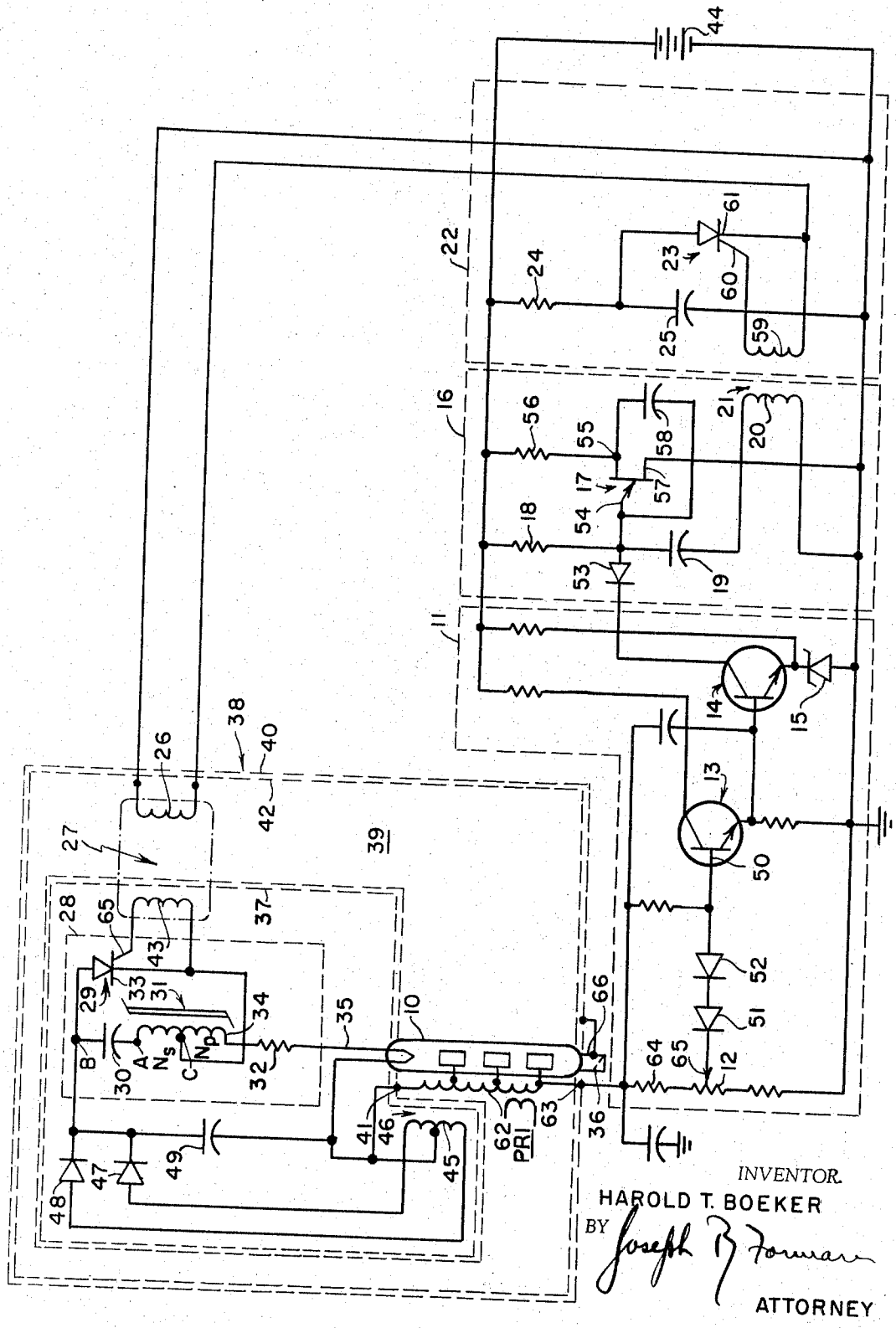
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TRANSISTORIZED CONSTANT EMISSION CURRENT REGULATOR USING A RESONANT TRANSFORMER IN THE POWER SUPPLY

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TRANSISTORIZED CONSTANT EMISSION CURRENT REGULATOR USING A RESONANT TRANSFORMER IN THE POWER SUPPLY

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This invention relates to current control and more particularly to an improved automatic tube current control for electron tubes such as X-ray and electron beam tubes.

In X-ray and electron beam generator equipment it has been found to be advantageous to utilize a resonant transformer instead of an iron core transformer in the power supply in order to realize the advantages of minimum size and weight, optimum configuration for ultra-high voltage applications and improvement in the voltage output waveshape. Past methods employed to achieve tube current control in such systems typically utilized servo motor control techniques. In such systems a reactor was connected in series with the tube filament, the inductance of the reactor being varied by controllably positioning a slug in the air gap, usually by means of stainless steel gear systems driven by a servo motor. Such servo control systems, having mechanical components, were sluggish in response to changes in load conditions. In addition, backlash in the gear systems and hunting problems made stabilization of the control system difficult. Moreover, such systems usually required frequent maintenance since foreign particles could easily enter the gearing system to bind the steel gears. As a result, these mechanical problems adversely affected the accuracy and reliability of such control systems.

The use of solid state circuitry in X-ray power supplies and electron beam generators makes possible an improvement in the control of the supply of power to the tube filament to thereby control the tube current. The employment of inexpensive and reliable solid state, rather than mechanical components having moving parts, permits the avoidance of many of the problems caused by the inherent mechanical limitations described above.

Accordingly, it is an object of this invention to provide, in X-ray and electron beam tube power supplies, an improved low cost and easily stabilized tube current control system having a fast response to changes in load conditions.

The servo motor control apparatus heretofore employed were inherently large in size and in weight. This was due to the large size of the component parts and also to the elaborate measures required to electrostatically isolate the high voltage portions of the resonant transformer from the current control apparatus. As a result, substantial amounts of power were expended in the operation of the servo motor control apparatus.

It is accordingly another object of this invention to provide a compact current control system for X-ray and electron beam tube power supplies, whereby large amounts of power may be controlled with a very small expenditure thereof.

Briefly stated and in accordance with the invention, in a resonant transformer power supply for an electron tube having an emitting electrode and accelerating electrodes, there is provided a system for controlling the tube current of said electron tube. Said system comprises an amplifier which is operative to detect the potential at the accelerating electrode most remote from said emitting electrode, said detected potential being determined by said tube current, and to produce an error signal corresponding to the deviation of the detected potential from a preselected level.

Pulsating means, comprising an inverter, is operative to pulsate a voltage applied to said emitting electrode by a source of D.C. potential at a frequency determined by the magnitude of said determined tube current, the inverter output terminals being connected in series with said emitting electrode and said source of D.C. potential. Electrostatic shielding means are provided to electrostatically isolate said source of D.C. potential, said emitting electrode and said inverter which are all interconnected with the high voltage end of the high voltage winding of said resonant transformer. By controlling the frequency of the pulses of current flowing through said emitting electrode, said inverter is operative to control the magnitude of the tube current thereby produced.

The novel features of the invention are set forth with particularity in the appended claims. The invention itself, however, both as to its organization and method of operation, together with further objects and advantages thereof, may be best understood by referring to the following description and accompanying drawing.

In the figure there is shown in schematic form, an X-ray tube current regulation system comprising an illustrative embodiment of the invention. In the following description it is understood that an X-ray tube is shown in the figure for illustrative purposes, and that a similar tube such as an electron beam tube, may be substituted therefor without requiring any significant modification in the accompanying circuitry.

In this circuit there is shown an X-ray tube **10** and a two stage D.C. amplifier **11** comprising potentiometer **12**, transistors **13** and **14**, and having a reference voltage determined by zener diode **15** connected in the emitter circuit of transistor **14**. A pulse generator **16** is shown to include a unijunction transistor **17** and a series RC charging circuit comprising a resistor **18**, a capacitor **19** and the primary winding **20** of a pulse transformer **21**. An oscillator **22** comprises a gate controlled rectifier **23** and includes a resistor **24** and a capacitor **25** in series arrangement, and the primary winding **26** of a signal transformer **27**.

An inverter **28** comprising a gate controlled rectifier **29** includes a capacitor **30**, a saturable current transformer **31** having a square loop characteristic, and a resistor **32** in series arrangement. Cathode **33** of rectifier **29** is connected to an intermediate point C on a winding **34** of transformer **31**. A source of D.C. potential which serves as the D.C. voltage supply for inverter **28** comprises an end winding **45** disposed proximate to the high voltage end **41** of the secondary winding **62** of a resonant transformer **46**, rectifiers **47** and **48**, and output capacitor **49**. Inverter **28**, connected in series with filament **35** of X-ray tube **10** and said source of D.C. potential provided across capacitor **49**, is operative to produce pulses of current in filament **35** at a rate equal to the switching frequency of rectifier **29**. The pulse duration of these current pulses is determined by the core characteristics of transformer **31**. As a result, there is produced a flow of current between filament **35** and target **36** of X-ray tube **10** when filament **35** is negative with respect to target **36**.

Inverter **28**, filament **35** and the source of D.C. potential comprising capacitor **49** are located within an electrostatic shield **37** suitably formed to electrostatically shield said members located therein. High voltage end **41**, which swings from positive high voltage to negative high voltage, filament **35** and shield **37** are interconnected. Space **39**, which is located between electrostatic shield **37** and outside wall **40** of a pressure vessel **38**, is filled with insulating gas under pressure to provide a wall of insulation therebetween. High voltage winding **62** is disposed in space **39** with the gas therein providing adequate insulation between high voltage end **41** and wall **40**. Extension **66** of X-ray tube **10**, which is connected

to wall **40** of pressure vessel **38**, is at substantially ground potential. A coupling transformer **27**, operative to couple the output of oscillator **22** to inverter **28**, is disposed in gas-filled space **39** with primary winding **26** located adjacent the inside face of wall **40** and secondary winding **43** located under electrostatic shield **37** arranged in such a manner as not to interfere with the magnetic flux produced by primary winding **26**. Secondary winding **43** is disposed at a suitable distance away from winding **26** so that the spacing therebetween is sufficient to provide adequate magnetic coupling between the primary and secondary windings **26** and **43** and at the same time provide the required electrostatic insulation under the particular operating conditions. A source of D.C. potential **44** serves as a D.C. voltage supply for amplifier **11**, pulse generator **16** and oscillator **22**.

Potentiometer **12** which is operative to sample the potential at low voltage end **63** of high voltage winding **62**, is connected to end **63** through biasing resistor **64**. Thus, as X-ray tube current flows through potentiometer **12**, a voltage is produced thereacross which is proportional to said tube current. A preselected portion of this voltage is applied by means of wiper arm **65**, to the input of amplifier **11** at base **50** of transistor **13**. Diodes **51** and **52** function to compensate for variations in the potential drop across the base emitter portion of transistor **13** due to temperature variations therein. A zener reference voltage **15** maintains transistor **14** non-conductive until the sampled input voltage applied to the input of amplifier **11** and thus amplified, sufficiently exceeds the voltage of reference **15** and causes transistor **14** to conduct. The output of amplifier **11** is connected to pulse generator **16** by means of a diode **53** and controls the repetition frequency of the trigger pulses produced by pulse generator **16**. Since the collector to emitter path of transistor **14** is in parallel with capacitor **19**, transistor **14**, when conducting, is operative to controllably shunt a suitable portion of the charging current for capacitor **19** and hence control the pulse repetition frequency of pulse generator **16**. The output trigger pulses of pulse generator **16** are suitably applied to the pulse oscillator **22** to control the repetition frequency of gating pulses produced by oscillator **22**.

When inverter **28** is just starting up, there will be no current flowing in X-ray tube **10** and hence there will be no voltage across potentiometer **12**, and base **50** will therefore be at ground potential, thus causing both transistors **13** and **14** to be non-conductive.

Pulse generator **16**, comprising unijunction transistor **17**, has its emitter **54** connected to the junction of resistor **18** and capacitor **19**. Transistor **17** has its base **55** connected to the positive terminal of source **44** through load resistor **56** and its base **57** connected to the negative terminal thereof. Transistor **17** is rendered conductive when the voltage on emitter **54** reaches a preselected level corresponding to the firing potential of transistor **17**. This level is determined by the magnitude of source **44** and the operating characteristics of transistor **17**. Since resistor **18** and capacitor **19** have fixed values, the time necessary for the charge on capacitor **19** to reach this firing potential is inversely proportional to the magnitude of the charging current through capacitor **19**. When transistor **17** is thus rendered conductive, capacitor **19** discharges via a discharge path comprising primary winding **20** of pulse transformer **21**, capacitor **19**, capacitor **58** and base **55** to base **57** diode path to ground. The time variant discharge current flowing through winding **20** thereby produces a voltage pulse thereacross to constitute the output trigger pulse.

It is evident that the repetition frequency of the trigger pulses thus produced by pulse generator **16** will be inversely proportional to the period of time required for capacitor **19** to charge up to the firing potential of transistor **17**. Since the collector to emitter conduction path of transistor **14** is connected in shunt with capacitor **19**,

the magnitude of charging current through capacitor **19** will vary inversely with the level of conduction of transistor **14**, which, as pointed out above, is determined by the magnitude of the tube current flowing through potentiometer **12**. Thus, the repetition rate of the trigger pulse output of pulse generator **16** will vary inversely as the magnitude of the tube current.

During the initial warm-up period, due to the absence of tube current, transistor **14** will be non-conductive and hence no part of the charging current flowing through resistor **18** will be diverted through transistor **14** by means of diode **53**. During this period, therefore, capacitor **19** will be charging up at a maximum rate and consequently the trigger pulse rate of pulse generator **16** will also be at a maximum.

Oscillator **22** comprises a series charging circuit comprising primary winding **26** of coupling transformer **27**, and the cathode to anode conduction path of gate controlled rectifier **23**. When transistor **17** is rendered conductive, the trigger pulse thereby produced across primary winding **20** is applied by secondary winding **59** across the gate and cathode terminals **60** and **61** respectively to thereby turn rectifier **23** "ON." Capacitor **25** at this point has been charged up through resistor **24**. Capacitor **25** now discharges via a discharge path comprising the anode to cathode diode path of rectifier **23** and winding **26** to ground, thereby causing this discharge circuit to oscillate. Upon reversal of current in this discharge path, rectifier **23** is returned to the blocking state. The short pulse of current thus produced by this oscillatory action generates a voltage pulse across primary winding **26** to produce a corresponding pulse on secondary winding **43** due to the magnetic coupling existing therebetween. The pulse thus produced on winding **43** constitutes the gating pulse which controls the switching operation of inverter **28** as described below.

The function of rectifiers **47** and **48** and capacitor **49** is to rectify and filter the A.C. voltage obtained from end winding **45** to thereby provide a D.C. supply for the operation of inverter **28**.

Consider one cycle in the operation of inverter **28**. Initially in the cycle, point A is at substantially zero potential. When the trigger pulse is applied to gate **65**, thereby turning rectifier **29** "ON," substantially the full line voltage appearing across capacitor **49** will be applied across portion N_s of winding **34**, quickly driving the core of transformer **31** to negative saturation. Due to such saturation, capacitor **30** will charge rapidly toward the supply potential, i.e., the potential at point B, and the then increasing load current will tend to drive the core toward positive saturation. Between positive and negative saturation, due to autotransformer action, point A on capacitor **30** will be charged above the potential at point B, to a level determined by the magnitude of the load current flowing through N_p. When positive saturation is reached, portion N_s will be essentially short circuited and the potential across capacitor **30** will reverse bias rectifier **29** thereby turning it "OFF." The RC time constant of the charging circuit comprising capacitor **30**, winding **34** and resistor **32** will determine the period of time that rectifier **29** is reverse biased. These components are therefore chosen so that the reverse bias will be applied to rectifier **29** for a period of time sufficient to render it non-conductive until it is again similarly triggered in a subsequent cycle.

Clearly, the frequency of the pulses of current in filament **35** thus produced by inverter **28** will be controlled by the repetition frequency of the gating pulses applied thereto. The gating pulse rate is, in turn, controlled by the trigger pulse repetition rate. Thus, as filament **35** warms up and the tube current accordingly increases, the frequency of inverter **28** will correspondingly be reduced until the preselected stable operating conditions are achieved. It is evident, therefore, that the feedback circuitry described above is operative to compensate for

variations in operating conditions to thereby maintain a preselected stable level of current flow in X-ray tube 10.

While the invention has been described by reference to a particular embodiment thereof, it will be understood that numerous modifications may be made by those skilled in the art without departing from the invention and it is, therefore, aimed in the appended claims to cover all such equivalent variations as fall within the true spirit and scope of the invention.

What is claimed as new and desired to be secured by Letters Patent of the United States is:

1. Apparatus for controlling the tube current of an electron tube having an emitting electrode and accelerating electrodes, said tube current being determined by the emission characteristics of said emitting electrode and the potential on the respective accelerating electrodes comprising, a voltage applied to said emitting electrode, pulsating means for pulsating said voltage applied to said emitting electrode, means for determining the magnitude of said tube current, and frequency control means operative in response to said determining means to control the frequency of said pulsating means in accordance with the magnitude of said determined current.

2. Apparatus as in claim 1 wherein the magnitude of said tube current is determined by the magnitude of the potential on the accelerating electrode most remote from said emitting electrode.

3. Apparatus as defined in claim 1 wherein said frequency control means comprises signal coupling means to connect the output of said frequency control means to the input of said pulsating means.

4. Apparatus as defined in claim 3 wherein said frequency control means comprises oscillator means, said pulsating means being operative at a frequency corresponding to said oscillator frequency.

5. Apparatus as defined in claim 4 wherein said coupling means comprisese transformer means having primary and secondary windings, said primary winding being the output of said oscillator means and said secondary winding being the input of said pulsating means.

6. Apparatus as in claim 4 wherein said oscillator means is operative to render said pulsating means operative at a frequency determined by the magnitude of said determined current.

7. Apparatus as in claim 5 in combination with a source of D.C. potential wherein said pulsating means comprises inverter means, said emitting electrode, said source of D.C. potential and the output terminals of said inverter means being in series arrangement with said emitting electrode and said inverter means being operative to control the frequency of the pulses of current flowing in said emitting electrode to thereby control said tube current.

8. Apparatus for controlling the tube current of an electron tube having an emitting electrode and accelerating electrodes, a resonant transformer including a secondary winding having one end thereof at a high potential with respect to a ground reference point, said tube current being determined by the emission of said emitting electrode and the potential applied to said accelerating electrodes by said secondary winding, a voltage applied to said emitting electrode, means for pulsating said voltage applied to said emitting electrode, means for determining the magnitude of said tube current, frequency control means operative in response to said tube

current determining means to control the frequency of said voltage pulsating means in accordance with the magnitude of said determined current, and shielding means to electrostatically shield the portions of said power supply situated at said high potential from said ground reference point.

9. Apparatus as defined in claim 8 whrein said shielding means comprises, an electrostatic shield surrounded by an enclosure, said voltage pulsating means being within said electrostatic shield.

10. Apparatus as defined in claim 9 wherein said shielding means includes electrostatic insulating material in the space between said shield and said enclosure, said emitting electrode and said resonant transformer secondary winding being disposed within said space between said shield and said enclosure.

11. Apparatus as defined in claim 10 wherein said emitting electrode and said high potential end of said resonant transformer secondary winding are connected to said shield, said enclosure being connected to said ground reference point.

12. Apparatus as defined in claim 11 wherein said frequency control means comprises oscillator means and signal coupling means, said signal coupling means being operative to connect the output of said frequency control means to the input of said pulsating means, said signal coupling means including transformer means having primary and secondary windings, said primary winding being disposed within said space between said shield and said enclosure and said secondary winding being located within said electrosatic shield.

13. Apparatus as defined in claim 7 wherein said pulsating means includes inverter means comprising, a gate controller rectifier having the anode connected to the positive terminal of said source of D.C. potential, the cathode being connected to one terminal of said secondary winding of said resonant transformer and the gate electrode connected to the other terminal of said secondary winding, a saturable current transformer having a square loop core characteristic, a first capacitor connected between said anode and one end terminal of said current transformer winding, current conducting means connected between said cathode and an intermediate point on the winding of said current transformer, a resistor connected between the other end terminal of said current transformer winding and one output terminal of said inverter means, the other output terminal of said inverter means connected to the negative terminal of said D.C. source, said emitting electrode being connected in series with the output terminals of said inverter means and said source of D.C. potential.

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