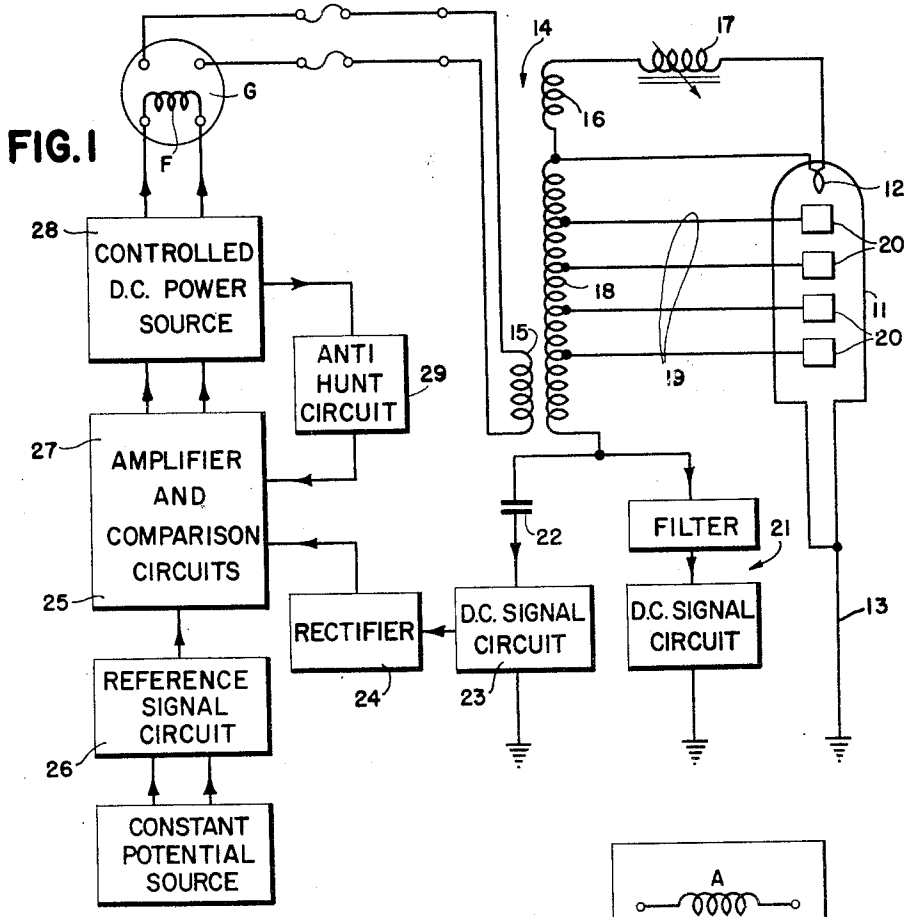
Sept. 6, 1960 H. T. BOEKER 2,951,947

VOLTAGE REGULATOR

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FIG. 1



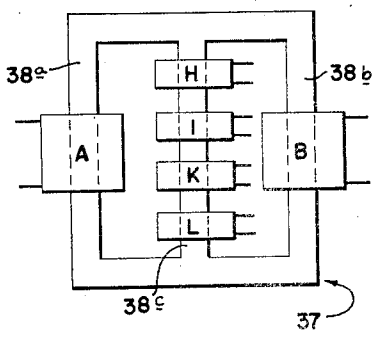


FIG. 2

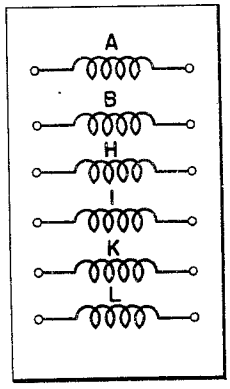


FIG. 3

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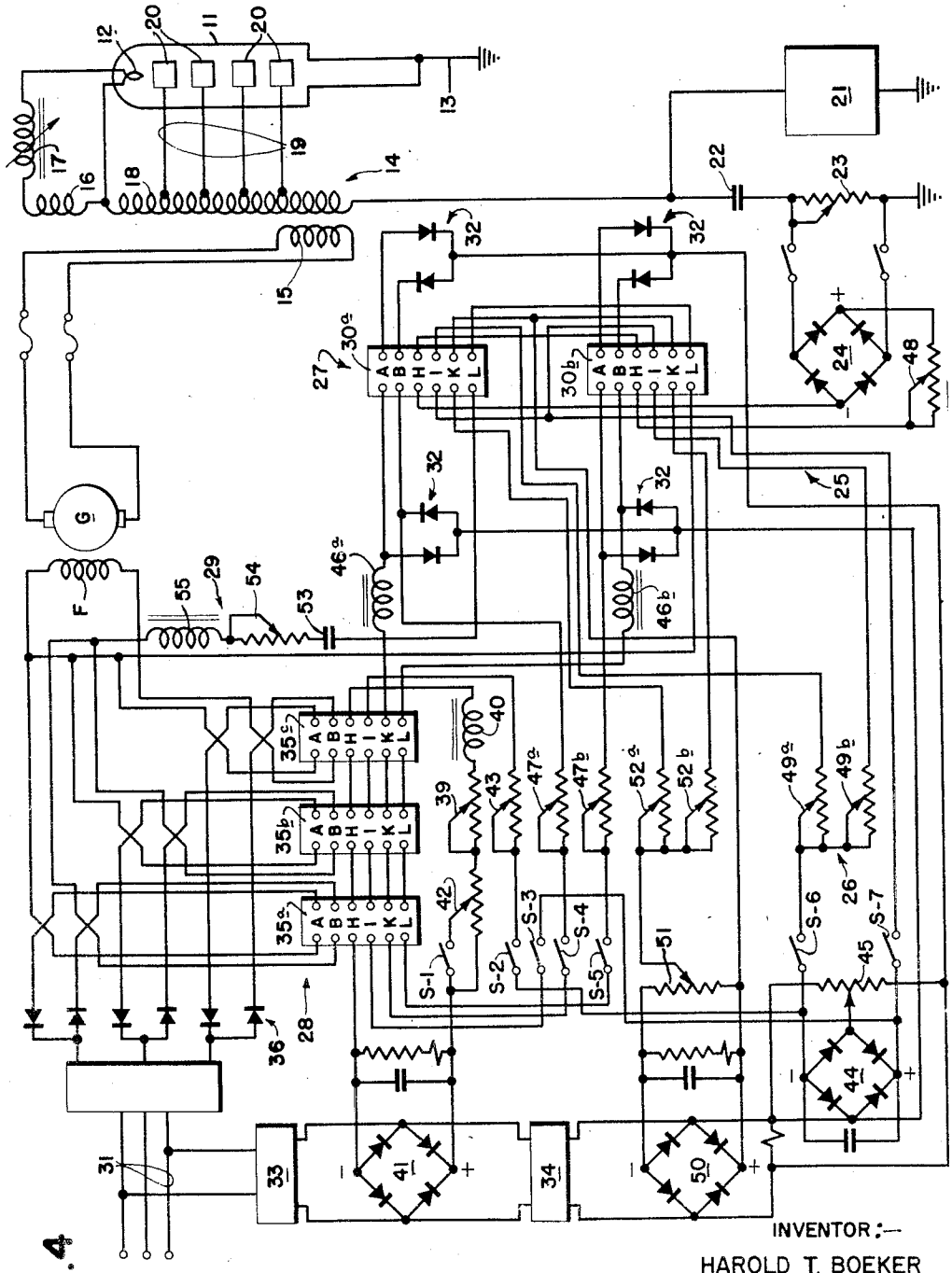


FIG. 4

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VOLTAGE REGULATOR

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7 Claims. (Cl. 250—103)

The present invention relates in general to electrical power supply systems and has more particular reference to voltage regulation, especially in systems employed for supplying operating energy to electron flow devices, such as electron generators.

An electron flow device of the character mentioned, as is well known, functions as the result of the emission of electrons, at the cathode of the device, and the delivery thence of such emitted electrons along a flow path toward an anode element, under the influence of electrical power applied between the anode and cathode of the device. Operation of an electron flow device may be controlled by varying the electron emissivity of its cathode or by adjusting the potential applied between the anode and cathode.

In the interests of obtaining uniformity of operation in an electron flow device, it is frequently desirable that the potential of the electron driving power applied between the anode and cathode of the flow device be held at a substantially uniform level; and an important object of the present invention is to provide improved means for maintaining the voltage at which actuating power is applied between the anode and cathode of an electron flow device, such as an electron generating tube, at a substantially uniform level despite variations in voltage in the power delivery system, as at the primary winding of a power supply transformer, which variations may be caused by changes in the transformer load due to heating of the components of the electron flow device, as well as by frequency variations in the power supply system.

Another important object of the invention is to provide a voltage regulating system, including means for deriving a circulating electrical current proportional to the voltage to be regulated, means for comparing the value of said current, at all times, with a reference current, in order to produce an error signal, and means for applying the error signal to appropriately adjust the regulated voltage.

Briefly stated, the present invention may be practiced by supplying A.C. electrical power between the anode and cathode of an electron flow load device, such as an electron beam generator, as through a conventional step up transformer, from an alternating current generator, preferably driven at constant speed and including a field winding adapted to be variably excited with D.C. electrical energy to determine the voltage at which the generator delivers electrical energy for operation of the load device. Electrical energy for exciting the field winding of the generator may be delivered from an A.C. source, such as a three phase supply line, through suitable, preferably selenium rectifiers and the output windings of a bank of three magnetic amplifiers or amplistats interconnected to form a controlled D.C. power source. This D.C. power source may be controlled by an error signal delivered to the control windings of the controlled power source amplistats from the output windings of a pair of amplistats connected in push-pull relationship to form a controlled amplifier, a pair of the control windings of said amplifying amplistats being connected, one to receive a rectified circulating current corresponding with the voltage to be regulated, and the other to receive a reference signal current whereby said windings form a comparison circuit adapted to develop an error signal in the amplifying amplistats for application thence for the control of the power source amplistats, another control winding of the amplifier amplistats being interconnected with the output side of the controlled power source through an anti-hunt circuit to stabilize the system against oscillation. By thus adjusting the controlled D.C. power source in response to an error signal representing a corresponding change in the voltage to be regulated, and by energizing the field winding of the power supply generator, the voltage to be regulated may be held at a substantially constant level.

The foregoing and numerous other important objects, advantages and inherent functions of the invention will become apparent as the same is more fully understood from the following description, which, taken in connection with the accompanying drawings, discloses preferred embodiments of the invention.

Referring to the drawings:

Fig. 1 is a simplified diagrammatic showing of a system embodying the present invention;

Fig. 2 shows a magnetic amplifier or amplistat of the sort employed in circuitry embodying the present invention;

Fig. 3 is a diagrammatic illustration of the device shown in Fig. 2; and

Fig. 4 is a wiring diagram showing circuitry embodying the present invention.

To illustrate the invention, the drawings show an electron flow device **11** comprising an electron beam generator of any preferred or conventional construction, the same embodying an electron emitting cathode **12** and a preferably grounded anode **13**, the generator being designed for operation at high voltages, of the order of one million volts and more, applied between the anode and cathode for the purpose of emitting a beam composed of high speed electrons at the anode.

Power for energizing the generator may be supplied through a transformer **14** having a primary winding **15**, connected with an A.C. power source, such as the generator G, the transformer also having a secondary winding **16** adapted for connection with the cathode **12**, preferably through an adjustable reactance winding **17**, for energizing the cathode for electron emission at a desired rate. The transformer also includes a secondary winding **18** of resonant character, for applying electron driving potential at a desired intensity level between the cathode **12** and the anode **13**, the secondary winding **18** being also provided with taps **19** adapted for connection with electron accelerating electrodes **20** disposed in longitudinally spaced relationship within the tube, between the cathode and anode, for the purpose of accelerating electrons as the same pass from the emitting cathode toward the anode.

The cathode remote end of the winding **18** may be connected with the grounded anode **13** through a filter network **21**, for maintaining the tube current which flows between the anode and the cathode at a substantially constant level, current flow through the network **21** being of unidirectional character. The cathode remote end of the transformer winding **18**, however, is also connected with the grounded end of the anode through a condenser **22** and a resistor **23**, whereby the alternating or fluctuating component of tube operating power may be applied in the circuit comprising the condenser **22** and the resistor **23**, in order to develop, at the resistor, potentials corresponding with that applied between the anode and cathode of the tube **11**.

An A.C. signal which at all times corresponds with voltage applied at the anode and cathode of the device **11**

may thus be developed in the branch circuit embodying the condenser 22 and resistor 23. This A.C. signal may be applied through a rectifier 24 to a comparison circuit 25 upon which a reference signal of selected, preferably uniform value may be applied through a suitable circuit 26. The comparison circuit operates to produce an error signal, by comparison of the circulating signal delivered through the rectifier 24 with the reference signal, said error signal being in turn delivered through an amplifier 27 and applied to correspondingly adjust a controlled D.C. power supply source 28 connected to supply field excitation for the generator G, an anti-hunt circuit 29 being interconnected between the power source 28 and the error signal amplifier 27 in order to feed back to the amplifier a rate signal adapted to damp out any tendency of the system to oscillate or hunt.

The operation of the foregoing arrangement is such that any tendency of current through the resistor 23 to change in proportion to corresponding change in the voltage to be regulated, provides an error signal of such polarity and magnitude in the comparison circuit as to adjust the controlled power source 28, which, acting through the field winding F of the generator G, alters the voltage applied upon the primary winding of the resonant transformer to the degree required to accomplish the desired regulation. The reference signal delivered through the circuit 26 may be derived from a voltage regulator tube or from a constant current transformer energized from a suitable power source. The comparison circuit 25 may embody a polarized relay or a suitable electronic circuit, but preferably comprises the control windings of a pair of magnetic amplifiers or amplistats connected in push-pull relation. The amplifier 27, likewise may embody a polarized relay or a suitable electronic amplifying system, but preferably comprises magnetic amplifying means such as the aforesaid amplistats. The controlled power source 28, if desired, may embody a motor driven rheostat connected with a constant potential D.C. power source or a suitable electronic amplifying system, but preferably comprises magnetic amplifying means, such as a bank of amplistats.

As shown more particularly in Fig. 4 of the drawings, the comparison circuit 25 and the amplifier 27 preferably comprise a pair of saturable core magnetic amplifiers or amplistats 30*a* and 30*b* connected in push-pull relationship and powered from one phase of a three-phase supply line 31 through preferably selenium rectifiers 32 and tandem connected transformers, including a voltage changing transformer 33 and a constant potential transformer 34. The system also embodies a bank of three amplistats 35*a*, 35*b* and 35*c* forming the controlled D.C. power source.

The magnetic amplifiers or amplistats 30*a*, 30*b*, 35*a*, 35*b* and 35*c*, as shown more particularly in Figs. 2 and 3 of the drawings, may each comprise a magnetic core 37 forming a pair of outer legs 38*a* and 38*b* and a central leg 38*c*. The legs 38*a* and 38*b* respectively are magnetically linked with output coils or gate windings A and B, the central leg 38*c* being magnetically linked with a plurality of coils H, I, K and L disposed thereon in coaxial, end to end abutting relationship, said coils being adapted to function as saturating, control reference, bias and rate windings.

The amplistat is a special form of magnetic amplifier. It is special in that rectifying elements are connected in series with the output or gate windings to provide unidirectional core flux saturation. Thus, the major portion of ampere-turns required for core saturation is obtained from the power source, and not from the signal. The self-saturation feature in magnetic amplifiers greatly increases the power gain of the device. Amplistats are capable of "sensing" small signal changes, amplifying them greatly, and imparting the amplified signals to the system to accomplish the desired control.

The amplistats 30*a* and 30*b* are arranged to form the amplifier 27 of the regulation system, the windings H thereof being interconnected in series with the rectifier 24, to influence the amplifier in accordance with the current circulating in the resistor 23, and thus to form a part of the comparison circuit 25. The coils I of the amplistats 30*a* and 30*b* are employed to apply the reference signal in the system, thereby forming another part of the comparison circuit. The windings L of the amplistats 30*a* and 30*b* may be employed to form a portion of the anti-hunt circuit 29.

The output or gate windings A and B of the amplistats 35*a*, 35*b* and 35*c* are connected respectively with the corresponding phases of the supply line 31 through preferably selenium rectifiers 36, the line remote sides of said output or gate windings being connected with the field winding F of the generator G. The amplistats 35*a*, 35*b* and 35*c* thus may serve as a controlled D.C. power source. To this end, the windings K and L of said power source amplistats may be connected with the output windings A and B of the amplifier amplistats 30*a* and 30*b*, while the windings H and I of the power source amplistats are employed for purposes of adjustment.

As shown, the control windings H of the amplifiers 35*a*, 35*b* and 35*c* may be interconnected in a series circuit, including an adjustable resistor 39 and a choke coil 40, said circuit extending between the opposite sides of a source of unidirectional power, such as a rectifier 41, which may be energized from the supply line 31 as through the transformer 33, said series circuit including, also, another adjustable resistor 42 having a normally open switch S–1 interconnected in series with the adjustable element tof the resistor, so as normally to include the entire resistance in the circuit and, upon closure of the switch S–1, to short out a portion of said resistor 42. The windings H thus serve to bias the three amplifiers 35*a*, 35*b* and 35*c* at ta desired locus on their characteristic operating curves.

The control windings I of the amplifiers 35*a*, 35*b* and 35*c* may be interconnected in a series circuit, including an adjustable resistor 43 and a pair of normally open switches S–2 and S–3, said circuit extending between the opposite sides of a source of constant potential D.C. power, such as a rectifier 44, which may be energized from the power line 31 as through the transformers 33 and 34, an adjustable resistor 45 being provided to adjust the level of A.C. voltage applied to the rectifier 44. The windings I thus provide means for additional manual control of amplifier operation.

The control windings K of the magnetic amplifiers 35*a*, 35*b* and 35*c* are connected in a series circuit, including a choke coil 46*a*, a normally closed switch S–4 and an adjustable balancing resistor 47*a*, said circuit extending between one side of the output winding A of the magnetic amplifier 30*a*, and the corresponding side of the winding B of said amplifier, which windings A and B are also connected with the power line 31 through the rectifiers 32 and the transformers 33 and 34.

The control windings L of the magnetic amplifiers 35*a*, 35*b* and 35*c* are interconnected in a series circuit, including a choke coil 46*b*, a normally closed switch S–5 and an adjustable balancing resistor 47*b*, said circuit extending between one side of the output winding B of the magnetic amplifier 30*b* and the corresponding side of the winding A of said amplifier, which windings A and B are also connected with the power line 31 through the rectifiers 32 and the transformers 33 and 34.

The windings H of the amplifiers 30*a* and 30*b* are interconnected in a series circuit, including an adjustable balancing resistor 48, said circuit being connected across the output side of the rectifier 24.

The windings I of the magnetic amplifiers 30*a* and 30*b* are connected in parallel relationship across the output side of the rectifier 44 through normally closed switches S–6 and S–7, to thereby apply a reference signal in the system for comparison with the signal applied through

the coils H of the amplifiers **30***a* and **30***b*. The signal applied to the coils H of the amplifiers **30***a* and **30***b* is proportional to the current circulating in the secondary windings of the transformer **14**, which current, in turn, is proportional to the voltage applied to the tube **11**. The signal in the coils H and the reference signal in the coils I combine in the amplifiers **30***a* and **30***b* to give a resultant error signal, which error signal is delivered thence to the amplistats **35***a*, **35***b* and **35***c*. Adjustable resistors **49***a* and **49***b* are respectively connected in series with the windings I of the amplifiers **30***a* and **30***b* for coil balancing purposes.

The windings K of the amplifiers **30***a* and **30***b* are interconnected in parallel relationship across the output side of a rectifier **50** which may be energized from the supply line **31**, as through the transformers **33** and **34**, an adjustable potentiometer **51** being provided for adjusting the voltage applied on the windings K. Adjustable resistors **52***a* and **52***b* are respectively connected in series with the windings K of the amplifiers **30***a* and **30***b* for coil balancing purposes. The windings K thus comprise bias windings for the purpose of adjusting the amplifiers **30***a* and **30***b* for operation at a desired energy output level within a selected range on the characteristic operating curves thereof.

The windings L of the amplifiers **30***a* and **30***b* may be connected in a series circuit, including a condenser **53**, an adjustable resistor **54** and a choke coil **55**, to form the anti-hunt circuit **29**, said circuit being connected across the opposite ends of the field winding F of the generator G. The windings L thus serve as rate windings for the purpose of stabilizing the system against oscillation or hunting, the arrangement serving to feed back a signal into the amplifier system **27** to buck out any tendency to oscillate.

The windings K and L of the amplifiers **35***a*, **35***b* and **35***c* thus serve to controllingly connect the push-pull amplifiers **30***a* and **30***b* with the amplifiers **35***a*, **35***b* and **35***c*, thereby constituting the same as a controlled D.C. power supply source for energizing the field winding of the generator G, in accordance with the circulating current in the resistor **23** which is a function of the voltage to be regulated.

The relay switches S–**1** through S–**7** are provided for disabling the system, so that it can be operated solely under manual control by adjustment of the resistor **45**.

The arrangement employing the three-phase amplistats **35***a*, **35***b* and **35***c* is especially well adapted for use in controlling electron flow devices operable at high voltage of the order of four million volts applied between the anode and cathode of the device. In place of the bank of three-phase amplistats, a D.C. generator may be employed to energize the field winding F on the alternator G under the control of the amplifier **27** comprising the amplistats **30***a* and **30***b*.

It is thought that the invention and its numerous attendant advantages will be fully understood from the foregoing description, and it is obvious that numerous changes may be made in the form, construction and arrangement of the several parts without departing from the spirit and scope of the invention, or sacrificing any of its attendant advantages, the forms herein disclosed being preferred embodiments for the purpose of illustrating the invention.

The invention is hereby claimed as follows:

1. The combination with a self-rectifying electron flow device and an energizing step-up transformer therefor, the electron flow device having an electron-emitting cathode, an anode to receive an impinging electron stream from the cathode, and beam-control electrodes between the cathode and the anode, and the transformer having a primary winding and a secondary winding with its secondary winding having its terminals connected to the cathode and to the anode, and having intermediate taps connected to the control electrodes, and the primary winding being energized from a controllable external source; of

(1) means responsive to the current traversing the secondary winding, said means being operative to subdivide said current into its D.C. component and its A.C. component;
(2) means for rectifying said A.C. component to develop a proportional operating D.C. signal;
(3) separate means to establish a reference D.C. signal;
(4) means for comparing the proportional operating D.C. signal with the reference D.C. signal to derive a difference or error signal; and
(5) means responsive to such error signal for controlling the energy from said external controllable source to the primary winding of the transformer to thereby control the voltage induced in the secondary winding and applied between the cathode and the anode of the electron flow device.

2. The combination with a self-rectifying electron flow device, and an energizing transformer therefor, as in claim 1, in which the external source consists of:

(6) an A.C. generator for energizing the primary winding of said transformer; and the error-signal-responsive means (5) includes
(7) means controlled by said error signal for controlling the energization of said A.C. generator to control the voltage generated by said generator to energize the transformer.

3. The combination as set forth in claim 2, in which: the generator (6) is operative to generate a voltage of frequency greater than commercial power frequency to enable the circuit of the transformer secondary winding to be readily tuned.

4. The combination with:

(*a*) an electron flow device, and
(*b*) an energizing transformer for such device, the device having,
  (1) an electron-emitting cathode,
  (2) a remotely spaced anode plate to serve as a target or receiver for electrons from the cathode, and
  (3) control electrodes between the cathode and the anode plate for accelerating and guiding the electrons in passage from the cathode to the anode; and the energizing transformer for the electron flow device having:
    (1) a primary winding for energization from an external source,
    (2) a step-up secondary winding for applying a high induced voltage between the cathode and the anode plate, and
    (3) progressive taps intermediate the terminals of the secondary winding for connection in corresponding progressive sequence to the control electrodes, so the tap connections will apply progressively increased voltages to the control electrodes in sequence from the cathode toward the anode; of
(*c*) an energizing source for the primary winding of the transformer;
(*d*) means responsive to the circulating current in the circuit of the secondary winding and effective to separate the A.C. component from the D.C. component of said current; and
(*e*) means responsive to the A.C. component for regulating the voltage applied to the transformer from said external source, to establish a predetermined secondary peak voltage in the transformer for application between the cathode and the anode terminals.

5. The combination as set forth in claim 3, in which

the regulating means (*e*) responsive to the A.C. component include:

(*f*) means to rectify the A.C. component to derive a D.C. signal voltage;

(*g*) separate means to generate a comparison reference voltage;

(*h*) means to compare the D.C. signal voltage and the reference voltage to obtain a difference or error voltage; and

(*i*) means responsive to such error voltage for regulating the voltage applied to the transformer from said external source in order thereby to establish a predetermined secondary peak voltage in the transformer for application between the cathode and the anode terminals.

6. The combination with a high-voltage X-ray tube having a cathode, an anode and control electrodes along the path between the cathode and the anode, of means for impressing a uniform peak voltage between the cathode and the anode under varying operating conditions, said means comprising:

(1) a transformer to supply energy to the tube, said transformer having a primary winding to be energized from an external source, and having a step-up secondary winding to be connected between the cathode and the anode, with taps on the secondary winding intermediate the terminals of the winding, said taps being for connection to the control electrodes of the X-ray tube;

(2) means in the circuit of the secondary winding to be traversed by the current in said winding, said means serving to divide such current into its A.C. and its D.C. components;

(3) means to establish a comparison standard value of current;

(4) means responsive to variations of said A.C. component of secondary current from said predetermined comparison standard value, said means being operative to provide a measure of such variations as a difference or error voltage; and

(5) means responsive to such difference or error voltage for controlling the energization of the transformer primary from said external source to induce a voltage in the secondary corresponding to the voltage desired for normal proper operation of the X-ray tube in generating an electron beam of desired energy.

7. The combination with a high voltage X-ray tube having a cathode, an anode and control electrodes along the path between the cathode and the anode, of means for impressing a uniform peak voltage between the cathode and the anode under varying operating conditions, said means comprising:

(1) a transformer to supply energy to the tube, said transformer having a primary winding to be energized from an external source and having a step-up secondary winding to be connected between the cathode and the anode, with taps on the secondary winding intermediate the terminals of the winding, said taps being for connection to the control electrodes of the tube;

(2) means in the circuit of the secondary winding to be traversed by the current in said winding, said means serving to divide such current into its A.C. and its D.C. components;

(3) means for rectifying the A.C. component to produce a D.C. operating signal voltage;

(4) means separately and independently available to establish a standard or reference signal voltage having an amplitude to define the value of the operating signal voltage at proper operating conditions of the X-ray tube; and

(5) means responsive to a variation of said operating signal voltage from such defined standard value, and operative to control the excitation of the primary winding of the transformer in accordance with such variation to control the voltage in the secondary winding to be applied between the cathode and the anode.

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