

Feb. 6, 1962

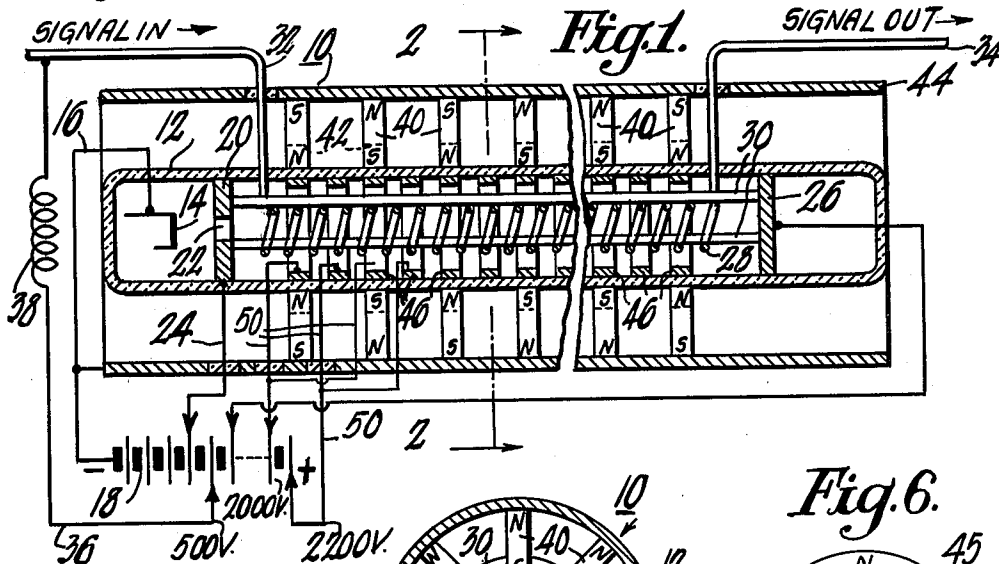
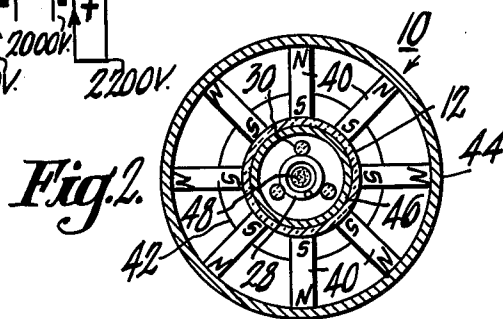
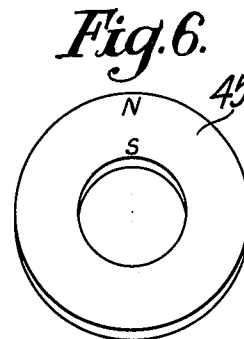
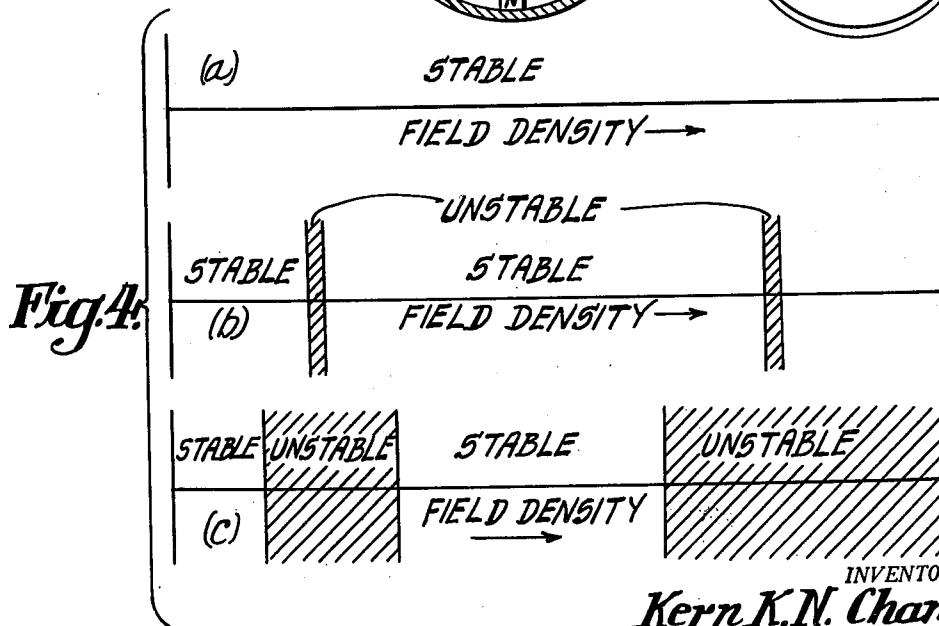
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3,020,440

ELECTRON BEAM DEVICE

Original Filed Nov. 17, 1954

2 Sheets-Sheet 1



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2 Sheets-Sheet 2

Fig. 3.

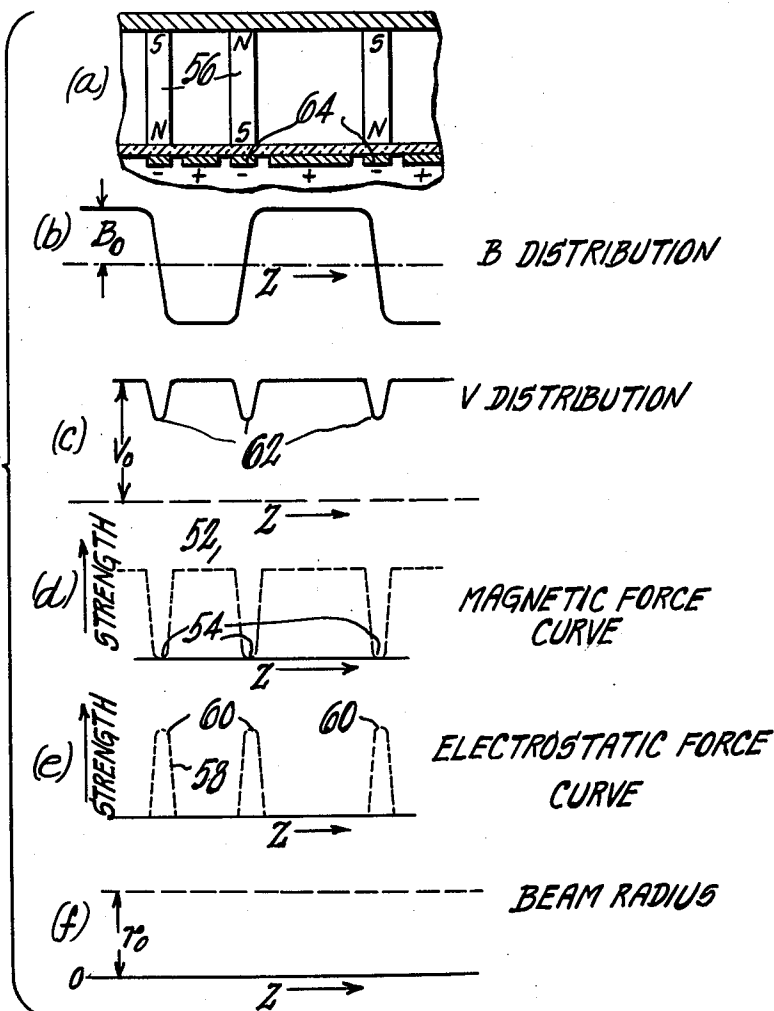
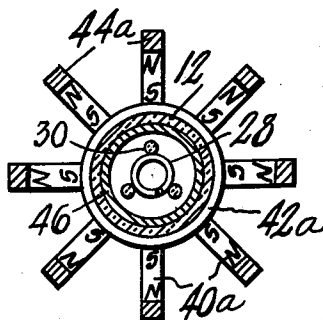


Fig. 5.



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3,020,440

ELECTRON BEAM DEVICE

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Continuation of application Ser. No. 469,423, Nov. 17, 1954. This application June 25, 1959, Ser. No. 822,967

18 Claims. (Cl. 315—3.5)

This invention relates to a beam device wherein a beam of charged particles is focused along a confined path. More particularly, the invention relates to a beam device having a beam of charged particles which spiral around an axis during the travel of the particles along the axis and wherein the particles in the beam recurrently reverse their direction of spiral motion due to the presence of a series of oppositely oriented magnetic fields.

This application is a continuation of my application Serial No. 469,423, filed November 17, 1954, assigned to the same assignee.

One feature of the invention concerns means for confining a beam of charged particles to a relatively narrow axial region within a beam device by means of improved periodic magnetic focusing means. This feature includes a periodic series of radially oriented magnets having magnetically permeable shunts around the portions of the magnets adjacent to the beam. Another feature of the invention concerns improved periodic focusing means for confining a beam of charged particles in such a device to a beam path of a relatively constant diameter. The beam confining means includes periodic magnetic focusing means for producing within and along the path a plurality of magnetic fields having, alternately, regions of relatively high flux density and regions of relatively low flux density, and periodic electrostatic focusing means for producing electrostatic focusing fields at the regions of relatively low magnetic flux density. Thus particles moving along that path are subjected to a substantially uniform beam confining force. While the invention proves advantageous in a device employing a beam of electrons, the invention may be used with devices employing other charged particles such as protons, alpha particles, or other charged ions. The invention may be employed in such devices as linear accelerators and in velocity modulated electron tubes known as klystrons, and finds especial use in electron tubes of the traveling wave type.

In a traveling wave tube an electron cloud in the form of an elongated cylindrical beam leaves a cathode and, while traveling toward a collector, interacts with a signal wave field traveling on a nearby delay line. The interaction is effected in such a way that energy is transferred from the electrons to the wave. The delay line may be composed of a linear array of coupled metallic resonant slots or cavities, a helix, or other waveguide structure capable of propagating a wave with an axial velocity which is a fraction, say one-tenth, of the velocity of light and which is approximately equal to the axial velocity of the electron beam.

In many microwave tubes in which an electron beam is directed through a linear delay line, mutual repulsion effects, which inherently exist between the electrons, cause the electron beam to spread. This electron spreading will cause many of the electrons to impinge upon the delay line with consequent harmful effects. The electron interception introduces noise within the tube and dissipates energy on the delay line in the form of heat. In order to operate a traveling wave tube in its most efficient manner it is necessary to employ proper focusing methods to minimize electron interception by the delay line.

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In the design of beam devices such as traveling wave tubes it has been conventional to use a continuous and uniform axial magnetic field to focus the electron beam along a path within such tubes. The use of the uniform magnetic field insured relatively good focusing performance. However, in the practical use of the uniform magnetic field, a serious design problem arises; the uniform magnetic field requires the use of a relatively large magnet for proper operation. This makes for a relatively massive structure. Then, too, the conventional electromagnets used to form such a magnetic field requires a relatively large amount of direct current power to maintain the desired magnetic field.

One method of overcoming these drawbacks in a device employing a beam of charged particles is the use of an axially periodic magnetic field to confine the beam along an axis. Such a method is described in Journal of Applied Physics, volume 25, Number 4, April 1954, pages 436 through 447. However, important design limitations are introduced when applied to devices which are adapted to operate at relatively high beam densities. The relatively high unused magnetic leakage flux of such devices reduces the maximum magnetic field available for focusing purposes.

Accordingly, it is one of the principal objects of the invention to provide an improved beam device capable of operation at relatively high beam perveance without the use of relatively massive magnets.

It is another object of the invention to provide an improved beam device employing a series of relatively dense magnetic fields to focus a beam of charged particles along an axis of the device.

It is a further object of the invention to provide an improved beam device having a beam of charged particles and employing a plurality of beam confining fields and wherein beam flow stability is substantially independent of the magnitude of the confining fields.

It is yet another object of the present invention to provide an improved electron tube of the traveling wave type and wherein a relatively dense stream of electrons is confined by a substantially uniform force to a beam of a relatively uniform diameter and to a relatively narrow axial region within the tube by periodic focusing fields.

According to the embodiment of the invention illustrated in the drawing, an elongated electron tube of the traveling wave type is provided having a magnetic and an electrostatic field producing structure. An electron beam, propagated along the tube axis and within a hollow delay line adapted to propagate a signal wave therealong with an axial velocity less than that of light, is continuously focused by a magnetic field structure comprising a series of radially-extending permanent magnets. The magnets are arranged in groups: each group of magnets surrounds a portion of the beam path. Successive groups of magnets are spaced along the beam path and have their north and south poles alternately directed adjacent to the beam path. A series of rings alternately biased at different positive potentials, which may be disposed between the signal wave propagating conductor and the magnets, provide a series of electron lenses along the tube axis. The electron-converging electrostatic fields of the lenses are disposed at the portions of the electron beam path which are in regions of substantially zero magnetic flux density. Thus the electron beam is subjected to a substantially continuous and uniform beam confining force at each point along its path and hence is caused to have a substantially uniform diameter.

The term "magnet" as used herein is intended to describe a member having substantially permanent magnetic properties, as distinguished from soft iron and similar magnetic materials which can be magnetized only temporarily.

While the invention is pointed out with particularity in the appended claims it may be best understood from the following detailed description and drawing where like numerals refer to like parts. The embodiments described are presented solely for illustrative purposes and not by way of limitation.

In the drawing:

FIGURE 1 is a longitudinal sectional view of a traveling wave tube employing one form of periodic beam confining means according to the invention.

FIGURE 2 is a transverse sectional view taken on line 2-2 of FIGURE 1.

FIGURE 3 is a diagram illustrating the relation between the relative magnitudes of the distances and the field forces encountered in a traveling wave tube employing another form of periodic magnetic and electrostatic beam confining means according to the invention.

FIGURE 4 is a diagram illustrating conditions of beam stability within a traveling wave tube under different circumstances.

FIGURE 5 is a transverse sectional view of a traveling wave tube employing a modification of the invention.

FIGURE 6 is a perspective view of a radially polarized, apertured disc magnet of a type which may be used in place of rod magnets in the tube shown in FIGURES 1 and 2.

Referring now to the drawing in greater detail there is shown in FIGURE 1 an elongated traveling wave tube embodying the invention. The traveling wave tube 10 includes a non-conductive envelope 12, which may be of a material such as glass, containing the various internal tube elements. A relatively dense stream of electrons is thermionically emitted from a cathode 14. The cathode, which may be provided with an electron emissive coating, is connected to a lead 16 which is in turn connected to the negative side of a power source 18. The cathode is provided with a heater (not shown). An accelerating anode 20, having an aperture 22, is supported near the cathode. A positive bias is supplied to the anode 20 through a lead 24. Electrons from the cathode are accelerated toward the accelerating anode 20 due to the positive bias on the latter. The electrons pass through the anode aperture 22 in a stream, are accelerated toward a helical conductor 28, and drift toward a collector 26 biased at a relatively high potential. Thus the electrons acquire a component of velocity in a direction parallel to the longitudinal tube axis.

A helical conductor 28, hereinafter referred to as the helix, is provided within the tube. As is known, a signal wave may be propagated along a helix. Then, while the signal wave may have a relatively high velocity along the spiraling path of the helix as compared to the axial velocity of the electrons, the velocity of the signal wave with respect to the longitudinal axis of the helix is far less. The longitudinal or axial velocity of the signal wave on the helix is determined by the diameter and the pitch of the helix. The axial velocity of the electron beam is adjusted to be substantially the same as the axial velocity of the signal wave on the helix. As seen in FIGURE 1 the helix 28 is supported by nonconductive rods 30 which may, for example, be of a ceramic.

The helix is provided with an input 32 and an output 34. While the input and output are represented in the drawing by leads it will be appreciated that the input and output may instead be coaxial cables or wave guides and inductively coupled to the helix. A lead 36 is shown joined to the helix by means of a connection to the input 32 and is connected to the power supply 18 so as to establish the desired helix potential, which may for example be 500 volts. A coil 38 is provided in series with the lead 36; the coil provides an inductance which blocks the flow of a radio frequency signal but which permits the flow of direct current bias to the helix.

A series of groups of radially oriented permanent magnets 40 is arranged along the helix and outside the

envelope 12. Each group of magnets is shown surrounding the envelope 12 with poles of the same polarity adjacent to the envelope. Successive groups of magnets have opposite poles adjacent to the envelope, i.e., the groups are alternately distributed in the axial direction. It will be appreciated that while the magnets shown in the drawing are permanent magnets, electromagnets may instead be used.

As shown in FIGURE 2, each group of magnets 40 may comprise eight rod magnets arranged radially with the same polarity adjacent to the envelope 12 and hence also to the helix 28. While the group of magnets shown in FIGURE 2 has the south poles adjacent to the envelope, the next successive group of magnets (not shown) has the north poles adjacent to the envelope.

According to one feature of the invention, magnet shunts 42 in the form of arcuate members of material characterized by relatively high magnetic permeability, such as soft iron or mu metal, are arranged between the poles of the rod magnets of each group of magnets and adjacent to the envelope. The shunts are used to improve the axial symmetry of the field and to increase the uniformity of the magnetic field produced by the magnets. While magnet shunts on the sides of the magnets adjacent to the electron beam are shown in the form of arcuate members between adjacent magnets of each group, the magnet shunts adjacent to the beam may be in the form of ring-shaped members. The members 42 are disposed around the envelope, and between the magnetic poles which are adjacent to the envelope, i.e., between the inward poles, and the envelope. The shunting of the inward poles of the radially oriented magnets by members characterized by a relatively high magnetic permeability increases the amount of the maximum magnetic field available along the tube axis.

An outer magnet shunt 44, of cylindrical shape, is positioned around and in contact with the poles of the magnets remote from the envelope 12 so as to shunt the magnetic flux of those poles.

Magnets of any shape capable of radial orientation around the envelope may be used instead of the rod shaped magnets of the drawing. Thus, magnets of wedge shape or apertured disc form may be used for the same purpose. A traveling wave tube has been made having a series of radially polarized magnets in the shape of apertured discs, alternate magnets being oppositely oriented. One such disc 45 is illustrated in FIGURE 6. A series of these radially polarized discs may be used in the tube shown in FIGURES 1 and 2, one disc 45 in place of each group of magnets 40 (one such group of magnets 40 being shown in FIGURE 2). A tube using such a series of disc shaped magnets may be provided with a plurality of shunting bars along the outside rims of the discs in a manner similar to that illustrated for the shunt bars 44a in FIGURE 5 for another embodiment of the invention. While rod or bar shaped magnets may be of a material such as that known as Alnico V, other materials may be more advantageously used for radially polarized apertured-disc magnets since Alnico V is relatively sensitive to self-demagnetization due to its relatively low coercive force. Materials known as ferrites have instead been used for such disc shapes. Ferrites are characterized in having a relatively high coercive force and lend themselves to geometries which cannot be satisfactorily achieved with more conventional magnetic materials. For example, a lead ferrite has been advantageously used having a composition of $PbO \cdot 4Fe_2O_3$ and having a hexagonal crystalline structure.

Referring now to FIGURE 5 there is shown a transverse sectional view of a modification of a traveling wave tube employing the invention. This tube makes use of a different arrangement of magnet shunt members. A plurality of outer magnet shunts 44a are used in place of the single cylindrical outer shunt shown in the tube of FIGURES 1 and 2. The outer shunts 44a are in the form of a plurality of bars aligned parallel to the tube

axis and extending along the length of the tube. Each of a plurality of radially oriented magnets 40a have their outwardly oriented poles in contact against a portion of a shunt bar. As shown in this modification, the magnet shunts adjacent to the inwardly oriented poles may be in the form of ring-shaped shunt members 42a outside an evacuated envelope 12 which encloses a helix 28. The ring-shaped shunt members 42a are disposed outside the envelope and between the helix and the magnetic poles adjacent to the helix. The magnet shunts of this figure are also of material characterized by relatively high magnetic permeability. The structure of the tube of FIGURE 5 is otherwise substantially the same as that of FIGURES 1 and 2.

Referring back to FIGURES 1 and 2, another feature of the invention resides in the use of combined electrostatic and magnetic focusing means to confine an electron beam within a relatively narrow axial region of a traveling wave tube. A series of ring members 46, hereinafter referred to as rings, are disposed within the envelope 12 and adjacent to the inside surface of the envelope. The rings 46 are adapted to form electrostatic electron lenses for an electron beam 48 which is propagated along the axis of the tube. Twice as many rings as groups of magnets are provided since it takes a group of at least two successive rings to form an electrostatic lens. As will be explained in greater detail below, each of the electrostatic lenses is oriented so that a converging electrostatic focusing field is provided at every region along the axis where the magnetic flux density is substantially zero. Since the axial magnetic flux density is substantially zero at each region along the axis opposite the midpoint of a magnetic pole, there will be two regions of substantially zero magnetic flux density for each magnetic period, that is, one region at each group of north poles and one at each group of south poles. Thus, it may be said that the period of the magnetic field is twice the period of the electrostatic field because for every magnetic period there are two regions of substantially zero axial magnetic flux density, as is shown in FIGURE 3b with respect to another embodiment of the invention. Therefore, an electron lens, having a converging field for the beam of electrons in the traveling wave tube, must be provided at each of the substantially zero magnetic field regions to prevent divergence of the beam at those regions.

The rings 46 are biased alternately at relatively high positive potentials which differ by a few hundred volts. For example, the rings in the drawing are shown connected by leads 50 to the power source 18 so as to be biased alternately at 2000 volts and 2200 volts. The potentials on the rings are shown to be approximately four times the potential 500 volts on the helix since it is necessary that the rings be biased at a relatively high potential with respect to the helix in order that the electrostatic fields of the rings penetrate to the electron beam within the helix. When a signal wave propagating circuit of a type other than a helix is used, electrostatic ring potentials of a lower magnitude relative to the helix may be used.

In order to position the converging fields of the electrostatic electron lenses at the regions of substantially zero axial magnetic flux density, the voltage minimums of the electrostatic ring series are introduced along the tube axis at each of the regions where the magnetic flux density is relatively low, e.g., where the magnetic flux density is substantially zero. To accomplish this in the arrangement shown in FIGURE 1, alternate rings 46 are located in the plane of an annular group of magnets and the intermediate rings 46 are located midway between the adjacent group of magnets. The rings 46 in the planes of the magnets are biased at the lower potential (2,000 volts) and the other rings 46 are biased at the higher potential (2,200 volts). Thus, each lower potential ring and the two next adjacent higher potential

rings form a well-known "Einzel" lens, as described on pages 348 and 349 of the textbook "Vacuum Tubes" by Spangenberg, McGraw-Hill Book Company, Inc., 1948. Each lens has its central lens plane in the plane of one group of magnets, and hence, at a region of substantially zero magnetic flux density. Since the rings 46 extend continuously along the groups of magnets, an electrostatic focusing field is established at each group of magnets, that is, at each region of zero magnetic flux density, as shown in FIGURES 3(a) to 3(e). This creates a focusing effect wherein alternate electrostatic and magnetic fields maintain the electron beam at a constant diameter. While the embodiment described is illustrated with respect to radially oriented magnets, the electrostatic lenses described may instead be used in combination with axially oriented magnets to provide the combined electrostatic and magnetic focusing means of the invention. Also, while the traveling wave tube of the drawing is described with respect to constant diameter flow, the invention may be employed to advantage in beam devices having an oscillating flow of charged particles, i.e. an alternately converging and diverging beam flow.

The relation between the magnitudes of the magnetic and electrostatic fields needed to maintain a constant focusing force, is illustrated by the following analysis:

Considerations of the motions of electrons near the center of axially symmetrical electrostatic and magnetic fields lead to the well-known paraxial ray equation including space charge:

$$r'' + \frac{V'r'}{2V} + \left(\frac{V''}{4V} + \frac{\eta}{8V} B_z^2 \right) r = \frac{I}{kV^{3/2}} \quad (1)$$

In Equation 1, r is the radial distance of a particular electron in the beam from the axis. r' and r'' are the first and second derivatives of the radial distance of a particular electron in the beam with respect to the axial distance, z . V is the electrical potential along the axis. V' and V'' are the first and second derivatives of the electric potential along the axis with respect to z . B_z is the axial component of the magnetic flux density.

$$\eta = \frac{e}{m}$$

the ratio between the electron charge and the electron mass. For this equation, it is assumed that the beam starts at zero magnetic field, for example, from a shielded cathode. In relatively dense electron beams such as are used in traveling wave tubes, the fields produced by the space charge in the beam become of relatively great importance. The term on the right hand side of Equation 1 takes into account the presence of space charge. I is the beam current in amperes, and k is a constant, $k = 4\sqrt{2\pi\epsilon_0\eta^{3/2}}$, where ϵ_0 represents the dielectric constant of free space.

Equation 1 has been applied to the theory of electron beams in traveling wave tubes and other structures involving linear electron flow. The equation is explained in greater detail in Chapter IX of a book entitled Theory and Design of Electron Beams, by J. R. Pierce, published by the D. Van Nostrand Company, Incorporated, in 1954.

Consider now a form wherein the electron flow starts at a certain given magnetic flux density, B_{00} . As can be shown, the paraxial ray equation corresponding to this case now becomes

$$r'' + \frac{V'r'}{2V} + \left[\frac{V''}{4V} + \frac{\eta}{8V} \left(B_z^2 - \frac{r_{00}^4}{r^4} B_{00}^2 \right) \right] r - \frac{I}{kV^{3/2}} = 0 \quad (2)$$

where r_{00} equals the radius of the cathode which produces the electron beam. Qualitatively, this Equation 2 is concerned with the action of the balanced radial forces on the electrons. The term involving beam current and

voltage is that part of the radial force which is contributed by the space charge and which tends to push the electrons radially outward. The inward forces which balance the space charge force, thereby focusing the electron beam to a given size, are the electrostatic forces (due to the electrostatic field) and the magnetic forces (due to the magnetic field which causes the electrons to spiral around the beam axis).

If r'' and r' are equal to zero in Equation 2, then parallel flow of the electrons in the beam at a certain radius r_0 is obtained. The condition is met where:

$$\left[\frac{V''}{4V} + \frac{\eta}{8V} \left(B_z^2 - \frac{r_0^4}{r_0^4} B_{00}^2 \right) \right] V^{3/2} = \frac{I}{kr_0^2} \quad (3)$$

This shows that B_z and V can be any arbitrary functions of z which satisfy Equation 3. While the tube structure shown in FIGURE 1 is provided with a series of equally spaced periodic magnetic and electrostatic lenses, the beam confining structure may be constructed so as to produce unequally spaced, alternate magnetic and electrostatic lenses. The portion of the view of a traveling wave tube structure shown in FIGURE 3a gives an example of such unequally spaced lenses. FIGURES 3b, 3c, 3d, and 3e, which are graphs of field strengths and force plotted in relation to the position of the structure in FIGURE 3a, illustrate conditions necessary to attain a focusing effect which will maintain a beam of charged particles at a constant radius. The constant radius beam is illustrated in relation to the aforementioned graphs in FIGURE 3f.

The rules, and hence the equations, which govern the relationship between the electrostatic and magnetic fields are equally applicable to all periodic fields. For a constant diameter beam flow to be achieved it is required that the relationship between the magnetic flux distribution, illustrated in FIGURE 3b, and the electrostatic flux distribution, illustrated in FIGURE 3c, be such that Equation 3 is satisfied. However, according to the equation, for relatively small voltage variations (such as those which may be experienced in a traveling wave tube of the type shown in FIGURES 1 and 2) it is necessary that the sum of the two terms in the brackets in Equation 3 be substantially constant if a beam of substantially constant diameter is to be obtained. Thus the electrostatic or the magnetic field distribution does not need to be given in analytic form in order to obtain the distribution of the corresponding magnetic or electrostatic fields for constant diameter flow. A graphical solution of Equation 3 may instead be found. The magnetic force curve and the electrostatic force curve, indicated in FIGURES 3d and 3e as dotted curves, readily allow a graphical solution to be found: If the shapes of the dotted curves of a particular example are those shown in the figures it then follows that their sums will give a substantially constant value and thus set up a condition for substantially constant diameter flow.

The curve 52 in FIGURE 3d is a graph of the magnetic force distribution. Points 54 in the drawing indicate regions of substantially zero flux density. It will be noted that these points 54 correspond to the centers of the magnetic poles 56 (FIGURE 3a).

The curve 58 in FIGURE 3e is a graph of the electrostatic force distribution. Points 60 in the drawing, corresponding to dips 62 in FIGURE 3c, indicate regions of converging electrostatic electron lenses.

Consequently, if the relationship between the magnetic force distribution and the electrostatic force distribution is maintained as shown in FIGURES 3d and 3e, the sum of the magnetic and electrostatic forces will give a resultant combined force of a substantially constant value. This is the condition for constant diameter beam flow.

From a practical point of view, even if the magnetic force (curve 52, FIGURE 3d) and the electrostatic force (curve 58, FIGURE 3e) do not exactly match, a voltage dip of substantially any shape (corresponding to a peak in

curve 58) occurring at the region along the axis where the magnetic flux density reaches a substantially zero value, will supply an electrostatic force such that the alternate electrostatic and magnetic forces will focus the beam.

This will result in an approximate balance to the dispersive effects due to space charge forces. Where the voltage dip is greater than that determined by Equation 3 the beam will experience a contraction of its radius at the region thereof adjacent to the field of the voltage dip. Conversely, where the voltage dip is smaller than that determined by Equation 3 the beam will experience an expansion of its radius at the region thereof adjacent to the field of the voltage dips.

Referring now to FIGURE 4 there is shown a diagram illustrating conditions of beam stability within a traveling wave tube under different circumstances. The notation "Field Density" in FIGURES 4a and 4b of the drawing refers to combinations of magnetic and electrostatic fields. The same notation in FIGURE 4c of the drawing refers to the use of either a magnetic or an electrostatic field but not to a combination of the two types of fields. FIGURE 4a illustrates beam flow stability for combinations of different values of magnetic and electrostatic flux densities which satisfy Equation 3. It will be noted by the notation on the diagram with respect to stable regions of operation that any magnitude of magnetic and electrostatic field densities which satisfies Equation 3 yields a stable beam flow.

FIGURE 4b illustrates beam flow stability for combinations of different values of magnetic and electrostatic flux densities which may be relatively easily achieved in practice without prolonged computation and manipulation of the individual magnets or of the voltages on the individual electrostatic rings. Thus FIGURE 4b may be taken to represent the beam flow stability for readily achievable field values which approximate Equation 3.

It will be noted that as the magnetic and the electrostatic field intensities are increased a critical band is reached whereupon the beam flow becomes unstable and electrons are rapidly lost from the beam. A relatively small increase in field density re-establishes stable beam flow until a further substantial increase in the combined field densities again reach a combination of magnetic and electrostatic field densities which manifest themselves as instability bands. However, it will be noted from the drawing that the unstable bands are relatively narrow and are separated by relatively wide stable bands. It must be borne in mind that while a tube may be "tuned" so as to operate away from the unstable bands illustrated in FIGURE 4b, by either increasing or decreasing the magnetic and electrostatic field intensities, the unstable bands may be completely eliminated, and the conditions depicted in FIGURE 4a obtained, by the relatively exact orientation of the magnets and the electrostatic rings as well as of the relative magnetic and electrostatic field magnitudes so as to satisfy Equation 3.

FIGURE 4c is included for purposes of comparison. This figure illustrates conditions of beam flow stability with the use of a series of magnetic fields or a series of electrostatic fields alone. It will be noted that in such a case, while field densities may be chosen so as to give stable beam flow, the beam alternately diverges and converges or suffers a perturbed oscillating flow rather a flow of constant diameter as in the case where both magnetic and electrostatic focusing fields are used. When magnets or electrostatic rings alone are used the instability bands cannot be eliminated by an appropriate orientation of the magnets, or of the rings, as the case may be. Indeed, the instability bands shown in FIGURE 4c become wider with a poorer orientation of the field producing means; a condition of disorientation may be relatively easily reached where the bands of stability are substantially non-existent.

Thus, it is seen that the invention provides a means for focusing a relatively dense beam of charged particles to

a beam of substantially constant diameter by means of a field producing structure of relatively small weight and size.

What is claimed is:

1. A beam device comprising means for projecting a beam of electrically charged particles along an extended path within said device, and periodic focusing means for producing stable beam flow along said path, said focusing means comprising means for producing a series of periodic magnetic focusing lenses and a series of periodic electrostatic focusing lenses alternating along said path with said magnetic focusing lenses.

2. A beam device comprising means for projecting a beam of electrically charged particles along a path within said device and means for focusing said beam of particles into a relatively constant diameter flow; said focusing means including magnetic focusing means for producing magnetic fields having at least three regions of relatively high flux density alternating with regions of substantially zero flux density along said path, and electrostatic focusing means for producing an electrostatic focusing field at each of said regions of substantially zero flux density.

3. The beam device as in claim 2, wherein said regions of substantially zero flux density are relatively short in a direction along said beam path as compared to said regions of relatively high flux density.

4. The beam device as in claim 2, wherein said regions of substantially zero flux density are equally spaced along said path.

5. The beam device as in claim 2, wherein said regions of substantially zero flux density are unequally spaced along said path.

6. A traveling wave tube adapted to be excited by a signal wave and comprising an evacuated envelope containing a delay line adapted to propagate said signal wave within said tube along an axis therein with a phase velocity substantially less than the speed of light, means for producing a relatively dense beam of electrons with a path of travel along said axis, and means for confining said beam to a substantially constant diameter flow along said path; said confining means including magnetic focusing means for producing magnetic fields having at least three regions of relatively high flux density alternating with regions of substantially zero flux density along said path, and electrostatic means for producing an electrostatic focusing field at each of said regions of substantially zero flux density.

7. The traveling wave tube as in claim 4, wherein said magnetic focusing means comprises a series of permanent magnets radially oriented around said envelope.

8. The traveling wave tube as in claim 6, wherein said magnetic focusing means comprises a series of radially-polarized apertured-disc permanent magnets.

9. An evacuated beam device comprising means for projecting a beam of electrically charged particles along a path within said device and means for confining said beam in a focused flow within said path; said confining means including a series of magnets for producing magnetic fields within said path, said magnetic fields having at least three regions of relatively high magnetic flux density alternating with regions of relatively low flux density along said path, and electrostatic focusing means for producing an electrostatic focusing field at each of said regions of relatively low flux density, said electrostatic focusing means including a series of electrodes adapted to be charged to suitable potentials so as to form a series of electron lenses which have their converging fields for said beam at said regions of relatively low flux density.

10. The beam device as in claim 9, comprising an evacuated envelope and wherein said magnets are disposed outside said envelope and adjacent to said path of said beam and said electrodes are rings disposed within said envelope around and adjacent to said path.

11. A beam device comprising means for projecting a beam of electrically charged particles along a path with-

in said device and means for confining said beam in a focused flow within said path; said confining means including a series of axially spaced groups of radially oriented radially polarized magnets for producing magnetic fields within said path, said magnetic fields having regions of relatively high magnetic flux density alternating with regions of relatively low flux density along said path, and electrostatic focusing means for producing an electrostatic focusing field at each of said regions of relatively low flux density, said electrostatic focusing means including a series of electrodes adapted to be charged to suitable potentials so as to form a series of electron lenses which have their converging fields for said beam at said regions of relatively low flux density.

12. An evacuated beam device comprising means for projecting electrically charged particles along a path within said device and means for confining said particles to a beam of relatively constant diameter within said path; said confining means including a series of radially oriented radially polarized magnets for producing magnetic fields within said path, said magnetic fields having regions of relatively high magnetic flux density alternating with regions of substantially zero flux density along said path, and electrostatic focusing means for producing an electrostatic focusing field at each of said regions of substantially zero flux density, said electrostatic focusing means including a series of rings adapted to be charged to suitable potentials so as to form a series of electron lenses which have their converging fields for the beam of charged particles at said regions of substantially zero flux density.

13. An elongated traveling wave tube adapted to be excited by a signal wave and comprising an evacuated envelope containing a helix adapted to propagate a traveling wave along the tube axis with a phase velocity substantially less than the speed of light, means for producing a beam of electrons with a path of travel along said axis, and means for confining said beam of electrons to a flow of relatively constant diameter within said path; said confining means including a series of axially-spaced radially-oriented radially polarized magnets for producing magnetic fields within said path, said magnetic fields having regions of relatively high magnetic flux density alternating with regions of substantially zero flux density along said path, and electrostatic focusing means for producing an electrostatic focusing field at each of said regions of substantially zero flux density, said electrostatic focusing means including a series of ring electrodes adapted to be charged to suitable potentials so as to form a series of electron lenses which have converging fields for said beam of electrons at said regions of substantially zero flux density.

14. In combination: an elongated traveling wave tube adapted to be excited by a signal wave and comprising an evacuated envelope containing a metallic circuit adapted to propagate a traveling wave along the tube axis with a phase velocity substantially less than the speed of light, means including a cathode for producing a beam of electrons with a path of travel along said axis, and means confining said beam of electrons to a relatively constant radius, r_0 , within said path; said confining means including a series of groups of magnets for producing a plurality of magnetic fields within said path, said magnetic fields having regions of relatively high magnetic flux density alternating with regions of relatively low magnetic flux density along said path, and electrostatic focusing means for producing an electrostatic focusing field at each of said regions of relatively low flux density; and a source of direct current potentials connected to said electrostatic focusing means for producing a predetermined electric flux density distribution along said tube axis; the relationship between the magnetic flux density distribution produced by said magnets and the electric flux density

distribution produced by said electrostatic focusing means being substantially equal to

$$\left[\frac{V''}{4V} + \frac{\eta}{8V} \left(B_z^2 - \frac{r_{00}^4}{r_0^4} B_{00}^2 \right) \right] V^{3/2} = \frac{I}{kr_0^2}$$

where V is the electric potential at any given point along the axis, V'' is the second derivative of said electric potential along the axis with respect to the distance therealong, η is the ratio between the electron charge and the electron mass, B_z is the axial component of the magnetic flux density at said point, B_{00} is the magnetic flux density at the origin of the electron flow, r_{00} is the radius of said cathode, I is the beam current in amperes, and k is equal to $4\sqrt{2\pi\epsilon_0\eta^{1/2}}$, where ϵ_0 represents the dielectric constant of free space.

15. A beam device comprising means for projecting a beam of electrically charged particles along a path within said device and means for focusing said beam into a focused flow along said path; said focusing means including a series of radially extending radially-polarized circumferentially-spaced magnets arranged in axially spaced sets for producing magnetic fields within said path, adjacent sets of said magnets being oppositely polarized, shunts of magnetically permeable material between said magnets in each set adjacent to said beam, and magnetic shunting means connecting adjacent portions of said magnets remote from said beam path whereby substantially all of the magnetic field of said portions of said magnets is concentrated along the path of said beam.

16. An elongated traveling wave tube adapted to be excited by a signal wave and comprising an evacuated envelope containing a helix adapted to propagate a traveling wave along the tube axis with a phase velocity substantially less than the speed of light, means for producing a beam of electrons with a path of travel along said axis, and means for focusing said beam of electrons along said path; said focusing means including a series of sets of radially oriented radially polarized bar magnets spaced along said path for producing magnetic fields within said path, each of said magnets in each of said sets having the same radial orientation, a plurality of magnetic shunting bars in substantially parallel orientation with respect to said axis and being disposed in contact with portions of said magnets remote from said beam path, and a plurality of magnetic shunting rings disposed each between said

beam and portions of each of said magnets of one set adjacent to said beam, whereby the magnetic fields of said magnets is concentrated along said beam path for improved focusing of said beam.

17. An evacuated beam device comprising means for projecting electrically charged particles along a path within said device and means for confining said particles to a beam of relatively constant diameter within said path; said confining means including a series of magnets for producing magnetic fields having at least three regions of relatively high magnetic flux density alternating with regions of substantially zero flux density along said path, and electrostatic focusing means for producing an electrostatic field at each of said regions of substantially zero flux density, said electrostatic focusing means including a series of rings adapted to be charged to suitable potentials so as to form a series of electron lenses which have their converging fields for the beam of charged particles at said regions of substantially zero flux density, the number of said rings being substantially twice the number of said magnets.

18. A traveling wave tube adapted to be excited by a signal wave and comprising an evacuated envelope containing a delayed line adapted to propagate said signal wave within said tube along an axis therein with a phase velocity substantially less than the speed of light, means for producing a relatively dense beam of electrons with a path of travel along said axis, and means for confining said beam in a focused flow of substantially constant diameter; said confining means including magnetic focusing means for producing magnetic fields having at least three regions of relatively high flux density alternating with regions of relatively low flux density along said path, and electrostatic means for producing an electrostatic focusing field at each of said regions of relatively low flux density, said magnetic focusing means comprising a series of permanent magnets of ferrite material.

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