March 8, 1966 J. M. LAFFERTY 3,239,715

ELECTRON EMISSION MONITOR FOR MAGNETRON-TYPE IONIZATION GAUGE

Filed Sept. 26, 1961

Fig. 1.

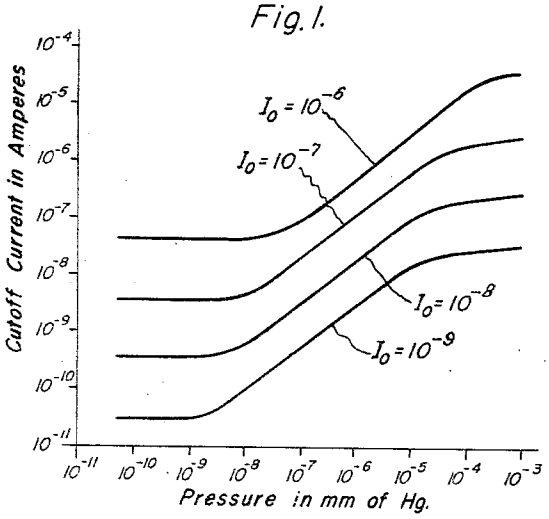


Fig. 2.

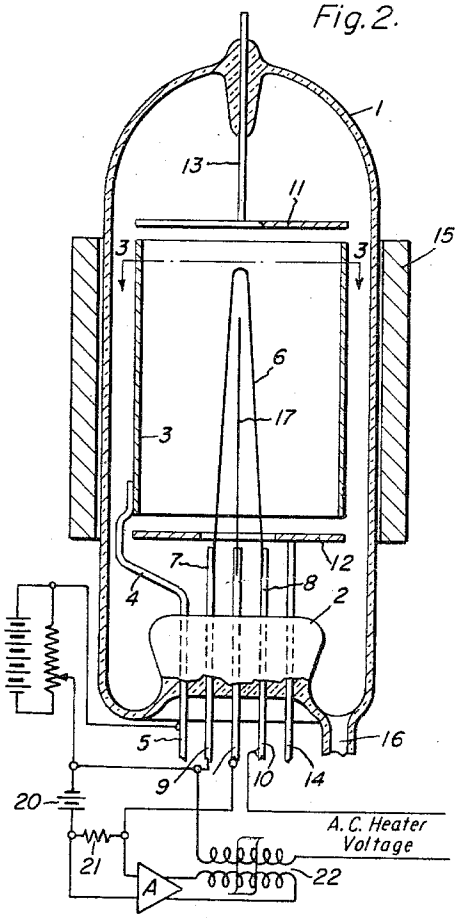


Fig. 5.

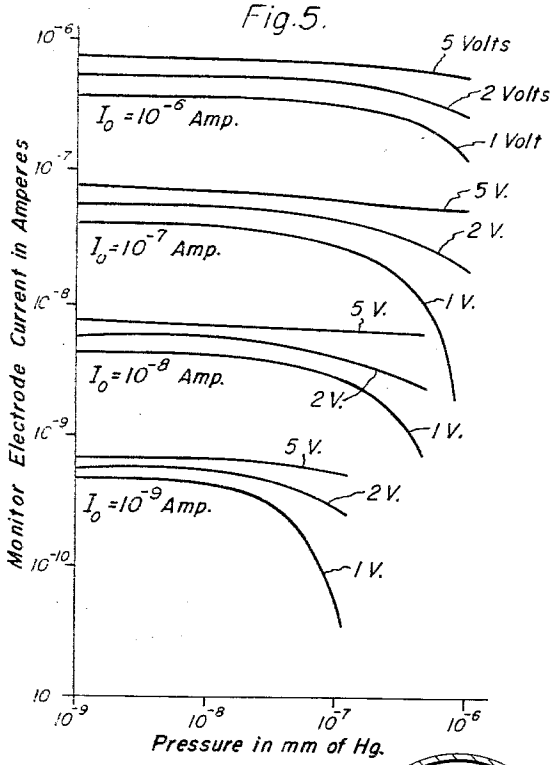


Fig. 4

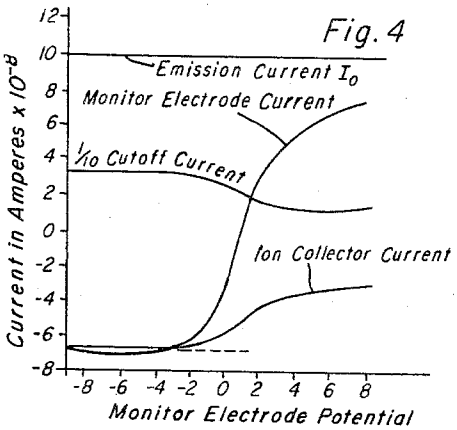
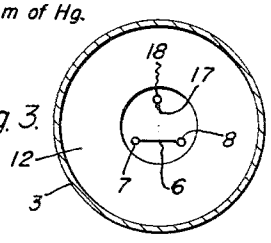


Fig. 3.



Inventor:
James M. Lafferty,
by Joseph V. Claeys
His Attorney.

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ELECTRON EMISSION MONITOR FOR MAGNETRON-TYPE IONIZATION GAUGE

James M. Lafferty, Schenectady, N.Y., assignor to General Electric Company, a corporation of New York

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11 Claims. (Cl. 315—108)

This invention relates to magnetron-type ionization gauges and ion sources and in particular to apparatus of this type wherein novel means are provided for monitoring the electron emission current therein.

Ionization gauges in the form of a simple triode-tube structure are well-known and widely used in the art for measuring gas pressure under high-vacuum conditions. Such apparatus include a thermionic cathode, an anode, and an ion collecting electrode.

Contamination of the cathode by various gases and by positive ion bombardment may produce changes in the thermionic activity of the cathode of such ionization gauges so that electron emission current varies even though the power supplied to the cathode remains constant. The desirability of maintaining a constant electron emission current in an ionization gauge for a series of pressure measurements has led to the development of a variety of means for regulating such electron emission. These various types of regulation means automatically control the power supplied to the thermionic cathode of the ionization gauge to adjust its temperature and provide a constant electron emission therefrom independent of moderate variations in its thermionic activity. Such regulation means are responsive to a signal derived by monitoring the electron emission current to the positively biased anode.

Since, in the conventional triode-tube type ionization gauge, the positively biased anode collects the temperature limited emission current, the anode current is essentially proportional to the emission current independent of the gas pressure. In a magnetron-type ionization gauge, such as, for example, my improved gauge described and claimed in U.S. Patent No. 2,884,550, which is assigned to the assignee of the present invention, however, there is no electrode which collects the temperature-limited emission current. For example, the anode current in such magnetron-type ionization gauges is found to be proportional to the emission current only at pressures below about 10^{-9} millimeters of mercury. At higher pressures the anode current is dependent on both emission current and gas pressure. In magnetron-type ionization gauges heretofore known, therefore, there has been no convenient and reliable way to monitor the electron emission current and thereby utilize the known emission regulation means for maintaining a constant electron emission current therein. Since magnetron-type ionization gauges of the type described and claimed in the above referenced United States patent are capable of measuring much lower gas pressures than prior art ionization gauges of the conventional triode-tube type, it is extremely desirable to provide these improved ionization gauges with simple and inexpensive means for providing for a constant electron emission current as well as means for determining the electron emission current under operating conditions.

It is an object of this invention, therefore, to provide a new and improved ionization gauge of the magnetron-type which substantially overcomes one or more limitations of prior art ionization gauges of this type.

It is a further object of this invention to provide a new and improved ionization gauge of the magnetron-type wherein means are provided for conveniently and accurately monitoring the electron emission current.

It is a still further object of this invention to provide

an improved ionization gauge of the magnetron-type having means adapted for deriving a signal proportional to the electron emission current therein for use with known regulation means for maintaining the electron emission current at a constant value independent of moderate variations in the thermionic activity of the cathode of the ionization gauge.

Ionization gauges of the magnetron type include a thermionic cathode, an anode, and an ion collecting electrode in close juxtaposition to one another, and electric bias means for operating the gauge under cut-off conditions whereby electrons from the cathode fail to reach the anode and form a rotating space charge cloud surrounding the cathode. Ions formed by electron collisions with gas molecules within the cathode-anode space are collected by the ion collecting electrode to give an indication of the gas pressure.

Briefly stated, an improved ionization gauge of the magnetron-type in accordance with one aspect of this invention, comprises means for monitoring the electron emission current from the cathode. This means includes an additional or "monitor" electrode in close juxtaposition to the cathode and disposed within the rotating space charge cloud which surrounds the cathode.

The novel features believed characteristic of the present invention are set forth in the appended claims. The invention itself, however, together with further objects and advantages thereof may best be understood by reference to the following detailed description taken in connection with the accompanying drawing in which:

FIGURE 1 shows a series of curves illustrating the relationship of anode cut-off current to gas pressure in a typical magnetron-type ionization gauge for several values of emission current,

FIGURE 2 is a vertical sectional view of a magnetron-type ionization gauge constructed in accordance with the present invention,

FIGURE 3 is a section along the line 3—3 of FIGURE 2 showing a suitable space relationship of the monitor electrode for collecting the electron emission current of the electron source,

FIGURE 4 illustrates the current-voltage characteristic of the electrode means for monitoring the emission current in accordance with this invention for an emission current of 10^{-7} ampere and a pressure of 2×10^{-6} millimeters of mercury, and,

FIGURE 5 illustrates the emisison current to the monitor electrode in accordance with this invention as a function of pressure for various values of emission current (I_0) and applied electrode potentials.

Since magnetron-type ionization gauges are capable of measuring much lower gas pressures than other types, they are extremely important devices for measuring gas pressures under high-vacuum conditions. In a magnetron-type ionization gauge operated with a magnetic field having an intensity greater than the cut-off value, however, there is no means of measuring the electron emission current by monitoring the anode current. This may best be shown by reference to FIGURE 1 which illustrates curves of anode cut-off current as a function of gas pressure for several values of emission current. The cut-off current is dependent on gas pressure for the emission currents shown except at very low pressures. For example, the anode current is proportional to the electron emission current only at pressures below about 10^{-9} millimeters of mercury; above that pressure the anode current depends upon both the electron emission current and the gas pressure. Thus, the anode current does not give an accurate indication of the electron emission current except at these very low pressures. A signal derived from the electron current to the anode, therefore,

is unsuitable for use with the conventional emission regulator means since the anode current in a magnetron-type gauge does not provide an indication of the electron emission current.

The absence of a convenient means of monitoring the electron emission from the cathode in ionization gauges of the magnetron-type may often limit their usefulness for many important applications. For example, to assure accuracy when making a series of pressure measurements, it is not only desirable, but often necessary, that the electron emission current be maintained at a constant value independent of the thermionic activity of the cathode. This limitation is overcome in acordance with this invention by providing a magnetron-type ionization gauge with an additional or monitor electrode means for collecting the temperature-limited electron emission current. The electron current to this additional electrode means is found to be essentially proportional to the electron emission current independent of pressure over an extended pressure range.

In FIGURE 2 there is shown a vertical sectional view of a magnetron-type ionization gauge incorporating means for monitoring the electron emission current in accordance with this invention. A suitable envelope is provided for enclosing the electrodes of the magnetron-type ionization gauge such as a glass or vitreous envelope **1** having a re-entrant portion **2** at one end thereof. An anode cylinder **3** is disposed within envelope **1** and mounted therein on a suitable support such as support pin **4**. Support pin **4** extends through and is hermetically sealed to re-entrant portion **2** of envelope **1** and is provided with an extension **5** which serves as a suitable terminal means for applying the appropriate operating potential to the anode cylinder **3**. A thermionic cathode **6** is mounted axially aligned with the longitudinal axis of anode cylinder **3**. For example, cathode **6** may be a doubled filament of tungsten or the like mounted within envelope **1** and disposed along the longitudinal axis of anode cylinder **3** by means of cathode support rods **7** and **8** respectively; cathode support rods **7** and **8** extending through and being hermetically sealed to re-entrant portion **2** of envelope **1** and being further provided with extensions **9** and **10** respectively which serve as suitable terminals for connection of the appropriate voltage to the cathode. Alternatively, cathode **6** may be an axial filament or a ribbon-type cathode supported at each end in well-known manner.

A pair of end plates **11** and **12** are provided near opposite ends of anode cylinder **3** for collecting ions and preventing escape of electrons from the cathode-anode space. Although both end plates **11** and **12** may be utilized for the collection of ions it is often convenient to provide that only one end plate, for example plate **11**, be employed as the "ion collecting electrode" while end plate **12** is employed as a "shield electrode." In this case the end plate **12**, denominated the "shield electrode," is operated at a voltage in the range of about 15 to 100 percent of the negative voltage applied to the end plate **11** denominated the "ion collecting electrode." The operation of an ionization gauge of this type is insensitive to the exact voltage applied to the shield electrode in this range of voltage. This arrangement reduces the sensitivity of the gauge, but has the advantage that only one end plate need be carefully insulated to prevent electrical leakage. End plates **11** and **12** may be conveniently supported by support rods **13** and **14** respectively which are further utilized as terminal means for applying the operating potential to shield electrode **12** and output means from ion collector electrode **11** respectively.

A cylindrical magnet **15**, which may be an electromagnetic coil or a permanent magnet, is fitted closely around the outside of envelope **1** and provides means for applying an axial magnetic field substantially perpendicular to the normal path of electrons from cathode to anode. The intensity of the magnetic field is correlated with the cathode-anode potential to assure operation beyond cut-off conditions. Typically the magnetron-type ionization gauge is operated at about two or three times the cutoff value. Under such operating conditions electrons from the cathode are caused to traverse spiral paths so that such electrons fail to reach the anode and form a rotating space charge cloud surrounding the cathode. Connection of the ionization gauge to a vacuum system whose pressure is to be measured is provided by a tubulation **16** provided, for example, in one end of envelope **1**. Under typical normal operating conditions a magnetic field of about 250 oersteds is applied to the magnetron ionization gauge with a positive voltage of about 300 volts applied to the anode cylinder **3**, a negative voltage of about 45 volts applied to the ion collector electrode **11**, and a negative voltage of about 10 volts applied to the shield electrode **12**.

For clarity and simplicity of explanation the above description has been with reference to an ionization gauge of the magnetron-type enclosed within a suitable envelope of glass or the like. It is to be understood, however, that various other constructions of such ionization gauges of this type are known in the art, such as for example, the ceramic-metal construction of the improved magnetron ionization gauge shown and described in my above referenced United States Patent No. 2,884,550. The particular construction of the basic magnetron-type ionization gauge itself is not part of the present invention and is not critical with respect thereto so that it is to be understood that any magnetron-type ion source structure is suitable in the construction of the improved ionization gauge in accordance with my present invention.

In accordance with the present invention, therefore, means are provided for collecting the temperature-limited electron emission current within the magnetron-type ionization gauge. To this end there is provided a monitor electrode **17** in close juxtaposition to thermionic cathode **6** and positioned so as to be well within the rotating space charge cloud established by the magnetron structure when the device is operated beyond cut-off conditions. For example, monitor electrode **17** may have a probe-like configuration as illustrated and may be conveniently disposed parallel with and closely adjacent to, the thermionic cathode. A suitable arrangement of monitor electrode **17** and cathode **6** may be as illustrated in more detail in FIGURE 3. In this way, monitor electrode **17** is well within the rotating space charge cloud surrounding the cathode. Preferably the monitor electrode **17** should be sufficiently small and so located that the potential distribution of the rotating space charge cloud is essentially unaltered thereby. For example, monitor electrode **17** may be conveniently in the form of a wire having a diameter as small as in consistent with adequate structural considerations. Electrode **17** may be suitably supported by a support rod **18** which extends through and is hermetically sealed to the re-entrant portion **2** of envelope **1**; the terminal portion of support rod **18** being suitable for use in applying the appropriate operating potential to monitor electrode **17**. It is desirable that only the small diameter monitor electrode **17** collect the temperature limited emission current from the cathode and, therefore, the larger diameter support rod **18** is preferably prevented from collecting such electrons. This may be provided, for example, by assuring that the end of support rod **18** does not extend beyond the plane of the shield electrode **12** and into the cathode-anode space where electrons would be collected thereby.

With an applied magnetic field and with a slight positive potential applied to monitor electrode **17**, the electron current thereto is found to be proportional to the temperature limited emission of the thermionic cathode independent of pressure over the normal operating range of the gauge. Further, the current to this monitor electrode is found to depend only upon the electron emission from the cathode and to be a small fraction thereof,

Thus, the current to this electrode can be used to monitor the emission of the cathode of the magnetron-type ionization gauge or utilized to control a regulation circuit means to regulate the power supplied to the cathode and thereby provide for a constant emission therefrom independent of moderate variations in its thermionic activity.

A suitable circuit for regulating the power supplied to the cathode is shown in FIGURE 2 and comprises a battery **20**, for applying a slight positive potential to monitor electrode **17**, and a resistor **21** in which the current to the monitor electrode **17** is developed. This voltage is amplified and applied to a first winding of saturable reactor **22** to control the A.C. impedance of the second winding which controls the heater voltage applied to the cathode **6** to maintain the electron emission at a constant level.

In FIGURE 4 there is shown the current-voltage characteristic A of monitor electrode **17**. Curve A illustrates the current-voltage characteristic of this electrode for a typical magnetron-type ionization gauge constructed in accordance with this invention with normal applied magnetic field of 250 oersteds and applied voltages of +300 volts, −45 volts and −10 volts to the anode cylinder, ion collector electrode, and shield electrode respectively and at a pressure of about 2 x 10^{-6} millimeters of mercury.

Under the above operating conditions and even at relatively high pressure FIGURE 4 shows that at negative voltages greater than about three volts applied to monitor electrode **17**, the ion current thereto is constant and approximately equal in magnitude to the ion collector electrode current. As the voltage of monitor electrode **17** is made less negative, electrons are able to reach it and subtract from the ion current until, as electrode **17** is made positive, the electron current to it increases rapidly causing the rotating space charge in the ionization gauge to decrease. This latter effect is evidenced by a decrease in both the ion colletcor current and the cut-off current to the anode. It will be further observed in connection with FIGURE 4, that at a positive voltage of about 12 volts the current to monitor electrode **17** is nearly equal to the emission of the thermionic cathode. Preferably, therefore, the voltage applied to monitor electrode **17** should be sufficiently large to assure that the electron current collected thereby is large compared to the ion current for the pressure range of operation, but not so large as to appreciably reduce the sensitivity of the gauge. Although the exact value of this voltage depends upon the particular construction of the magnetron gauge, for a gauge such as illustrated in FIGURES 2 and 3 the voltage applied to monitor electrode **17** may be in the range of about 1 to 5 volts.

In FIGURE 5 there is shown the relation between the electron current to electrode **17** and pressure for several values of cathode emission current (I_0) and for potentials applied to electrode **17** of 1, 2 and 5 volts respectively. In FIGURE 5, therefore, it is shown that with a constant potential applied to electrode **17**, the current thereto is proportional to the emission current provided the ion current to electrode **17** is negligible. A comparison of FIGURES 1 and 4 shows that the electron current to electrode **17** is far less dependent on gas pressure than is the anode cut-off current. For example, with about 5 volts positive on electrode **17** and under normal operatnig conditions where the emission current is about 10^{-7} amperes, the electron current to electrode **17** decreases less than 25 percent for pressures from 10^{-9} to 10^{-6} millimeters of mercury while the anode cut-off current increases nearly two orders of magnitude over the same pressure range. With 2 volts positive on electrode **17** and for the same emission current, the current to electrode **17** is reduced to 17 percent at 10^{-7} millimeters of mercury. The variation in the current to electrode **17**, therefore, is sufficiently small to permit use of the current to this electrode to monitor the emission current of the thermionic cathode over an extended pressure range.

The relationship of the various electrodes, one to the other, may be shown in still more detail by the following description of a specific ionization gauge which is representative of a typical magnetron-type ionization gauge incorporating the present invention. The following description is given by way of example only and is in no way intended as limiting the present invention.

One typical magnetron-type ionization gauge, for example, such as that described in my article in the Journal of Applied Physics, vol. 32, No. 3, March 1961, pages 424–434, has an anode cylinder 15/16 inch in diameter and 1⅛ inches in length. End plates, functioning as ion collector and shield respectively, are 1 inch in diameter and displaced 1/16 inch from the ends of the anode cylinder. The anode cylinder and end plates are constructed of .005 inch molybdenum sheet material while the supporting leads are of molybdenum wire .040 inch in diameter. A thermionic cathode of the "hairpin-type" ¾ inch in length and constructed of .008 inch diameter tungsten wire is positioned along the axis of the anode cylinder with the tip thereof displaced from the immediate region of the ion collector electrode to assure the supression of positive ion emission. For increased sensitivity and ability to measure pressures lower than about 10^{-8} millimeters of mercury the magnetron-type ionization gauge may be operated in accordance with the teaching of my above referenced Patent No. 2,884,550 wherein cathode-anode currents of about 0.1 to 1.0 microampere are utilized.

In accordance with the present invention the above ion gauge is provided with means for monitoring the electron emission current by the combination therewith of a monitor electrode. The monitor electrode is a probe-type electrode constructed of .010 inch diameter tungsten wire ⅝ inch in length positioned parallel with the thermionic cathode and displaced .040 inch therefrom. Thus, as shown in detail in FIGURE 3 the monitor electrode is equally spaced from the base members of the doubled cathode. Normal operating conditions for such an ionization gauge are a magnetic field of about 250 oersteds and applied potentials of about +300 volts to the anode cylinder, about −45 volts to the ion collector electrode, about −10 volts to the shield electrode, and from about +2 to +5 volts to the monitor electrode.

There has been described hereinbefore, therefore, an improved magnetron-type ionization gauge in which novel means are provided for monitoring the electron emission current of the thermionic cathode thereof; such means including the provision, in combination with the magnetron structure, of an additional electrode, referred to in the specification and claims as a "monitor electrode," in close juxtaposition with the thermionic cathode and so positioned with respect thereto to be within the rotating space charge cloud established in the magnetron structure when operated beyond cut-off conditions. The electron current to this electrode, being essentially independent of pressure over an extended operating range, may be employed to monitor the electron emission from the thermionic cathode or to serve as a signal to operate an emission regulator for the magnetron ionization gauge to maintain the electron emission of the cathode constant independent of moderate variations in its thermionic activity.

While only certain preferred features of this 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 magnetron-type ion source having an electron emitter, an anode in close juxtaposition with said electron emitter, and electrical bias and magnetic field means for

operating said ion source beyond cut-off conditions whereby the electrons from said electron emitter fail to reach said anode and form a rotating space charge cloud surrounding said electron emitter, the improvement comprising: an electron-collecting electrode member in juxtaposition to said electron emitter and disposed within said rotating space charge cloud for monitoring the electron current in said ion source, said electrode member being small relative to said space charge cloud to reduce ion collection thereby.

2. In a magnetron-type ionization gauge having an electron emitter, an anode in close juxtaposition with said electron emitter, and electrical bias and magnetic field means for operating said ionization gauge beyond cut-off conditions whereby the electrons from said electron emitter fail to reach said anode and form a rotating space charge cloud in the cathode-anode space and surrounding said electron emitter, the improvement comprising: a probe-like monitor electrode member disposed within said cathode-anode space and positioned within said rotating space charge cloud; and means for applying a voltage to said monitor electrode of sufficient magnitude that the electron current collected thereby is large compared to the ion current, said monitor electrode being operative to collect electron current from said electron emitter without appreciably affecting the sensitivity of said ionization gauge.

3. The ionization gauge of claim 2 wherein the monitor electrode potential is in the range of about 1 to 5 volts.

4. In a magnetron-type ionization gauge having a thermionic cathode, an anode, and an ion collecting electrode and electrical bias and magnetic field means for operating said ionization gauge beyond cut-off conditions whereby electrons from said cathode are caused to travel spiral paths and fail to reach said anode forming a rotating space charge cloud surrounding said cathode, the improvement comprising: a probe-like monitor electrode in juxtaposition to said cathode and positioned within said rotating space charge cloud for collecting the temperature-limited electron emission current from said cathode.

5. The ionization gauge of claim 4 wherein said monitor electrode comprising a wire and is disposed closely adjacent to and spaced from said thermionic cathode.

6. The ionization gauge of claim 5 wherein the diameter of said probe-like monitor electrode is sufficiently small and said electrode so positioned that the potential distribution of said rotating space charge cloud is essentially unaltered by said monitor electrode.

7. In a magnetron-type ionization gauge having a thermionic cathode, an anode, and an ion collecting electrode, and electrical bias and magnetic field means for operating said ionization gauge beyond cut-off conditions whereby electrons from said cathode are caused to travel spiral paths and fail to reach said anode forming a rotating space charge cloud surrounding said cathode, the improvement comprising: a probe-like monitor electrode in juxtaposition to said cathode and positioned within said rotating space charge cloud; and means for applying an appropriate operating voltage to said monitor electrode to cause said monitor electrode to collect the temperature-limited electron emission current from said cathode without appreciably affecting the sensitivity of said ionization gauge.

8. The ionization gauge of claim 7 wherein the operating voltage applied to said monitor electrode is correlated with respect to the position of said monitor electrode within said rotating space charge cloud to assure that said monitor electrode is at substantially the same potential as that of the region of said space charge cloud within which it is disposed.

9. The ionization gauge of claim 8 wherein said thermionic cathode is of the doubled filament type having spaced base members and said monitor electrode comprising a wire positioned approximately equidistant from the said base members of said thermionic cathode.

10. The ionization gauge of claim 9 wherein the operating voltage applied to said monitor electrode is in the range of about 1–5 volts.

11. In a magnetron-type ionization gauge having a thermionic cathode, an anode, and a collector electrode disposed in close juxtaposition to one another; electric bias and magnetic field means for operating said gauge beyond cut-off conditions whereby electrons from said cathode fail to reach said anode and form a rotating space charge cloud surrounding said cathode; and means controlling the electrical current supplied through said cathode at a rate to maintain electron current between said cathode and said anode at a value of 0.1 to 1.0 microampere, the improvement comprising: means for monitoring the electron current in said gauge, said means including an electron-collecting electrode in close juxtaposition to said cathode within said rotating space charge cloud, and means for maintaining said additional electrode at a slight positive potential with respect to said cathode.

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GEORGE N. WESTBY, *Primary Examiner.*

V. LAFRANCHI, *Assistant Examiner.*