Dec. 18, 1951 C. M. TURNER 2,578,908

ELECTROSTATIC GENERATOR

Filed May 26, 1947 4 Sheets-Sheet 1

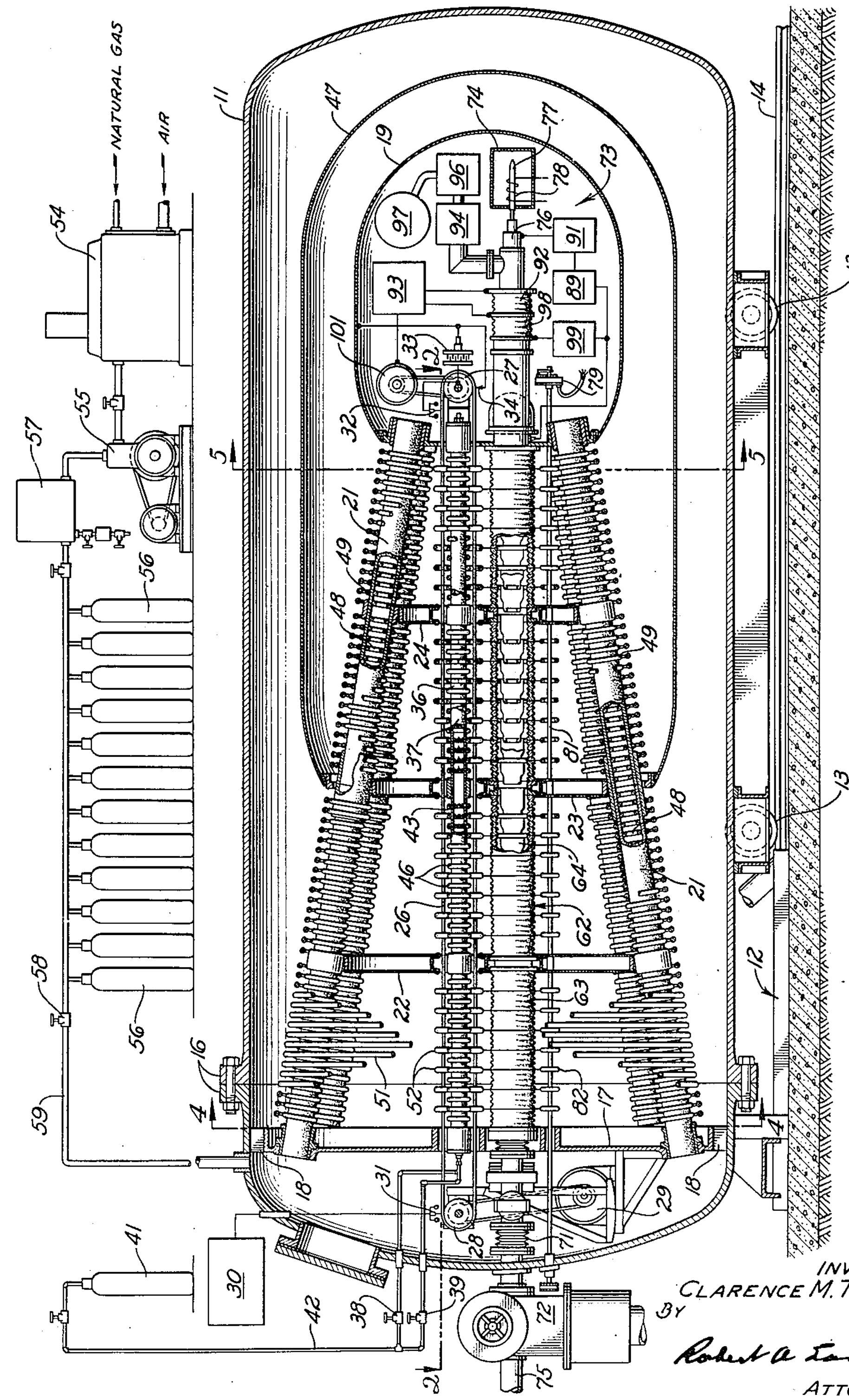

Fig. 1

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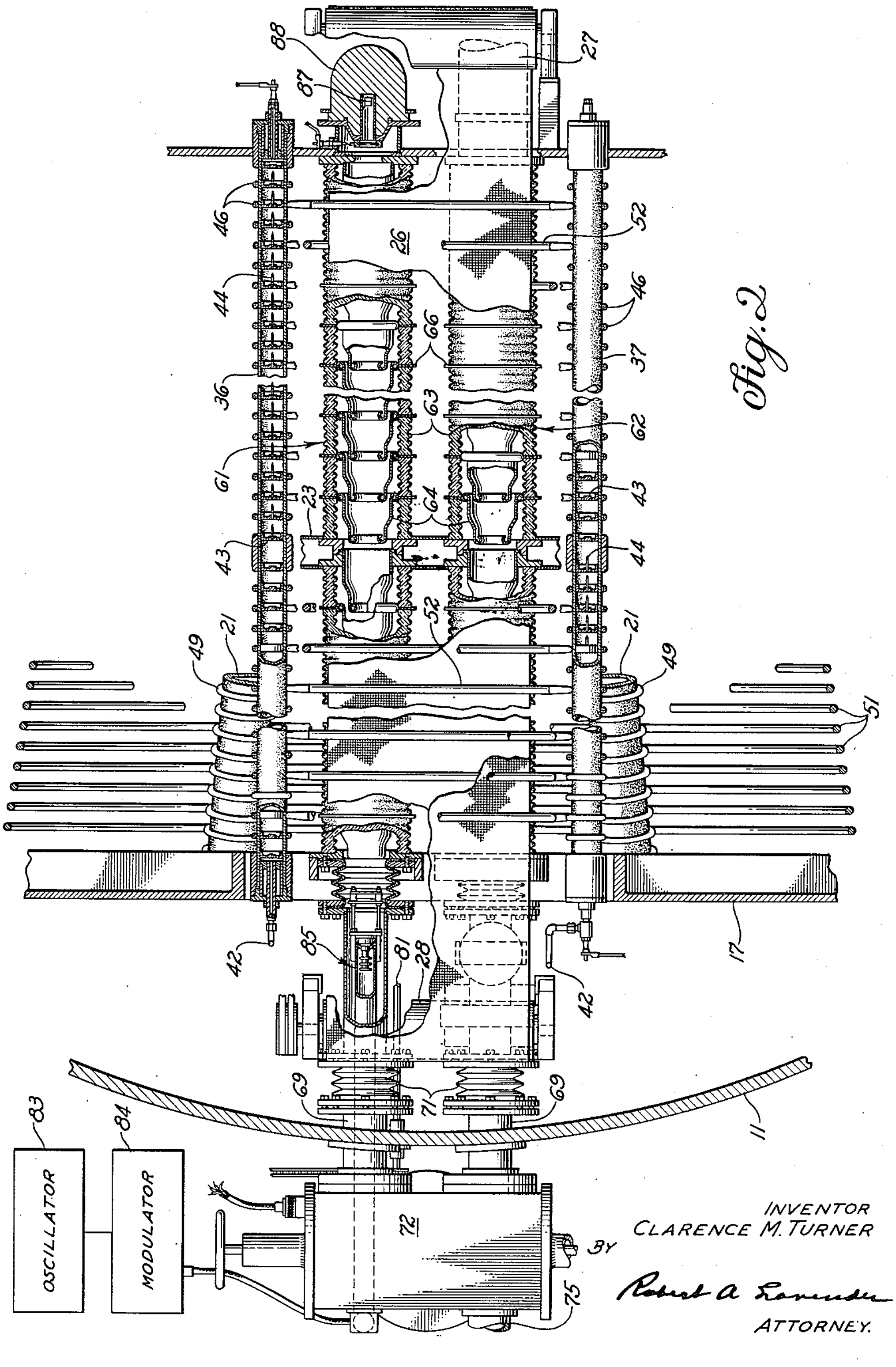

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4 Sheets-Sheet 3

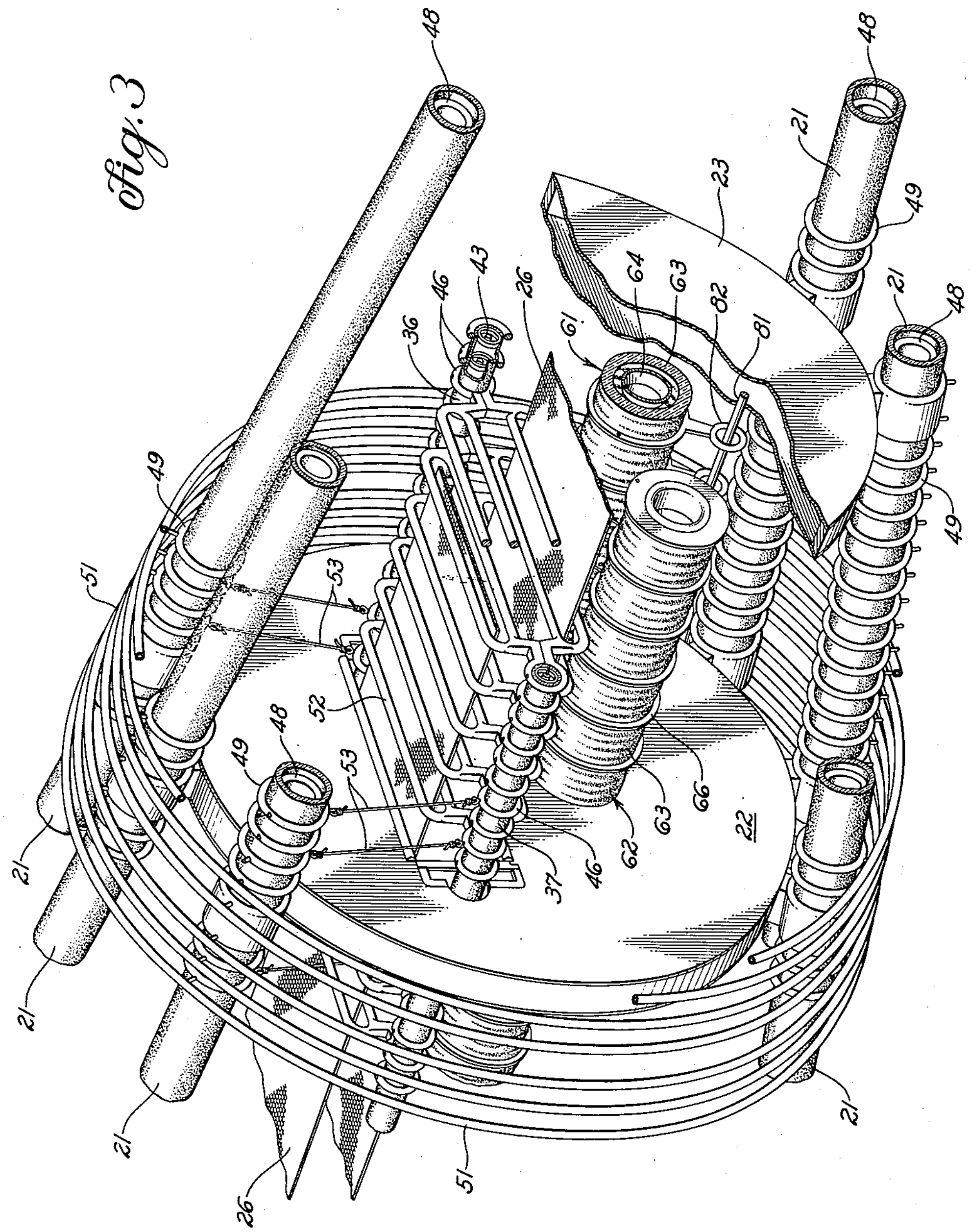

Fig. 3

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Fig. 4

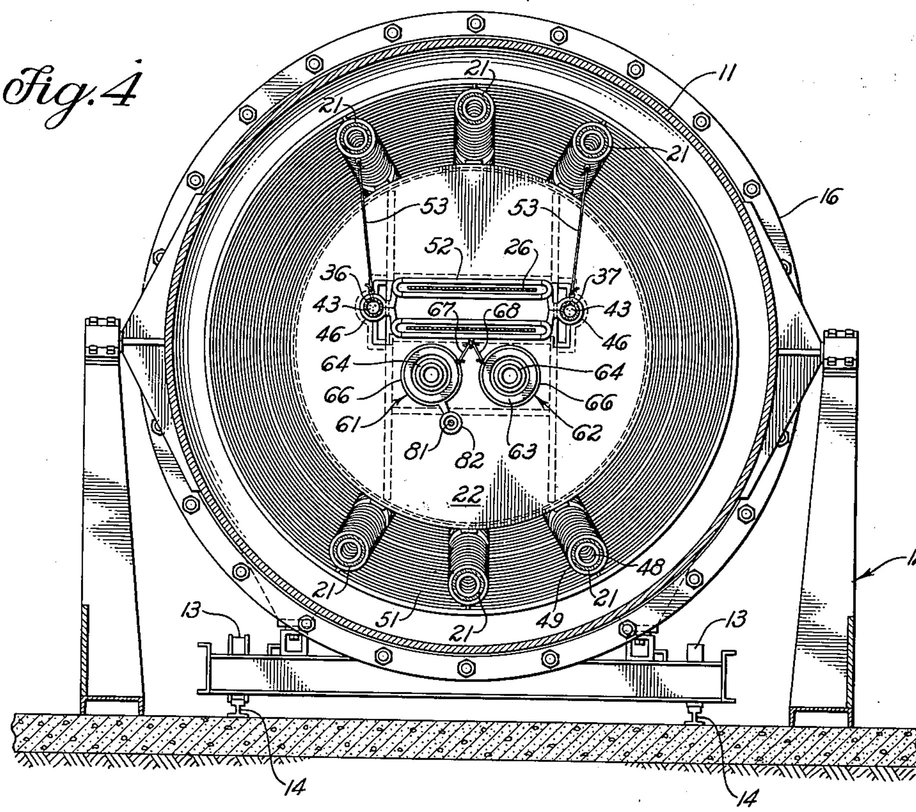
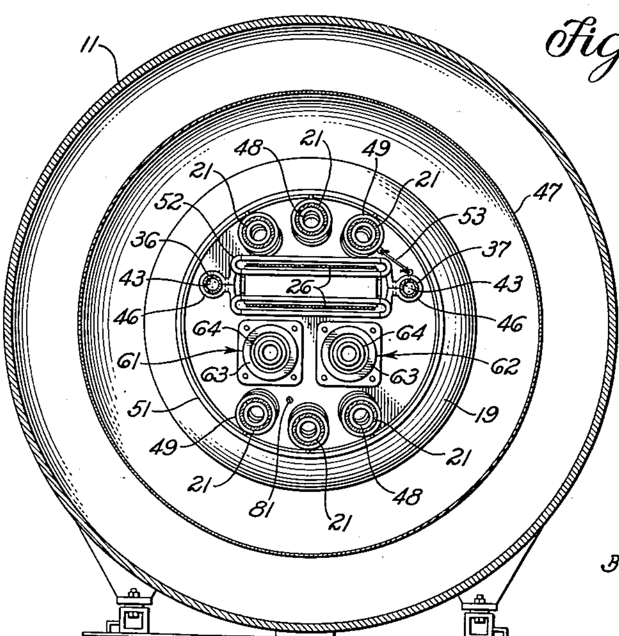


Fig. 5



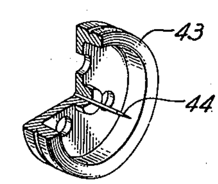


Fig. 6

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ELECTROSTATIC GENERATOR

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Application May 26, 1947, Serial No. 750,465

20 Claims. (Cl. 315—5)

The following invention relates to apparatus for the acceleration of ions and more particularly to an improvement in Van de Graaff machines for the acceleration of protons or the like.

Ions moving at high velocities have become increasingly useful in the study of nuclear physics and in medical research. Several devices for accelerating particles to extremely high energies have been developed including, for example, the cyclotron as set forth in U. S. Patent 1,948,384, Lawrence, and the linear accelerator disclosed by R. Wilderoe, Archives fur Elektrot 21,387, (1929).

These and other devices have, in general, supplanted the Van de Graaff machine since far greater energies have been made possible by the principle of repeated accelerations through a relatively small accelerating field.

However, at least one such device, namely, the linear accelerator, is effective in operation only when the particles or ions to be accelerated are already formed into a beam and possess energies preferably of at least a few million electron volts.

To this end as well as for general research, particularly in medical fields where a beam of relatively low intensity is frequently desired, the Van de Graaff machine, as modified by my invention, provides a relatively simple and reliable machine, capable of producing an effectively large ion beam.

At the outset it should be noted that the Van de Graaff machine is an electrostatic ion accelerator which unlike other devices, such as the cyclotron or the linear accelerator, does not utilize the repeated acceleration of a charged particle through a relatively small potential difference to give the particle its final high energy. In this machine the full potential is actually developed by electrostatic means and the particles are accelerated in one application of the accelerating field.

The Van de Graaff machine is characterized by the use of a flexible belt of insulating material which conveys a static charge placed thereon to an insulated high voltage electrode, usually of spheroidal configuration, where the charge is removed and accumulated on the outer surface. The potential of the electrode is thus raised, with respect to ground, to a value which is limited principally by the tendency for ionization and attendant flashover to occur, either along the charging belt, the electrode support members, or directly to ground through the surrounding atmosphere.

This maximum potential to which the electrode may be charged without flashover has been extended in several recent modifications of the early designs, perhaps the most notable being an arrangement of rings and corona gaps to divide the total potential difference into many small increments. In this manner an approach has been made toward a uniform potential gradient.

Further flashover prevention has been obtained by housing the machine in a pressurized tank containing compressed air, nitrogen or some other gas or gaseous mixture having suitable dielectric characteristics.

In machines equipped with such pressurized housings it has been found advantageous to surround the high voltage electrode with one or more spaced concentric shells at intermediate potentials since it has been demonstrated that a greater potential gradient may exist without breakdown over a short gap than over a long one. Further, with cylindrical geometry the electrical field is divergent from the surface of the charged electrode with the result that a nonuniform gradient is produced. Intermediate electrodes maintained at opportune potentials provide a more uniform field gradient across the air gap.

The addition of such intermediate shells imposes the problem of voltage distribution between adjacent shells which may be greatly different from that expected because of corona discharges and leakage due to the extremely high potentials dealt with. In prior designs relatively crude mechanical means for adjusting the gap spacings of the system of corona gaps have been employed with more or less unsatisfactory results.

Ions which are to be accelerated by the electric field associated with the charged electrode are produced by one of the numerous ion sources which have been developed.

In a typical source unit for the production of protons, gaseous hydrogen is admitted to a chamber containing both a heated filament, and an arc discharge, where ionization occurs. The hydrogen ions or protons, as they are properly called, are withdrawn from the ionization chamber and directed through collimating holes into the accelerating tube by charged electrodes.

In ion sources of present design it is impossible to achieve complete ionization of the source material and a residue of nonionized vapor escapes to the evacuated accelerating tube. Deleterious effects from the reduced vacuum within the accelerating tube include partial loss of the main beam of ions due to scattering as the result of collisions between ions and nonionized particles, and the production of X-ray radiation caused by the collision of electrons of secondary emission with the accelerating tube electrodes.

Further limitations of Van de Graaff generators have been found in the size and energy of the beam which is produced. Because of the electrostatic means of charging the electrode, only a limited continuous beam of ions may be accelerated without exceeding the capacity of the charging system to maintain a high accelerating potential.

It is therefore an object of the invention to provide an improved apparatus for accelerating ions in a beam.

It is a further object of the invention to provide improved electrostatic means for the acceleration of ions to extremely high velocities.

It is another object of this invention to provide a means and method for producing a pulsed, discontinuous, beam of ions which is effectively larger than ion beams previously produced.

Another object of this invention is to provide a means for bunching the ions in the beam into alternate spaces of dense and sparse ionic density.

Another object of this invention is to provide means for bunching the ions in the beam so as to provide a beam of greater instantaneous concentration.

Another object of the invention is to provide an apparatus for modulating a beam of accelerated ions to produce a pulsed beam of increased effective size composed of ions bunched or grouped regularly into zones of dense configuration interspaced with zones of sparse configuration.

Another object of this invention is to provide a means for changing the velocity of a given portion of the ions in a beam with respect to others and to thereby bunch the ions in the beam into successive groups or bunches interspaced with intervals relatively devoid of ions.

Another object of the invention is to provide an improved means and method of adjusting the potential of the intermediate electrode of an accelerator of the character described.

Still another object of the invention is to provide a means for electrically and remotely adjusting the potential gradient between the high voltage electrode and the intermediate electrode, and the potential gradient between the intermediate electrode and the outer housing so that they may be made equal to one another.

It is a further object of this invention to provide an improved arrangement for evacuating the ion accelerating tube.

Another object of the invention is to provide an apparatus for withdrawing nonionized vapor from the vicinity of the ion source.

Still another object of the invention is to provide a means for reducing the scattering of ions in a beam due to collision with gas molecules.

Still another object of the invention is to provide a means for reducing the X-ray radiation produced in the accelerating system of an ion accelerator by electron bombardment of the accelerating tube liners and the ion source.

Additional objects, together with some of the advantages to be derived in utilizing the methods and apparatus of the present invention, will become apparent in the following specification and drawings of a Van de Graaff machine illustrating and describing various preferred embodiments of the invention adapted to the requirements of a linear accelerator for the further acceleration of protons. In the drawings like numerals are used throughout to designate like parts.

Figure 1 is a full sectional view of the assembled machine showing the general arrangement of the components and their relation to one another;

Fig. 2 is a longitudinal section of the cantilever span taken along the line 2—2 of Fig. 1 and showing the accelerating tubes and the potential dividing elements;

Fig. 3 is an oblique sectional view of a portion of the cantilever span showing to advantage, the corona rings and charging belt;

Fig. 4 is a right sectional view of the low potential end of the assembly, taken along line 4—4 of Fig. 1;

Fig. 5 is a right sectional view of the structure showing the high voltage end and taken along line 5—5 of Fig. 1; and

Fig. 6 is a perspective view of one of the corona gap members, with a portion broken away for clarity of disclosure.

Referring now in detail to the drawings it will be seen that there is shown in Fig. 1 a hollow cylindrical tank 11 with axis horizontally oriented, being supported in part by a pedestal or base member 12 and in part by wheels or rollers 13 resting on a track 14. Tank 11 is composed of two portions removably secured to each other at a flanged seam 16 which is sealed by a gasket, not illustrated, to form a pressure-tight closed vessel.

Within the fixed portion of the tank 11 a vertical face plate 17 is removably attached to structural brackets 18 which are welded to the interior of the tank. The vertical face plate 17 is a structural support member to which are affixed the principal elements of the interior structure. These elements are related and are in some instances of dual utility, but in the interest of clarity it is deemed best to divide them into three groups to be considered individually before attempting to portray the over-all operation.

Consider first the group of elements which provide the high potential reached in the machine. Reference is again made to Fig. 1.

The high voltage electrode 19 is a hollow metal surface of revolution supported from the face plate 17 by cantilever structure members 21 composed of Textolite tubing or the like. Shown encircling these support members are numerous rings 48, 49, both internally and externally placed and comprising part of a system for the uniform distribution of potential along the spans, as will be described hereinafter.

To stiffen and further brace the cantilever structure 21, transverse diaphragms 22, 23, and 24 are interposed between the main members. See also Fig. 3, which illustrates the cantilever structure more clearly.

A charging belt 26 Fig. 1, composed of insulating material such as cotton canvas or the like, passes through openings in the base of the high voltage electrode 19, and through further openings in the stiffening diaphragms 22—24 and the face plate 17, said belt being supported by wide pulleys 27 and 28. Pulley 27 is located within the high voltage electrode while pulley 28 is adjustably secured to the distal side of the face plate 17 to provide a convenient means for obtaining the proper tension in the belt. An electric motor 29 of suitable rating provides motive power to the charging belt.

A moderately high positive potential, of the order of fifty kilovolts, as provided by a high voltage rectifier 30, is applied to a row of needle points 31, suitably supported in a transverse line with respect to the direction of belt travel and closely spaced above the belt surface. Due to corona discharge from the row of needle points 31 toward the pulley 28 a static charge is sprayed onto the intervening belt surface as it travels from left to right as shown in Fig. 1. The static charge is thus conveyed to the interior of the high voltage electrode 19 where the belt passes beneath a second row of needle points 32 located adjacent to the incoming belt surface and connected to the pulley 27. Pulley 27, which is insulated electrically from the high voltage electrode, is positively charged by this arrangement, and a corona discharge takes place across the adjustable gap 33 to the high voltage electrode which also becomes charged but always to a lower potential than that of the pulley by the amount of the voltage drop across the gap 33.

It should be noted that the charge on the belt passes freely to the pulley 27 by way of the needle points 32 irrespective of the potential which is attained by the outer surface of the high voltage electrode. An increment of belt material upon entering the hollow electrode passes into a field-free space and hence the belt by virtue of its charge is at a positive potential with respect to the inner surface of the electrode. If now the charge on the belt is of sufficient magnitude a corona discharge is sustained from the belt to needle points 32 and across the adjustable gap 33 to the electrode.

Since the belt pulley 27 is always maintained at a more positive potential than that of the high voltage electrode 19, negative charge is sprayed onto the charging belt as it leaves the electrode by means of a third row of needle points 34 which is connected to the gap 33 and also to the electrode 19. Thus, the effective capacity of the belt to charge the electrode is greatly increased since positive charge is carried to the high voltage electrode and negative charge removed.

Adjustment of the gap 33 provides a convenient means of altering the aforementioned potential difference between the belt pulley and the electrode and therefore provides a means for adjusting the rate at which the belt charges the high voltage electrode.

Having developed a potential at the surface of the high voltage electrode, the elements necessary to prevent unequal potential distribution and to inhibit flashover due to ionization will be described.

Consider the plane of the stiffener or diaphragm 23 which is approximately midway between the high voltage electrode 19 and the grounded face plate 17. Assuming a uniform potential gradient this plane will be at midvoltage; there being approximately equal increments of the total voltage in either direction from this point.

To obtain such an approximately uniform potential gradient, two small tubes, 36 and 37 of Textolite or the like are interposed, extending from the face plate to the high voltage electrode, in a position adjacent and parallel to the edges of the charging belt as shown clearly in the sectional view Fig. 2. These tubes are sealed at the high voltage ends and connected by separately adjustable pressure regulating valves 38 and 39 respectively to a reservoir 41 of compressed nitrogen gas admitted through piping 42, as best shown in Fig. 1. Within tubes 36 and 37 at close regular intervals, are located perforated metal disks 43 substantially as shown in the perspective view Fig. 6.

Along the span between the high voltage electrode and the aforementioned central diaphragm 23 the metal disks within tube 36 are provided with needle electrodes 44 as illustrated in Figs. 2 and 6 while the disks within tube 37 are not so equipped. However, in the other interval, between the central diaphragm 23 and the face plate 17, disks within tube 37 are provided with needle electrodes and such are omitted in tube 36, as shown in Fig. 2. The needle points, where present, are directed toward the high voltage electrode and are opposed by the plane surfaces of the next adjacent disk members, there remaining small gaps between the points of the needles and the planar surfaces.

In the plane of each of the aforesaid disks is a smooth metal ring 46 which encircles the outer surface of the tube and is electrically connected through the walls of the tube to the corresponding disk member.

When a high potential has been reached, a corona discharge takes place between the needle points and the disks within the tubes 36 and 37 which results in a flow of current from the high voltage electrode through tube 36 to the central diaphragm 23, across said diaphragm to tube 37 and thence through the tube 37 to the face plate and to ground. In this manner increments of potential drop are incurred across each of the corona gaps which appear between the external spaced rings 46 as a series of potential steps or increments of equal size, within the limit of accuracy of the spacing of the corona gaps.

By differential adjustment of pressure regulating valves 38 and 39 the corona discharge characteristics and hence the current in the two portions of the span may be altered to effect an adjustment of the potential at the midpoint which is of importance in adjusting the potential of an intermediate shell 47 supported by the cantilever span at the plane of the aforesaid central diaphragm 23.

The intermediate shell 47 is a metallic surface of revolution, concentric with the high voltage electrode and so placed as to divide the space between the high voltage electrode and the tank into approximately equal intervals. The potential of the intermediate shell is easily adjusted as outlined above to provide equal increments of potential from the shell to the tank and from the shell to the high voltage electrode. The utility of this arrangement is based on the demonstrable principle that greater potential gradients may be withstood over the shorter spaces between the shell and ground and between the shell and the high voltage electrode than over the longer space from the high voltage electrode to ground. Further, the intermediate electrode provides a more uniform field gradient across the air gap which otherwise tends to be nonuniform because of the divergence of the field lines.

Having obtained a series of points along the total potential difference which are equally spaced in distance and in potential it is logical now to employ them to the equalization of the potential gradients along other surfaces where flashover is likely to occur. To this end, rings of metal as best shown in Fig. 3 are provided at similarly spaced intervals along the interior and exterior surfaces of the cantilever structure members as shown at reference numerals 48 and 49. Inner and outer rings 48 and 49 respectively are electrically joined by mounting fasteners passing through the walls of the tubes, and the corresponding pairs of rings thus formed are connected together by large hoops 51 which encircle the entire cantilever structure.

The planes defined by the large hoops 51 are planes of constant potential, being normal to the direction of the change in potential. Outer rings 49 are connected by wires 53 shown in Fig. 3 to each of the corresponding rings 46 which encircle the corona gaps within tubes 36 and 37, insuring, in this manner, that the planes of constant potential thus bounded are along a field of uniform potential gradient.

Returning to the two small tubes 36 and 37 it will be seen in Fig. 2 and to further advantage in Fig. 3 or 4 that alternate corresponding ring members 46 on the two tubes are joined by belt shield members 52 which encircle the upper and lower spans of the charging belt 26 and provide uniform potential gradient along the same.

By the foregoing arrangement of gaps, rings and shells the potential which has been developed by the charging system is distributed uniformly along components of the cantilever structure and between the high voltage electrode and the walls of the tank.

Still further aid in suppressing ionization is procured by filling the tank 11 with the products of combustion of natural gas with air. The apparatus for effecting this is shown diagrammatically in the upper portion of Fig. 1. Natural gas and air are burned within a suitable combustion unit 54 and the exhaust gases which consist principally of carbon dioxide, nitrogen, and water vapor are forced by a compressor unit 55 into pressure cylinders 56, first passing through a cooling unit 57 in which most of the water vapor is removed by condensation. The remaining inert gas mixture is admitted to the main tank 11 through pressure reducing valve 58 and pipe 59. The pressure within the tank 11 is regulated to values of the order of 200 pounds per square inch or less which is deemed sufficient to insure freedom from flashover at potentials of well over four million volts.

Before considering the remaining elements comprising the ion accelerating system and related equipment, it should be recalled that the subject invention is specifically adapted to the requirements of a linear accelerator. In the recent design of linear accelerators a pulsed radio frequency field is employed to accelerate protons in a discontinuous beam. By this arrangement, a distinctly greater instantaneous accelerating field may be obtained from an oscillator of comparatively small average power capabilities.

By a similar arrangement a greater proton beam may be produced momentarily by a Van de Graaff machine by pulsing the ion source in synchronism with the ion demand of the linear accelerator with which it is associated. Such an increased beam would, if continuously produced, lower the accelerating potential of the high voltage electrode to such an extent as to render the device ineffective. However, by pulsing the ion source for short intervals, interspaced with longer intervals for recovery, a high potential is maintained and an effectively large beam is obtained.

Further, by bunching the ions in the beam into groups of relatively dense configuration alternated with zones of relatively sparse configuration, so arranged as to arrive in direct phase relationship with the high frequency accelerating field of the associated linear accelerator, a considerable increase in effective beam size is effected.

Returning now to the drawings with the foregoing schemes in mind, we find in Fig. 2 an electron accelerating tube 61 and an ion accelerating tube 62 of identical construction disposed in parallel fashion between the vertical face plate 17 and the high voltage electrode 19.

The accelerating tubes are composed of numerous corrugated ceramic sections 63 interspaced with a like number of re-entrant metal liners 64 formed substantially as shown sectionally both in Fig. 1 and Fig. 2. Each of the liners is provided with a flanged portion 66 which extends beyond the ceramic section and is connected electrically to a coplanar member of the system of potential points as shown clearly at reference numerals 67 and 68, Fig. 4.

The purpose of the liners is to prevent damage to the ceramic sections due to corona discharge and to provide a focusing effect of accelerating field upon accelerated particles. The accelerating tubes are extended by suitable piping 69 and flexible sections 71, Fig. 2, to a vacuum manifold 72 which communicates with appropriate pumping equipment for maintaining a vacuum of the order 10^{-5} mm. of mercury of less. The ion beam emerges from the system through a suitable aperture 75 in the wall of the vacuum manifold.

A conventional ion source 73 of the filament-arc type is employed. The source comprises a charge reservoir 74 communicating with an ionization chamber 76. A palladium regulator tube 77 and a heating element 78 provide control over the passage of the charge, which is hydrogen gas, from the charge reservoir to the ionization chamber. The palladium tube, which is increasingly permeable to hydrogen with increased temperature, provides a suitable controlling device; the temperature being adjusted by controlling the electric current passing through the heater element by means of a multiple position switch 79. Switch 79 is operated from outside the housing 11 by means of a long extension shaft 81 composed of Textolite tubing or a similar substance. Potential dividing rings 82 are distributed along the length of the extension shaft and are connected to commensurable potential points of accelerating tube 61 (Fig. 3) to provide flashover protection.

Referring now to Fig. 2. Pulsed radio frequency energy from a suitable oscillator 83 or from the particular oscillator which supplies the field for a linear accelerator is impressed by a conventional modulator stage 84 upon the control electrode of an electron gun 85 located in the electron accelerating tube 61. A beam of electrons modulated at intervals by pulses of radio frequency energy passes through the electron accelerating tube to impinge upon a target 87 composed of graphite or the like, located within a lead shield 88. The radio-frequency component of target current is amplified and rectified by a conventional R. F. amplifier and detector 89 and the modulation envelope which is obtained is utilized to operate a trigger circuit 91 which establishes the arc within ionization chamber 76 at the beginning of each radio frequency pulse. Ions are thus periodically produced and are immediately drawn into the accelerating chamber 92 by a local accelerating field of several kilovolts produced by a high voltage rectifier 93 located within the high voltage electrode and applied to accelerating electrodes.

Ion sources of present design are incapable of producing complete ionization and for the purpose of preventing hydrogen gas in an associated state from entering the accelerating tube a vacuum system located within the high voltage electrode, including an oil diffusion pump 94 and a mechanical backing pump 96 is provided. The backing pump discharges into a closed reservoir 97 which is of sufficient volume to retain, at moderate pressure, the accumulation of hydrogen which is produced during several hours' operation. An alternate arrangement provides for recirculating the output from the backing pump into the charge reservoir.

By withdrawing the nonionized hydrogen from the system at a point near that at which it enters, a better vacuum is maintained throughout the accelerating tube, and scattering of the ion beam is materially reduced since collisions between accelerated ions and relatively slow moving gas molecules are limited thereby.

Reduced gas pressure in the accelerating tube also results in reduced X-ray radiation. Gas molecules become ionized by collision with the accelerated particles liberating electrons which are accelerated by the field in the opposite direction taken by the positive particles. These electrons strike the liners of the accelerating tube or the metal surfaces near the source unit with sufficient velocity to emit X-ray spectra.

The ionized hydrogen atoms, or protons as they are properly termed, which emerge from the ionization chamber under the electrostatic force of the accelerating field are projected into the buncher cavity 98 as an interrupted beam of protons.

The buncher cavity 98 is resonant to the radio frequency of the oscillator 83 and is excited with radio frequency energy from an amplifier 99 connected to the target 87. A bunching action is obtained among the ions traversing the cavity by virtue of the radio frequency field through which they pass. Certain of the ions receive more energy in this chamber than others because of the changing instantaneous field. As they proceed through the main accelerating field within the ion accelerating tube 62, the ions of greater energies overtake other ions which are of average energy while certain other ions of less than average energy are themselves overtaken by ions of average speed. Since this bunching action is produced by radio frequency field changes in the buncher cavity as the result of the radio frequency voltage from the oscillator providing the accelerating field for a linear accelerator to be associated therewith, it is only necessary to provide the correct phase relationship at the buncher cavity in order to cause the "bunches" of ions to enter the accelerating field of the linear accelerator at the optimum instant for further acceleration. Such phasing is readily accomplished by suitably adjusting the length of the radio frequency transmission line between the oscillator and the modulator.

Electrical power for the devices within the high voltage electrode, for example, the amplifier 99, amplifier-detector 89, arc triggering circuit 91, the high voltage power supply 93, the diffusion pump 94, mechanical backing pump 96 and numerous other electrical loads, is provided by a suitable generator 101 which is operated from mechanical energy of the charging belt pulley 27 transmitted by the belt 26 from the motor 29.

The operation of the improved Van de Graaff machine may be summarized as follows:

A high potential for the acceleration of protons is produced at the surface of an insulated electrode by the accumulation of static charge. For this purpose an endless belt of insulating material is employed to convey positive charge to the electrode and to remove negative charge.

Flashover and corona discharge impose limitations on the maximum potential which may be attained and this limit is extended by securing an approximately uniform potential gradient through the use of a series of corona gaps and associated rings. Further flashover prevention is obtained through the use of an intermediate shell surrounding the high voltage electrode to divide the air path to the housing into two gaps across which equal voltage gradients are maintained.

The corona gaps are divided into two portions for the purpose of adjusting, by differential changes in nitrogen pressure surrounding the corona gaps, the potential of the intermediate shell, in order to effect said equality of potential gradients.

Still further assistance in reducing the tendency for flashover to occur is obtained by enclosing the machine in a pressurized tank containing the inert by-products of natural gas burned with air.

Pulses of radio frequency energy synchronized with the pulses of the field of an associated linear accelerator are transmitted along an electron accelerating tube as modulation on a stream of electrons from an electron gun, and caused to actuate the arc of a conventional filament-arc ion source. Ions, so produced, are given an initial acceleration by a local high voltage power supply which projects them through a resonant cavity excited by amplified radio frequency voltage also obtained from the modulated electron stream.

Due to the changing radio frequency field through which the ions pass they are bunched into alternate transverse strata of dense and sparse configuration and, after receiving an accelerated speed by their fall through the main accelerating field, emerge as a pulsed beam of bunched ions. By adjusting the phase relationship of the modulation applied to the electron stream these bunches may be made to arrive at the first accelerating space of the linear accelerator at the opportune time for maximum acceleration.

Reduced scattering of the beam of ions and a lower X-ray radiation level are produced through an improved arrangement for evacuating the accelerating system which includes a main vacuum system and an auxiliary pumping system located in the high voltage electrode to withdraw nonionized vapor from vicinity of the source.

If the subject invention is not associated with a linear accelerator the radio frequency control signals may be generated by any suitable pulsed oscillator and the advantage of a large instantaneous or peak beam may be obtained for the bombardment of tissue or other substances in the study of radiation effects.

While I have described the salient features of this invention with respect to a particular and preferred embodiment thereof, it will be further understood that various modifications may be made, and it is intended that the appended claims shall cover all such modifications as fall within the true spirit and scope of the invention.

What is claimed is:

1. In an apparatus for accelerating positive ions the combination comprising a hollow electrode, insulating means supporting said electrode; means for charging said electrode to a high positive potential whereby an intense electrical field is produced thereabout; an ion source unit disposed within said hollow electrode; an evacuated tube of insulating material extending from the interior of said hollow electrode exteriorly thereof to a grounded surface; an electron emissive element disposed at one end of said evacuated tube; a target element disposed within the electrode-contained, opposite end portion of said tube and in the path of a beam of electrons projected from said electron emissive element and passing through said tube; separately energized modulating means connected to said element and serving to modulate said beam of electrons with pulses of oscillatory electrical energy; control means connecting the target element and the ion source unit for controlling the operation of the latter in response to the modulation of said target directed beam whereby pulses of ions are periodically produced; an ion accelerating tube disposed between said hollow electrode and said grounded surface and receiving at predetermined spaced points along a potential gradient the electrostatic charge from said electrode; means disposed between said source unit and said accelerating tube for projecting the pulses of ions from the source unit into said ion accelerating tube, and means disposed within said electrode for energizing said last means and connected to the latter, whereby the ions are further accelerated by electrostatic forces between the electric field and the like fields of said ions.

2. A method for controlling the production of charged particles of high energy including, establishing an electrostatic field having a potential gradient ranging by successive increments from ground to a high positive potential, generating a discontinuous stream of electrons and passing the same through said field while accelerating the electrons along the potential gradient, directing the accelerated electrons against a target, generating a discontinuous stream of positive ions and passing the same through said field while accelerating the positive ions along the potential gradient, and controlling the generation of said positive ions in dependence upon the timing of the electrons striking the target.

3. A method for accelerating charged particles including, establishing an electrostatic field having a potential gradient ranging by successive increments from ground to a high positive potential, intermittently generating a quantity of positive ions, accelerating the ions and projecting the same into the positive electrostatic field along the potential gradient, and further accelerating the movement of the positive ions by applying thereto the repelling forces of the positive electric field upon the positive ions as they move along said potential gradient.

4. An electrostatic generator having in combination, an enclosing tank, a hollow high voltage electrode, means for charging said electrode with static electric charges, potential gradient means joining the electrode and the tank and serving to establish a plurality of predetermined points on a potential gradient therebetween, said last named means also constituting a support for said electrode, an electron accelerating tube extending into the electrode from a portion of the tank remote from said electrode, means adjacent the remote end of said tube for producing bunches of accelerated electrons traversing the length thereof for control of an ion source, a source unit of positive ions disposed in said electrode, control means including a target in the path of said beam and connected to said source for effecting a pulsating generation of ions, and means including an ion accelerating tube for conducting the ions from the source to an exit opening in said tank, said ion accelerating and electron accelerating tubes being connected to the spaced points on the potential gradient means whereby the electrostatic charge stored upon said electrode is transmitted to said tubes for accelerating the movements of ions and electrons during their passage through said respective tubes.

5. An electrostatic generator as described in claim 4, in which said tank contains an inert gas maintained under super-atmospheric pressure.

6. An electrostatic generator as described in claim 4 in which said tank contains an inert gas maintained under super-atmospheric pressure and comprising essentially a mixture of carbon dioxide and nitrogen.

7. In an electrostatic generator enclosed within a tank maintained at ground potential and having an accelerating tube for charged particles and an electrode adapted to be charged to a high potential with respect to ground; hollow, potential gradient means supporting the electrode from the tank, a plurality of corona discharge elements spaced along the interior thereof, means for supplying inert gas at various pressures to the interior of said first means for varying the discharge characteristics of said elements, a shell surrounding the electrode and positioned intermediate the latter and said tank and connected to one end of said potential gradient means for providing a major subdivision of the potential gradient between the electrode and the tank, and electrical connections between said corona discharge elements and the accelerating tube whereby the charge of the electrode may be applied to spaced points on the accelerating tube along a desired potential gradient of comparatively small subdivisions.

8. In an electrostatic generator enclosed within a tank maintained at ground potential and having a charged electrode at high potential with respect to ground and an accelerating tube for charged particles; a pair of hollow, potential gradient tubes serving to connect the electrode and the tank, means for supplying inert gas to the interior of said tubes, regulating means for independently adjusting the gas pressure in either tube, a shell surrounding the electrode and positioned intermediate the electrode and the tank, said shell being connected to the potential gradient tubes intermediate their ends and having a potential substantially one-half that of the charged electrode, a plurality of corona discharge means located in one potential gradient tube between the electrode and the junction of said shell with said tube, a plurality of corona discharge means located in the other potential gradient tube between the tank and the junction of said shell with said tube, and electrical connections between each corona discharge means and corresponding points along the accelerating tube whereby the charge of the electrode may be applied to spaced points on the accelerating tube along a desired potential gradient of comparatively uniform subdivisions.

9. In an electrostatic generator having in combination an electrode adapted to be charged to

a high positive potential with respect to ground and a potential gradient means connecting the electrode to ground; a segmental, evacuated, electron accelerating tube, an electron emissive element disposed at one end of said tube, a target element in the path of the electron stream within the tube and located at the opposite end thereof, a modulated radio-frequency oscillator unit connected to said emissive element, an ionization chamber for the production of positive ions, a cavity resonator connected to said chamber and serving to group said ions into bunches, control means responsive to the stream of electrons impinging upon the target and serving to energize both the ionization chamber and said resonator, a segmental evacuated, ion accelerating tube communicating with said resonator, electrically driven accelerating means for projecting the ions at high velocity from the resonator into the latter tube and connections from the potential gradient means to the segments of both the electron and ion accelerating tubes whereby bunches of electrons and ions passing respectively therethrough are accelerated by the action of the charge on said electrode.

10. An electrostatic generator as described in claim 9 in which the electron accelerating tube includes a series of segments composed of insulating material and having re-entrant metal liners positioned between adjacent segments and extending into the interior of said tube in order to provide a focusing effect upon the accelerated bunches of electrons passing through said tube.

11. An electrostatic generator of the character described in claim 9 in which the ion accelerating tube includes a series of segments composed of insulating material and having re-entrant metal liners positioned between adjacent segments and extending into the interior of said tube in order to provide a focusing effect upon the accelerated bunches of ions passing through said tube.

12. In an electrostic generator having an electrode adapted to be charged to a high positive potential with respect to ground; the combination of means for charging said electrode including a charging belt, a pulley located within the electrode and supporting the belt, charge applying means adapted to spray static charges upon the belt, charge removing means connected to the pulley and adapted to remove the static charge from the belt and an adjustable gap means connected to said pulley and to said electrode whereby upon adjustment of the gap the magnitude of corona discharge thereover may be regulated and the rate at which the belt charges the electrode may be adjusted.

13. A method for producing bunches of charged particles of high energy including, establishing an electrostatic field having a potential gradient ranging by successive increments from ground to a high positive potential, generating a discontinuous stream of electrons and passing the same through said field while accelerating the electrons along the potential gradient, directing the accelerated electrons against a target, generating a discontinuous stream of positive ions, bunching the ions, passing the stream of bunched ions through said field while accelerating the same along the potential gradient, and controlling both the generation of the ions and the bunching of the ions in dependence upon the timing of the electrons striking the target.

14. In an electrostatic generator enclosed within a tank maintained at ground potential and having an electrode adapted to be charged to a high potential with respect to ground and serving to accelerate charged particles moving through an accelerating tube; a hollow potential gradient means joining the electrode and the tank, gas supply means supplying inert gas to the interior of said potential gradient means, corona discharge means surrounded by said gas and positioned within said potential gradient means, and electrical connections between said corona discharge means and the accelerating tube whereby the charge of the electrode may be applied to spaced points on the accelerating tube along a desired potential gradient.

15. In an apparatus for accelerating positive ions the combination comprising a hollow electrode, insulating means supporting said electrode; means for charging said electrode to a high positive potential whereby an intense electric field is produced thereabout; an ion source unit disposed within said hollow electrode; an evacuated tube of insulating material extending from the interior of said hollow electrode exteriorly thereof to a grounded surface; an electron emissive element disposed at one end of said evacuated tube; a target element disposed within the electrode-contained opposite end portion of said tube and in the path of a beam of electrons projected from said electron emissive element and passing through said tube; separately energized modulating means disposed outside of said electrode and connected to said element for modulating said beam of electrons with pulses of oscillatory electrical energy; control means connecting the target element and the ion source unit for controlling the operation of the latter in response to the modulation of said target directed beam whereby pulses of ions are periodically produced; an ion accelerating tube disposed between said hollow electrode and said grounded surface and receiving at predetermined spaced points along a potential gradient the electrostatic charge from said electrode; means including a cavity resonator which is resonant to the input of said modulating means and disposed between said source unit and said accelerating tube for projecting the pulses of ions from the source unit into said ion accelerating tube, and means disposed within said electrode for energizing said last means and connected to the latter.

16. In an electrostatic generator the combination comprising a hollow electrode, a support therefor serving to insulate the electrode from ground, means for charging said electrode to a high positive potential with respect to ground whereby an intense electric field is produced about said electrode, an ion source unit disposed within the electrode, first and second hollow tubes of insulating material extending from within said hollow electrode to an external grounded surface, means for evacuating said tubes, an electron emissive element disposed within said first tube adjacent the grounded surface, a target element disposed within the portion of said first tube extending within the electrode, whereby electrons projected from said emissive element pass along the first tube and impinge upon said target element, separately energized modulating means disposed externally of the electrostatic generator and connected to said electron emissive element thereby to modulate the beam of electrons with pulses of oscillatory electrical energy, control means connect-

ing the target element and the ion source unit for controlling the operation of the latter in response to the modulation of said beam of electrons striking said target element whereby pulses of ions are periodically produced, an ion accelerating chamber disposed within said electrode and serving to connect the ion source unit and the end of said second hollow tube, said accelerating chamber being adapted to project said pulses of ions from the source unit into the second hollow tube, and tube liner means disposed within said second hollow tube and adapted to receive the electrostatic charge from said electrode, whereby ions accelerated into the tube are further accelerated by the electrostatic forces of said tube liner means while passing therethrough.

17. In an electrostatic generator, a support adapted to be maintained at ground potential, a hollow electrode adapted to be charged to a high positive potential with respect to said support, insulating means for mounting said electrode upon said support, means for charging said electrode, a hollow, ion accelerating tube of insulating material, said tube having one end mounted upon said support and the other end extending into said electrode, means for evacuating said tube, a supply of ionizable gas within said electrode, means adjacent the electrode-contained end of said tube for ionizing said gas, means for projecting the positive ions therefrom into said evacuated tube and means for removing non-ionized gas from said ionizing means, to prevent contamination of said tube.

18. In an apparatus for accelerating positive ions the combination comprising a hollow electrode, insulating means supporting said electrode; means for charging said electrode to a high positive potential whereby an intense electrical field is produced thereabout; an ion source unit disposed within said hollow electrode; an evacuated tube of insulating material extending from the interior of said hollow electrode exteriorly thereof to a grounded surface; an electron gun disposed at one end of said evacuated tube; a target element disposed within the electrode-contained, opposite end portion of said tube and in the path of a beam of electrons projected from said electron gun and passing through said tube; separately energized modulating means connected to said gun and serving to modulate said beam of electrons with pulses of oscillatory electrical energy; control means connecting the target element and the ion source unit for controlling the operation of the latter in response to the modulation of said target directed beam whereby pulses of ions are periodically produced; an ion accelerating tube disposed between said hollow electrode and said grounded surface and receiving at predetermined spaced points along a potential gradient the electrostatic charge from said electrode; means disposed between said source unit and said accelerating tube for projecting the pulses of ions from the source unit into said ion accelerating tube, means disposed within said electrode for energizing said last means and connected to the latter, whereby the ions are further accelerated by electrostatic forces between the electric field and the like fields of said ions, and an elongated tank maintained at ground potential and serving as a housing for said apparatus and separating the latter from said modulating means.

19. An electrostatic generator as described in claim 12, including potential gradient means extending from said electrode to points spaced from but adjacent said charge applying means and comprising a pair of hollow, insulating tubes having corona discharge means disposed interiorly thereof, said tubes extending one along each side of said belt in spaced, symmetrical relation thereto.

20. An electrostatic generator as described in claim 12 including potential gradient means extending from said electrode to points spaced from but adjacent said charge applying means and comprising a pair of hollow, insulating tubes having corona discharge means disposed interiorly thereof, said tubes extending one along each side of said belt in spaced, symmetrical relation thereto, and belt shield members of electrically conductive material disposed longitudinally of the span of said belt in spaced relation and interconnecting the corresponding corona discharge means of said spaced, insulating tubes.

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