Jan. 27, 1953

J. BALL

2,627,035

MILLIAMPERAGE STABILIZER

Filed Nov. 22, 1947

4 Sheets-Sheet 1

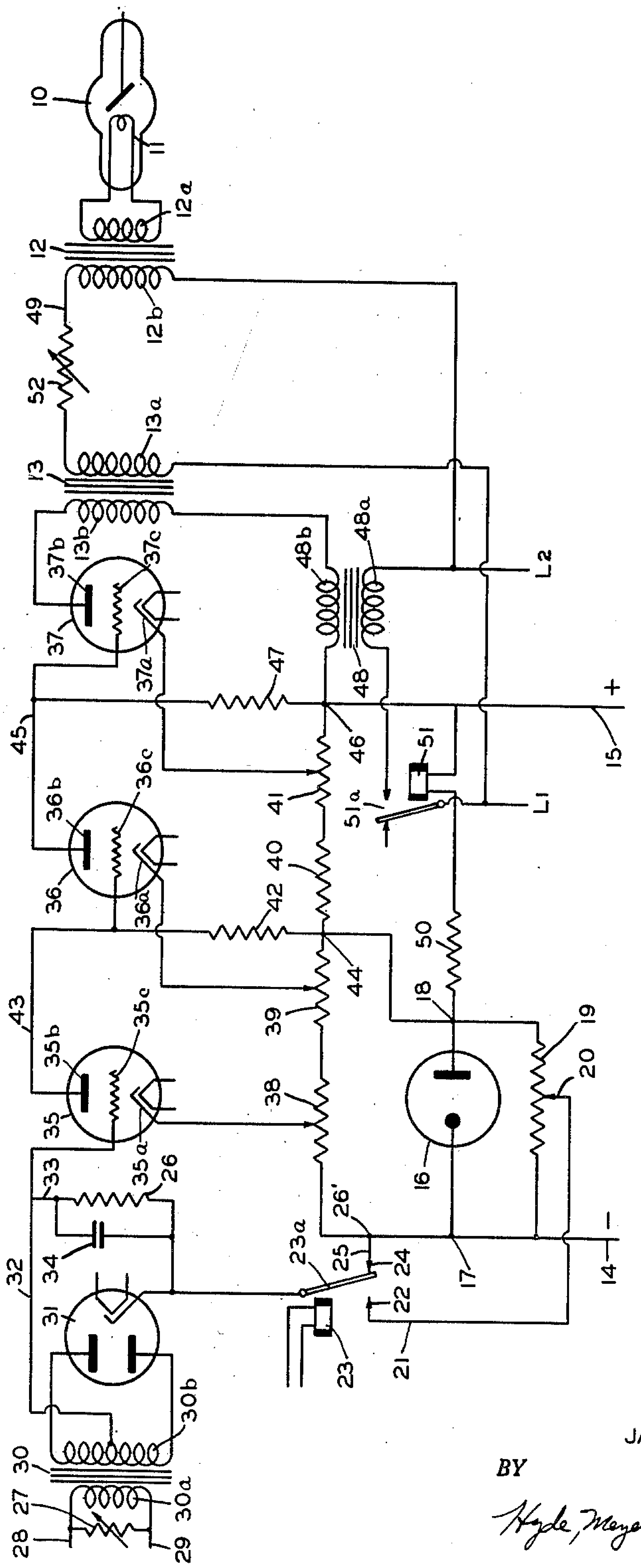

FIG-1

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Jan. 27, 1953 J. BALL 2,627,035

MILLIAMPERAGE STABILIZER

Filed Nov. 22, 1947 4 Sheets-Sheet 2

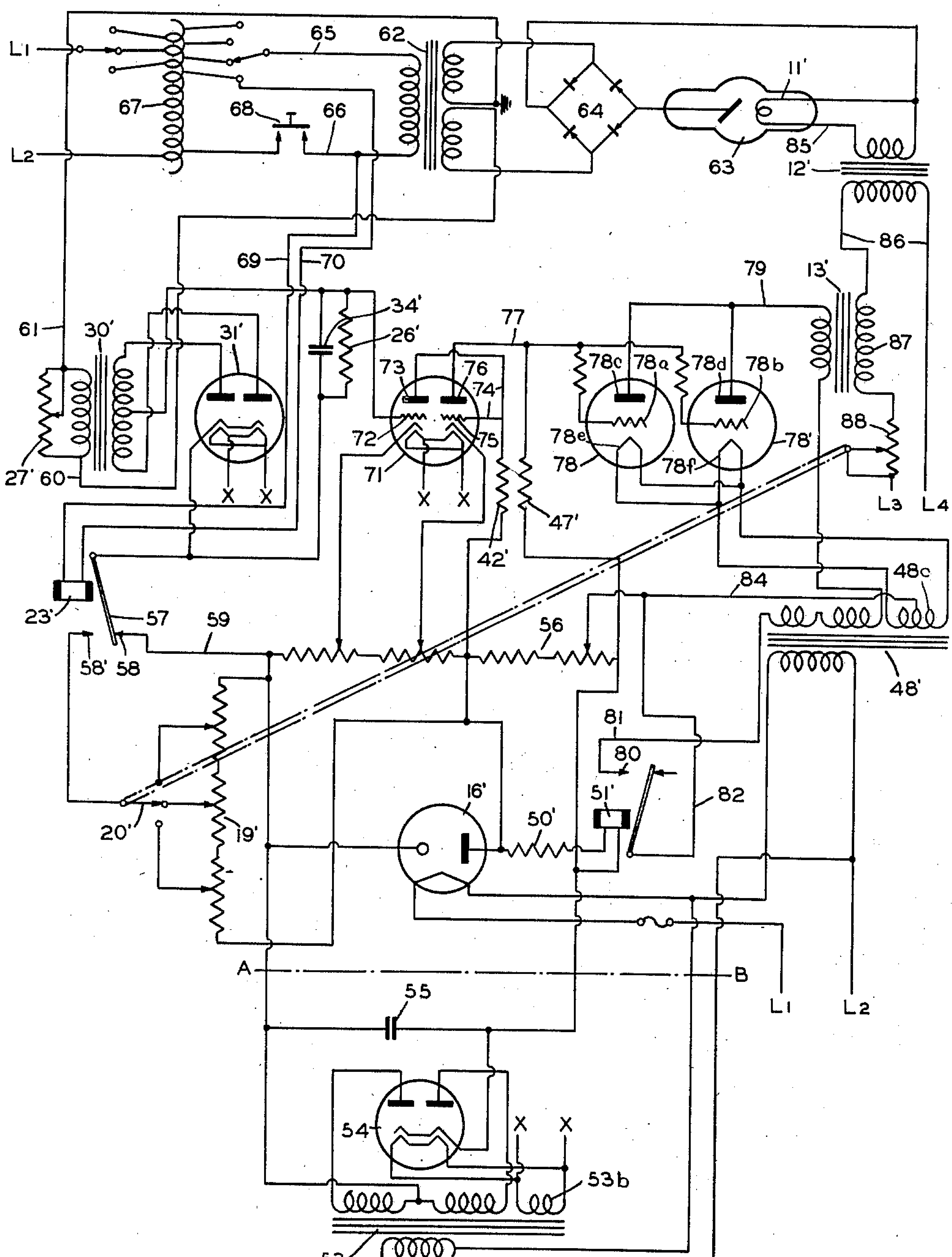

FIG.-2

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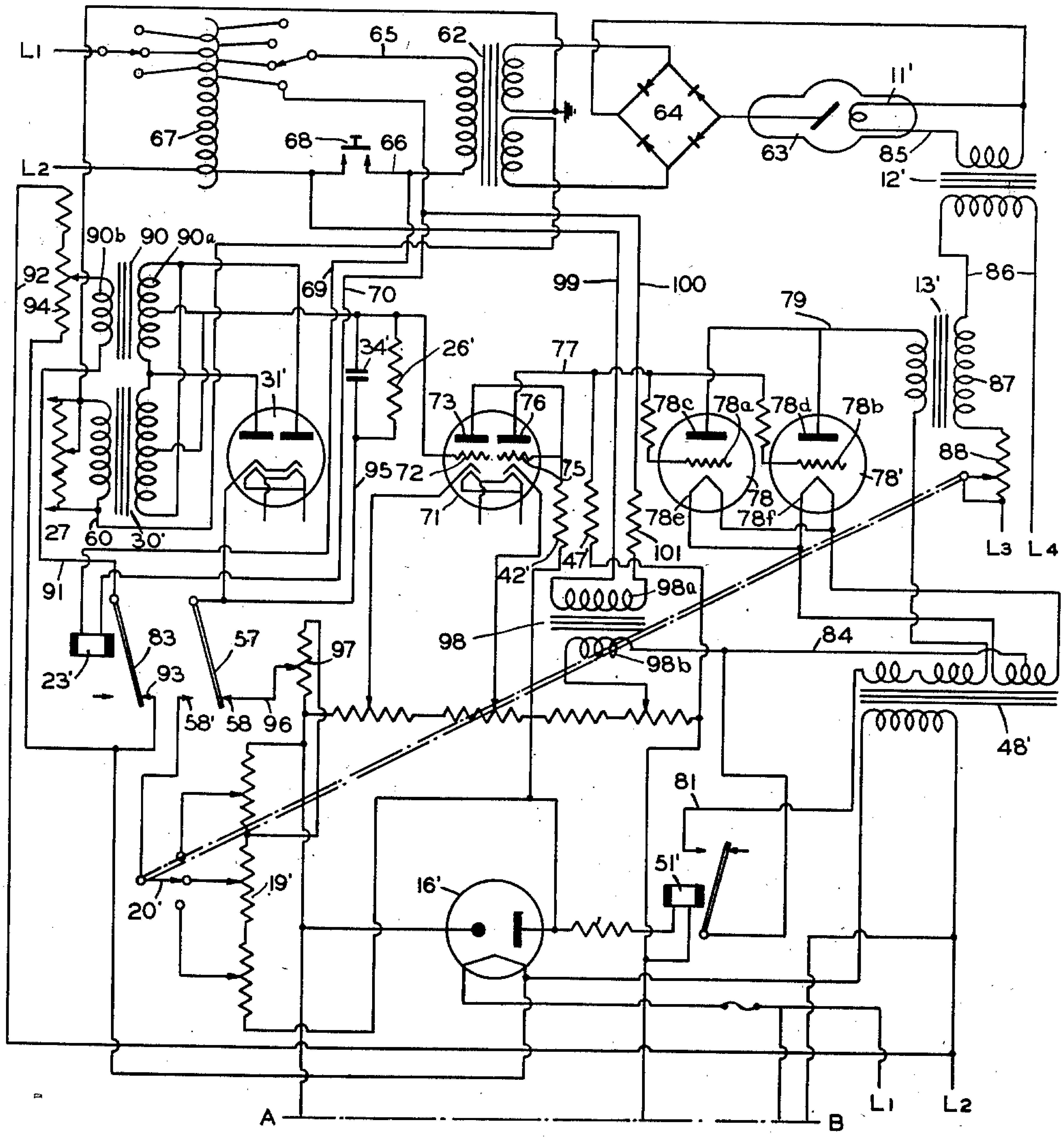

FIG.-3

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Jan. 27, 1953 | J. BALL | 2,627,035

MILLIAMPERAGE STABILIZER

Filed Nov. 22, 1947 | 4 Sheets-Sheet 4

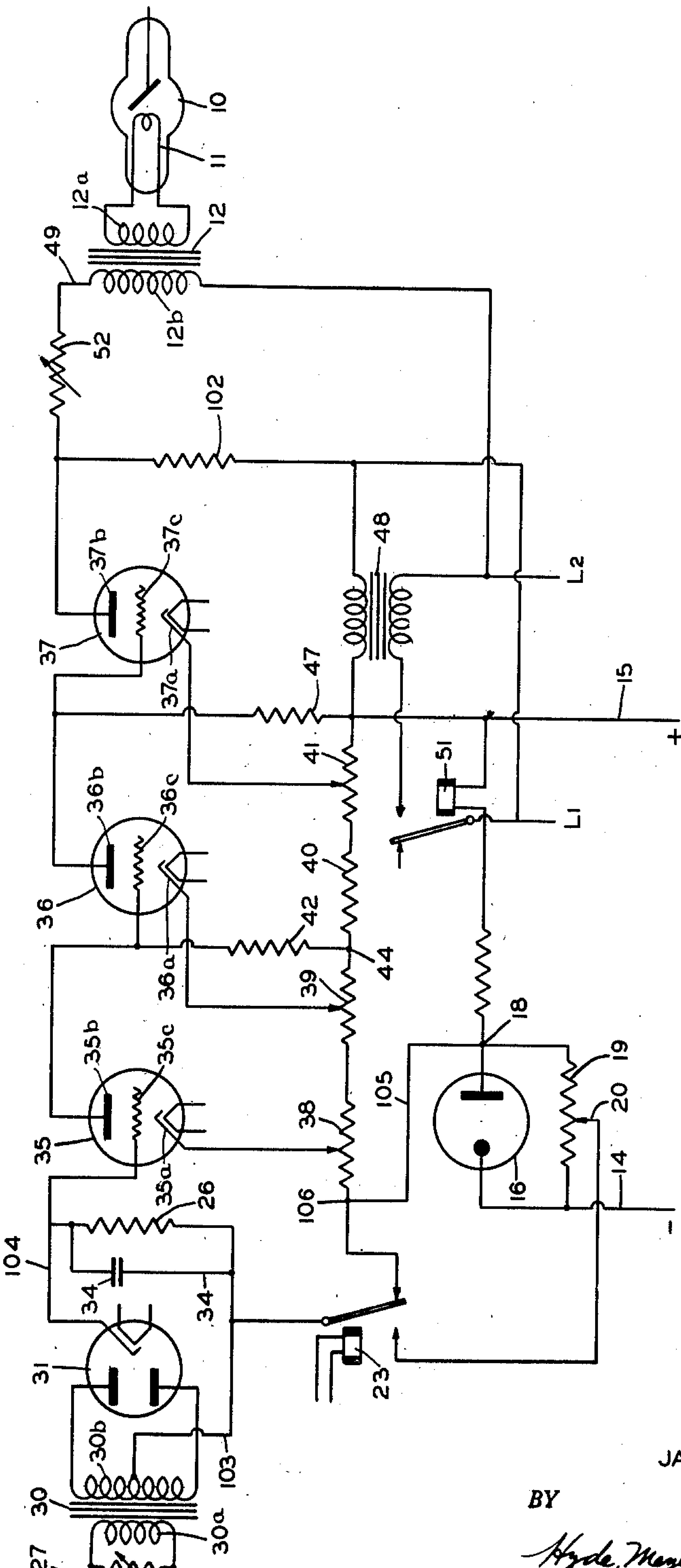

FIG-4

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UNITED STATES PATENT OFFICE

2,627,035

MILLIAMPERAGE STABILIZER

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Application November 22, 1947, Serial No. 787,491

16 Claims. (Cl. 250—97)

1

This invention relates to X-ray systems and more particularly to improved means for stabilizing, or maintaining substantially constant, the discharge current flowing through the X-ray tube.

It is usually desirable to operate an X-ray tube at a constant load current at a level previously selected by the operator. Many factors tend to cause a variation in the load current and since the latter, together with time, and expressed as milliampere-seconds, determines the quality of the resulting radiograph, it is essential that the milliamperage flowing through the tube discharge be maintained as constant as possible.

An object of the present invention is to take a predetermined fixed and constant value of the discharge milliamperage and to feed the same into a comparison circuit so as to wholly or partially cancel the same against the actual milliamperage, of opposite sign, corresponding to the discharge of the X-ray tube. The difference, if any, of these compared values is then fed through an amplifier to the control grid of a space charge device so as to provide an output voltage of the proper sign to be added to or subtracted from the excitation of the X-ray tube filament so as to vary the same up or down as may be necessary to maintain the desired actual load current for the X-ray tube. Various means may be used to carry out the above purpose as will be apparent from the accompanying description.

Another object of the present invention is to preset the excitation of the thermionic cathode or filament of the X-ray tube to a stand-by value which may be either above or below the desired value so that upon initiation of an exposure, my improved stabilizing device will very quickly bring the excitation of the X-ray tube filament to the value necessary to maintain the desired discharge through the X-ray tube.

Another object of the present invention is to provide improved means for varying the excitation of the X-ray tube filament under stand-by conditions responsive to fluctuations in the supply line voltage so that the conditions in the exciting circuit for the X-ray tube filament are as near as possible to the desired conditions immediately prior to initiation of an exposure.

Still another object of the present invention is to provide in the stabilizing circuit a corrective factor for the space charge of the X-ray tube so that the excitation of the X-ray tube filament is corrected immediately for changes in the space charge which might otherwise cause a variation in X-ray tube operation from the predetermined chosen level.

2

Other objects and advantages of my invention will be apparent from the accompanying drawings and description and the essential features thereof will be set forth in the appended claims.

In the drawings,

Fig. 1 is a diagrammatic view illustrating the theory of my invention in simplified form;

Fig. 2 is a diagrammatic view showing one manner of carrying out the invention of Fig. 1 more in detail;

Fig. 3 is a modification of Fig. 2 showing means for compensating the stabilizer system for line voltage fluctuations in stand-by condition and means for compensating the stabilizer system for the space charge of the X-ray tube; while

Fig. 4 is a diagrammatic view similar to Fig. 1, showing a modification using a resistance coupling between the stabilizer circuit and the X-ray tube filament circuit.

In Fig. 1, I have shown a simplified diagram to illustrate the principle of my invention. An X-ray tube is shown at **10** having a filament **11** supplied with current from the secondary **12a** of a filament transformer **12**. The primary **12b** of this transformer includes a winding **13a** which is subjected to the stabilizer corrections. A D. C. power supply is provided between the terminals **14** and **15** and a portion of this supply is held constant by the voltage regulator tube **16** connected between the points **17** and **18**. On a resistor **19** connected between points **17** and **18** a contact **20** picks off a positive voltage which corresponds to the milliamperage which is desired to flow in the X-ray tube. The contact **20** is connected by line **21** to a contact **22**. A relay **23** is provided with an armature **23a** which normally engages contact **24** which in turn through line **25** is connected with a point **26'** of approximately zero voltage. The relay **23** is energized when the X-ray tube is energized, thus causing the armature **23a** to open contact **24** and close against contact **22**. This applies the selected voltage from resistor **19** which is applied across resistor **26** in the stabilizing system. This positive voltage is compared with a negative voltage resulting from the actual discharge of the X-ray tube as will presently appear.

A resistor is connected by lines **28** and **29** in series in the usual grounded central secondary circuit of the high tension transformer supplying the X-ray tube **10**. When the tube is operating, a voltage is developed across the primary winding **30a** of a transformer **30**. This develops a voltage in the secondary winding **30b** which is rectified in the rectifier tube **31** and the rectified current is supplied through lines **32** and **33** to the resistor 26. The condenser 34 and the resistor 26 filter the current from rectifier 31. This also may be said to constitute an anti-hunting circuit since the values of resistor 26 and condenser 34 can be varied to give the correct time delay to eliminate hunting. It will be remembered that the relay 23 is energized at the time the X-ray tube starts operating so as to connect the armature 23*a* with the contact 22 applying a positive voltage from resistor 19 to the resistor 26. The voltage applied through the transformer 30 is negative and, if the milliamperage flowing through the X-ray tube is exactly the desired amount as picked off on the resistor 19 the two voltages applied to the resistor 26 will exactly balance each other and no change will take place in the stabilizer circuit.

Should the milliamperage be too high or too low, the difference will be fed through the amplifier tubes 35 and 36 to the control grid of control tube 37 which will provide a corrective factor in the X-ray tube filament circuit which includes the windings 12*b* and 13*a* previously described. Referring back to tubes 35 and 36, these constitute a direct coupled D. C. amplifier. The cathode 35*a* of this triode is connected to a variable positive voltage by means of the potentiometer 38. Voltage to the plate 35*b* of this tube is supplied from the voltage divider 38, 39, 40 and 41 through the load resistor 42. In one embodiment of my invention cathode 35*a* is connected to potentiometer 38 and so adjusted that tube 35 passes approximately five milliamperes. When the tube 35 is passing current, since the plate 35*b* is connected through line 43 with the grid 36*c* of tube 36, the potential of grid 36*c* is negative with respect to the junction 44 of the potentiometers 39 and 40. Thus, in order to make tube 36 pass current, it is necessary to apply a bucking potential to cancel this negative bias developed across resistor 42. This is done by connecting the cathode 36*a* of tube 36 to the potentiometer 39. Thus, the potential on grid 36*c* is the sum of the bias developed across resistor 42 and the bias from the potentiometer 39.

In one embodiment 39 is adjusted so that tube 36 passes about ten milliamperes. When current is passing in tube 36 and the plate 36*b* is connected by line 45 with the grid 37*c* of tube 37, this makes the potential of grid 37*c* negative with respect to the junction 46 which supplies current to the plate 36*b* through the load resistor 47. In order to make tube 37 pass current, it is necessary to apply a bucking potential by connecting the cathode 37*a* to the potentiometer 41. The bias on the grid 37*c* is again the sum of the bias developed by the plate current of tube 36 through the resistor 47 and the adjustable bias of 41. In one embodiment potential 41 is adjusted so that the plate current of tube 37 is approximately thirty milliamperes.

It should be noted that the plate voltage for tube 37 is obtained from the secondary 48*b* of a transformer 48 whose primary 48*a* is connected to an A. C. source L1, L2 of approximately 110 volts. The fact that the control tube 37 is operating on alternating current renders the device almost instantaneous in its stabilizing action. The plate current developed in tube 37 passes through the winding 13*b* of transformer 13 causing a current in the winding 13*a* which, as mentioned previously, is in the circuit 49 which supplies the filament transformer 12.

The resistor 50 is provided to control the current through the voltage regulator 16. A relay 51 is in series with this circuit and provides a safety relay. The normally open contacts 51*a* of this relay are in circuit with the primary 48*a* of the transformer 48. This prevents application of voltage to the X-ray tube filament circuit from transformers 13 and 48 until D. C. voltage is applied to the voltage dividing network, which occurs when all of the tube filaments have reached their emission point. This is done because, although tube 37 is shown as a heater type tube, I actually use a filament type tube which attains emission much faster than the heater type tubes and the rest of the circuit.

The resistor 52 in the filament transformer circuit is the usual limiting resistor which is set by the operator when selecting the desired conditions for X-ray tube operation.

The operation of the device of Fig. 1 when a net voltage is developed across resistor 26 should now be apparent. If the milliamperage, as detected in resistor 27, is too high, the negative voltage developed across resistor 26 will be greater than the positive voltage selected from resistor 19, resulting in a net negative voltage which will drive the grid 35*c* of the triode 35 in a negative direction. This will reduce the plate current of tube 35 to a lower value, which will reduce the voltage drop across resistor 42 and consequently, the grid 36*c* of tube 36 will become more positive. Therefore, the plate current of tube 36 will increase and correspondingly, the voltage across resistor 47 will increase, making the grid 37*c* of tube 37 more negative. This reduces the plate current of tube 37 and consequently, the voltage developed in the windings 13*b* and 13*a* of transformer 13 will also drop which will reduce the output of filament transformer 12 so as to reduce the current in filament 11 and therefore, the milliamperage developed by the X-ray tube will be lowered.

In a similar manner, should the milliamperage developed across resistor 27 be too low, a net positive voltage will be developed in resistor 26 which will make the grid 35*c* of tube 35 more positive giving a completely opposite reaction to that above described through tubes 35, 36 and 37 which will increase the current in the plate circuit of tube 37 and therefore increase the contribution of transformer 13 to the filament transformer 12 causing a rise in the current of filament 11 and an increase in the milliamperage developed by the X-ray tube. In the apparatus just described, the resistor 27 is fixed and is determined by the characteristics of the transformer 30 and the amplifier circuit 35, 36, 37. The actual milliamperage which is maintained by the stabilizer is determined only by the setting of the contact 20 with reference to the resistor 19 and this is selected by the operator in predetermining the X-ray tube operating conditions desired.

In the modification of Fig. 2, I have shown a diagrammatic view from actual electrical circuits for carrying out the invention which has been set forth above in simplified form in connection with Fig. 1. Detailed explanation is unnecessary because it follows the teachings of Fig. 1 very closely. The D. C. power supply is provided by means of a power pack which includes a transformer 53 having its primary connected to the low voltage source L1, L2 and having its secondary connected through a rectifier tube 54 to supply rectified direct current filtered by means of the condenser 55 and the resistance network analogous to 38, 39, 40 and 41 previously described. This voltage divider circuit and the various potentiometers are herein indicated generally at 56. The voltage regulator tube 16′, the resistor 50′ and the relay 51′ perform the same functions as the parts 16, 50 and 51 respectively already described. A set of resistors 19′ and the contact 20′ provide means for the operator to pick off a selected discharge milliampere to be applied to the resistor 26′ analogous to the parts 19, 20 and 26 of Fig. 1. The relay 23′ has an armature 57 which is normally connected through contact 58 and line 59 with a point of substantially zero voltage of the D. C. power supply. A resistor 27′ is analogous to the resistor 27 of Fig. 1 and is connected by lines 60 and 61 into the central grounded secondary circuit of the high tension transformer 62 which supplies the X-ray tube 63 with current through the rectifying bridge circuit 64. The primary of transformer 62 is connected by lines 65 and 66 to an auto transformer 67. The supply for the auto transformer is indicated at L1, L2 at approximately 110 volts. A contact button 68 in the line 66 initiates an X-ray exposure. The relay 23′ is connected by lines 69 and 70 in parallel with the primary circuit of transformer 62 so that relay 23′ is energized each time an exposure is made. The voltage developed across the resistor 27′ is fed through transformer 30′ rectified in the rectifier 31′ and fed to the condenser and resistor combination 34′, 26′ analogous to the parts 27, 30, 31, 34 and 26 of Fig. 1. The tube 71 is a substitute for the tubes 35 and 36 of Fig. 1. This is a double triode tube. The net current applied to resistor 26′ when an X-ray exposure is made (being the sum of the voltages supplied from 19′ and 27′) is fed to the grid 72 of the tube 71. The plate current from plate 73 is fed through line 74 to the grid 75. The plate current from plate 76 is fed through line 77 to the grids 78*a* and 78*b* of triodes 78 and 78′ in parallel connection. In circuit with plates 73 and 76 are load resistors 42′ and 47′ which are analogous to the resistors 42 and 47 of Fig. 1. The plates 78*c* and 78*d* of the two triodes 78 and 78′ are connected in parallel by line 79 through the primary of transformer 13′ which is analogous to transformer 13 of Fig. 1. Also in this plate circuit is the secondary of power transformer 48′ analogous to transformer 48 of Fig. 1. Here the contact 80 of relay 51′ is connected by lines 81 and 82 in series in the plate circuit of the tubes 78 and 78′ in the secondary winding of transformer 48′ instead of in the primary of this transformer as shown in Fig. 1. The reason for this is that winding 48*c* is provided for transformer 48′ to supply current to the filaments 78*e* and 78*f* of the two triode control tubes. However, the purpose of the relay 51′ is the same as in Fig. 1, namely, to provide time for the slower heating tubes to come up to temperature before power is supplied to tubes 78 and 78′. The transformer 48′ has a central tap connected with line 84 which is in the plate circuit 78*c*, 78*d*, 79 and connects into the resistor network 56 to properly bias the tubes 78 and 78′ as does the potentiometer 41 in connection with tube 37 of Fig. 1. The filament circuit 85 for X-ray tube 63 is supplied through transformer 12′ which is analogous to transformer 12 of Fig. 1. The primary circuit 86 for this filament transformer includes the secondary winding 87 of the transformer 13′ for making effective the end result of the stabilizer system on the X-ray tube filament circuit. In the circuit 86 is limiting resistor 88 which is preset by the operator to select the proper charge on the tube filament 11′ in stand-by condition of the apparatus as will be presently described. The operation of Fig. 2 is entirely analogous to the operation of Fig. 1 already described. In stand-by condition the resistor 26′ is connected through armature 57 of relay 23′ and contact 58 and line 59 with a point of substantially zero voltage in the D. C. supply system. When an X-ray exposure is started by depressing button 68 relay 23′ is energized and armature 57 contacts 58′ so as to apply the selected positive voltage from 19′ to the resistor 26′. As current flows through the X-ray tube it is manifested in the central grounded secondary winding of transformer 62 and impresses the voltage across resistor 27′. This voltage appears on resistor 26′ as a negative voltage which is there compared with the positive voltage supplied from 19′ and the net voltage plus or minus if any is fed to grid 72 of the tube 71. If the milliamperage at 27′ is too high the grid 72 will be driven in a negative direction and this will pass through the amplifier and appear in plate circuit 79 to reduce the plate current and therefore to reduce the contribution of transformer 13′ to the filament circuit 86. Thus, the filament current of X-ray tube 63 will be lowered so as to drop the milliamperage to the desired level. In like manner, if the milliamperage at 27′ is too low, a net positive voltage will appear at 26′ which upon being fed through tubes 71, 78 and 78′ will increase the plate current in circuit 79 so that transformer 13′ will increase the current in filament circuit 86 thus increasing the current in the X-ray tube filament 11′ so as to increase the milliamperage flowing in the X-ray tube.

A secondary winding 53*b* is provided in transformer 53 and the leads therefrom marked XX supply the cathode heating current for the heating circuits marked XX of the tubes 31′ and 71.

The filament circuit 86 is normally supplied from a low voltage source L3, L4 through a series limiter 88. These are picked off by the operator when setting the control conditions desired for X-ray tube operation. As has been described, the stabilizer system can here increase or decrease the milliamperage of the X-ray tube according to the level at which the exposure is started. One of the functions of the series limiter 88 is to control the speed of reaction so as to overcome tube inertia which would be encountered if the X-ray tube filament current were turned down lower than normal. By means of the limiter, the X-ray tube filament current may be preset to any desired value. If it is desired to increase the life of the X-ray tube, the stand-by current supplied to the filament 11′ may be set by means of the limiter 88 below its normal value. If a speedier reaction of the tube is required, such as for short exposures at high milliamperage, then the limiter 88 may be so set that the X-ray current is at the exact value desired or even slightly higher so that the current is above normal value so that the moment an exposure starts the stabilizer system will be called upon to lower the X-ray filament current which of course can be accomplished much faster than trying to raise the filament current. The selection of resistor values at 20′ and 88 may be subject to simultaneous control as indicated by dot-dash lines in Fig. 2.

Referring now to Fig. 3, it will be noted that this figure is exactly like Fig. 2 except that I have omitted the power pack for rectified direct current supply which would be connected below the line A—B as indicated in Figs. 2 and 3. In addition, I have added to Fig. 3 an arrangement for correcting the filament current for fluctuations of line voltage in the stand-by condition of the apparatus and a correction for the space charge of the X-ray tube.

Referring to the left-hand portion of Fig. 3, I have shown a transformer 90 whose secondary winding 90*a* is in parallel with the secondary winding of transformer 30′. The primary winding 90*b* of transformer 90 is connected to the low voltage input L1, L2 through lines 91 and 92 respectively. It will be noted that line 91 is connected through switch 83 which forms one of the armatures of relay 23′. When this relay is deenergized, the switch 83 is closed against contact 93. When relay 23′ is energized switch 83 breaks engagement with contact 93. A voltage for the winding 90*b* is picked off by means of the voltage divider 94, which when rectified by 31′ and applied at 26′ will have a negative value. In stand-by condition, the resistor 26′ is connected by line 95, armature 57 of relay 23′, contact 58 and line 96 with a positive voltage picked off by means of rheostat 97. Rheostats 97 and 94 are so adjusted that the contribution of their additive voltages to resistor 26′ and to the grid 72, of the first stage of amplification, is zero at a standard voltage at the source L1, L2. Thus, should the line voltage increase or decrease, under stand-by conditions, the voltage on the grid of the first tube will go either negative or positive respectively, and so operate through the stabilizer system to effect transformer 13′ in a direction to decrease or increase the filament current respectively to compensate for line voltage variations. Thus, when the desired conditions for operation of the filament 11′ have been preselected by the operator by the setting of the limiter 88 and the selection of the desired positive voltage on the resistor 19′, upon initiation of an exposure the condition of the filament 11′ and its energizing circuit will be at the desired level regardless of fluctuations in the line voltage at the source L1, L2.

It will be understood by those familiar with this art that my improved stabilizer system as previously described, will regulate for space charge effects within the X-ray tube. However, in order to make this correction substantially instantaneous, I have shown in Fig. 3 a space charge compensating transformer 98. The primary winding 98*a* of this transformer is connected by lines 99 and 100 to the high tension primary circuit 65, 66 ahead of the contactor button 68. The transformer secondary winding 98*b* is in series with line 84 which controls the bias of tubes 78 and 78′ through a connection with the filaments 78*e* and 78*f*. Thus, the bias of control tubes 78 and 78′ is varied according to the kilovoltage selected on the auto transformer 67. The transformer 98 is so phased with the transformer 48′ that as the kilovoltage is increased the bias on the control tubes 78 and 78′ increases in a negative direction and automatically lowers the X-ray filament voltage applied to the filament 11′. In one type of X-ray tube, a .95 ampere in the filament transformer primary 85 gives 200 milliamperes' discharge current through the X-ray tube at 80 kilovolts. In the same tube 1.0 ampere in the filament primary circuit gives 200 milliamperes through the X-ray tube at 60 kilovolts, and 1.1 amperes in the filament primary gives 200 milliamperes through the X-ray tube at 40 kilovolts. The design of the space charge correction transformer 98 may be designed to a curve of the above quantities or to suit the characteristics of the X-ray tube actually being used.

Taps may be provided or a series resistor 101 in the primary circuit to vary the correction for different X-ray tubes.

In the modification of Fig. 4 I have shown how a resistance coupling may be utilized between the stabilizer circuit and the X-ray tube filament circuit in place of the transformer coupling shown at 13 in Fig. 1. All of the parts of Fig. 4 which are exactly like those in Fig. 1 have been given the same reference characters. The differences only will be described.

In the plate circuit of tube 37 in circuit with plate 37*b* I have placed a resistor 102. It will be noted that this resistor is in series with the limiting resistor 52, line 49 and the filament transformer primary 12*b* in the circuit which controls the filament current supplied to the X-ray tube. There is a difference in electrical effect between the transformer coupling of Fig. 1 and the resistance coupling of Fig. 4. In the case of Fig. 1, as the plate current from tube 37 increases, the transformer 13 increases the filament current. The effect of the same circuit in Fig. 4 using the resistor 102 is exactly opposite, for instance, in Fig. 4 as the plate current from tube 37 increases, the resistor 102 will have a greater drop and will decrease the filament current supplied to the X-ray tube. It will be understood that the voltage applied to transformer 12 is a function of the voltage applied at L1, L2 (generally 110 volts) minus the drop in the resistance modulator 102 and the control resistor 52. In order to bring the correction in the X-ray tube filament circuit to operate in the right direction in Fig. 4, it is necessary to go back to the stabilizer input from the resistor 27 in the second central grounded secondary of the X-ray tube energizing circuit shown at the left-hand side of the diagram of Fig. 4. The connection from the transformer secondary 30*b* through the rectifier tube 31 is so changed by the line connections 103 and 104 as to apply a positive potential to the resistor 26 and to the grid 35*c* of tube 35. It then becomes necessary to select a negative value on the resistor 19 by adjustment of the tap. The connection of lines 14 and 15 from the rectifying circuit through tube 16 have been so changed in Fig. 4 as to provide a negative potential at resistor 19. In order to do this the electrical connection between points 17 and 26′ of Fig. 1 has been omitted, the electrical connection between points 18 and 44 of Fig. 1 has been omitted and line 105 has been provided between points 18 and 106 in Fig. 4.

The operation of the circuits of Fig. 4 should now be apparent. If the milliamperage, as detected in resistor 27 when the X-ray tube is operating, is too high, the positive voltage developed across resistor 26 will be greater than the negative voltage selected from the resistor 19, resulting in a net positive voltage across resistor 26 which will drive the grid 35*c* of the triode 35 in a positive direction. This will increase the plate current of tube 35, which will increase the voltage drop across resistor 42 and consequently, the grid 36*c* of tube 36 will become more negative. Therefore, the plate current of tube 36 will decrease and correspondingly, the voltage across resistor 47 will decrease, making the grid 37*c* of tube 37 more positive. This increases the plate current of tube 37 and consequently there will be a greater drop across resistor 102 which will decrease the current supplied to filament 11 through transformer 12.

In a similar manner, should the milliamperage developed across resistor 27 be too low, a net negative voltage will be developed in resistor 26 which will make the grid 35c of tube 35 more negative giving a completely opposite reaction to that above described through tubes 35, 36 and 37 which will decrease the current in the plate circuit of tube 37 and therefore decrease the voltage drop across resistor 102 so that the filament current supplied to X-ray tube filament 11 will increase. This will increase the milliamperage developed by the X-ray tube up to the desired level.

There is a disadvantage in the use of the resistance modulator 102 of Fig. 4 as against the transformer coupling shown in Figs. 1, 2 and 3. The current in the resistor 102 is quite high for a high vacuum type tube. Thus, either tube 37 must be capable of a very high plate current or the filament circuit must be operated from a higher voltage than 110 in order to utilize a lower current in the primary of transformer 12, in which case tube 37 might be a small tube.

In all of the forms of my invention herein disclosed, the tube 37 might be a gas filled tube of the Thyratron type which would work very well with the resistance modulator 102 of Fig. 4 since a gas filled tube of this type can be obtained in small dimensions but carrying a much greater plate current than the high vacuum tubes.

In all of the drawings and description I have indicated a two-stage amplifier ahead of the tube 37. This amplification may be increased or decreased as to the number of stages depending upon the sensitivity of response desired. If a Thyratron type tube were substituted for 37, since these tubes have a greater sensitivity, it is quite possible to cut down the number of stages of amplification and even to operate this system directly from the input system with no amplification.

Those familiar with circuits of this type will understand that if the number of stages of amplification shown herein were increased or diminished, the electrical sign of the input to resistor 26 and grid 35c of Figs. 1 and 4 (or the input to resistance 26′ and grid 72 of Figs. 2 and 3) would have to be changed upon the adding or subtracting of a single stage of amplification. It is well understood that each stage of amplification changes the electrical sign of the output and the manner of changing the electrical sign of the input is clearly shown from a comparison of Figs. 1 and 4.

What I claim is:

1. A stabilizer for discharge current flowing through an X-ray tube comprising an X-ray tube, an electrical power supply connected thereto through a high tension transformer having a central grounded secondary circuit, a resistor connected in series in said circuit, a transformer having a primary winding connected for energization by the potential developed across said resistor, a rectifier tube, said transformer having a secondary winding connected to provide the input to said rectifier tube, said rectifier tube having a connected output circuit including a second resistor connected to receive a potential of one electrical sign corresponding to the potential developed across said first named resistor, means connected to said X-ray tube and to said second resistor for coincidentally energizing said X-ray tube for an exposure and for applying to said second resistor a predetermined potential of opposite electrical sign, an amplifier circuit connected with said second resistor to receive as input the sum of said potentials applied to said second resistor, said X-ray tube having a filament and an energizing circuit connected to said filament, and a modulator connected in said filament energizing circuit and responsive to the output of said amplifying circuit for decreasing and increasing the current supplied to said filament responsive respectively to preponderance of said potential of one sign or of opposite sign applied to said second resistor.

2. A stabilizer for discharge current flowing through an X-ray tube comprising an X-ray tube, an electrical power supply connected thereto through a high tension transformer having a central grounded secondary circuit, a resistor connected in series in said circuit, a transformer having a primary winding connected for energization by the potential developed across said resistor, a rectifier tube, said transformer having a secondary winding connected to provide the input to said rectifier tube, said rectifier tube having a connected output circuit including a second resistor connected to receive a potential of one electrical sign corresponding to the potential developed across said first named resistor, means connected to said X-ray tube and to said second resistor for coincidentally energizing said X-ray tube for an exposure and for applying to said second resistor a predetermined potential of opposite electrical sign, an amplifier circuit connected with said second resistor to receive as input the sum of said potentials applied to said second resistor, said X-ray tube having a filament and an energizing circuit connected to said filament, a space charge device having a connected output circuit and having a control grid connected with said amplifying circuit output and with said output circuit of said space charge device for decreasing and increasing the current supplied to said filament responsive respectively to preponderance of said potential of one sign or of opposite sign applied to said second resistor.

3. In a control for an X-ray tube having a filament and a connected circuit for energizing said filament under tube stand-by conditions and said tube having a source of electrical energy for operating said tube, adjustable switch means connected between said source and said tube for selecting one of various kilovoltages at which said tube is to be operated, and electrical source means operatively connected with said kilovoltage selecting switch means to increase and decrease the current in said filament energizing circuit as said kilovoltage selected by said selecting means decreases and increases respectively.

4. The combination of claim 3 wherein said last named means includes a transformer wound to correspond to a curve of filament current variation relative to kilovoltage variation to cause a constant milliamperage in the X-ray tube discharge current, a current modulator connected in said filament energizing circuit, one winding of said transformer being connected to said tube energy source, and the other winding of said transformer being connected to said modulator.

5. In a control for an X-ray tube having a filament and a circuit connected to said filament for energizing said filament under stand-by conditions and said tube having a source of electrical energy for operating said tube including kilovoltage selector means and a high tension transformer having a central grounded secondary circuit, the combination therewith of means connected in said central secondary circuit for developing a potential responsive to the discharge current of said tube, means connected with and electrically responsive to said potential for varying said filament energizing circuit including a space charge device, a control electrode in said space discharge

device responsive to said potential, an electrical source independent of energization of said X-ray tube, and means connected with and energized from said last named source responsive to said kilovoltage selector means for varying the bias of said space charge device, whereby to modify said filament energizing circuit in step with space charge variations in said X-ray tube dependent upon the kilovoltage selected.

6. A stabilizer for discharge current flowing through an X-ray tube comprising electrical means connected with said tube and providing an electrical effect of one sign and of a value corresponding to the said discharge current, electrical circuit means connected to said first named means for adding to said effect an electrical effect of opposite sign and of a predetermined value, an amplifier circuit having the sum of said added effects connected as input and terminating in a space charge device having a plate and a control grid connected with said amplifier circuit, said plate having a connected plate circuit which is the output from said amplifier, an alternating current supply connected to said plate circuit, an electrical circuit including a transformer having a primary and having a secondary connected to the filament of said X-ray tube, and an operative electrical connection between said two last named circuits including a resistance modulator electrically connected with said transformer primary and with said plate circuit for affecting said filament responsive to said sum of said electrical effects.

7. A stabilizer for discharge current flowing through an X-ray tube comprising electrical means connected with said tube and providing an electrical effect of one sign and of a value corresponding to the said discharge current, electrical circuit means connected to said first named means for adding to said effect an electrical effect of opposite sign and of a predetermined value, an amplifier circuit having the sum of said added effects connected as input and terminating in a space charge device having a plate and a control grid connected with said amplifier circuit, said plate having a connected plate circuit which is the output from said amplifier circuit, an electrical circuit including a transformer having a primary and having a secondary connected to the filament of said X-ray tube, and an operative electrical connection between said two last named circuits for varying said filament circuit responsive to said plate circuit including a resistance modulator electrically connected with said transformer primary and with said plate circuit.

8. In a control for an X-ray tube having a filament, a first circuit for energizing said filament under tube stand-by conditions, a second circuit for energizing said filament under tube operating conditions, a source of electrical energy, switch means between said source and said circuits for connecting said source alternatively to said first or to said second circuit, said first circuit including an electrical element connected with said source and having an electrical value subject to fluctuations of said electrical source when said tube is not operating, electrical means providing an electrical value equal to the value of said element when said source is normal, an electrical circuit connected with said last named means and with said element to receive and electrically compare said two values, an amplifier circuit having an input connected with said electrical comparison circuit, and a modulator connected with said first circuit and controlling the energization of said first circuit and connected with and responsive to the output of said amplifier circuit, whereby said filament current is increased and decreased as said source fluctuates below and above a normal standard value, and said filament is under predetermined conditions any time said switch means connects said source to said second circuit.

9. In a control for an X-ray tube having a filament, a first circuit for energizing said filament under tube stand-by conditions, a second circuit for energizing said filament under tube operating conditions, a source of electrical energy, switch means between said source and said circuit for connecting said source alternatively to said first or to said second circuit, said first circuit including an electrical element connected with said source and having an electrical value subject to fluctuations of said source and providing an electrical value of one sign, electrical means providing an electrical value of opposite sign equal to said value of one sign when said source is at a normal standard value, an electrical circuit connected with said last named means and with said element to receive and to provide the electrical sum of said two values, and means connected with and responsive to said last named electrical circuit and to said first circuit for varying said filament energizing circuit, whereby under stand-by conditions said filament current is increased and decreased as said source fluctuates below and above a normal standard value, and said filament is under predetermined conditions any time said switch means connects said source to said second circuit.

10. A stabilizer for discharge current comprising an X-ray tube having an energizing circuit connected thereto, said stabilizer comprising means in said circuit for providing an electrical voltage of one sign and of a value corresponding to the said discharge current, means connected with said first named means for adding to said voltage an electrical voltage of opposite sign and of a predetermined value, an amplifier connected to and energized by said last named means and terminating in a space charge device having a plate and a control grid connected with said amplifier, and an electrical circuit connected with the filament of said X-ray tube and including a modulator in circuit with said plate for varying said filament circuit responsive to said plate circuit.

11. A stabilizer for discharge current comprising an X-ray tube having an energizing circuit connected thereto, said stabilizer comprising means in said circuit for providing an electrical voltage of one sign and of a value corresponding to the said discharge current through said tube, means connected with said first named means for adding to said voltage an electrical voltage of opposite sign and of a predetermined value, an amplifier connected to and energized by said last named means and terminating in a space charge device having a plate and a control grid connected with said amplifier, said plate having a connected plate circuit, an alternating current supply connected to said plate circuit, and a circuit connected to the filament of said X-ray tube and including a modulator connected in circuit with said plate for varying said filament circuit responsive to said plate circuit.

12. A stabilizer for discharge current comprising an X-ray tube having an energizing circuit connected thereto, said stabilizer comprising means in said circuit for providing an electrical voltage of one sign and of a value corresponding to the said discharge current, means connected with said first named means for adding to said

voltage an electrical voltage of opposite sign and of a predetermined value, an amplifier connected to and energized by said last named means and terminating in a space charge device having a plate and a control grid connected with said amplifier, said plate having a connected plate circuit, an alternating current supply connected to said plate circuit, and a circuit connected to the filament of said X-ray tube for energizing said filament and including a modulator in circuit with said plate, said modulator including a transformer having a primary winding in said plate circuit and having a secondary winding in said filament energizing circuit.

13. A stabilizer for discharge current comprising an X-ray tube having an energizing circuit connected thereto, said stabilizer comprising means in said circuit for providing an electrical voltage of one sign and of a value corresponding to the said discharge current, means connected with said first named means for adding to said voltage an electrical voltage of opposite sign and of a predetermined value, an amplifier connected to and energized by said last named means and terminating in a space charge device having a plate and a control grid connected with said amplifier, said plate having a connected plate circuit, an alternating current supply connected to said plate circuit, and a circuit connected to the filament of said X-ray tube for energizing said filament and including a modulator, said modulator including an inductive coupling having one winding in said plate circuit and having another winding in said filament energizing circuit.

14. In a control for an X-ray tube having an energizing circuit connected thereto and a filament heating circuit connected thereto, the combination of means connected with a unidirectional current source and preset by an operator for selecting from said unidirectional current source a predetermined substantially constant voltage calibrated in terms of the desired discharge current through said X-ray tube, means connected in said energizing circuit for providing a voltage corresponding to the actual discharge current resultant from operation of said X-ray tube, an electrical circuit connected with each of said means to receive and compare said two voltages, and means connected with and responsive to the output from said last named circuit and electrically connected with said filament heating circuit for varying the latter in a direction to equalize said voltages.

15. A stabilizer for discharge current comprising an X-ray tube having an energizing circuit connected thereto, said stabilizer comprising a source of electricity independent of energization of said first named circuit, means in circuit with said source for providing an electrical voltage of one sign and of a value corresponding to the expected value of said discharge current, means connected with said first named circuit for adding to said voltage an electrical voltage of opposite sign and corresponding to the actual value of said discharge current, and means connected with said two last named means and responsive to variations in said net sum of said electrical voltages for varying the filament current of said X-ray tube.

16. In a control for an X-ray tube having an energizing circuit connected thereto and having a filament and having a separate circuit connected to said filament for energizing said filament under tube stand-by conditions independently of the energization circuit for said tube, said tube energizing circuit including kilovoltage selecting means adjustable to select any one of a plurality of kilovoltages at which said tube is to be operated, and an electrical modulator in said filament energizing circuit operatively connected with said kilovoltage selecting means for varying the current in said filament energizing circuit corresponding to the selection of a higher or lower kilovoltage by said selecting means and prior to the energization of said X-ray tube.

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The following references are of record in the file of this patent:

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