desirable that a tube protective circuit be included in the system to prevent the input power applied to the X-ray tube from exceeding a maximum tube 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 preventing the input power applied to an X-ray tube from exceeding a maximum tube rating, even though the voltage and current parameters are varied in accordance with stepless and smooth variations, thereby overcoming the noted disadvantages, and others, of such previous systems.

In accordance with one aspect of the present invention, there is provided an X-ray protective system for preventing the input power applied to an X-ray tube from exceeding a predetermined level. The system includes a first variable device for applying a voltage signal of a predetermined value to the X-ray tube, a second variable device for applying a current signal of a preselected value to the X-ray tube, a voltage monitoring circuit, and a current monitoring circuit. A multiplying circuit is coupled to the voltage and current monitoring circuits to thereby develop an output signal having a value representative of the value OF the mathematical product of the signals developed by the voltage and current monitoring circuits. In addition, a compensating circuit is coupled to the multiplying circuit for developing a control signal whenever the output signal from the multiplying circuit exceeds a predetermined value. An actuatable circuit is coupled to the compensating circuit for, upon receipt of the control signal, decreasing the value of the current signal applied to the X-ray tube to thereby prevent excessive input power from being applied to the X-ray tube.

In accordance with another aspect of the present invention, the multiplying circuit includes an impedance device having an input circuit for varying the impedance of the impedance device in accordance with the value of a signal applied to the input circuit, and an output circuit for developing an output signal having a value which varies in accordance with variations in the impedance of the impedance device. The input circuit of the impedance device is coupled to the current monitoring circuit so that the impedance varies in accordance with the value of the signal developed by the current monitoring circuit.

In accordance with another aspect of the present invention, the voltage monitoring circuit is coupled to the output circuit of the impedance device so that the signal developed by the output circuit varies in accordance with variations in the impedance of the impedance device, as well as with variations in the value of the signal developed by the current monitoring circuit.

In accordance with still another aspect of the present invention, the impedance device includes a source of

light coupled to the input circuit and a light sensitive device, such as a photocell, coupled to the output circuit and disposed to receive light energy emanating from the light source.

In accordance with another aspect of the present invention, the multiplying circuit develops an output signal having a value represented by the equation:

$$S_1 = (S_2) (S_3),$$

where S_1 equals the value of the output signal developed by the multiplying circuit. S_2 equals the value of the signal developed by the voltage monitoring circuit, and S_3 equals the value of the signal developed by the current monitoring circuit.

In accordance with another aspect of the present invention, there is provided a method of preventing the input power applied to an X-ray tube from exceeding a maximum tube input power rating. The method includes the step of applying a voltage signal of a preselected value to an X-ray tube, applying a current signal of a preselected value to the X-ray tube, developing a first signal having a value representative of the value of the applied voltage signal, and developing a second signal having a value representative of the value of the applied current signal. The method also includes the steps of developing an output signal having a value representative of the value of the mathematical product of the first and second signals, and decreasing the value of the power to be applied to the X-ray tube if the output signal exceeds a predetermined value.

In accordance with another aspect of the present invention, the method includes the step of decreasing the value of the current signal applied to the X-ray tube to thereby prevent excessive input power from being applied to the X-ray tube.

It is therefore an object of the present invention to provide a protective circuit for an X-ray tube for preventing the input power applied to the X-ray tube from exceeding a maximum power rating for the tube.

Another object of the present invention is to provide a protective circuit for an X-ray tube which continuously monitors the value of a voltage signal and a current signal applied to the X-ray tube as these signals are varied to prevent the resultant input power applied to the X-ray tube from exceeding a predetermined power level.

Another object of the present invention is to provide a protective circuit for an X-ray tube with an extremely fast response time for decreasing the input power applied to an X-ray tube to a safe level.

A further object of the present invention is to provide an X-ray tube protective system for monitoring continuously smooth variations in the voltage and current signals applied to the X-ray tube thereby eliminating the incremental step monitoring circuits known heretofore.

In accordance with a still further aspect of the present invention, there is provided an X-ray tube protective system with improved monitoring accuracy.

A further object of the present invention is to provide an X-ray tube protective system which monitors the input power applied to the X-ray tube even through the current and voltage signals applied to the tube are varied in accordance with smooth and continuous variations.

These and other objects and advantages of the invention will become apparent from the following description of a preferred embodiment of the invention as read

in conjunction with the accompanying drawings in which:

BRIEF DESCRIPTION OF THE DRAWINGS

FIGS. 1 through 5 are electrical schematic diagrams illustrating in detail the circuitry of the X-ray tube protective circuit of the present invention.

DESCRIPTION OF A PREFERRED EMBODIMENT

FIGS. 1 through 5 illustrate the electrical circuitry of an X-ray tube protective system which is generally comprised of an X-ray tube X-1, a Variac Tr-1 for controlling the voltage or kilovoltage signal applied to the anode-cathode circuit of the X-ray tube X-1, and a potentiometer P-1 for controlling the current or milliampere signal applied to the X-ray tube X-1.

More particularly, and with reference to FIG. 1, the X-ray tube protective system is supplied by a 236 volt, threephase, alternating-current supply source. Extending from the supply source are three supply lines L-1, L-2, L-3. Connected between the lines L-1, L-2 is a Thyrector 10. The supply line L-1 is also connected through a pair of normally-open relay contacts 12 of a relay R-1 to one of the terminals of the Variac T-1.

The supply line L-3 is connected through a pair of normally-open relay contacts 14 of the relay R-1 to an output terminal B, which is in turn connected to one of the terminals of an autotransformer T-2.

The tap of the autotransformer T-2 is connected to a movable contact 16 of the Variac T-1. The other terminal of the autotransformer T-2 is connected to one of the input terminals of a voltage sensing transformer T-3 and to an output terminal A, and the other input terminal of the voltage sensing transformer T-3 is connected to the output terminal B. The output terminals of the voltage sensing transformer T-3 provide a pair of output terminals C, D.

A warning lamp L-4 is connected between supply line L-2, and the junction point between the pair of relay contacts 12 and the terminal of the Variac T-1. The other terminal of the autotransformer T-2 is connected through a normally-open start switch S-1 to the supply line S-3. This terminal of the Variac T-1 is also connected through a pair of normally-closed relay contacts 18 to one of the terminals of a normally-open key switch S-2. The other terminal of key switch S-2 is connected to an output terminal E.

The output terminal E is connected to one of the terminals of a coil 20 of the relay R-1 and the other terminal of this coil is connected directly to the supply line L-2. The input terminals of a transformer T-4 are coupled in parallel with the relay coil 20, and one of the output terminals of this transformer is connected directly to the supply line L-2. The other output terminal of transformer T-4 is connected through an X-ray indicator lamp L-5 to a junction point J-1.

Connected between junction point J-1 and the supply line L-3 is a filament timer 22. The input terminals of a pair of transformers T-5, T-6 are connected in parallel across the junction point J-1 and the supply line L-1. Also, the supply line L-2 is connected directly to the junction point J-1. The terminals of the center tapped output windings of the transformers T-5, T-6, respectively, provide the output terminals H, I, J, K, L, M. Also, the center-tap terminal of transformer T-5 is connected directly to ground.

As illustrated in FIG. 1, the supply line L-3 is connected through a resistor 24 to one of the stationary terminals of a filament potentiometer 26. The other stationary terminal of the filament potentiometer 26 is connected directly to the movable terminal of this potentiometer and to one of the output terminals of a stabilizer transformer T-7. Connected across and in parallel with the resistor 24 is a pair of normally-open relay contacts 25 of the relay R-1.

The stabilizer transformer T-7 takes the form of a saturable transformer having four sets of input windings 28, 30, 32, 34, which are connected in parallel with each other. The other output terminal of stabilizer transformer T-7 provides the output terminal N.

Connected across the input terminals of the stabilizer transformer T-7 are the output terminals of a four-diode bridge rectifier circuit comprised of the diodes D-1, D-2, D-3, D-4. Also connected directly across the input terminals of the stabilizer transformer T-7 is a capacitor 36.

One of the input terminals of the diode bridge BR-1 is connected to the collector of an NPN transistor Q-2, and the other input terminal of the bridge is connected to the emitter of an NPN transistor Q-1. The base of transistor Q-1 is connected directly to the emitter of transistor Q-2, the collector of transistor Q-1 is connected directly to the collector of transistor Q-2, and the emitter of transistor Q-1 is connected to ground. Also, a zener diode Z-1, polarized as shown in FIG. 1, is connected from the emitter of transistor Q-1 to the collector of this transistor. In addition, the base of transistor Q-2 provides the output terminal P and the emitter of transistor Q-1 is connected directly to ground. The KV meter 38 is connected from ground to an output terminal O.

Reference is now made to FIG. 2 which generally illustrates the high voltage transformer circuit HV-1, as well as the circuit connected between this circuit and the X-ray tube X-1.

More particularly, the high voltage transformer circuit HV-1 includes a high voltage transformer T-8 having its input terminals connected to the output terminals A, B. One of the output terminals of the transformer T-8 is connected to the cathode of a diode D-5 and to the anode of a diode D-6. The other output terminal of transformer T-8 is connected through a capacitor C-1 to the anode of the diode D-5 and through a capacitor C-2 to the cathode of the diode D-6. The junction point between capacitor C-2 and the cathode of diode D-6 is connected through a milliamperemeter 40 to an output terminal Q and through a Zener diode Z-2, polarized as shown in FIG. 2, to ground. The junction point between the capacitor C-1 and the anode of diode D-5 is connected through a resistor 42 to one of the terminals of a pair of normally-closed relay contacts 44 of a relay R-3. The other terminal of the pair of relay contacts 44 is connected directly to ground. The relay R-3 includes a coil 46 having its input terminals connected to the output terminals E, G, respectively.

The input terminals of a high voltage filament transformer T-9 are respectively connected between the output terminals, G, N, and the output terminals of this transformer are connected across the filament terminals of the X-ray tube X-1. One of the output terminals of transformer T-9 is also connected to the junction point between the capacitor C-1 and the anode of

diode D-5. In addition, the anode of the X-ray tube X-1 is connected directly to ground.

Reference is now made to FIG. 2A which illustrates a pair of NPN transistors Q-3, Q-4 having their collectors respectively connected to a pair of output terminals R, V, their bases respectively connected to a pair of output terminals T, X, and their emitters respectively connected to a pair of output terminals S, W.

The output terminal R is also connected through a capacitor C-3 to the input terminal I and the output terminal I is connected directly to another output terminal U. Similarly, the output terminal V is connected through a capacitor C-4 to the output terminal L, and the output terminal L is connected through a series-connected power lamp L-6 and resistor 45 to another output terminal Z. Finally, the output terminal Z is connected through a relay coil 46 of the relay R-2 to an output terminal AA.

Reference is now made to FIG. 3, which illustrates a pair of voltage regulator, integrated circuits IC-1, IC-2. These integrated circuits preferably take the form of Model TO-5 voltage regulator circuits manufactured by Fairchild Camera and Instruments Corp. With respect to both of the integrated circuits IC-1, IC-2, the terminals 3, 4, are connected in common, and the terminals 7, 8 are connected in common. The terminal 2 of integrated circuit IC-1 is connected through a capacitor C-5 to terminal 9 of this circuit. Similarly, the terminal 2 of the integrated circuit IC-2 is connected through a capacitor C-7 to terminal 9 of this circuit. Terminal 8 of integrated circuit IC-1 is connected directly to the output terminal R, and is connected through a pair of diodes D-7, D-8, polarized as shown in FIG. 3, to the output terminals J, H, respectively. Similarly, terminal 8 of integrated circuit IC-2 is connected directly to the output terminal V, and through a pair of diodes D-10A, D-11, polarized as shown in FIG. 3, to the output terminals M, K, respectively.

The terminal 6 of integrated circuit IC-1 is connected to the output terminal T. Terminal 10 of this circuit is connected through a resistor 48 to an output terminal EE, terminal 1 is connected directly to output terminal EE, and terminal 2 of this circuit is connected directly to an output terminal FF. In addition, the terminal 10 of the integrated circuit IC-1 is connected directly to an output terminal S and the terminal 5 is connected to the output terminal U and to an output terminal GG.

Similarly, the terminal 6 of integrated circuit IC-2 is connected to the output terminal X, the terminal 10 of this circuit is connected through a resistor 50 to the output terminal GG, terminal 1 is connected directly to terminal GG, and terminal 2 is connected to an output terminal NN. Finally, the terminal 10 of integrated circuit IC-2 is connected directly to the output terminal W, and the terminal 5 of this circuit is connected to the output terminal Y and to an output terminal OO.

FIG. 3 also illustrates an operational amplifier A-1 having its non-inverting input terminal connected to an output terminal DD, and its inverting input terminal connected through a pair of series-connected resistors 50, 52, to a negative 14 volt supply source. The junction point between the series-connected resistors 50, 52 is connected through a resistor 54 to the output terminal GG.

The operational amplifier A-1 is coupled directly to both the negative 14 volt supply source and a positive 14 volt supply source, and the output terminal of this amplifier is connected through a resistor 54 to the base of an NPN transistor Q-5. The collector of transistor Q-5 is connected directly to the positive 14 volt supply source and the emitter of this transistor is connected through a resistor 56 to the inverting input terminal of amplifier A-1.

Also connected to the emitter of transistor Q-5 is one of the terminals of a lamp 58 having its other terminal connected directly to the output terminal GG. The lamp 58 is optically coupled to a photocell 60 having its output terminal connected to a pair of output terminals HH, II.

The output terminal AA is connected through a diode D-9, polarized as shown in FIG. 3, to the positive 14 volt supply source, and output terminal Z is connected directly to the positive 14 volt supply source. Also, output terminal AA is connected directly to the collector of an NPN transistor Q-6 having its emitter connected to the output terminal GG. The base of transistor Q-6 is connected through a resistor 62 to the output terminal GG, and through a resistor 64 to the collector of an NPN transistor Q-7.

The collector of transistor Q-7 is connected through a resistor 66 to the positive 14 volt supply source, the emitter of this transistor is connected through a resistor 68 to output terminal GG, and the base of this transistor is connected through a resistor 70 to the output terminal GG. Also, the emitter of transistor Q-7 is connected to the emitter of an NPN transistor Q-8 having its collector connected through a parallel-connected capacitor C-6 and resistor 72 to the base of the transistor Q-7. The collector of transistor Q-8 is also connected through a resistor 74 to the positive 14 volt supply source. In addition, the base of transistor Q-8 is connected through a series-connected diode D-10, polarized as shown in FIG. 3, and resistor 76 to the output terminal GG, and the base of this transistor is also connected through a resistor 78 to an output terminal KK.

Reference is now made to FIG. 4, which generally illustrates a series-connected resistor string comprised of a resistor 80, a potentiometer 82, a resistor 84, a resistor 86, a potentiometer 88, and a resistor 90 connected between the positive 14 volt supply source and the negative 14 volt supply source. The output terminal EE is connected directly to the positive 14 volt supply source, output terminal FF is connected to the movable contact of potentiometer 82, output terminal GG is connected to the junction point between resistors 84, 86, output terminal NN is connected to the movable contact of potentiometer 88, and output terminal 00 is connected directly to the negative 14 volt supply source.

The output terminals C, D are connected to the input terminals of a four-diode bridge network, BR-2 comprised of the diodes D-12, D-13, D-14, D-15. One of the output terminals of the bridge network BR-2 is connected to the output terminals GG, QQ. The other output terminal of bridge network BR-2 is connected through a series-connected resistor 92, potentiometer 94, and resistor 96, to output terminal QQ. The junction point between that output terminal of the bridge network BR-2 and the resistor 92 is coupled through a capacitor C-8 to the output terminal QQ, and the

junction point between resistor 92 and potentiometer 94 is coupled through a capacitor C-9 to the output terminal QQ.

The movable contact of potentiometer 94 is connected directly to the non-inverting input terminal of an operational amplifier A-2 having its output terminal connected directly to an output terminal PP. Also, the output terminal PP is connected directly to the non-inverting input terminal of the amplifier A-2 and this amplifier is connected to both the positive and negative 14 volt supply sources.

The output terminal HH is connected directly to an output terminal RR and is also connected through a resistor 98 to the output terminal II. The output terminal II is connected directly to a non-inverting input terminal of an amplifier A-3 and is also connected through a resistor 100 to the output terminal GG. The output terminal of amplifier A-3 is connected directly to the inverting input terminal of this amplifier and is also connected through a resistor 102 to the non-inverting input terminal of an operational amplifier A-4. Also, the non-inverting input terminal of amplifier A-4 is connected through a resistor 104 to the negative 14 volt supply source.

The inverting input terminal of the operational amplifier A-4 is connected through a resistor 108 to the output terminal GG, and the output terminal of this amplifier is connected through a diode D-16, polarized as shown in FIG. 4, and a resistor 106 to the inverting input terminal. A capacitor C-10 is connected in parallel with the resistor 106.

The output terminal GG is, in addition, connected through the series-connected resistor 112, potentiometer P-1, resistor 114, and potentiometer 116 to the negative 14 volt supply source. The movable contact of the potentiometer 116 is also connected to the negative 14 volt supply source, and the movable contact of potentiometer P-1 is connected directly to the non-inverting input terminal of an amplifier A-5. The output terminal of amplifier A-5 is coupled directly to the inverting input terminal of this amplifier and is also connected through a resistor 118 to the inverting input terminal of another operational amplifier A-6.

The inverting input terminal of amplifier A-6 is also connected through a resistor 110 to the junction point between the diode D-16 and the resistor 106. The non-inverting input terminal of this amplifier is connected to a common line which extends between the output terminal GG and an output terminal TT. In addition, the output terminal of amplifier A-6 provides an output terminal SS which is connected through a resistor 120 to the inverting input terminal of this amplifier. The amplifiers A-3, A-4, A-5, A-6 are each connected to and supplied with power by the positive and negative 14 volt supply sources.

Reference is now made to FIG. 5 which illustrates an operational amplifier A-7 having its non-inverting input terminal coupled directly to the output terminal PP and its inverting input terminal connected through a resistor 126 to the output terminal QQ. A pair of series-connected resistors 122, 124 are coupled between the output terminals PP, QQ, and the output terminal QQ is connected through a series-connected capacitor C-11 and resistor 132 to the inverting input terminal of amplifier A-7. The output terminal of amplifier A-7 is also connected through a potentiometer 134 to the output terminal 0, and the movable contact of potentiometer

eter 134 is connected directly to the output terminal of amplifier A-7.

An operational amplifier A-8 which is utilized for circuit compensation has its non-inverting input terminal connected directly to the junction point between the resistors 122, 124, and its output terminal connected through a resistor 136 to the base of an NPN transistor Q-9. The collector of transistor Q-9 is connected directly to the positive 14 volt supply source and the emitter of this transistor is connected directly to the inverting input terminal of the amplifier A-8. Also, the emitter of transistor Q-9 is connected to one of the terminals of a lamp 138 having its other terminal connected directly to the output terminal QQ. A photocell 140 disposed to receive light energy emanating from the lamp 138 has one of its output terminals connected directly to output terminal QQ and its other output terminal connected directly to the inverting input terminal of an amplifier A-9. A resistor 142 is connected across the output terminals of the photocell 140.

The non-inverting input terminal of the amplifier A-9 is connected directly to an output terminal KK, the output terminal of this amplifier is connected through a resistor 144 to the junction point between capacitor C-11 and resistor 132. Also, the output terminal of amplifier A-9 is connected through a resistor 146 to the inverting input terminal of this amplifier.

The output terminal KK is, in addition, connected to the inverting input terminal of an amplifier A-10 having its non-inverting input terminal connected directly to the output terminal SS, and its output terminal connected through a resistor 150 to the output terminal P. Also, the output terminal of amplifier A-10 is connected through a resistor 148 to the inverting input terminal of this amplifier.

The inverting input terminal of amplifier A-10 is, in addition, connected through a resistor 152 to output terminal Q, is connected through a resistor 154 to the output terminal TT, and is connected through a Zener diode Z-3, polarized as shown in FIG. 5, to the output terminal TT. Finally, a pair of series-connected resistors 156, 158 are coupled between the output terminals KK, TT, and the junction point between these resistors provides the output terminal DD. All of the amplifiers A-7, A-8, A-9, A-10 are also coupled to and supplied power by the positive and negative 14 volt supply sources.

OPERATION OF X-RAY TUBE PROTECTIVE CIRCUIT

In the operation of the X-ray system, the operator may vary the position of the movable contact 16 of the Variac T-1 in order to vary the voltage or kilovoltage signal applied to the X-ray tube X-1. In order to vary the current or miliampere signal applied to the X-ray tube X-1, the potentiometer P-1 may be varied by the operator.

In order to initiate an exposure, the key switch S-2 is moved to a closed position. Then the start switch S-1 is moved to a closed position to thereby energize the coil 20 of relay R-1. Upon energization of the relay coil 20, the contacts 12, 14 close to thereby couple the Variac T-1 across the 236 volt supply source. Also, upon energization of the relay coil 20 of relay R-1, the contacts 25 close.

When the Variac T-1 becomes energized, a voltage signal is applied to the autotransformer T-2, which is in turn applied to the high voltage power transformer T-8. The signal developed by the high voltage power transformer T-8 is then applied to the cathode of the X-ray tube X-1.

Also, upon closure of the relay contacts 12, 14, the transformer T-4 becomes energized to thereby illuminate the X-ray lamp L-2, and relay R-3 is energized to thereby cause the contacts 44 to open. When the contacts 44 open, the bleeder resistor 42 is removed from the cathode circuit of the X-ray tube X-1. At this time the X-ray tube begins emitting X-rays. The filament timer 22 commences timing whenever a voltage signal is applied to the filament of the X-ray tube X-1.

The voltage or kilovoltage signal applied to the X-ray tube X-1 is continuously monitored by the voltage sensing transformer T-3. This transformer is merely a step-down transformer to convert the high voltage signal developed by the autotransformer T-2 to a lower voltage signal. This lower voltage signal varies in accordance with variations in the voltage signal applied to the X-ray tube.

The lower voltage signal developed by the sensing transformer T-3 is then applied through the four-diode bridge network BR-2, a filter network comprised of the capacitors C-8, C-9 and resistor 92 to a voltage divider circuit including the potentiometer 94 and the resistor 96. The signal developed across the potentiometer 94 is then applied to the non-inverting input terminal of the voltage follower amplifier A-2, and the signal developed by the voltage follower amplifier A-2 is then applied to the non-inverting input terminal of the operational amplifier A-7.

Also, the signal developed by the voltage follower amplifier A-2 is applied to a voltage divider network including the resistors 122, 124, and is in turn applied to the non-inverting input terminal of the operational amplifier A-8. The circuitry including the amplifier A-8, the transistor Q-9, the lamp 138, and the photocell 140, generally provides the function of compensating or varying the gain of the amplifier A-9 according to the value of the voltage or kilovoltage signal applied to the X-ray tube X-1. The compensating voltage signal is applied to the inverting input terminal of the amplifier A-9.

More particularly, as the voltage or kilovoltage signal applied to the X-ray tube X-1 increases, the signal applied to the non-inverting input terminal of amplifier A-8 increases thereby causing transistor Q-9 to become more forward biased. As transistor Q-9 becomes more forward biased, the brilliance of the lamp 138 increases to thereby proportionally decrease the resistance across photocell 140. This decrease in resistance of the photocell 140 causes the signal applied to the inverting input terminal of amplifier A-9 to increase in value.

This variation in gain or compensation of the amplifier A-9 is necessitated by the fact that a change of 5 milliamperes in the 100 kilovoltage region requires more compensation than a change of 5 milliamperes in the 50 kilovolt region. The signal developed by the amplifier A-9, which is the voltage compensation signal, is applied back to the inverting input terminal of the amplifier A-7.

A current signal or miliampere command signal is developed across the potentiometer P-1. This signal is then applied to the non-inverting input terminal of the voltage follower amplifier A-5. The signal is then amplified and applied to the inverting input terminal of the amplifier A-6. When the product of the voltage or kilovoltage signal and the current signal or miliampere signal applied to the X-ray tube is less than a maximum rating for the tube, the signal applied to the amplifier A-6 is inverted and applied to the amplifier A-10.

A current signal or miliampere feedback signal is applied through the miliampere meter 40 and through a voltage divider network including the resistors 152, 154 to the inverting input terminal of the amplifier A-10. Accordingly, if the resistor 154 is a 200 ohm resistor, a current of 5 miliamps will cause a 1 volt signal to be developed across the resistor 154, while a current of 15 miliamps will cause a 3 volt signal to be developed across the resistor 154.

Thus, if the potentiometer P-1 is adjusted so that a positive 1 volt signal is applied to the non-inverting input terminal of the operational amplifier A-10, this amplifier will have a positive output voltage. This positive output voltage is then applied to the transistors Q-1, Q-2, to thereby forward bias these transistors.

As the transistors Q-1, Q-2 become forward biased the secondary windings 28, 30, 32, 34 of the saturation transformer T-7 become shorted thereby causing the transformer T-7 to become saturated. As the transformer T-7 becomes saturated, the reactance of the primary winding decreases thereby causing the voltage applied to the primary winding of the filament transformer T-9 to increase. This increased voltage on the primary winding of filament transformer T-9 causes an increased voltage to be applied to the filament of the X-ray tube X-1, thereby causing an increase in the current flow through the X-ray tube.

As the current flowing through the X-ray tube X-1 increases, there is an increase in voltage across the feedback resistor 154. When the voltage developed across the resistor 154 attains a value equal to 1 volt, the output signal developed by the operational amplifier A-10 decreases from the initial positive output voltage in order to maintain stabilization at 5 miliampere.

If the current or MA compound signal is increased to 15 miliampere, a voltage signal equal to 3 volts is applied to the operational amplifier A-10 thereby causing the saturation transformer T-7 to stabilize the miliampere feedback signal at 15 miliamps.

The compensated voltage signal which is developed by the operational amplifier A-7 is applied across the voltage divider network comprised of the resistors 98, 100. The photocell 60 is coupled across the resistor 98 so that as the resistance of the photocell 60 changes, there is a change in the value of the voltage developed across the resistor 100. This voltage, is in turn applied to the non-inverting input terminal of the operational amplifier A-3.

The signal which is developed across the resistor 158 is representative of the actual current or miliampere signal applied to the X-ray tube X-1. This signal is applied to the amplifier A-1, and is in turn amplified by the circuitry including the transistor Q-5 and applied to the lamp 58. Thus, the change in resistance of the photocell 60 is proportional to the change in the actual current or MA signal applied to the X-ray tube. Accordingly,

the signal developed across resistor 100 is proportional to the actual power applied to the X-ray tube.

The value of the resistor 100, and the value of the other circuit components are chosen so that a voltage drop of 3 volts is obtained across the resistor 100 whenever the maximum allowable power is applied to the X-ray tube X-1. If, however, the power applied to the X-ray tube exceeds a predetermined level, the voltage developed across the resistor 100 exceeds 3 volts, this signal is passed through the amplifier A-3 to the voltage divider network comprised of the resistors 102, 104.

When the voltage applied to the voltage divider network including resistors 102, 104 exceeds 3 volts, a positive signal is applied to the non-inverting input terminal of amplifier A-4, is amplified by the amplifier A-4, and causes a positive voltage signal to be applied to the anode of diode 16.

When a positive signal is applied to the anode of diode 16, a positive signal is applied to the non-inverting input terminal of amplifier A-6. This positive signal applied to the non-inverting input terminal of A-6 causes the output signal developed by the amplifier A-6 to decrease in value thereby causing the signal applied to the non-inverting input terminal of amplifier A-10 to decrease. With a decrease in the value of the signal applied to the non-inverting input terminal of amplifier A-10, there is a decrease in the value of the signal developed by the amplifier A-10. As indicated above, a decrease in the value of the signal developed by amplifier A-10, causes the current applied to the filament of the X-ray tube X-1 to decrease to a safe level.

Accordingly, when the voltage developed across the resistor 100 which is proportional to the power applied to the X-ray tube increases above a predetermined level, the compensating circuitry including the amplifiers A-3, A-4, A-6, A-10, and the transformer T-7 causes the current applied to the X-ray tube to be reduced to a safe operating level.

Also, an electronic circuit breaker circuit including the transistors Q-6, Q-7, Q-8, and the relay R-2, de-energizes the entire X-ray control system whenever the voltage developed across the miliampere feedback resistor 154 exceeds a predetermined value. For example, in the illustrated circuit, whenever the voltage developed across resistor 154 exceeds 5 volts, i.e., the miliampere current exceeds 25 miliampere, a Schmitt trigger circuit comprised of the transistors Q-7, Q-8, is triggered, thereby causing transistor Q-6 to become forward biased. When transistor Q-6 becomes forward biased, the relay coil 46 of relay R-2 becomes energized thereby opening the normally-closed relay contact 18, which in turn causes the relay coil 20 of relay R-1 to become de-energized. Upon de-energization of the relay coil 20, the contacts 12, 14, 25 open to de-energize the Variac T-1 to thereby remove the power applied to the high voltage transformer T-8. In order to again initiate operation of the X-ray tube X-1, it is necessary that the switch S-1 again be closed to thereby cause the relay R-1 to become actuated in order to close relay contacts 12, 14.

Although the invention has been described in conjunction with a preferred embodiment, it is contemplated that various changes in form and parts may be

made without departing from the spirit and scope of the invention as defined by the appended claims.

Having thus described my invention, I claim:

1. An X-ray tube protective system for preventing the substantially instantaneous input power applied to an X-ray tube from exceeding a predetermined level and comprising:

first continuously variable circuit means for applying a voltage signal of a preselected value to an X-ray tube;

second continuously variable circuit means for applying a current signal of a preselected value to the X-ray tube;

voltage monitoring circuit means for developing a first signal having a value representative of the value of the applied voltage signal;

current monitoring circuit means for developing a second signal having a value representative of the value of the applied current signal;

multiplying circuit means coupled to said voltage monitoring circuit means and said current monitoring circuit means for developing an output signal having a value representative of the value of the power represented by the mathematical product of said first and second signals;

compensating circuit means coupled to said multiplying circuit means for developing a control signal indicating when said output signal exceeds a predetermined value indicating the predetermined power level; and,

actuatable circuit means coupled to said compensating circuit means for, in response to said control signal, limiting the value of one of the current and voltage signals applied to the X-ray tube to a level sufficiently low to prevent input power in excess of said predetermined power level from being applied to said X-ray tube, while still permitting adjustment of the level of said limited signal within a range less than said sufficiently low level.

2. An apparatus as defined in claim 1 wherein said multiplying circuit means includes impedance means having input circuit means for varying the impedance of said impedance means in accordance with the value of a signal applied to said input circuit means and output circuit means for developing an output signal having a value which varies in accordance with variations in the impedance of said impedance means; said current monitoring circuit means coupled to said input circuit means of said impedance means so that said impedance varies in accordance with the value of said second signal; and said output circuit means of said impedance means being coupled to said compensating circuit means.

3. An apparatus as defined in claim 1 wherein said voltage monitoring circuit means is coupled to said output circuit means of said impedance means so that a signal developed by said output circuit means varies in accordance with variations in the impedance of said impedance means and with variations in the value of said first signal.

4. A method of preventing the input power applied to an X-ray tube in an X-ray system from exceeding a predetermined level and comprising the steps of:

varying the value of a voltage signal applied to the X-ray tube in order to apply a voltage signal of a preselected value to the X-ray tube;

varying a current signal applied to an X-ray tube in order to apply a current signal of a preselected value to the X-ray tube;

developing a first signal having a value representative of the value of the voltage signal applied to the X-ray tube;

developing a second signal having a value representative of the value of the current signal applied to the X-ray tube;

electrically multiplying the first and second signals in order to obtain an output signal having a value which is a function of the power represented by the mathematical product of the first and second signals; and,

limiting the value of one of said current and voltage signals applied to the X-ray tube to a maximum level sufficient to maintain the power level below the predetermined power level, while permitting the variation of said limited signal among a range of values less than said maximum level.

5. A method as defined in claim 4 including the step of decreasing the value of the current signal applied to the X-ray tube when the value of the output signal exceeds a predetermined level to thereby prevent excessive output from being applied to the X-ray tube.

6. An X-ray tube protective system for preventing the substantially instantaneous input power applied to an X-ray tube from exceeding a predetermined level and comprising:

first variable circuit means for applying a voltage signal of a preselected value to a said X-ray tube;

second variable circuit means for applying a current signal of a preselected value to a said X-ray tube;

voltage monitoring circuit means for developing a first signal having a value representative of the value of the applied voltage signal;

current monitoring circuit means for developing a second signal having a value representative of the value of the applied current signal;

multiplying circuit means coupled to said voltage monitoring circuit means and said current monitoring circuit means for developing an output signal having a value representative of the value of the mathematical product of said first and second signals;

compensating circuit means coupled to said multiplying circuit means for developing a control signal indicating when the power represented by said mathematical product and by the value of said output signal exceeds a predetermined value; and,

actuatable circuit means coupled to said compensating circuit means for, in response to said control signal, limiting the maximum attainable value of one of said current and voltage signals to be applied to a said X-ray tube to a level less than or equal to that level necessary to attain said predetermined power level, while simultaneously permitting variation of one of said current and voltage signals for operation of the tube at power levels less than that represented by said predetermined value of said output signal.

7. An apparatus as defined in claim 6 wherein said multiplying circuit means includes impedance means having input circuit means for varying the impedance of said impedance means in accordance with the value of a signal applied to said input circuit means and out-

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put circuit means for developing an output signal having a value which varies in accordance with variations in the impedance of said impedance means; said current monitoring circuit means coupled to said input circuit means of said impedance means so that said impedance varies in accordance with the value of said second signal; and said output circuit means of said impedance means being coupled to said compensating circuit means.

8. An apparatus as defined in claim 7 wherein said voltage monitoring circuit means is coupled to said output circuit means of said impedance means so that a signal developed by said output circuit means varies in accordance with variations in the impedance of said impedance means and with variations in the value of said first signal.

9. An X-ray tube protective system for preventing the input power applied to an X-ray tube from exceeding a predetermined maximum level and comprising:

first variable circuit means for applying a continuously variable voltage signal to a said X-ray tube;

second variable circuit means for applying a continuously variable current signal to a said X-ray tube;

voltage monitoring circuit means for developing a first signal having a value representative of the value of the applied voltage signal;

current monitoring circuit means for developing a second signal having a value representative of the value of the applied current signal;

multiplying circuit means coupled to said voltage monitoring circuit means and said current monitor-

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ing circuit means for developing an output signal having a value representative of the value of the instantaneous power represented by the mathematical product of said current and voltage signals;

compensating circuit means coupled to said multiplying circuit means for developing a control signal indicating when the power represented by said output signal exceeds a predetermined value; and,

actuatable circuit means coupled to said compensating circuit means for, in response to said control signal, limiting the maximum attainable value of said current signal to be applied to a said X-ray tube to a level less than or equal to that level necessary to attain said predetermined maximum power level, while simultaneously permitting variation of said current signal below said maximum attainable value for operation of the tube at power levels less than predetermined maximum level.

10. An apparatus as defined in claim 9 wherein said multiplying circuit means includes impedance means having input circuit means for varying the impedance of said impedance means in accordance with the value of a signal applied to said input circuit means and output circuit means for developing an output signal having a value which varies in accordance with variations in the impedance of said impedance means; said current monitoring circuit means coupled to said input circuit means of said impedance means so that said impedance varies in accordance with the value of said second signal; and said output circuit means of said impedance means being coupled to said compensating circuit means.

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UNITED STATES PATENT OFFICE
CERTIFICATE OF CORRECTION

Patent No. 3,842,280 Dated October 15, 1974

Inventor(s) Norman A. Herrick

It is certified that error appears in the above-identified patent and that said Letters Patent are hereby corrected as shown below:

Column 2, line 35 "OF" should be - - of - -

Column 11, line 46, "compound" should be - - command - -

Claim 3, line 1, "1" should be - - 2 - -

Signed and sealed this 14th day of January 1975.

(SEAL)
Attest:

McCOY M. GIBSON JR.
Attesting Officer

C. MARSHALL DANN
Commissioner of Patents