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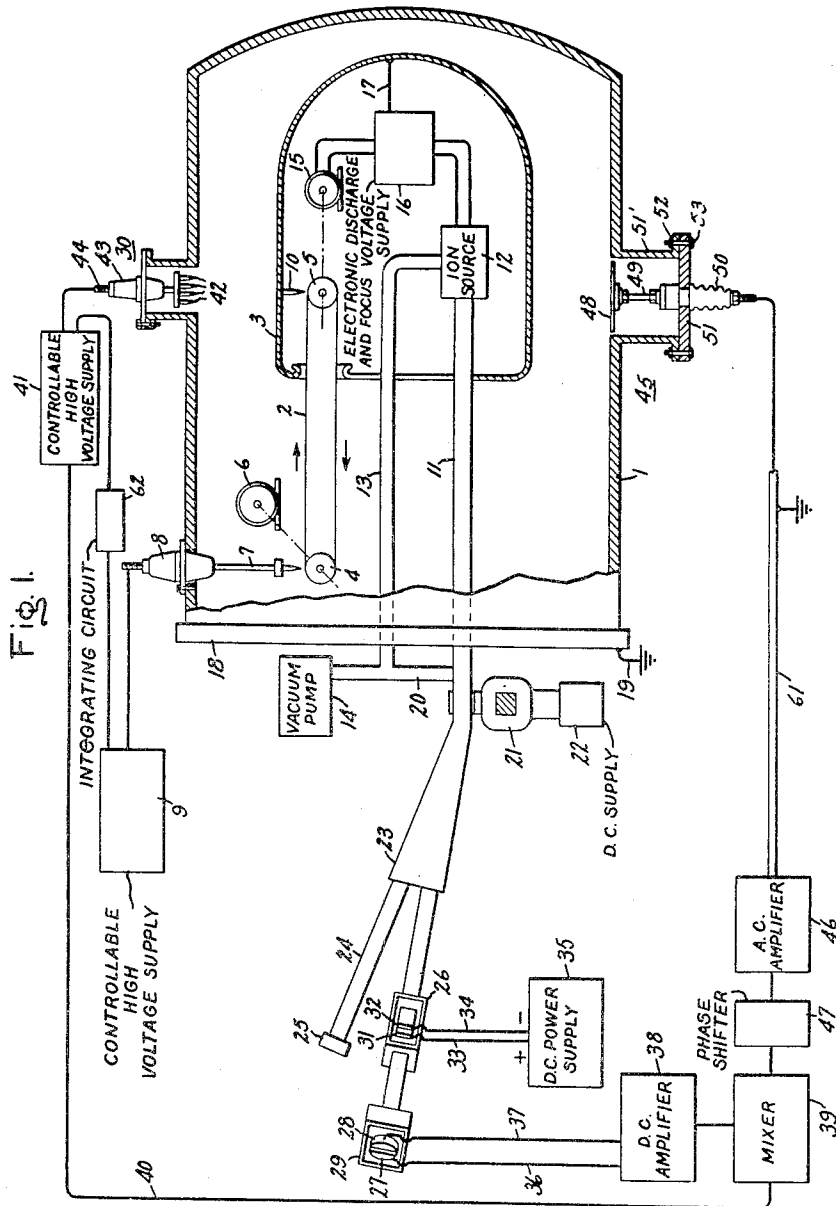
H. W. BOUSMAN

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VOLTAGE REGULATION FOR ELECTROSTATIC GENERATORS

Filed June 27, 1950

2 SHEETS--SHEET 1



Inventor:
Henry W. Bousman,
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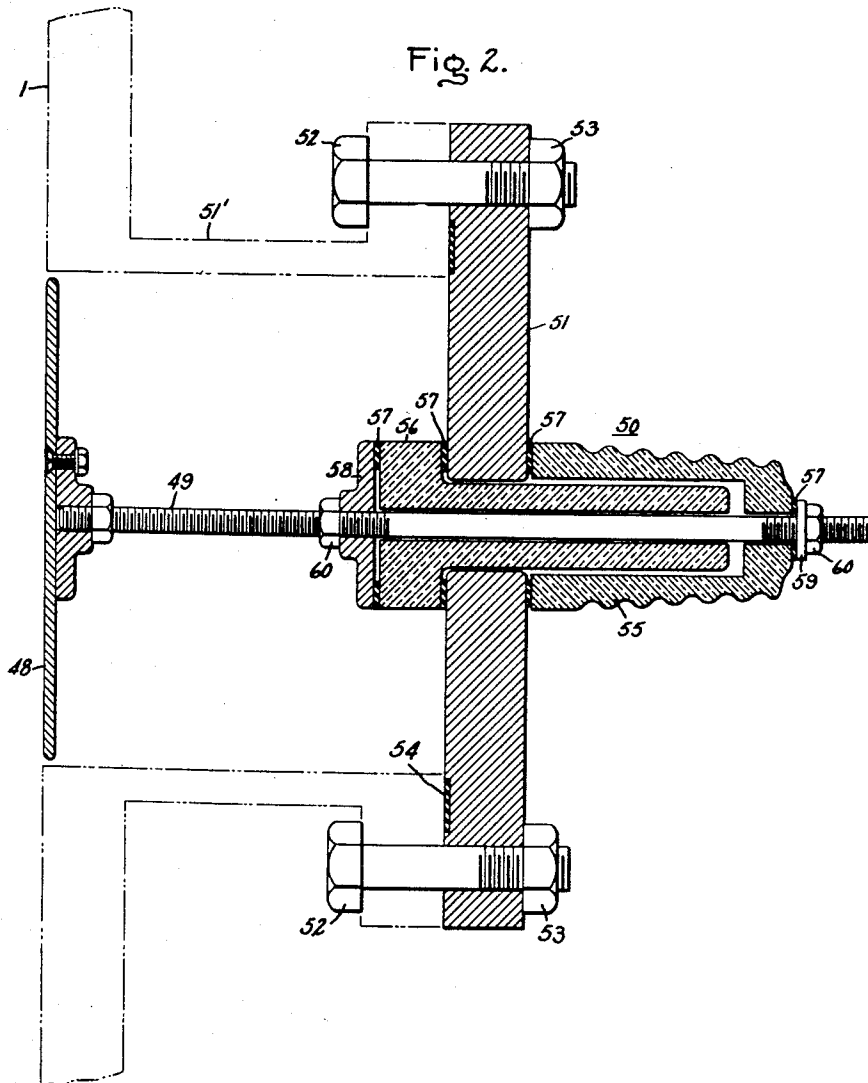
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UNITED STATES PATENT OFFICE

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VOLTAGE REGULATION FOR ELECTRO-
STATIC GENERATORSHenry W. Bousman, Scotia, N. Y., assignor to
General Electric Company, a corporation of
New York

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11 Claims. (Cl. 322-2)

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This invention relates generally to electrostatic generators and, more particularly, to systems and means for regulating the terminal voltage of electrostatic generators.

Electrostatic generators have long been utilized in certain applications for the production of high voltages. Such apparatus usually comprises a moving dielectric belt upon which charges are sprayed by an ionizing electrode. These charges are carried by the dielectric belt through a desired distance and then are collected within a rounded hollow terminal electrode. As the belt continues to deposit charges upon the terminal electrode, the voltage thereof builds up until the charge deposited by the belt is equaled by the amount of charge leakage from the terminal electrode.

In recent years, the increased interest in the field of nuclear physics has caused considerable attention to be drawn to the aforementioned type of electrostatic generator as a means of supplying high voltages for the acceleration of charged particles, e. g. protons or electrons. The employment of an electrostatic generator for such a purpose is described in an article entitled "Control Equipment for 2.5 m. e. v. Van De Graaf Giving an Ion Beam Constant to ± 1.5 k. e. v.," appearing in the Physical Review, volume 70, page 117 (1946), and written by J. L. McKibben, D. H. Frisch, and J. M. Hush. This article, along with others dealing with similar subject matter, point out, however, that in order for the electrostatic generator, to be most useful in the field of nuclear physics, its terminal voltage must be closely regulated. This requirement is predicated upon the necessity of producing essentially mono-energetic neutron beams from certain nuclear reactions resulting from the bombardment of a given material with protons. If the terminal voltage of the electrostatic generator varies, the energy of the accelerated charged particles, or protons, will vary accordingly and, if the proton energy variation exceeds certain limits, a mono-energetic neutron beam can no longer be produced.

It is, therefore, an object of the present invention to provide systems and means for maintaining the terminal voltage of an electrostatic generator within desired close limits under either free-running or load conditions.

In accordance with one aspect of the invention more fully described and disclosed hereinafter, capacitive means are provided in an electrostatic generator to be responsive to variations in the terminal electrode voltage. In this man-

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ner, a signal substantially instantaneously responsive to variations of the terminal electrode voltage is obtained and fed back through a feedback loop to a controllable high voltage supply which provides voltages for a corona leak electrode. The voltage upon the corona leak electrode determines the amount of leakage current down from the terminal electrode and, hence, provides a means of varying the terminal electrode voltage. Consequently, the present invention provides systems and means for controlling the terminal voltage of an electrostatic generator within close limits.

Other objects and advantages of this invention will be apparent from the following description taken in connection with the accompanying drawing in which Fig. 1 is a schematic illustration of electrostatic generator apparatus and control means therefor suitably embodying the invention; and Fig. 2 is a more detailed view of the capacitor plate shown in Fig. 1.

Referring now to the drawing, there is shown electrostatic generator apparatus comprising an airtight gas-filled enclosing tank 1, a traveling charge carrier or belt 2 and a hollow terminal electrode 3. The flexible dielectric belt 2 is supported and driven in the direction indicated by the arrows by means of pulleys 4 and 5. Belt 2 may be driven at an essentially constant speed by a motor 6 suitably attached to pulley 4. Positive charges are sprayed upon belt 2 by an ionizing electrode 7 which may comprise a series of needles suitably supported from tank 1 by means of an insulator 8. Positive potential with respect to grounded pulley 4 is applied to ionizing electrode 7 from a high voltage supply 9 which may be controlled in a manner more fully described hereinafter to determine the amount of charge sprayed upon belt 2 by ionizing electrode 7.

After the charges have been sprayed upon belt 2, they are transported to a suitable position within collector electrode 3 where they are collected by a collector electrode 10, which may comprise a series of needles, and transferred to terminal electrode 3 in a manner well known to those skilled in the art. This process of charge accumulation upon terminal electrode 3 continues until the charge leakage away from terminal electrode 3 and belt 2 to various portions of the apparatus counterbalances the amount of charge sprayed upon belt by electrode 7. The resultant high voltage of terminal electrode 3, which may be of the order of 3,000,000 volts, may then be employed as a means of accelerating ions

along ion accelerating tube 11. Ions are provided by an ion source 12 which may be evacuated through an exhaust tube 13 attached to vacuum pump 14. Ion source 12 may comprise means for generating an electronic discharge and a supply of hydrogen (not shown), the molecules of which are bombarded by the electronic discharge to form protons and molecular H_2 ions. Voltages for maintaining the electronic discharge within ion source 12 and for focusing the generated ions may be supplied by an alternating current generator 15 driven from pulley 5. The output of generator 15 may be rectified and employed to energize a suitable electronic high voltage supply circuit or circuits 16 which perform the function of providing the correct focusing and electronic discharge potentials for ion source 12. To apply high voltage to the ions generated within source 12, connection to the terminal electrode 3 may be made at a suitable point within supply 16, as indicated by conductor 17. It will be understood by those well skilled in the art that accelerating tube 11 and exhaust tube 13 should be formed of insulating material having conductor rings spaced along the length thereof for the purposes of grading the potential between terminal electrode 3 and the face plate 18 of tank 1 to prevent spark over. Other structural considerations which must be observed in the construction of electrostatic generator apparatus as above described may be found in an article entitled "Electrostatic Generator Operating Under High Pressure—Operational Experience And Accessory Apparatus," appearing in the Physical Review, volume 53, page 642 (1938).

The ions supplied by ion source 12 are accelerated through the potential difference between terminal electrode 3 and face plate 18, which may be maintained at ground potential as indicated at 19, within accelerating tube 11, which may be evacuated through a connection 20 to vacuum pump 14. After this acceleration has been imparted to the ions, the protons and molecular H_2 ions may be caused to follow divergent paths by means of a transverse magnetic field created by an electromagnet 21 energized by direct current supply 22. As will be well understood by those skilled in the art, the protons have a smaller mass than the molecular H_2 ions, and, hence, their trajectory will have a smaller radius within the magnetic field whereupon they may be directed through extension 23 of accelerator tube 11 along tube 24 to a target 25 for the purpose of producing a desired nuclear reaction. The molecular H_2 ions, having a larger mass, will be influenced less than the protons by the magnetic field and, hence, may be directed along extension 24' through an electrostatic analyzer 26 to a pair of collector electrodes 27 and 28 suitably enclosed by envelope 29. Since the molecular H_2 ions are generally not desired for the purpose of producing nuclear reactions as are the protons, they are separated as above described by the magnetic field and employed for the purpose of controlling the voltage on terminal electrode 3 in a manner which will appear presently.

It will now be apparent that any variation in the voltage of terminal electrode 3 will cause a similar variation in the energy of the accelerated ion beam, inasmuch as the energy imparted to the ions will be directly proportional to the accelerating voltage. As has been mentioned heretofore, the energy spectrum of the protons must be maintained within narrow limits in order that they may be advantageously utilized for nuclear reactions, such as the production of mono-

energetic neutron beams. It is well known that electrostatic generators are inherently unstable, at least to the extent that the terminal voltage produced by such apparatus varies over a relatively wide range due to spark over, intermittent corona leakages, variations of charge collection upon the terminal electrode, etc. Consequently, if such apparatus is to be utilized advantageously in the aforementioned manner, means must be provided for regulating the terminal voltage within relatively narrow limits. According to the present invention, such control is provided by supplying a composite signal to a corona leak electrode 30 whereby the charge leakage from and hence the terminal voltage of, electrode 3 may be regulated as desired.

In order to derive a signal from the ion beam traversing accelerating tube 11 responsive to changes in the voltage of terminal electrode 3, the molecular H_2 ions are separated from the protons by means of electromagnet 21, as hereinbefore mentioned, and then are focused at the desired energy level by means of electrostatic analyzer 26, which serves as an energy selector, so that they fall in equal amount upon collector electrodes 27 and 28. Electrostatic analyzer 26 comprises a pair of curved deflecting plates 31 and 32 energized through conductors 33 and 34 by a direct current power supply having the polarity indicated. The power supply 35 should have a manually operable output voltage control so that the electrostatic field between plates 31 and 32 may be adjusted to the correct value for focusing the molecular H_2 beam to fall equally upon collector electrodes 27 and 28 at a desired voltage of terminal electrode 3. Collector electrodes 27 and 28 are connected respectively by conductors 36 and 37 to a direct current amplifier 38. Amplifier 38 should be of the type well known to those skilled in the art for amplifying a difference signal, i. e. have a zero output when the currents generated by molecular H_2 ions falling upon collector electrodes 27 and 28 are equal in magnitude and an output differing from zero when the ions are not evenly distributed between electrodes 27 and 28. The output of amplifier 38 is fed through a mixer 39, which may be of the conventional resistance type, and a conductor 40 to a controllable high voltage supply 41. High voltage supply 41 energizes corona electrode 30, which may comprise a series of needles 42 supported within tank 1 through an insulator 43 and a conductor 44.

As has been disclosed by R. N. Ashby and A. O. Hanson in an article appearing in the "Review of Scientific Instruments," volume 13, page 128 (1942) corona electrode 30 may be employed as a variable corona leak to control the charge upon and voltage of terminal electrode 3. The needles 42 must, however, be maintained at a voltage below the voltage of terminal electrode 3, but not excessively low. If the potential of needles 42 is too high, control of the charge upon terminal electrode 3 is lost or spark over occurs between needles 42 and tank 1; if the voltage upon needles 42 is too low, spark over between needles 42 and electrode 3 occurs. Therefore, if the average voltage of high voltage supply 41 is maintained within proper limits, control of the voltage of terminal electrode 3 may be realized. Consequently, the signal derived from the molecular H_2 ion beam and fed into controllable high voltage supply 41 may be employed as described to decrease the output of supply 41 when the voltage of terminal electrode increases and to in-

crease the output of voltage supply 41 when the voltage of terminal electrode 3 decreases. With this negative feedback arrangement, a measure of control of the terminal electrode voltage of the electrostatic generator may be obtained.

From experience, however, it has been found that, if the signal from amplifier 38 alone is employed, a ripple voltage appears upon terminal electrode 3. This is apparently due to the time constant of the transit of negative O₂ ions from needles 42 to terminal electrode 3. This transit time will depend upon the spacing between needles 42 and terminal electrode 3 and upon the pressure within airtight tank 1. For a particular generator designed to operate at 3.5 m. e. v., this transit time has been found to be approximately 7 milliseconds at a pressure of 150 pounds per sq. in. gauge in either nitrogen or air. Sufficient O₂ molecules are always present, due to gas occlusion in the walls of the tank 1, etc., to serve as absorbers of all of the electrons produced at points 42 and, hence, the negative O₂ ions are the actual charge carriers rather than electrons themselves. The approximately 7 millisecond lag in charge transference, together with the time constants of circuit elements, results in a ripple frequency in the voltage of terminal electrode 3 of about 10 to 70 cycles per second. In addition to the time required for charge transference, there is a delay encountered in the transit time of the ions along accelerating tube 11, such time being of the order of 1 microsecond.

Since amplifier 38 must, of necessity, be a direct current amplifier in order to amplify the current generated by molecular H₂ ions striking collector plates 27 and 28, it is not practicable to compensate for this ripple frequency in the above-described feedback loop; because, if at the ripple frequency the gain of this loop is increased sufficiently to compensate for the ripple voltage, instability due to the long time delay will result. According to the present invention, this difficulty is overcome by providing a second feedback loop responsive to voltage variations of terminal electrode 3 whereby a composite signal may be obtained for controlling the potential of corona leak electrode 30. This second feedback loop comprises a capacitive means 45, an alternating current amplifier 46, and a phase shifter 47. As illustrated in the more detailed view of Fig. 2, capacitive means 45 comprises a capacitor plate 48 supported with its inner surface essentially parallel to the inner surface of tank 1 by means of a stud 49, an insulator 50, a base 51 and an extension 51' of tank 1. The whole assembly may be retained in airtight relationship against extension 51 by means of bolts 52, nuts 53 and rubber gasket 54. Insulator 50 comprises a hollow outer sleeve 55 and an inner hollow portion 56, through both of which extends stud 49 as shown. An airtight relationship is maintained here by means of rubber gaskets 57, clamp 58, washer 59 and nuts 60. It will be apparent that the relative position of capacitor 48 with respect to the inner surface of tank 1 may be adjusted by means of stud 49 and nuts 60.

It will now be observed that the capacitance from terminal electrode 3 to capacitor plate 48 in series with the capacitance from plate 48 to tank 1 and the capacitance of a coaxial input lead 61 interconnecting stud 49 and the input to amplifier 46 will form a capacitance voltage divider. From this divider, a proportion of the voltage changes of terminal electrode 3 are fed back through amplifier 46, phase shifter 47 and

mixer 39 to the input of high voltage supply 41, such a signal being limited only by the finite speed of light and not by the transit time of charge transference between capacitance plate 48 and terminal electrode 3. Phase shifter 47, which may be of the common resistance-capacitance type well known to those skilled in the art, is employed to advance the signal derived from capacitance plate 48 to compensate for the transit time of the negative O₂ ions between needles 42 and terminal electrode 3, thus enabling the gain of alternating current amplifier 46 to be increased considerably without the incurrence of instability in the circuit. Mixer 39, which may be of the well known resistance type, is employed to mix the signals from amplifier 38 and phase shifter 47, whereby a composite signal may be transmitted to high voltage supply 41. By varying the amount of signal fed in from phase shifter 47 to mixer 39, an optimum regulatory composite signal may be obtained to give regulation within ± 1 kilovolt at 2.5 million volts.

The composite signal transmitted to high-voltage supply 41 in the manner hereinbefore described provides very good regulation for both short and long time intervals. However, it may be that after a sustained period of operation the average voltage of high voltage supply 41 may fall without the hereinbefore described range required by needles 42. Hence, an integrating circuit 62 may be connected between the output of high voltage supply 41 and high voltage supply 9 for the purpose of altering the charge supplied to belt 2 thereby to compensate for long period variations of the voltage upon terminal electrode 3 which result in the average voltage of needles 42 falling without the control range.

It will be understood by those skilled in the art that controllable high voltage supplies 9 and 41 may be of a conventional type such as those referred to in an article appearing in the proceedings of the I. R. E., volume 37, No. 2, page 199 (February 1949). Suitable circuits for direct current amplifier 38 and alternating current amplifier 46 may be found in the voluminous literature describing such amplifiers.

In addition to the advantages of the invention mentioned hereinbefore, it will be noted that the signal derived from capacitance plate 48 does not depend upon the existence of an ion beam within accelerating tube 11; hence, this signal may be employed to regulate the potential upon terminal electrode 3, as above described, even though an ion beam is not being accelerated and the generator is employed to energize a dissipative load in a manner well known to those skilled in the art.

While the invention has been described by reference to particular embodiments thereof, it will be understood that numerous changes may be made by those skilled in the art without actually departing from the invention. I, therefore, aim in the appended claims to cover all such equivalent variations as fall within the true spirit and scope of the foregoing disclosure.

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

1. The system of controlling the terminal voltage of an electrostatic generator having a charge collecting electrode, means for transporting electrical charge to said electrode, and a corona leak electrode for varying the charge leakage from said collecting electrode, said system comprising

voltage supplying means having an output variable in response to an input signal for supplying voltage to said corona leak electrode, means responsive to variations in the voltage of said collecting electrode for deriving a signal substantially instantaneously responsive to variations of said collecting electrode voltage, and a feedback loop interconnecting the input of said variable output voltage supplying means and said last mentioned means whereby the potential of said corona leak electrode may be substantially instantaneously varied to control the charge leakage from and hence the voltage of said collecting electrode.

2. The system of controlling the terminal voltage of an electrostatic generator having a terminal electrode, means for transporting electrical charge to said electrode, and a corona leak electrode for varying the charge leakage from said terminal electrode, said system comprising voltage supplying means having an output variable in response to an input signal for supplying voltage to said corona leak electrode, means responsive to variations in the voltage of said terminal electrode for deriving a signal substantially instantaneously responsive to variations of said terminal electrode voltage, phase shifting means for advancing the phase of said signal derived from said terminal electrode voltage, and a feedback loop interconnecting said phase shifting means and the input of said variable output voltage supplying means whereby the potential of said corona leak electrode may be substantially instantaneously varied to control the charge leakage from and hence the voltage of said terminal electrode.

3. The system of controlling the terminal voltage of an electrostatic ion accelerator having a terminal electrode, means for transporting electrical charge to said electrode to build up a high terminal voltage, means for generating and accelerating ions in a beam to a high energy with said terminal voltage, and a corona leak electrode for varying the charge leakage from said terminal electrode, said system comprising voltage supplying means having an output variable in response to an input signal for supplying voltage to said corona leak electrode, means for deriving a signal from said ion beam responsive to changes in the voltage of said terminal electrode, capacitive means responsive to variations in the voltage of said terminal electrode for deriving a signal substantially instantaneously responsive to variations of said terminal electrode voltage, means for mixing said signals derived from said ion beam and said capacitive means to obtain a composite signal, and a feedback loop interconnecting said mixing means and the input of said variable output voltage supplying means whereby the potential of said corona leak electrode may be varied in response to said composite signal to control the charge leakage from and hence the voltage of said terminal electrode.

4. The system of controlling the terminal voltage of an electrostatic ion accelerator having a terminal electrode, means for transporting electrical charge to said electrode to build up a high terminal voltage, means for generating and accelerating ions in a beam to a high energy with said terminal voltage, and a corona leak electrode for varying the charge leakage from said terminal electrode, said system comprising voltage supplying means having an output variable in response to an input signal for supplying volt-

age to said corona leak electrode, means for deriving a signal from said ion beam responsive to changes in the voltage of said terminal electrode, capacitive means responsive to variations in the voltage of said terminal electrode for deriving a signal substantially instantaneously responsive to variations of said terminal electrode voltage, phase shifting means in circuit with said capacitive means for advancing the phase of said signal derived from said capacitive means, means for mixing said signals derived from said ion beam and said capacitive means to obtain a composite signal, and a feedback loop interconnecting said mixing means and the input of said variable output voltage supplying means whereby the potential of said corona leak electrode may be varied in response to said composite signal to control the charge leakage from and hence the voltage of said terminal electrode.

5. The system of controlling the terminal voltage of an electrostatic ion accelerator having a terminal electrode, a moving charge carrier and variable charge supplying means for spraying charge upon said carrier for transportation to said electrode to build up a high terminal voltage, means for generating and accelerating ions in a beam to a high energy with said terminal voltage, and a corona leak electrode for varying the charge leakage from said electrode, said system comprising voltage supplying means having an output variable in response to an input signal for supplying voltage to said corona leak electrode, means for deriving a signal from said ion beam responsive to changes in the voltage of said terminal electrode, capacitive means responsive to variations of said terminal electrode for deriving a signal substantially instantaneously responsive to variations of said terminal electrode voltage, phase shifting means in circuit with said capacitive means for advancing the phase of said signal derived from said capacitive means, means for mixing said signals derived from said ion beam and said capacitive means to obtain a composite signal, a feedback loop interconnecting said mixing means and the input of said variable output voltage supplying means whereby the potential of said corona leak electrode may be varied in response to said composite signal to control the charge leakage from and hence the voltage of said terminal electrode, and means including an integrating circuit interconnecting said variable charge supplying means and said variable output voltage supplying means for maintaining the average potential of said corona leak electrode within desired control limits.

6. Electrostatic generator apparatus comprising a terminal electrode, means for transporting electrical charge to said electrode to build up a high terminal voltage, an airtight conductive tank enclosing said terminal electrode and said charge transporting means, a corona leak electrode disposed within said tank, variable voltage supplying means connected to said corona leak electrode for varying the charge leakage from said terminal electrode, a capacitance voltage divider including a capacitance plate disposed within said tank in opposed relation to said terminal electrode for deriving a signal substantially instantaneously responsive to variations in the voltage of said terminal electrode, and means for feeding said signal back to said variable voltage supplying means whereby the potential of said corona leak electrode may be substantially instantaneously varied to control the charge leak-

age from and hence the voltage of said terminal electrode.

7. Electrostatic generator apparatus comprising a charge collecting electrode, means for transporting electrical charge to said electrode, a corona leak electrode for varying the charge leakage from said collecting electrode, voltage supplying means having an output variable in response to an input signal for supplying voltage to said corona leak electrode, means including a capacitor plate positioned within the electric field of said charge collecting electrode for deriving a signal substantially instantaneously responsive to variations of said collecting electrode voltage, and a feedback circuit interconnecting the input of said variable output voltage supplying means and said last mentioned means whereby the potential of said corona leak electrode may be substantially instantaneously varied to control the charge leakage from and hence the voltage of said collecting electrode.

8. Electrostatic generator apparatus comprising a terminal electrode, means for transporting electrical charge to said electrode, a corona leak electrode for varying the charge leakage from said terminal electrode, voltage supplying means having an output variable in response to an input signal for supplying voltage to said corona leak electrode, means including a capacitor having at least one plate located in the electric field of said terminal electrode for deriving a signal substantially instantaneously responsive to variations of said terminal electrode voltage, phase shifting means for advancing the phase of said signal derived from said terminal electrode, and a feedback circuit interconnecting said phase shifting means and the input of said variable output voltage supplying means whereby the potential of said corona leak electrode may be substantially instantaneously varied to control the charge leakage from and hence the voltage of said terminal electrode.

9. Electrostatic ion accelerator apparatus comprising a terminal electrode, means for transporting electrical charge to said electrode to build up a high terminal voltage, means for generating and accelerating ions in a beam to a high energy with said terminal voltage, a corona leak electrode for varying the charge leakage from said terminal electrode, voltage supplying means having an output variable in response to an input signal for supplying voltage to said corona leak electrode, means for deriving a signal from said ion beam responsive to changes in the voltage of said terminal electrode, means including a capacitor having at least one plate located within the electric field of said terminal electrode for deriving a signal substantially instantaneously responsive to variations of said terminal electrode voltage, means for mixing said signals derived from said ion beam and said last mentioned means to obtain a composite signal, and a feedback circuit interconnecting said mixing means and the input of said variable output voltage supplying means whereby the potential of said corona leak electrode may be varied in response to said composite signal to control the charge leakage from and hence the voltage of said terminal electrode.

10. Electrostatic ion accelerator apparatus comprising a terminal electrode, means for transporting electrical charge to said electrode to build up a high terminal voltage, means for

generating and accelerating ions in a beam to a high energy with said terminal voltage, a corona leak electrode for varying the charge leakage from said terminal electrode, voltage supplying means having an output variable in response to an input signal for supplying voltage to said corona leak electrode, means for deriving a signal from said ion beam responsive to changes in the voltage of said terminal electrode, means including a capacitor having at least one plate located within the electric field of said terminal electrode for deriving a signal substantially instantaneously responsive to variations of said terminal electrode voltage, phase shifting means in circuit with said means including said capacitor for advancing the phase of said signal derived from said last mentioned means, means for mixing said signals derived from said ion beam and said means including said capacitor to obtain a composite signal, and a feedback circuit interconnecting said mixing means and the input of said variable output voltage supplying means whereby the potential of said corona leak electrode may be varied in response to said composite signal to control the charge leakage from and hence the voltage of said terminal electrode.

11. Electrostatic ion accelerator apparatus comprising a terminal electrode, a moving charge carrier and variable charge supplying means for spraying charge upon said carrier for transportation to said electrode to build up a high terminal voltage, means for generating and accelerating ions in a beam to a high energy with said terminal voltage, a corona leak electrode for varying the charge leakage from said electrode, voltage supplying means having an output variable in response to an input signal for supplying voltage to said corona leak electrode, means for deriving a signal from said ion beam responsive to changes in the voltage of said terminal electrode, means including a capacitor having at least one plate located within the electric field of said terminal electrode for deriving a signal substantially instantaneously responsive to variations of said terminal electrode voltage, phase shifting means in circuit with said means including said capacitor for advancing the phase of said signal derived from said last mentioned means, means for mixing said signals derived from said ion beam and said means including said capacitor to obtain a composite signal, a feedback circuit interconnecting said mixing means and the input of said variable output voltage supplying means whereby the potential of said corona leak electrode may be varied in response to said composite signal to control the charge leakage from and hence the voltage of said terminal electrode, and means including an integrating circuit interconnecting said variable charge supplying means and said variable output voltage supplying means for maintaining the average potential of said corona leak electrode within desired control limits.

HENRY W. BOUSMAN.

REFERENCES CITED

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

- "Generating Voltmeter for Pressure-Insulated High Voltage Sources" by Trump et al., pp. 54-56 of *Review of Scientific Instruments*, vol. 11, No. 2, February, 1940.