

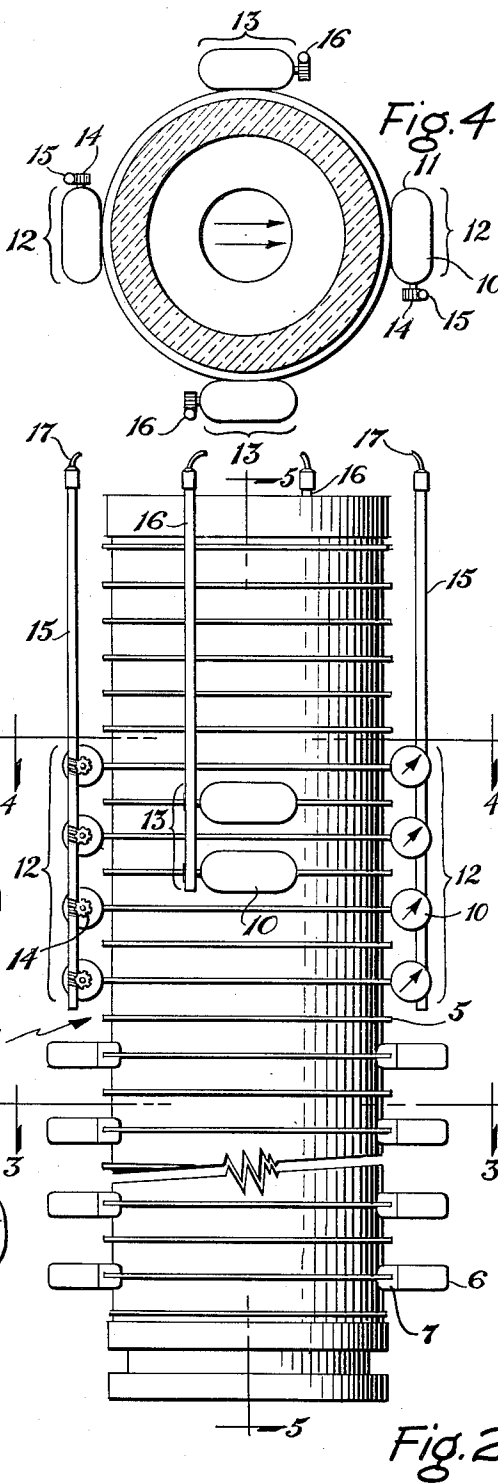
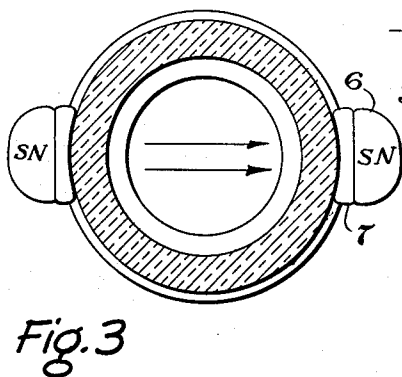
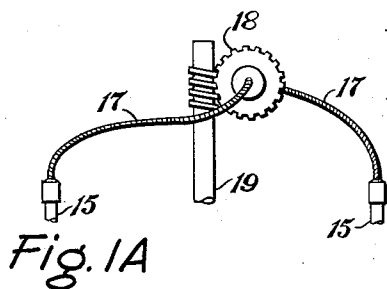
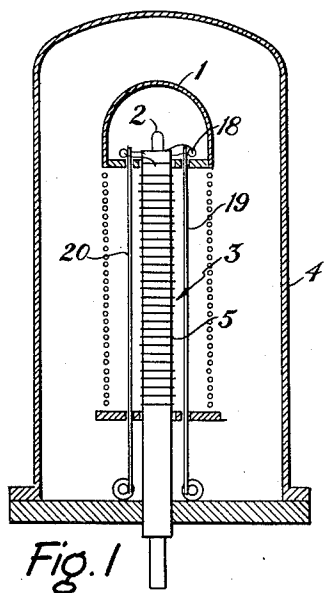
Jan. 26, 1960

R. J. VAN DE GRAAFF
APPARATUS FOR REDUCING ELECTRON LOADING
IN POSITIVE-ION ACCELERATORS

2,922,905

Filed June 30, 1958

2 Sheets-Sheet 1



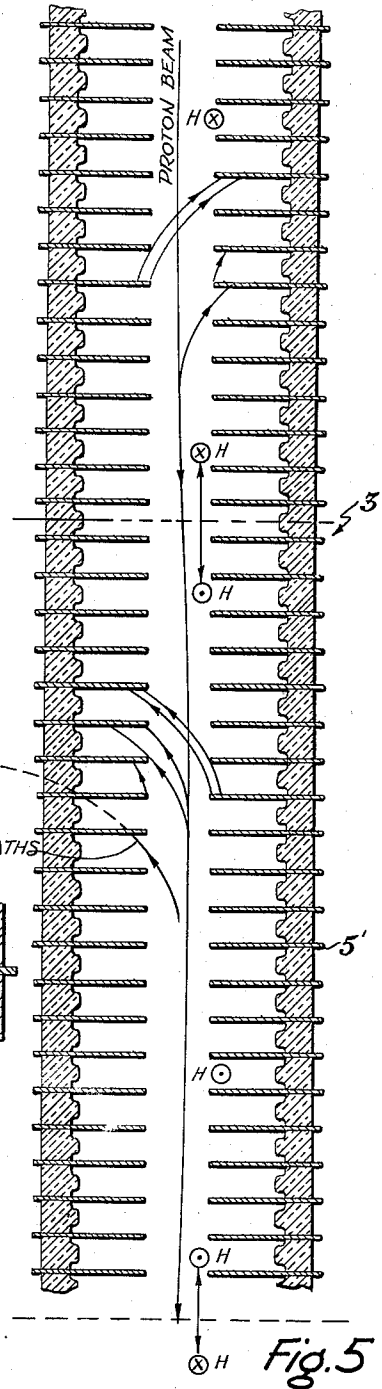
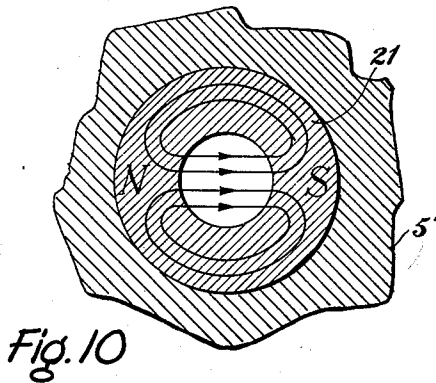
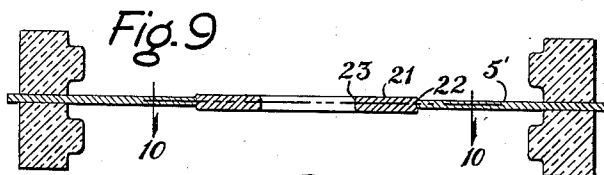
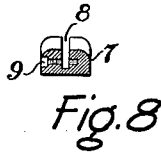
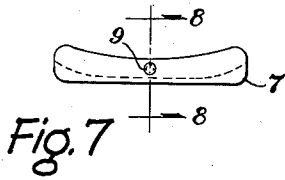
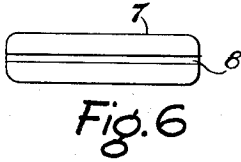
Jan. 26, 1960

R. J. VAN DE GRAAFF
APPARATUS FOR REDUCING ELECTRON LOADING
IN POSITIVE-ION ACCELERATORS

2,922,905

Filed June 30, 1958

2 Sheets-Sheet 2



1

2,922,905

APPARATUS FOR REDUCING ELECTRON LOADING IN POSITIVE-ION ACCELERATORS

Robert J. Van de Graaff, Lexington, Mass., assignor to High Voltage Engineering Corporation, Burlington, Mass., a corporation of Massachusetts

Application June 30, 1958, Serial No. 745,721

9 Claims. (Cl. 313—63)

This invention relates to the acceleration of charged particles to high energy and in particular to apparatus for reducing electron loading in positive-ion accelerators. In accordance with the invention, the evacuated acceleration tube of the positive-ion accelerator is provided with a series of magnets which produce magnetic fields within the acceleration tube transverse to its axis, the strength of the magnetic fields being such that electrons are deflected away from the axis with only negligible deflection of the positive ions. The invention is useful with positive-ion accelerators in which the acceleration is produced by a high potential difference. Therefore, while in the following detailed description particular reference is made to a belt electrostatic generator, it is to be understood that the invention is not limited thereto but includes other high-voltage accelerators. The invention may best be understood from the following detailed description thereof, having reference to the accompanying drawings in which:

Fig. 1 is a diagrammatic view in vertical central section showing a positive-ion accelerator in which the invention may be used to advantage;

Fig. 1A is a detail showing a portion of the apparatus of Fig. 1;

Fig. 2 is a view in side elevation of the acceleration tube of the apparatus of Fig. 1 and showing one embodiment of the invention;

Fig. 3 is a section along the line 3—3 of Fig. 2;

Fig. 4 is a section along the line 4—4 of Fig. 2;

Fig. 5 is a section, but on a reduced scale, along the line 5—5 of Fig. 2 and showing diagrammatically the trajectories of various charged particles;

Fig. 6 is a side view of a mount for a permanent magnet to be used in the apparatus shown in Figs. 2 and 3;

Fig. 7 is a top view of the mount in Fig. 6;

Fig. 8 is a cross section along the line 8—8 of Fig. 7;

Fig. 9 is a view in longitudinal central section of a portion of a modified form of the acceleration tube of the apparatus of Fig. 1 and showing another embodiment of the invention, wherein a permanent magnet is provided within the acceleration tube; and

Fig. 10 is a view along the line 10—10 of Fig. 9.

Referring to the drawings and first to Fig. 1 thereof, therein is shown an electrostatic accelerator of the type disclosed in U.S. Patent No. 2,252,668 to Trump. Electric charge is conveyed to a high-voltage terminal 1 by an endless insulating belt (not shown) and the electric field produced by the accumulated charge on the terminal 1 is used to accelerate positive ions from a positive-ion source 2 within the terminal 1 through an evacuated acceleration tube 3. The apparatus is enclosed in a tank 4 which is filled with an insulating gas under pressure. The electric field within the acceleration tube 3 not only accelerates positive ions in this manner, but also accelerates towards the high-voltage terminal 1 any stray electrons which may be released within the acceleration tube 3. These electrons may acquire fairly high energies and, upon striking the electrodes of the acceleration tube

2

3, may release secondary electrons so that the electron current in the tube 3 may reach considerable proportions.

This electron current constitutes a drain on the charge accumulated on the terminal 1, which must be replenished by the charging mechanism, and therefore represents a load which limits the voltage attainable. Moreover, these electrons, upon striking the electrodes of the acceleration tube 3 and other objects, produce X-rays which ionize the insulating gas. This ionization causes charge to leak off the terminal 1 through the insulating gas, thus producing an additional load which must be supplied by the charging mechanism and which therefore further limits the voltage attainable. This phenomenon is known as electron loading. The invention minimizes electron loading by providing magnetic fields within the acceleration tube 3 transverse to the axis of the tube. The electrons, which are traveling in an axial direction owing to the axial electric field, are therefore deflected out towards the walls of the tube. In this way, the stray electrons are prevented from traveling any considerable axial distance and therefore are prevented from acquiring any substantial amount of energy. Upon striking electrodes of the acceleration tube or other objects, these low-energy electrons generate much less X-radiation than high-energy electrons.

It is also desirable to reduce the X-rays, because they make radiation background in the neighborhood of the accelerator. The cumulative effect of this is undesirable for personnel and may even at time be dangerous. Also, the presence of this background interferes greatly with certain types of nuclear research. A test on a 6-megavolt accelerator has shown that with the use of magnets along the tube, the X-ray background in the surrounding region was reduced by a factor of about one hundred as measured with an ionization chamber. Also, measurements made with a scintillation counter showed that the maximum energy of individual X-ray photons was reduced by a factor of about ten, rendering them far more absorbable by concrete walls and other material. It may also be noted that the addition of magnets reduced the seasoning time of the tube to reach six megavolts to about four days, whereas a similar tube tried previously in the same generator had required several weeks of seasoning. Thus the invention serves not only to reduce background radiation but also to help prevent total-voltage breakdown. Moreover, the background radiation is reduced in two ways: not only is the quantity of radiation reduced, but the remaining radiation is very much softer and easily stopped by absorbers.

A preferred embodiment of apparatus for producing these magnetic fields is shown in Figs. 2, 3 and 5. Referring thereto, each of a multiplicity of the intermediate electrodes 5 of the acceleration tube 3 is provided with a pair of permanent magnets 6 which are magnetized in such a way as to produce a magnetic field between them transverse to the axis of the tube 3. At each extremity of the acceleration tube 3 the magnetic field extends in one direction, but in the central section the magnetic field extends in the opposite direction. In general, the sections thus defined by the orientation of the magnetic field tend to be of increasing length in the direction of travel of the positive-ion beam. However, when the number of sections is small and is odd, the length of the last section may be about the same length as that of the penultimate section. The purpose of this reversal of the magnetic field is to minimize the total deflection of the positive-ion beam. The trajectories of the charged particles are shown in Fig. 5. The stray electrons are released with very low energy and relatively small mass, so that the radius of curvature of their trajectories is therefore relatively small so that the electrons are easily deflected away from the axis of the tube 3. The positive

3

ions have a mass at least 1800 times that of the rest mass of the electrons, so that the radius of curvature of their trajectory is accordingly very much greater, and their trajectory is almost rectilinear. Moreover, the positive ions soon acquire relatively high energy and this energy increases throughout the length of the acceleration tube 3, so that the radius of curvature of their trajectory becomes greater. It is in order to compensate for the varying energy of the positive ions that the length of each section of the acceleration tube 3 generally increases from the terminal 1 to the grounded end of the tube.

The acceleration tube 3 may be of the conventional type such as that disclosed in the U.S. Patent No. 2,517,260 to Van de Graaff and Buechner, except that the intermediate electrodes 5 must have an outer diameter sufficiently large to support the permanent magnets 6. In order to support the permanent magnets 6 a mounting arrangement such as that shown in Figs. 6-8 may be used. Referring to Figs. 6-8, the mounting arrangement includes a block 7 of magnetic material one side of which is concave and has a groove 8 whose width is large enough to receive one of the intermediate electrodes 5. Each intermediate electrode 5 has two holes drilled in it near its outer periphery, and each mount 7 is affixed to the corresponding electrode 5 by means of a screw 9 which passes through the hole in the intermediate electrode 5. The magnet 6 may simply be cemented against the flat outer surface of the mount 7, or the magnet 6 may be attached to the mount 7 in any other suitable manner.

Each magnet 6 is magnetized so that the flat surface has one polarity and the rounded surface another polarity, as indicated in Fig. 3. Of course, half the magnets will have their north poles at the flat surface, and the other half will have their south poles at the flat surface, so that a transverse magnetic field is created inside the acceleration tube, as shown by the arrows in Fig. 3. A magnetic field of the order of 100 gauss will usually be adequate, and is readily achieved by the foregoing construction.

It is apparent from the trajectories shown in Fig. 5 that while the electrons are deflected so as to be intercepted by an electrode 5 after having traveled usually a length corresponding to at most 3 electrode spaces, the positive ions are deflected only slightly, so that they remain at all times close to the axis of the acceleration tube 3. Nevertheless, the magnets 6 do introduce a deviation in the position of the positive-ion beam which is difficult to predict precisely. Accordingly, the invention also comprehends a novel means for controlling the position of the positive-ion beam which is particularly useful in connection with the electron-deflecting magnets 6, but which is not limited thereto and also may be used in other situations where it is desired to control the direction of a beam of charged particles.

Referring to Figs. 2 and 4, the positive ions emitted from the positive ion source 2 are first formed into a beam by conventional initial focusing devices (not shown), and then the beam thus formed is directed by means of a double array of magnet pairs. Each magnet pair comprises two cylindrical permanent magnets 10 having rounded ends 11 and being magnetized uniformly throughout the axial length thereof in a direction perpendicular to said axis, as shown by the arrows in Fig. 2. One array 12 of magnet pairs is arranged as an extension of the electron-deflecting magnet system 6. This first array 12 of magnets 10 therefore serves to adjust the position of the positive ion beam in the plane of Fig. 2 of the drawings. The second array 13 of magnets 10 is identical to the first array 12, except that it is arranged perpendicular thereto and except for the fact that fewer magnets 10 are needed in the second array 13 because they do not have to compensate for the deflecting action of the electron-deflecting magnets 6.

The magnets 10 of each pair are mutually connected so that rotation of one magnet produces a similar rota-

4

tion of the other magnet of the pair. The magnets 10 of the first array 12 are each connected by means of a suitable worm gear arrangement 14 to two short insulating rods 15. The magnets 10 of the second array 13 are similarly connected to two short insulating rods 16. As shown in Fig. 1A, the short insulating rods 15 which correspond to the first array 12 are connected by means of flexible shafts 17 and a worm gear arrangement 18 to an insulating rod 19 extending from the high voltage terminal 1 of the accelerator to ground. Rotation of the rod 19 by any suitable device (not shown) at ground potential then produces a rotation of all the magnets 10 in the first array 12, and a second insulating rod 20 is used similarly to rotate the magnets 10 in the second array 13. As shown by the arrows in Fig. 2, all the magnets 10 in each array are arranged with their magnetic fields parallel to each other. When the direction of these magnetic fields is parallel to the axis of the acceleration tube 3, the magnetic field produced thereby within the tube 3 does not exert a deflecting force on the positive ion beam; but as the magnets 10 are rotated, a uniform component (shown by the arrows in Fig. 4) of magnetic field transverse to the axis of the acceleration tube 3 is produced which increases in strength as the magnets are rotated, reaching a maximum when the magnets 10 are lined up with their magnetic fields transverse to the axis of the acceleration tube 3.

The beam-director shown in Figs. 2 and 4 is thus a device which is adjustable from the control board of the positive-ion accelerator, so that from the control board one can turn one knob to control the position of the beam in one plane, and one can turn another knob to control the position of the beam in the plane perpendicular thereto.

By using this beam-director it is possible to use strong fields to deflect the electrons and still be able to adjust the position of the positive-ion beam. Without the beam-director one cannot be sure that the net effect is zero on the positive ions even though magnetic field reversal as shown in the diagram of Fig. 5 is employed. Thus this beam-director makes the principal idea of the invention really workable and practical.

The main advantage of the beam-director shown in Figs. 2 and 4 is the fact that it is a control feature which can operate near the high-voltage terminal 1 where the particles are still slow and relatively easy to change in direction.

A second advantage of the beam-director shown in Figs. 2 and 4 is the fact that it may be positioned so that the point of curvature of the beam is relatively distant from the grounded end of the tube 3. This is worthwhile because it is usually desirable to adjust the position of the intersection of the beam with a plane perpendicular to it near the point of use of the beam and at the same time to make a minimum change in the angle of the intersection. For example, the beam may be introduced into an analyzing magnet and it may be desired to adjust the position of entrance of the beam into the magnet without changing the angle of incidence. The method of magnetic deflection incorporated in this beam-director can also, of course, be used at the grounded end of the tube, although at such grounded end one can use other beam-directing equipment, such as electrostatic plates.

The device shown in Figs. 2 and 3 is one in which permanent magnets are added to an existing type of acceleration tube. If the acceleration tube were built for this purpose separately, there would be many advantages in having the permanent magnets placed inside the tube. This would make the device very much simpler and the magnetic fields would be more usefully applied. However, the adjustable magnets of the beam-director are outside the acceleration tube, since it is necessary to adjust their orientation.

Referring now to Figs. 9 and 10 of the drawing, therein is shown a modified embodiment of the invention,

wherein the electron-deflecting magnets are placed inside the acceleration tube. The acceleration tube 3' shown in Figs. 9 and 10 may be identical to that shown in Fig. 2, except that the electron-deflecting magnetic field is provided by annular permanent magnets 21 each of which is supported upon the inside periphery of an electrode 5'. Each such permanent magnet 21 may comprise a ring of magnetic material which is magnetized so as to produce a transverse magnetic field within the acceleration tube 3' as shown in Fig. 10, wherein the ring 21 is shown as having two poles. On the outer periphery of the magnet ring 21 may be inscribed a circumferential groove 22 and an electrode 5' may be shrunk into this groove 22. The magnetic field is thus concentrated in the region desired. The electrode 5' for supporting the ring magnet 21 is identical to the other electrodes 5 of the tube except that its central aperture is larger. The inner edges 23 of each magnet 21 are rounded so that there is very little distortion of the electric field within the tube introduced thereby.

Having thus described the principle of the invention together with several illustrative embodiments thereof, it is to be understood that although specific terms are employed, they are used in a generic and descriptive sense and not for purposes of limitation, the scope of the invention being set forth in the following claims.

I claim:

1. Apparatus for reducing electron loading in high-voltage positive-ion accelerators, comprising, in combination with a positive-ion accelerator having an evacuated acceleration tube within which there exists an unobstructed path along which charged particles can be accelerated to energies in excess of one million electron volts, means for creating a magnetic field within said tube transverse to the axis thereof of a strength sufficient to deflect electrons away from said axis without appreciable deflection of positive ions.

2. Apparatus for reducing electron loading in high-voltage positive-ion accelerators, comprising, in combination with a positive-ion accelerator having an evacuated acceleration tube, means for creating a series of magnetic fields within said tube transverse to the axis thereof of a strength sufficient to deflect electrons away from said axis without appreciable deflection of positive ions, said series of magnetic fields being arranged in longitudinal sequence along the tube, the orientation of said magnetic fields alternating so as to produce a focusing effect on positive ions being accelerated within said tube.

3. Apparatus for reducing electron loading in high-voltage positive-ion accelerators, comprising, in combination with a positive-ion accelerator having an evacuated acceleration tube which includes a multiplicity of alternating non-magnetic electrodes and insulating rings, a multiplicity of pairs of permanent magnets attached to said electrodes in such a manner as to create a magnetic field within said tube transverse to the axis thereof of a strength sufficient to deflect electrons away from said axis without appreciable deflection of positive ions.

4. Apparatus for reducing electron loading in high-voltage positive-ion accelerators, comprising, in combination with a positive-ion accelerator having an evacuated acceleration tube which includes a multiplicity of alternating non-magnetic electrodes and insulating rings, a series of annular permanent magnets attached to a corresponding series of said electrodes and radially inwardly thereof, each of said annular permanent magnets being magnetized so as to have poles between which a magnetic field is produced within said tube transverse to the axis thereof of a strength sufficient to deflect electrons away from said axis without appreciable deflection of positive ions.

5. Apparatus for reducing electron loading in high-voltage positive-ion accelerators, comprising, in combination with a positive-ion accelerator having an evacuated acceleration tube which has a source of positive ions at

one end thereof, a first array of pairs of rotatable permanent magnets flanking said tube near said source of charged particles with their axes mutually parallel and transverse to the axis of said tube, said magnets being magnetized all in the same direction transverse to their respective axes, means for rotating said magnets about their respective axes; a second array of pairs of rotatable permanent magnets flanking said tube near said source of charged particles with their axes mutually parallel and transverse to the axis of said tube and to the axes of the magnets in said first array, said magnets of said second array being magnetized all in the same direction transverse to their respective axes, and means for creating a magnetic field within said tube, in the region thereof more remote from said source of positive ions than said arrays of pairs of rotatable permanent magnets, transverse to the axis of said tube of a strength sufficient to deflect electrons away from said axis without appreciable deflection of positive ions.

6. The method of controlling the position of a beam of charged particles at the exit end of an acceleration tube, which method comprises: creating a substantially uniform magnetic field component transverse to the axis of said beam near the point of injection of said beam into said acceleration tube, and controlling the direction of said beam by varying the strength and direction of said magnetic field component.

7. Apparatus for controlling the position of a beam of charged particles comprising, in combination with an acceleration tube, a first array comprising at least one pair of rotatable permanent magnets flanking said tube with their axes mutually parallel and transverse to the axis of said tube, said magnets being magnetized all in the same direction transverse to their respective axes, means for rotating said magnets about their respective axes; a second array comprising at least one pair of rotatable permanent magnets flanking said tube with their axes mutually parallel and transverse to the axis of said tube and to the axes of the magnets in said first array, said magnets of said second array being magnetized all in the same direction transverse to their respective axes, and means for rotating said magnets in said second array about their respective axes.

8. Apparatus in accordance with claim 7 wherein each of said permanent magnets comprises a solid cylinder rotatable about its axis and having rounded ends.

9. Apparatus for controlling the position of a beam of charged particles at comparatively near the point of use thereof without substantially altering the angle of incidence of said beam at said point, comprising, in combination with an acceleration tube having a source of charged particles at one end thereof, a first array comprising at least one pair of rotatable permanent magnets flanking said tube near said source of charged particles with their axes mutually parallel and transverse to the axis of said tube, said magnets being magnetized all in the same direction transverse to their respective axes, means for rotating said magnets about their respective axes; a second array comprising at least one pair of rotatable permanent magnets flanking said tube near said source of charged particles with their axes mutually parallel and transverse to the axis of said tube and to the axes of the magnets in said first array, said magnets of said second array being magnetized all in the same direction transverse to their respective axes, and means for rotating said magnets in said second array about their respective axes.

References Cited in the file of this patent

UNITED STATES PATENTS

2,282,401	Hansell	May 12, 1942
2,417,797	Hipple	Mar. 18, 1947
2,775,708	Parsons et al.	Dec. 25, 1956
2,806,161	Foster	Sept. 10, 1957
2,820,142	Kelliher	Jan. 14, 1958
2,831,996	Martina	Apr. 22, 1958