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X-RAY APPARATUS

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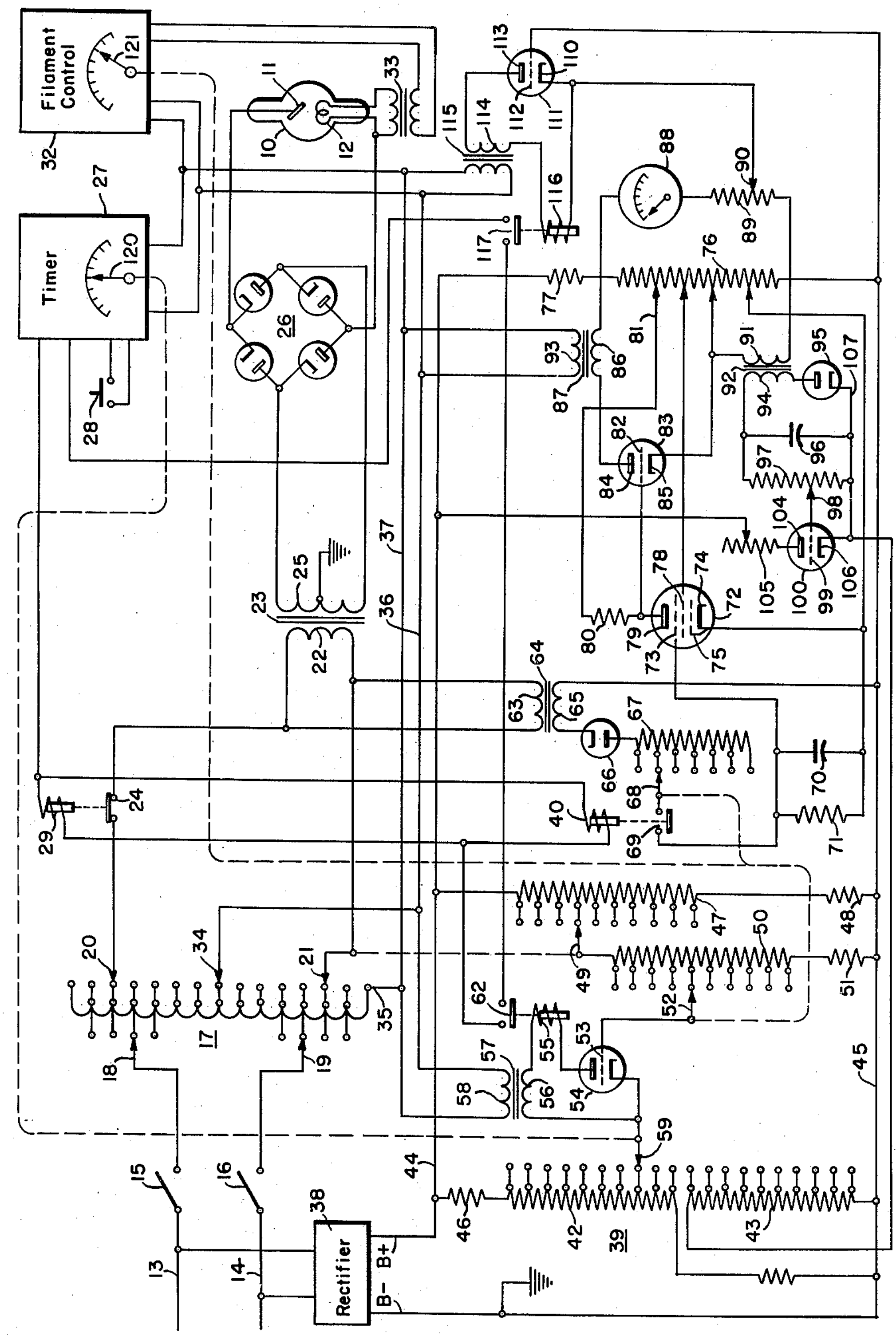

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X-RAY APPARATUS

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The present invention relates to control circuits for electrical discharge devices, and, more particularly, relates to control circuits to protect against overheating of X-ray tubes.

It is the present practice to build X-ray tubes designed with anodes surrounded by cooling facilities and tube structure which would be inadequate to keep the anode temperature below injurious values were the X-ray tube to be operated for continuous X-ray emission. Because of this, particularly the anode, in practice, may be overheated if the X-ray tube is called upon to emit X-rays for too long a period of time. The length of the safe period of time in this respect depends upon the intensity of the X-ray emission, and such period is shorter for high intensities of X-ray emission than for low intensities of such emission.

If the entire X-ray tube, including the anode thereof, is at room temperature, when the X-ray emission is initiated, it is known in the art that a curve can be plotted to show the maximum period of time for which the emission control timer may be set without heating the X-ray tube anode to a dangerous temperature. Such a curve may be called a "tube rating chart" and is plotted as a function of time versus the product of the potential applied to the anode of the X-ray tube as kilovolts, and the anode current of the X-ray tube in terms of milliamperes.

It is known in the prior art to interlink the X-ray emission timer with the respective controls by which the anode voltage and the anode current are adjusted such that the X-ray tube cannot be operated if the timer is manually preset to correspond to time values lying outside the bounds indicated as safe by a tube rating chart. However, such a chart is not applicable if the X-ray tube has previously been operated at fairly frequent intervals, such that the anode heat content does not have sufficient time to be dissipated, and heat energy as a result is stored in the X-ray tube anode.

Accordingly, it is an object of the present invention to provide a control circuit for X-ray apparatus which provides full protection for the X-ray tube, whether the anode of the X-ray tube is at room temperature or is at some elevated temperature.

It is a further object of the present invention to provide a control circuit for X-ray apparatus which is operative to protect the X-ray tube when the anode is heated to a temperature above ambient or room temperature, and, in addition, is operative to permit the X-ray apparatus to release its full available and desired power when the tube anode is at room or ambient temperature.

It is an additional object of the present invention to provide a control circuit which responds to respectively the tube anode voltage and the anode current and the exposure time duration setting, which are manually prechosen, and is operative to compare these manual settings with predetermined and known maximum safe values allowed by the tube rating chart for the particular X-ray tube employed.

It is a different object of the present invention to provide a pre-firing or pre-emission protection circuit for preventing the usage of an X-ray tube apparatus if the product of respectively the pre-selected anode voltage and tube current and emission time duration is not suitable for the temperature condition of the X-ray tube.

It is a still further object of the present invention to provide a control circuit responsive to values which are automatically fed into the control circuit in response to the manual pre-selection of anode voltage, anode current and emission time settings.

It is a still additional object to provide a control circuit which is responsive to past-firing or past-operation of the X-ray tube apparatus, and which is operative to prevent the operation of the X-ray tube if the heat energy stored in particularly the tube anode becomes in excess of the maximum desired or allowable value.

It is a still different object to provide a control circuit for X-ray apparatus which responds to the energy stored or accumulated in particularly the X-ray tube anode, and for preventing injurious operation of the X-ray tube after the maximum allowable value of such energy is present.

It is another object to provide a control which responds to or follows the cold rating chart when the temperature condition of the tube will allow it to thereby permit longer exposure times, and which responds to or follows the hot rating chart to effect shorter exposure times when the tube temperature condition requires that the latter be done.

These and other objects of the invention are effected as will become apparent from the following description and claims taken in accordance with the accompanying drawing which form a part of this application, and in which there is shown a schematic diagram of a control circuit for X-ray apparatus in accordance with the present invention.

The X-ray apparatus shown in the drawing includes an X-ray tube **10** having an anode **11** and a cathode or filament **12**. Operating alternating current is supplied for the tube **10** from a suitable voltage supply including main leads **13** and **14**, with suitable switches **15** and **16** and an autotransformer **17**. The primary connection of the autotransformer **17** with the main leads **13** and **14** is through selector switches or taps **18** and **19** which are connected to predetermined taps on the autotransformer **17** and serve to adjust the transformer voltage in accordance with line voltage. The secondary connections of the autotransformer **17** include a pair of selector switches **20** and **21** having their respective rows of contacts connected with the secondary taps of the transformer coil in order to adjust the anode voltage in terms of kilovolts of the X-ray tube **10**. The switches **18** and **19** are line voltage adjust switches for correcting hour to hour changes in voltage of the supply source. Switch **20** is provided for making fine adjustment of voltage applied to the high tension transformer while switch **21** provides adjustment of that same voltage, but in larger increments. The switch **20**, in particular, is operative to make smaller changes in the anode voltage of the X-ray tube **10** than the switch **21**, and these switches are operative as anode voltage controls for the X-ray tube. Connected between the switches **20** and **21** is the primary winding **22** of a high voltage transformer **23**. The primary winding **22** is connected in series with a main control switch **24**. The secondary **25** of the high voltage transformer **23** has connected across it a rectifier bridge **26** which, in turn, is connected across the anode circuit of the X-ray tube **10**. The secondary winding **25** has a grounded center connection A timing device or timer **27** is provided which is controlled by a manually operated push button **28**. The timing device is operative to energize a relay winding **29** which controls the main switch **24**.

A filament control circuit **32** is provided which is operative to control the voltage across the filament 12 of the X-ray tube 10, and, hence, the temperature of this filament 12 through a filament transformer 33. As well known to those skilled in this art, this filament control circuit can include a series connected adjustable resistor, with the adjustment member for the resistor comprising the anode current selector. A pair of taps 34 and 35 are connected to suitable points on the winding of the autotransformer 17 for providing through leads 36 and 37 the operating voltage for both the timer device 27 and the filament control device 32 and other circuits hereinafter to be described. The filament control 32 is operative as an anode current control for the X-ray tube 10.

A pair of leads 44 and 45 are provided which may be connected to any suitable and available B+ supply or reference voltage supply, such as the output of a rectifier apparatus 38 which may be connected across the supply leads 13 and 14. A time responsive or indicative resistance member 39 comprising a first portion 42 and a second portion 43 is provided with the first portion being connected between the B+ lead 44 and ground lead 45. A suitable dropping resistor 46 is provided in series with the first portion 42 of the time resistance. A kilovolt resistance 47 is connected between the B+ lead 44 and the B− lead 45 through a suitable dropping resistor 48. A tap connection 49 is provided off the kilovolt or anode voltage responsive or indicative resistor 47 and is connected to one end of an anode current or ma. responsive or indicative resistor 50, the other end of said anode current resistor 50 being connected to the B− lead 45 through a suitable dropping resistor 51. A variable tap 52 is provided from the anode current resistor, and is connected to the control grid 53 of gas-filled control tube 54. The anode of the control tube 54 is connected to the cathode of this same tube through a relay control winding 55 and the secondary winding 56 of an A.-C. supply transformer 57. The primary winding 58 of the latter supply transformer 57 is connected between the supply leads 36 and 37. An adjustable tap 59 is connected to one of a respective row of contacts provided with the two portions 42 and 43 of the time resistor 39, and it is connected to the cathode of the control tube 54. The relay winding 55 is operative to control an auxiliary switch 62 which is connected in series with the main switch relay control winding 29.

The primary winding 63 of control transformer 64 is connected in parallel with the primary winding 22 of the high voltage transformer 23. The secondary winding 65 of this control transformer 64 is connected in series with a suitable rectifier tube 66, an adjustable tap anode current charging resistor 67 provided with an adjustable tap 68, a switch member 69 and a parallel circuit arrangement including a charging condenser 70 and a shunt resistor 71.

An electrometer tube 72 comprising a pentode having an anode, a suppressor grid and a control grid is provided, with the suppressor grid 73 thereof connected to the cathode 74 through the resistor-condenser circuit including condenser 70 and resistor 71. The control grid 75 of this tube is connected to the cathode 74. The screen grid 78 of this tube is connected to a suitable point on a bias resistor 76 which is connected through a suitable dropping resistor 77 between the B+ lead 44 and the B− lead 45. The anode 79 of the electrometer tube 72 is connected through a suitable dropping resistor 80 to an adjustable tap 81 on the bias resistor 76. The anode 79 is also connected to the control grid 82 of a second control tube 83 with the anode 84 and the cathode 85 of tube 83 being connected through the secondary winding 86 of a power supply transformer 87, a heat indication meter 88, a potentiometer 89 having an adjustable tap 90, and the primary winding 91 of a charging transformer 92. The primary winding 93 of the supply transformer 87 is connected between the supply leads 36 and 37.

The secondary winding 94 of the charging transformer 92 is connected through a diode rectifier 95 across a resistor condenser circuit including a condenser 96 and a shunt resistor 97 which is connected in parallel with the condenser 96. The shunt resistor 97 is provided with a tap 98 which is connected to the control grid 99 of a control tube 100. The control tube 100 has an anode 104 connected through an adjustable dropping resistor 105 to the B+ lead 44. The tube 100 has a cathode 106 connected to lead 107 between the diode rectifier 95 and the condenser 96. The cathode 106 is also connected through the second portion 43 of the timer resistor 39 to the B− lead 45.

The adjustable tap 90 on potentiometer 89 is connected to the cathode 110 of a gaseous discharge tube 111. The control grid 112 for the tube 111 is connected to the B− lead 45. The anode 113 of the tube 111 is connected through the secondary winding 114 of a supply transformer 115 and relay control winding 116 to the cathode 110. The control winding 116 is operative to control a second auxiliary switch 117 which is connected in series with the first auxiliary control switch 62 and the relay control winding 29 for the main switch 24.

The adjustable tap on the winding of the autotransformer 17 for providing large adjustments or changes in the anode voltage of X-ray tube 10 is ganged to commonly operate with the adjustable tap 49 on the kilovolt resistor 47. The adjustment arm 120 for the timer device 27 is ganged to operate with the adjustable tap 59 on the timer resistor 39, such that the adjustable tap 59 operates in common or is changed proportional to the adjustment or movement timer arm 120 of the timer device. In this respect, the adjustable tap 59 is operable with first portion 42 and second portion 43 of the timer resistor 39. The manual control arm 121 of the filament control device 32 is ganged to commonly operate with the adjustable tap 68 of the resistor 67 and the adjustable tap 52 of the anode current resistor 50, such that adjustments or changes are made in the position of respectively each of the adjustable taps 68 and 52 in proportion to the movement or changes made in the position of the manual control arm of the filament control device.

In accordance with the operation of the X-ray control circuit for X-ray apparatus of the present invention, since the time resistor 39 and the kilovolt resistor 47 and the anode current resistor 50 are energized by the same substantially constant reference B+ voltage, the values of these respective resistor members can be pre-selected or predetermined to correspond to the particular X-ray tube 10 which is employed, such that the various provided steps on the timer resistance 39 can be made to correspond with respective emission time settings, such as 1/60 of a second, 1/30 of a second and 1/20 of a second, and etc., up to some exposure time value such as 15 seconds, and to cover the corresponding range of operation of the timer device 27. Similarly, the adjustable tap 68 on the resistor 67, and the adjustable tap 52 on the anode current, or milliampere resistor 50, are provided with settings or taps which correspond to the milliampere or anode current settings of the filament control device 32. The anode voltage or kilovolt resistor 47 is provided with suitable taps or settings to correspond with the anode voltage or kilovolt changes effected by the adjustable tap 21 of the autotransformer 17. Prior to the closing of manual control switch 28 for the timer device 27, an operator of the present X-ray apparatus manually presets the values of the anode voltage in kilovolts, the anode current in milliamperes and the exposure time by means of respectively the adjustable tap 21 of the autotransformer 17, the manual control arm 121 of the filament control device 32 and the manual control arm 120 of the timer device 27. If the initial pre-operation choice of these values is not suitable for the particular X-ray tube being employed, which maximum safe values for these quantities can be obtained from the well known tube rating chart for the particular tube **10** being employed, the gaseous control tube **54** will operate to prevent the closing of the main switch **24** by means of the relay control winding **29**. The gaseous control tube **54** prevents the operation of the X-ray tube **10** in response to a grid bias applied to the control grid **53** in the form of a control signal received from the adjustable tap **52** on the anode current resistor **50** and in the form of a control signal received from the adjustable tap **49** on the anode voltage resistor **47**. In this respect, since the resistor **47** is effectively connected between the B+ lead **44** and the B− lead **45**, the position of the adjustable tap **49** on the resistor **47**, as determined by the anode voltage setting initially made by the adjustment of the adjustable tap **21** on the autotransformer **17**, will determine the percentage of the voltage drop across resistor **47**, which is applied across the resistor **50**. In this way, the voltage applied across the resistor **50** can be made to be proportional to the anode voltage applied across the X-ray tube **10**. Similarly, the position of the adjustable tap **52** on the resistor **50** will provide a certain percentage of the voltage drop across the resistor **50** and apply this percentage of the voltage drop to the control grid **53** of the gaseous control tube **54**. In this way, a voltage proportional to the product of the anode voltage and the anode current of the X-ray tube **10** is applied to the control grid **53**.

Similarly, since the first portion **42** of the timer resistance **39** is connected through a dropping resistor **46** across the reference B+ voltage between the B+ lead **44** and the B− lead **45**, the position of the adjustable tap **59** will apply to the cathode of the control tube **54** a voltage or signal which can be made proportional to the exposure time desired and manually set on the timer device **27** by means of the manual control arm **120**.

In this respect, the resistance value of the time resistance **39** and the respective resistance values between the various available time settings on the first portion **42**, and the second portion **43** of the time resistance **39**, can be predetermined, such that for the various time settings provided for the adjustable tap **59** on the time resistor **39**, a voltage is obtained and applied to the cathode of the gaseous control tube **54**, which is proportional to the product of the anode voltage times the anode current, which is allowable for the particular time represented by the respective time settings on the time resistor **39**, which information is obtainable from the well-known tube rating charts available for each X-ray tube, as known to those skilled in this art. Hence, the gaseous control tube **54**, in operation, effectively compares the allowable anode voltage times the anode current product with the manually preset anode voltage times the anode current product, to determine whether the manual control button **28** for the time device **27** can be safely closed. In this respect, the allowable anode voltage times the anode current product is compared to the voltage obtained by the time selector resistor **39** which is connected to the cathode of the gaseous discharge device **54**.

The ohmic values of the time resistor **39**, the anode current resistor **50** and the anode voltage resistor **47** are predetermined and connected across the reference voltage source **38**, such that the voltages obtained from the respective adjustable taps **59**, **52** and **49** correspond to the allowed and known safe values from the tube rating chart for the particular X-ray tube **10** employed. The effective product of the latter voltages is provided by the above described comparison by the gaseous control tube **54**. Voltages corresponding to the manually preset anode voltage and the anode current are obtained from the tap **49** on the resistor **47** which is ganged to be adjusted in common with the anode voltage setting tap **21** on the autotransformer **17**, and adjustable tap **52** on the resistor **50** which is ganged to move in common with the anode current determining manual control arm **121** of the filament control device **32**. If the comparison between these respective anode voltages times the anode current as a product with the time voltage, as compared by the gaseous control tube **54**, is not favorable for the safe operation of the X-ray tube **10**, then the tube **54** will conduct to energize the relay control winding **55** and open the first auxiliary control switch **62** to prevent the closing of the main switch **24** by means of the timer device **27** energizing the control relay winding **29**.

Assuming that the manually preset values of the exposure time, as determined by the adjustment of the manual control arm **120** of the control device **27**, of the anode current, as determined by the adjustable tap **121** of the filament control device **32**, and of the anode voltage, as determined by the adjustable tap **21** of the autotransformer **17**, are suitable for the safe operation of the X-ray tube **10**, and, further, assuming that the temperature of the anode **11** is substantially at ambient or room temperature, then when the manual start switch **28** is closed, the timer device **27** will be operative to energize the relay control winding **29** to close the main switch **24** and initiate the operation of the X-ray tube **10**. The timer device **27**, in this respect, determines the closing time of the main switch **24** and the opening time of the main switch **24**, such that the timer device **27** thereby determines the operative time, or the X-ray emission time, of the X-ray tube **10**.

When energy is applied to the primary winding **22** of the high tension transformer **23**, it is also applied to the primary winding **63** of the control transformer **64**, such that the charging of the condenser **70** is thereby initiated providing the control switch **69** is closed, as determined by the timer device **27**, to correspond to the operating cycle of the X-ray tube **10**. The series connected resistor **67** determines the charging rate of the condenser **70** as also does the voltage applied to the primary winding **63** of the control transformer **64**, which latter voltage corresponds to the anode voltage applied to the X-ray tube **10**. It should be noted that the effective resistance of the anode current charging resistor **67**, as determined by the adjustable tap **68**, should be decreased as the anode current is increased, such that the series current of the circuit, including the resistor **67**, will correspondingly increase relative to the X-ray tube anode current. In this way, the charging rate of the condenser **70** can be made to substantially correspond to the rate at which heat energy is fed into the X-ray tube. The condenser **70** is shunted by a shunt resistor **71** which removes the charge from the condenser **70** at a rate corresponding to the thermal cooling characteristic curve of the particular X-ray tube **10** which is actually employed. In actual practice, the leakage of charge from the condenser **70** by the resistor **71** can be made to very accurately correspond to the known prior art tube rating chart by the X-ray tube **10** employed.

The diode **66** has a heated type of cathode, such that its heated cathode would be effective to generate thermionic currents between the anode and cathode of tube **66** even without normal plate voltage applied to the tube **66**. These thermionic currents would be operative to put a slight charge on condenser **70** regardless of the operative cycle of X-ray tube **10** were it not for the switch **69** controlled by the timer device **27** through control winding **40**. Thusly, switch **69** is provided to control the charging of condenser **70** to correspond to the operation of X-ray tube **10**.

The accumlated charge on the condenser **70** is applied as a control bias to an electrometer tube **72** which is well known in the art and has the characteristic of measuring or responding to voltage without drawing any appreciable grid current from the measured circuit. The plate current of electrometer tube **72** varies inversely with the negative charge on the condenser **70**. This is true since the diode rectifier **66** is so poled that the upper plate of the condenser **70**, as viewed in the drawing, is negatively charged relative to the lower plate of the condenser **70**, and, accordingly, an increasingly negative bias voltage is applied to the suppressor grid **73** of the electrometer tube **72** in proportion to the thermal energy stored in the X-ray tube **10**. Since the anode **79** of electrometer tube **72** is connected to the control grid **82** of the tube **83**, the grid voltage of tube **83** varies directly with the charge on the condenser **70**, that is to say, as the grid **73** of electrometer tube **72** goes more negative, grid **82** of tube **83** goes more positive, and, in effect, due to the operation of the electrometer tube **72**, the charge on the condenser **70** is isolated by the tube **72**. The grid voltage or bias of tube **83** determines the plate current of tube **83**, and, accordingly, the series-connected heat indicator meter **88** will give a visual concept of the heat content or accumulated heat stored in the X-ray tube **10**.

An alternating current voltage is connected across tube **83** by means of supply transformer **87**, and alternating current supply voltage is supplied in this respect so that a voltage can be taken from the plate circuit of tube **83** through the control transformer **92** and rectified through diode rectifier **95** in the form of a direct current voltage for the purpose of charging the condenser **96**. The latter direct current voltage is isolated from the D.-C. plate circuit of the tube **83**. This is important since the output of the transformer **92**, as rectified by diode rectifier **95**, is used to charge the condenser **96** proportionally to the plate current of the tube **83**, and, hence, proportionally to the heat content of the X-ray tube **10**, and, particularly, the anode **11** of the X-ray tube **10**. The voltage built up on condenser **96** is sampled by a shunt resistor **97** provided with a tap **98** which takes a portion of the voltage across the condenser **96** and applies it to the control grid of tube **100**. Tube **100** is connected in series with the second portion **43** of the time resistor **39**, and this series circuit is connected between the B+ supply lead **44** and the B− lead **45**. Hence, the tube **100** determines the voltage applied across the second portion **43** of the time resistor **39**, and, in this way, the voltage applied across the portion **43** is made proportional to, and to correspond with, the heat content of the X-ray tube **10**. In other words, as the voltage built up across the condenser **96** increases, due to greater heat content in the X-ray tube **10**, the grid of the tube **100** is made more negative, such that the plate current of the tube **100** is decreased, and, hence, the voltage applied across the second portion **43** of the time resistor **39** is correspondingly decreased.

The point of division between the first portion **42** and the second portion **43** of the time resistor **39** is made to correspond to substantially 1½ seconds of X-ray tube **10** operation as determined by the timer device **27**. In this respect, the manual control arm **120** of the timer device **27** is effective to determine whether the adjustable tap **59** of the time resistor **39** is operative with the first portion **42** or the second portion **43**, such that if the time setting for the timer device **27** is less than 1½ seconds, the first portion **42** is used, and if the manual time setting of the timer device **27** is greater than 1½ seconds, the second portion **43** is used. The substantially 1½ seconds of time exposure demarcation between the first portion **42** and the second portion **43** of the time resistor **39** has been empirically determined, and is based upon the heat dissipation characteristics of the X-ray tube **10**. Obviously other values of time exposure demarcation in this respect may be used, if desired. On particularly short exposure operation of the X-ray tube **10**, the heat content of the tube **10** is relatively immaterial, since on particularly short exposures there is not enough time for the heat accumulated in the anode to pass or be dissipated in the rest of the tube structure, so the primary concern is to avoid overheating the surface of the anode **11** instantaneously. However, on long exposures, the whole structure of the X-ray tube **10** is heated such that the thermal gradient provided between the tube anode **11** and the rest of the structure of the X-ray tube **10** is insufficient to adequately dissipate the heat energy stored in the anode **11**. The exposure time of 1½ seconds has been determined through practice and experience as the dividing line or time demarcation where the temperature of the tube structure, other than the anode **11**, and, hence, the available thermal gradient for the dissipation of the heat in the anode **11** becomes important regarding the protection of the anode **11** and X-ray tube **10**. Therefore, the first portion **42** of the time resistor **39** is connected between the B+ lead **44** and the B− lead **45** available as a reference voltage. For time exposure values above 1½ seconds, the second portion **43** of the time resistance **39** has a voltage applied across it which correpsonds to the past history of operation of the X-ray tube in terms of the heat content or heat energy stored in the anode **11** and the remaining structure of the X-ray tube **10**.

An additional control feature of the circuit shown in the drawing is provided by the tube **111** which is provided at its cathode **110** with a bias voltage from the adjustable tap **90** on the resistor **89** connected in the plate circuit of the control tube **83**. Since the plate current of the control tube **83** is proportional to the heat content of the X-ray tube **10**, the series connected resistor **89** provides a voltage drop which is proportional to this heat content. Therefore, the cathode **110** of the tube **111** is biased such that the tube **111** is made to conduct when the heat content in the X-ray tube **10** exceeds a predeterminable maximum safe value, which safe value is available from tube charts provided by the manufacturers of X-ray tubes and are well known in the art. A tube chart of the type under consideration can be found in Wiseglass Patent 2,353,979, assigned to the assignee of the present invention. An alternating current voltage is provided by supply transformer **115** to control the operation of gaseous discharge tube **111**, such that the tube **111** operates as a gaseous rectifier tube, and is nonconductive until the proper grid cathode bias voltage relationship is present. One advantage of using an alternating current control voltage for the tube **111** is to provide a cut-off control for the tube when the heat content of the X-ray tube **10** returns to a safe and allowable value.

In accordance with the present invention, the first portion **42** of the time resistor **39** is calibrated to correspond to the cold tube rating charts for X-ray tubes as well known to those skilled in the art, and the second portion **43** of the time resistor **39** is calibrated to correspond to the hot tube rating charts known in the art.

While we have shown our invention in particularly one form only, it will be obvious to those skilled in the art that it is not so limited, but is susceptible of various other changes and modifications without departing from the spirit and scope thereof. For example, a light system may be arranged to show the operation of the first auxiliary switch **62** and the second auxiliary switch **117**, if desired.

Further, the amount of heat energy stored in the X-ray tube **10** may be employed to alter the time reference voltage, instead of obtaining it from the circuit including portion **43** of time resistor **39**, by changing the temperature of a thermally sensitive resistor member or by operating a bimetallic member such as a helix that rotates a potentiometer or like device in series with its supply voltage.

We claim as our invention:

1. In apparatus including an electrical discharge device having an anode and a cathode, with a voltage supply circuit connected to said device for applying energy to said device between said anode and said cathode, the combination of a timing device connected to said circuit for controlling said circuit in accordance with a selected time interval during which energy may be applied, voltage indicative means operable to provide a first signal corresponding to the voltage applied to said device, current indicative means operable to provide a second signal corresponding to the current level at which energy is to be applied, and time indicative means con-

nected to be commonly operable with said timing device to provide a third signal corresponding to said selected time interval, an integrating measuring system connected with said voltage supply circuit for producing a fourth signal having a magnitude corresponding to the energy accumulated in said discharge device after the device has been in operation, means connected with said measuring system for reducing the magnitude of said fourth signal at a rate corresponding to the rate of dissipation of said accumulated energy, means responsive to the resultant magnitude of said fourth signal and coupled to one of said indicative means so as to modify the signal provided thereby in accordance with said fourth signal, switch means connected in said voltage supply circuit between said source and said discharge device, trigger means connected to said switch means so as to actuate said switch means to prohibit delivery of energy to said discharge device, said voltage indicative means, said current indicative means and said time indicative means being connected to said trigger means to apply the combination of said first, second, and third signals thereto for actuating said trigger means when the combination of said voltage, said current level, said time interval corresponds to a quantity of energy exceeding the remaining available thermal capacity of said device.

2. In apparatus including an electrical discharge device having a cathode and an anode, with a voltage supply circuit connected to said device for applying a voltage between said anode and said cathode, and with respectively a current selector, a voltage selector and a time interval selector connected to said circuit, the combination of voltage means operable to derive a first signal proportional to the selected voltage to be applied to said device, said voltage means being commonly operable with said voltage selector, current means operable to derive a second signal proportional to the selected anode current of said device, said current means being commonly operable with said current selector, time means operable to derive a third signal proportional to the selected time interval during which energy is to be applied to said device, said time means being commonly operable with said time interval selector, accumulated energy measuring means for providing a fourth signal substantially corresponding to the thermal condition of said device as determined by the amount of energy accumulated therein, circuit means connected between said measuring means and one of said signal deriving means for modifying the signal derived thereby in accordance with the magnitude of said fourth signal, and control means connected between said voltage supply circuit and all said signal deriving means, said control means being constructed and arranged to disable said voltage supply circuit in response to a combination of said first, second and third signals corresponding to a quantity of energy exceeding the difference between the thermal energy capacity of said load and the energy accumulated therein.

3. A system for delivering energy to a heat generating electrical load in which the generation of heat is a function of a plurality of adjustable variables, comprising a circuit connected with said load for delivery of energy thereto, switch means in said circuit for controlling energy delivery to said load, adjustable means for preselecting the potential at which said energy is to be delivered, adjustable means for preselecting the intensity level at which current is to flow to said load, adjustable means for determining the elapsed time interval during which energy may be delivered to said load, first, second and third control signal supply means each being commonly operable with one of said adjustable means so as to supply respectively a first control signal corresponding to the potential at which said energy is to be delivered, a second control signal corresponding to the intensity level at which said current is to flow and a third control signal corresponding to said time interval, stored heat energy measuring means for deriving a fourth control signal corresponding to the thermal energy accumulated in said load after the system has been in operation, circuit means connected between said measuring means and one of said control signal supply means for modifying the control signal supplied thereby in accordance with said fourth control signal, and trigger means controllingly connected to said switch means, said first, second and third control signal supply means being connected to said trigger means so as to apply said control signals thereto, with said trigger means being so constructed and arranged as to actuate said switch means to prohibit delivery of energy to said load when the quantity of energy to be delivered plus said accumulated thermal energy exceeds the safe thermal capacity of said load.

4. An X-ray exposure system, comprising an X-ray tube, circuit means connected with said tube for the delivery of energy to said tube, a timing device for controlling said circuit means in accordance with a selected exposure time, a protective relay connected with said circuit means for preventing energization of said tube by overload conditions, means for supplying a voltage depending upon the rate at which energy is supplied by said circuit means to said X-ray tube, and means for supplying another voltage depending upon the selected exposure time, measuring means coupled with said X-ray tube for deriving a control signal corresponding to the thermal energy accumulated in said tube, means connected between said measuring means and one of said voltage supply means for modifying the voltage supplied thereby in response to said control signal, voltage difference responsive means connected to control said protective relay and adapted for operation at a predetermined difference between a pair of control voltages, both said voltage supply means being connected with said difference responsive means so as to apply control voltages thereto for actuating said difference means when the combination of said energy rate, said selected exposure time and said accumulated thermal energy corresponds to a quantity of energy exceeding the safe thermal capacity of said tube.

5. The combination, with an electron discharge device having an anode and an electron emitting cathode, of switch means for controlling the delivery of operating power between said anode and cathode, adjustable means for varying the anode-cathode potential at which said power is to be delivered, adjustable means for exciting the cathode for electron emission at various intensity levels, adjustable timer means for determining the elapsed time interval during which operating power is to be delivered to the device, an electron valve having a control electrode and adapted for operation at a predetermined bias level and controllingly connected with said switch means, means commonly operable with said anode potential adjustment means for supplying a first control signal substantially corresponding to the potential at which operating power is to be delivered, means commonly operable with said cathode excitation adjustment means for supplying a second control signal corresponding to the preselected intensity level at which anode current is to flow, means commonly operable with said adjustable timer means for supplying a third control signal dependent upon the time interval during which said power is to be delivered, circuit means connected between said commonly operable means and said electron valve for applying said first, second and third control signals thereto so as to operate said valve when the combination of said control signals exceeds said predetermined bias level, a thermal energy measuring network coupled with said discharge device so as to produce a fourth control signal substantially dependent on the thermal energy content of said device, and means connected between said network and at least one of said control signal supplying means for modifying said com-

bination of control signals in accordance with said fourth control signal so that said combination control signals is responsive to the thermal condition of said discharge device to operate said valve when the quantity of energy to be delivered plus the thermal energy content of said device exceeds the safe thermal capacity thereof.

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