

Sept. 27, 1966

R. L. WATTERS

3,275,883

EMISSION CURRENT REGULATOR FOR ION GAUGE

Filed Nov. 1, 1963

2 Sheets-Sheet 1

Fig. 1.

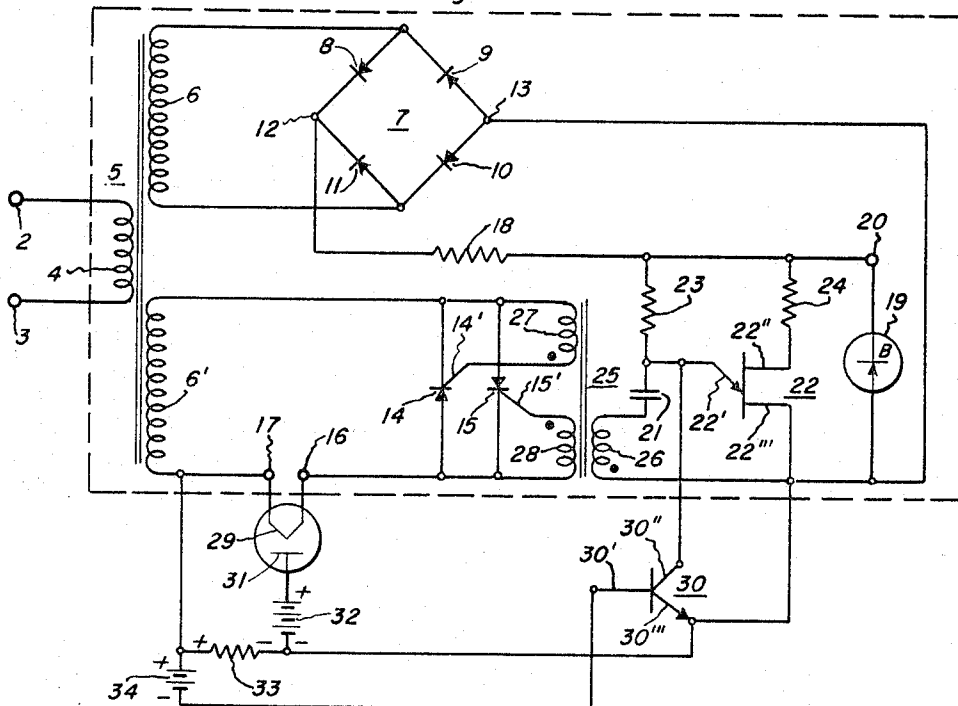
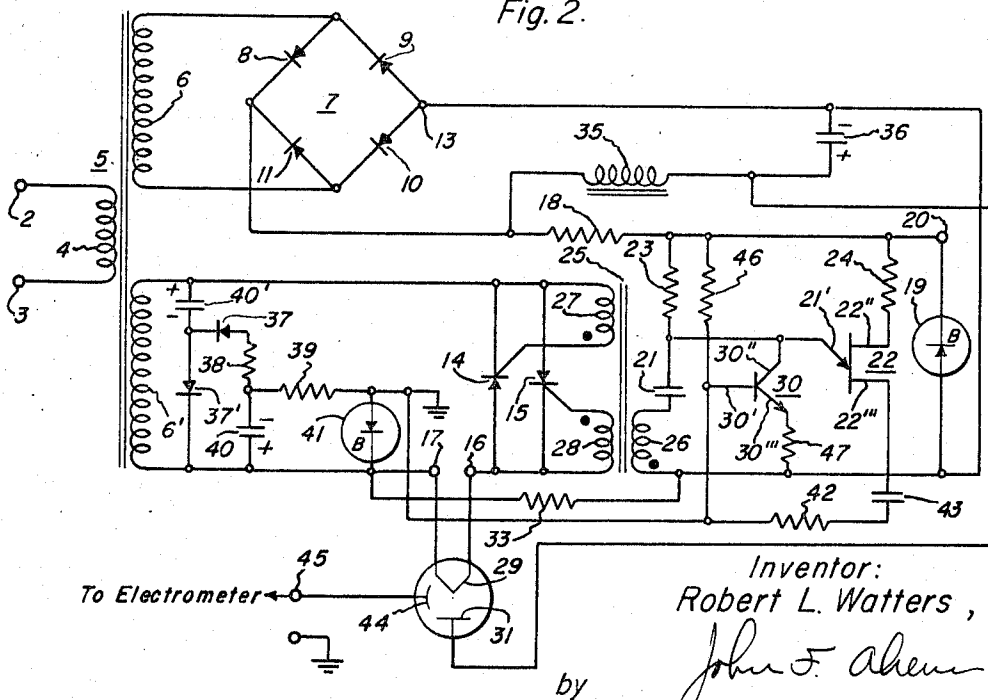


Fig. 2.



Inventor:
Robert L. Watters,
by *John F. Ahern*
His Attorney.

Sept. 27, 1966

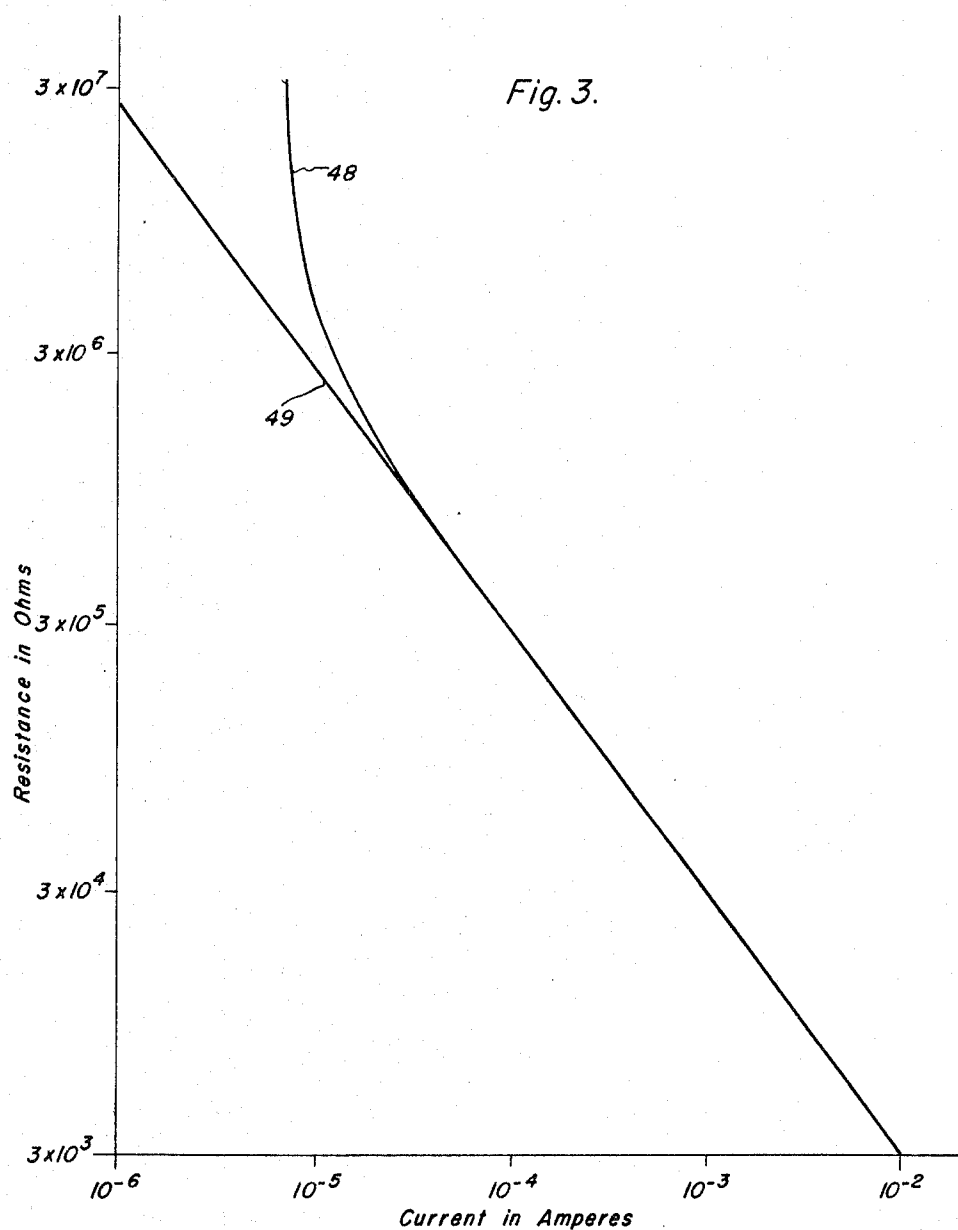
R. L. WATTERS

3,275,883

EMISSION CURRENT REGULATOR FOR ION GAUGE

Filed Nov. 1, 1963

2 Sheets-Sheet 2



Inventor:
Roberts L. Watters,
by *John F. Ahern*
His Attorney.

1

3,275,883 EMISSION CURRENT REGULATOR FOR ION GAUGE

Robert L. Watters, Schenectady, N.Y., assignor to General Electric Company, a corporation of New York
Filed Nov. 1, 1963, Ser. No. 320,654
3 Claims. (Cl. 315—106)

The present invention relates generally to power supplies for thermionic electron-emissive filaments, and more particularly pertains to such a supply for an ion gauge filament that maintains the thermionic electron emission from the filament constant at a predetermined magnitude.

Ion gauges are becoming increasingly popular for a multitude of applications, including measurement of pressure and detection of leaks in evacuated systems. One common type of ion gauge uses a thermionic electron-emissive filament to provide a stream of electrons which ionize gas particles in the electron stream. The ions are subsequently collected and the quantity thereof serves as an indication of pressure or the extent to which an ionizable gas is present in the vicinity of the filament. In most applications, the thermionic electron emission is in the order of one milliamperere. An effective and relatively inexpensive power supply for regulating emission in this order of magnitude is disclosed and claimed in my co-pending application Serial No. 320,629, filed and assigned to the assignee herein.

While the above-mentioned application discloses an emission regulated filament power supply for ion gauges that is suitable for most applications, it is sometimes required that substantially constant electron emission in the order of one microampere be obtained. For example, such a requirement oftentimes arises when pressures lower than 10^{-6} millimeters of mercury are to be measured. In such applications the electron stream acts as an ion pump, reducing the pressure in the immediate vicinity of the ion gauge filament. Thus, an error is introduced into the measurement because the pressure sensed by the ion gauge is different from the actual pressure within the region of the evacuated system where it is desired to know the magnitude of pressure. Thus, in some applications it is desirable to reduce the electron emission, from the ion gauge filament, to a magnitude in the order of one microampere to minimize ion pumping and to achieve a more accurate determination of pressure. In ion gauges used for pressure measurement it is desirable to regulate the electron emission from the filament to keep emission constant at a predetermined value.

In ion gauges for measuring low pressures with an electron stream having a magnitude in the order of one microampere, the quantity of ions impinging upon the ion collector of the ion gauge is small. To facilitate measurement of the small ion current, as by an electrometer, it is desirable that the electron collector be operated at zero or ground potential. The latter criterion requires that the filament of the ion gauge be positively biased with respect to ground potential.

There is a need for a filament power supply for ion gauges that is capable of maintaining the thermionic electron emission from the filament at a predetermined magnitude in the order of one microampere or less. Additionally, the filament power supply is advantageously adapted to bias the filament positively with respect to ground potential.

2

Accordingly, it is one object of the present invention to provide a filament power supply for ion gauges that is capable of maintaining thermionic electron emission from the filament constant at a magnitude in the order of one microampere.

Another object of the present invention is to provide a filament power supply for ion gauges that provides a substantially constant thermionic emission in the order of one microampere and provides a positive bias voltage for the filament.

Briefly, in accordance with a preferred embodiment of my invention, the filament of an ion gauge is connected in series circuit relationship with a source of alternating current power and a pair of controlled rectifiers. The rectifiers control the power supplied to the filament in accordance with their respective conduction angles which, in turn, depend upon the charging rate of capacitive means disposed in the control circuit of a unijunction transistor that selectively fires, or renders conductive, the controlled rectifiers. A source of substantially constant charging voltage is connected to the capacitive means and a transistor is connected in shunt with the capacitive means.

A series loop network is provided including the electron collector of the ion gauge, a source of unidirectional voltage having a magnitude sufficient to bias the ion gauge collector to a voltage at which it collects substantially all the electrons from the ion gauge filament, a resistor and one terminal of the filament. The resistor and a source of constant voltage are connected in series circuit relationship in the base-emitter circuit of the transistor. The constant voltage source is connected to decrease conduction of the transistor and the resistor is connected such that the voltage caused to appear thereacross, by the emission current, increases conduction in the transistor. Thus, the charging rate of the capacitive means varies inversely as changes in the electron emission, providing regulation of emission current. By grounding the negative terminal of the constant voltage source in the transistor base-emitter circuit, a positive bias for the filament is effected relative to ground potential.

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

FIGURE 1 is a simplified schematic circuit diagram of a power supply in accordance with my invention;

FIGURE 2 is a complete schematic circuit diagram of a preferred power supply in accordance with the present invention; and,

FIGURE 3 is a logarithmic plot of emission current versus the magnitude of a resistor in the control circuit of a preferred embodiment of my invention.

FIGURE 1 is a schematic circuit diagram of a simplified embodiment of the present invention, given for purposes of illustration and description. Power supply 1, generally indicated by the enclosure defined by the dashed lines 1', is a type well-known in the art and, consequently, will not be described at length herein. A detailed discussion and explanation of the operation of power supply 1 and the basic cooperation between the various components thereof is described in the Silicon

Controlled Rectifier Manual, Second Edition, published by the Semiconductor Products Department of the General Electric Company, particularly commencing at page 112 thereof.

Briefly, a pair of terminals 2 and 3 are provided that are adapted to be connected to a source of alternating current power, such as the readily available 117 volt 60 cycle commercial supply. When terminals 2 and 3 are connected to a source of alternating current power, winding 4 of transformer 5 is energized, inducing a corresponding voltage in secondary windings 6 and 6'. Winding 6 is connected to a full-wave rectifying bridge 7 that includes four diodes 8, 9, 10 and 11, connected as shown. Junctions 12 and 13 of bridge 7 provide a source of full-wave rectified sinusoidal voltage. Secondary winding 6' of transformer 5 is connected in series with two oppositely poled, or reversely connected, controlled rectifiers 14 and 15 and terminals 16 and 17, that are adapted to be connected to a device to be controllably energized, such as the filament of an ion gauge.

The control circuit of power supply 1 includes a source of substantially constant voltage including resistor 18 and zener, or voltage breakdown, diode 19 that are connected in series and to junctions 12 and 13 of rectifier bridge 7. The voltage at junction 20, between resistor 18 and zener diode 19, is referred to herein as a source of substantially constant voltage relative to terminal 13 of bridge 7, because the reference voltage supplied by zener diode 19 is generally very much less than the maximum amplitude of the voltage available between terminals 12 and 13. It is to be understood, of course, that the actual voltage waveform appearing between junction 20 and terminal 13 is a clipped sine wave. Nevertheless, for purposes of the present discussion, the voltage may be considered to be substantially constant, since this is in fact the case during the great preponderance of any given cycle of operation.

The conduction angles of controlled rectifiers 14 and 15 are determined by the charging rate of capacitive means, including capacitor 21, that is connected in the base one-emitter circuit of unijunction transistor (UJT) 22. Unijunction transistor 22 is conditioned for proper circuit operation by connecting emitter 22' thereof to junction 20 by emitter resistor 23 and by connecting base two 22'' thereof to junction 20 by means of base resistor 24. Pulses to initiate conduction in the controlled rectifiers 14 and 15 are coupled by pulse transformer 25, from primary winding 26 thereof, to secondary windings 27 and 28, that are connected to the gating electrodes 14' and 15' of respective controlled rectifiers 14 and 15. Primary winding 26 of transformer 25 is connected in series with capacitor 21 in the base one 22'''-emitter 22' circuit of UJT 22.

Operation of the power supply at FIGURE 1 is as follows. At the beginning of the cycle of energization, capacitor 21 is substantially entirely discharged and commences charging by the current flowing through resistor 23, which is connected to junction 20 that serves as a source of substantially constant voltage relative to terminal 13. Primary winding 26 of transformer 25 exhibits a low value of inductance. Thus, primary winding 26 may be considered as a low magnitude impedance that may be entirely neglected for purposes of considering the charging rate of capacitor 21.

After capacitor 21 is charged to a sufficient voltage, normally in the order of one half of the voltage between base one 22''' and base two 22'', UJT 22 fires, or becomes heavily conductive, rapidly discharging capacitor 21 through the base one-emitter circuit thereof. The greatly increased current, during discharge of capacitor 21, through primary winding 26 induces a substantial voltage in secondary windings 27 and 28 of transformer 25.

Windings 27 and 28 are adapted to energize the gating electrodes 14' and 15' of controlled rectifiers 14 and

15, respectively, upon such occurrence and initiate conduction therein. In response to the gating signal, only one of controlled rectifiers 14 and 15 becomes conductive, depending upon the instantaneous polarity of the voltage from winding 6', allowing current to flow in any electrically energizable device connected to terminals 16 and 17. Conduction continues until the end of the half cycle during which conduction was initiated.

Thus, the charging rate of capacitor 21 determines the time delay from the beginning of a power cycle until energization of a device connected to terminals 16 and 17 occurs. When capacitor 21 charges rapidly, conduction is initiated in the early portion of a cycle and maximum power is supplied to the device connected to terminals 16 and 17. Conversely, when the charging rate of capacitor 21 is slow, little power is supplied.

In accordance with the present invention terminals 16 and 17 are utilized to supply electrical energy to the filament 29 of an ion gauge. A transistor 30, having base 30', collector 30'' and emitter 30''' electrodes, is connected with the collector 30'' and emitter 30''' electrodes in shunt, or parallel circuit relationship, with capacitor 21. As pointed out above, winding 26 of transformer 25 may be neglected because its influence on the charging rate of capacitor 21 is negligible.

A series loop network is provided including ion gauge electron collector 31, a source of unidirectional voltage 32, having a sufficient voltage magnitude to bias electron collector 31 to a voltage at which it collects substantially all of the electrons from the filament, a resistor 33, and one terminal of filament 29. The latter connection may be conveniently effected by conductive means connecting resistor 33 to one or the other of terminals 16 and 17. Of course, many equivalent circuits for connection to filament 29 are known, including center tapped filament transformers, center-tapped filaments and various low impedance resistance voltage divider networks.

Resistor 33 is connected in series voltage-opposing relationship with a source 34 of constant voltage in the base-emitter circuit of transistor 30. That is to say, the voltage appearing across the resistor bucks, or counters, the voltage of source 34. The source of constant voltage is connected to cause decreased conduction of transistor 30, and in the case of the NPN unit shown, this requires that source 34 tends to bias the base of transistor 30 negatively with respect to the emitter thereof. Resistor 33 is connected such that voltage caused to appear between the extremities thereof by emission current tends to increase conduction of transistor 30. Thus, resistor 33 is connected such that the voltage between its terminals biases the base of NPN transistor 30 positive with respect to the emitter thereof. Of course, the reverse polarity relationships are used when transistor 30 is used in a control circuit where it is selected to be of the PNP type.

Operation of the control circuit of the present invention is as follows. During normal operation, when the electron emission from filament 29 to electron collector 31 is at the desired level of magnitude, the voltage caused to appear across resistor 33 is substantially equal to the voltage of source 34, and transistor 30 achieves a state of conductance intermediate the maximum and minimum values thereof. The actual difference between the two voltage magnitudes is in the order of one half volt. Under these conditions the charging rate of capacitor 21 is less than when transistor 30 is substantially nonconducting and greater than when transistor 30 is conducting heavily.

When the electron emission from filament 29 to electron collector 31 increases, the voltage between the terminals of resistor 33 increases, resulting in increased conduction by transistor 30. When transistor 30 becomes more conductive, a greater proportion of the current through resistor 23 is diverted through the collector-emitter path of transistor 30. The result is a slower charging rate for capacitor 21 and a decrease in the conduction

5

angle of the controlled rectifiers. As the controlled rectifiers conduct during a lesser portion of the power cycle, power supplied to filament 29 through terminals 16 and 17 is decreased, providing a reduction in electron emission therefrom. Conversely, when the electron emission from the filament 29 decreases, the reverse of the aforementioned phenomena occur and the power supplied to filament 29 is increased to provide compensation. In this way, the electron emission from filament 29 is maintained substantially constant.

Filament 29 is caused to operate with a positive bias potential with respect to ground by grounding the negative terminal of source 34. In this way the ion collector (not shown) of the ion gauge is operated at ground potential and yet is negatively biased, as required, with respect to filament 29. Such an arrangement provides substantial advantage for measuring the magnitude of ion current flow with known electrometers.

FIGURE 2 is a detailed schematic circuit diagram of an ion gauge filament power supply in accordance with the present invention. The operation of the circuit of FIGURE 2 is substantially that described in connection with FIGURE 1, and like components in the two figures are similarly numbered.

In FIGURE 2, source 32 of FIGURE 1 has been replaced by a source of unidirectional current derived from junctions 12 and 13 of rectifier bridge 7 and filtered by inductor 35 and capacitor 36. In like manner, source 34 has been replaced by a voltage doubler rectifying network deriving power from winding 6' and including rectifier diode 37 and 37', resistor 38, resistor 39, capacitors 40 and 41, and zener diode 41. Capacitor 40', rectifier diode 37, resistor 38 and capacitor 40 are connected in series circuit relationship across the terminals of winding 6'. Diode 37' shunt the latter three elements. Resistor 39 and zener diode 41 are connected in series circuit relationship in parallel with capacitor 40. The junction of resistor 39 and zener diode 41 is grounded to provide a positive bias for filament 29 with respect to ground potential.

The circuit of FIGURE 2 includes a resistor 42 and a capacitor 43 connected in series circuit relationship from ground to junction 13 of network 7. The purpose for this resistor-capacitor combination is to correct the phase response of the voltage regulator to provide stability. The ion gauge includes an ion collector 44 connected to an output terminal 45 that is adapted to be connected to an electrometer to provide an indication of the magnitude of ion current.

Of particular significance is resistor 46 that is connected from junction 20 to the base of transistor 30. By connecting resistor 46 as shown, the useful range is extended from 10^{-5} down to approximately 10^{-6} amperes. Resistor 47 is connected in the emitter circuit of transistor 30 to provide improved stability.

The emission current level maintained constant by the circuit of FIGURE 2 is variable by varying the value of resistance of resistor 33. In some applications, it is desirable to provide a plurality of fixed resistors and switching means to enable predetermined discreet emission current values to be maintained. In other applications it is desirable to provide a variable resistor in the place of the fixed resistor shown schematically.

By way of illustration and not to be considered in a limiting sense, the following specific component values have been found to provide a particularly advantageous emission current regulated element power supply for an ion gauge in accordance with the present invention:

Rectifying diodes 8, 9, 10,
11, 37 and 37' ----- Each type 1N1695.
Zener diode 19 ----- Type 1N1528.
Zener diode 37 ----- 3 type 1N1523.
Controlled rectifiers 14 and
15 ----- Each type 2N1770A.
Transistor 30 ----- Type 2N336.

6

Unijunction transistor 22 -- Type 2N489.
Transformer 5 ----- Secondary winding 6, 125 volts, 50 milliamperes.
Secondary winding 6', 12 volts, 4 amperes.
Used separate units, Stancor PA 8421 and UTC FT-10, respectively.
Transformer 25 ----- Type UTC H-51.
Inductor 35 ----- Type UTC R-14.
Resistor 18 ----- 5000 ohms, 10 watts.
Resistor 23 ----- 18,000 ohms, 2 watts.
Resistor 24 ----- 150 ohms, 1 watt.
Resistor 33 ----- 3×10^3 ohms to 3×10^7 ohms.
Resistor 38 ----- 100 ohms, 2 watts.
Resistor 39 ----- 620 ohms, 2 watts.
Resistor 42 ----- 110 ohms, 1 watt.
Resistor 46 ----- 3.6 megohms, $\frac{1}{4}$ watt.
Resistor 47 ----- 510 ohms, 1 watt.
Capacitor 21 ----- 0.25 microfarad, 20 volts.
Capacitor 36 ----- 40 microfarads, 150 volts.
Capacitor 40 and 40' ----- Each 50 microfarads, 25 volts.
Capacitor 43 ----- 100 microfarads, 10 volts.

The above-mentioned specific filament power supply when used with a type 5966 ion gauge provides constant emission current over the range from 10^{-2} amperes to 10^{-6} amperes. This range was achieved by varying resistor 33 from 3000 ohms to 30 megohms. Thus, while the filament power supply of this invention is singularly adapted for controlling small magnitude emission current, it is also adapted to control much larger currents.

FIGURE 3 is a log-log plot of emission current versus the resistance magnitude of resistor 33 in the aforementioned specific example of a regulator in accord with my invention. Curve 48 is plotted for the regulator without resistor 46. Curve 49 is plotted from data taken when the base of transistor 30 is resistively connected to the source of constant charging voltage, as by resistor 46 in FIGURE 2. The remarkable improvement, particularly at low emission current levels, that attends connection of resistor 46 in the circuit is evidenced by the difference in linearity between curves 48 and 49 in the low current region of the graph.

While only certain preferred features of the invention have been shown by way of illustration, many modifications and changes will occur to those skilled in the art. It is, therefore, to be understood that the appended claims are intended to cover all such modifications and changes as fall within the true spirit and scope of the invention.

What I claim as new and desire to secure by Letters Patent of the United States is:

1. In a power supply for the filament of an ion gauge having a thermionic electron-emissive filament and an electron collector, said supply including capacitive means in the control circuit thereof and means for applying power to said filament during a portion of an alternating current power cycle that varies in the opposite direction as changes in the rate of charging of said capacitive means, the improvement of means for varying said rate of charging to effect substantially constant electron emission from said filament comprising: a source of substantially constant charging voltage connected to said capacitive means; a transistor having base, collector and emitter electrodes; means connecting said transistor collector and emitter electrodes in shunt with said capacitive means; a series loop network including said electron collector, a source of unidirectional voltage energizing said electron collector to a voltage relative to said filament at which it collects substantially all of the electrons from said filament, a resistor, and one terminal of said filament; and conductive means connecting said resistor and a source of constant voltage in series voltage-opposing relationship in the base-emitter circuit of said transistor, said source

7

of constant voltage being connected to cause decreased conduction of said transistor and said resistor being connected such that the voltage generated therein by the flow of emission current therethrough increases conduction of said transistor.

2. The power supply of claim 1 including a resistor connected from the base electrode of said transistor to said source of substantially constant charging voltage to provide regulated thermionic emission in the order of one microampere.

8

3. The power supply of claim 2 wherein the negative terminal of said source of constant voltage in the base-emitter circuit of said transistor is grounded to provide positive biasing of said filament with respect to ground potential.

5

No references cited.

JAMES W. LAWRENCE, *Primary Examiner*.

10 C. R. CAMPBELL, *Assistant Examiner*