

Dec. 12, 1961

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3,013,173

MAGNETIC BEAM FOCUSING METHOD AND APPARATUS

Filed Feb. 16, 1959

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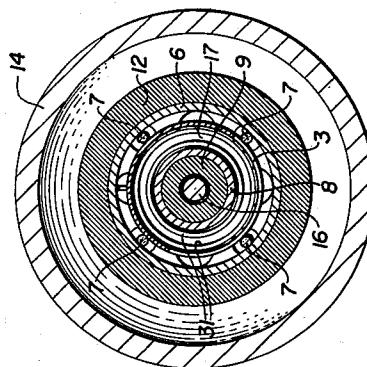
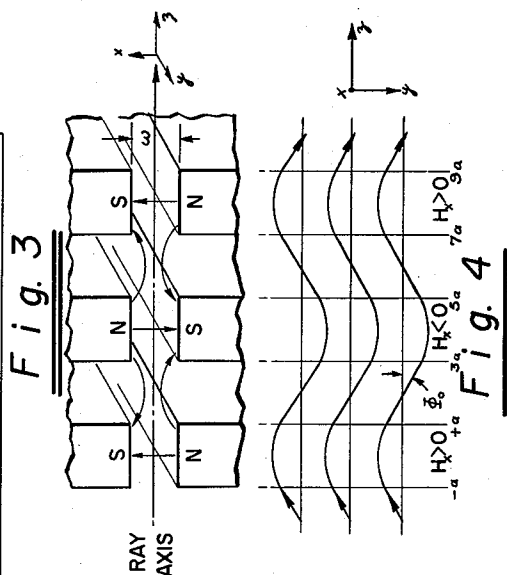
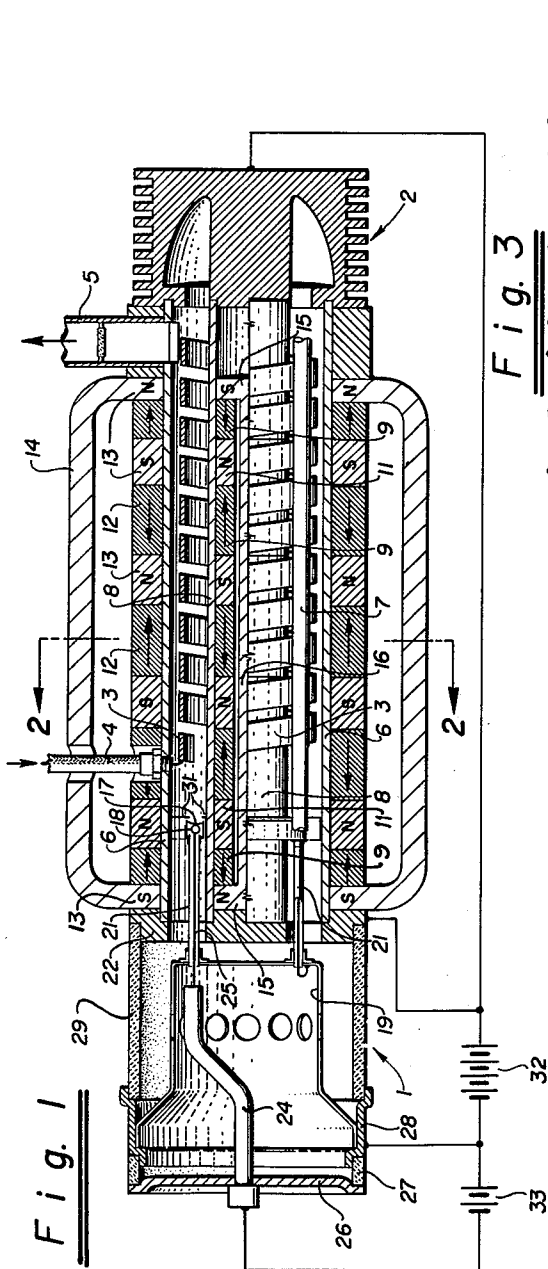


Fig. 2

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Dec. 12, 1961

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Fig. 5

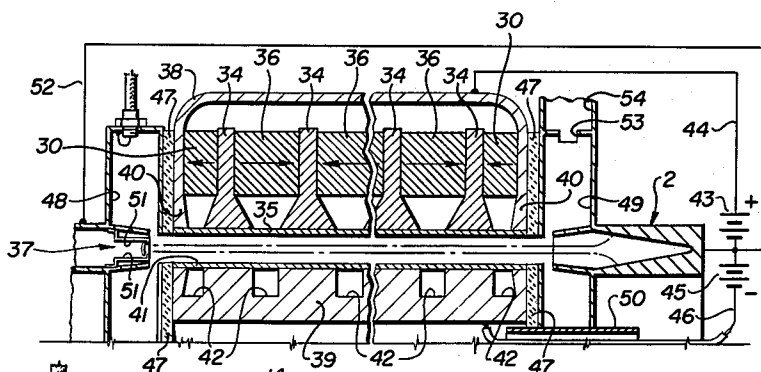


Fig. 6

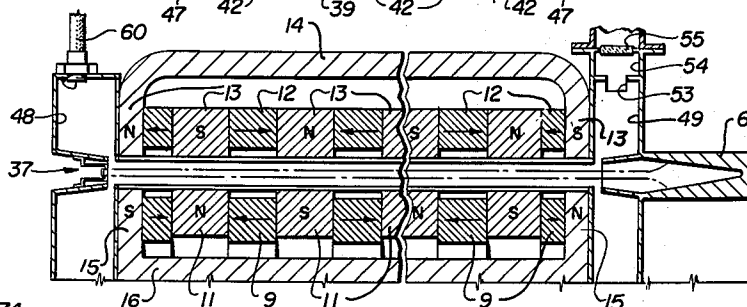


Fig. 7

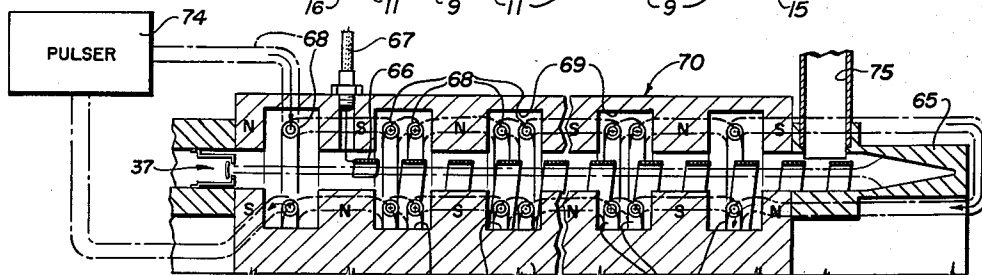
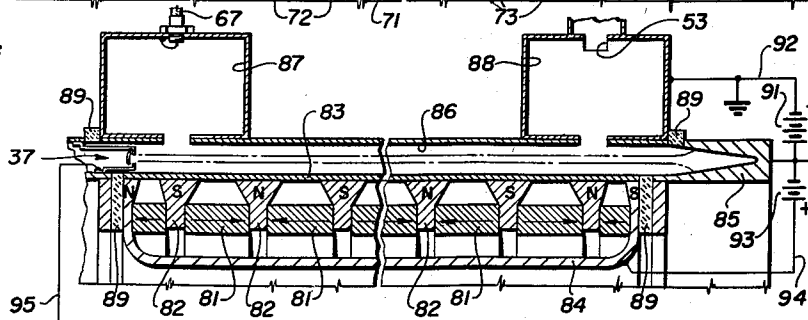


Fig. 8



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MAGNETIC BEAM FOCUSING METHOD AND APPARATUS

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Filed Feb. 16, 1959, Ser. No. 793,495
21 Claims. (Cl. 313—84)

The present invention relates in general to magnetic focusing of charged particle beams and more specifically, to a novel periodic magnetic beam deflection focusing method and apparatus. Such magnetic beam deflection focusing is especially useful for focusing relatively thin sheet or annular beams where it is desired to obtain high current density beams as are employed in high power, high frequency velocity modulation vacuum tubes, linear accelerators and the like.

Heretofore periodic magnetic focusing has been employed for focusing beams of charged particles. But in these prior art magnetic focusing schemes, the magnetic field has been directed axially of the beam. When the magnetic field is directed axially of the beam, the magnetic flux path length external of the magnet structure is relatively long such that relatively large magnet structures are required to produce the focusing field. Moreover, much of the magnetic flux which is generated is confined to spaces which are not occupied by the beam and thus this flux is ineffective for focusing the beam. In addition, the prior art periodic longitudinal magnet focusing method introduces an undesired coupling between the radial and azimuthal degrees of freedom in the beam resulting in beam instability at high current densities.

The present invention provides a novel magnetic beam focusing apparatus in which the focusing magnetic field is directed transversely to a beam such that the magnetic flux path is short thus requiring less magnet structure for focusing a given beam current. Moreover, the focusing magnet structure may be closely spaced to the beam whereby most of the magnetic energy outside of the magnet threads through spaces occupied by the beam. Such efficient use of the magnetic potential allows focusing of extremely high current density beam with a minimum of magnet structure.

The principal object of the present invention is to provide a periodic magnetic beam focusing method and apparatus which is capable of focusing high current density sheet beams with a minimum of required magnetic energy whereby the size, weight, and cost of the magnetic focusing structure may be minimized in use.

One feature of the present invention is the provision of a periodic magnetic beam focusing method and apparatus wherein a magnetic field is directed transversely of the beam path whereby high current density beams may be focused with a minimum of required magnetic energy.

Another feature of the present invention includes the provision of permanent magnets disposed on both sides of a sheet beam of charged particles whereby a transversely directed magnetic field is obtained for focusing of the beam.

Another feature of the present invention includes the provision of an electric field directed transversely of a sheet beam of charged particles, said electric field cooperating with a transversely directed magnetic field for focusing of the beam.

Another feature of the present invention includes the provision of a magnetic beam focusing structure for periodically focusing sheet beams in which permanent magnets are disposed on one side of the beam and a nonpermanent magnetic pole piece is disposed on the

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other side of the beam for obtaining a transversely directed focusing magnetic field.

Another feature of the present invention is the provision of a novel periodic magnetic deflection focusing apparatus and method wherein a low inductance conductive coil is disposed on one side of a sheet beam of charged particles; said low inductance coil adapted to be rapidly energized to produce a magnetic field directed transversely of the beam for focusing thereof.

Another feature of the present invention is the provision of a novel magnetic focusing structure for periodically focusing charged particle tubular beams wherein a permanent magnet structure is disposed within the hollow interior of the beam and a magnetic pole piece is disposed around the outside perimeter of the beam whereby a transversely directed focusing magnetic field is obtained while facilitating placement of beam field interaction structures around the beam.

Other features and advantages of the present invention will become apparent upon a perusal of the specification taken in connection with the accompanying drawings wherein,

FIG. 1 is a longitudinal cross-sectional view of a traveling wave tube utilizing the novel magnetic deflection focusing features of the present invention,

FIG. 2 is a cross-sectional view of a portion of the structure of FIG. 1 taken along line 2—2 in the direction of the arrows,

FIG. 3 is a perspective schematic diagram depicting the principle of operation of the focusing structure of the present invention,

FIG. 4 is a schematic diagram depicting the trajectories of the electrons in the plane of a sheet beam as it passes through a structure shown in FIG. 3,

FIG. 5 is a longitudinal cross-sectional view of a portion of a tube structure employing the features of the present invention,

FIG. 6 is a longitudinal cross-sectional view of a tube structure employing an embodiment of the present invention,

FIG. 7 is a longitudinal cross-sectional view of a portion of the tube structure employing the teachings of the present invention.

FIG. 8 is a longitudinal cross-sectional view of a portion of a tube employing an embodiment of the present invention, and

FIG. 9 is a longitudinal cross-sectional view of an alternative magnetic focusing structure for use in the present invention.

Referring now now to FIG. 1 there is shown a traveling wave tube amplifier employing the novel magnetic deflection focusing apparatus of the present invention. More specifically, an electron gun assembly 1 forms and projects an annular electron beam lengthwise of the tube structure, the electrons of said annular beam being collected within an annular recessed portion of a collector electrode 2 disposed at the other end of the tube. A helical conducting tape 3 forms the slow wave structure and is positioned circumscribing the outer peripheral edge of the annular beam, said beam being directed lengthwise of the helical slow wave structure 3.

R.F. energy, which it is desired to amplify, is coupled onto the helical slow wave structure 3 via the intermediary of a coaxial transmission line 4 having the center conductor connected directly to the helical tape 3. The R.F. energy is then propagated about the helical slow wave structure, the fields thereof interacting with the annular electron beam to produce amplification of the wave energy in accordance with conventional traveling wave tube principles. The amplified output energy of

he slow wave tube is coupled into an output waveguide and thence fed to a suitable load, not shown.

An outer tubular envelope 6 as of, for example, copper tubing is vacuum sealed at one end thereof to the electron gun assembly 1 and at the other end thereof to collector 2. The outer tubular envelope 6 serves to support and position the helical slow-wave structure 3 therewithin via a plurality of dielectric spacing rods 7 disposed longitudinally of the tube apparatus and between the outer tubular envelope 6 and the helix 3. The rods are preferably made of a good heat resistance dielectric material as of, for example, sapphire which can withstand high temperatures.

An inner tubular envelope 8 as of, for example, copper is vacuum sealed at its ends to the gun assembly 1 and collector assembly 2 respectively and is disposed within the hollow interior of the electron beam.

A plurality of alternately spaced annular permanent magnets 9, as of ferrite, and annular magnetic pole pieces 11, as of iron, are carried within the hollow interior of the inner tubular envelope 8. The permanent magnets 9 are arranged with polarities to produce opposite polarities of the consecutive longitudinally spaced nonpermanently magnetized pole pieces 11. Similarly a plurality of alternately longitudinally spaced annular permanent magnets 12 and annular magnetic pole pieces 13 are carried externally of the outer tubular envelope 6. The permanent magnets 12 are arranged to polarize the pole pieces 13 such that successive longitudinally spaced pole pieces 13 have opposite polarities.

The inner and outer permanent magnets 9 and 12 and pole pieces 11 and 13 are selected of substantially the same length and disposed in the proper relationship such that an outer magnetic pole 13 of a certain polarity will be disposed opposite an inner pole 11 of the opposite polarity to produce a dipole magnetic field which is directed transverse to the beam path. Since successive inner and outer pole pieces 11 and 13 are of opposite polarities, there is produced an alternating transverse dipole magnetic field longitudinally spaced of the beam path which is utilized for focusing the beam.

The permanent magnets 9 and 12 disposed at the ends of the magnet structure are made to have half the magnetomotive force of the other permanent magnets 9 and 12 as by making the end permanent 9 and 12 half length. Also the outer end pole pieces 13 and inner pole pieces 11 are made to have substantially twice the reluctance of the other similar pole pieces by making them somewhat less than half length.

A hollow cylindrical magnetic yoke 14 as of, for example, iron is carried externally of the outer tubular envelope 6 and completes the magnetic circuit between the ends of the alternately spaced permanent magnets 12 and pole pieces 13. Two disk-shaped end magnetic pole pieces 15 are disposed inside the inner tubular envelope 8 substantially at the ends of the alternately spaced magnetic members 9 and 11 for terminating the inner magnetic circuit. The two disk-shaped inner magnetic pole pieces 15 are interconnected via an internal magnetic core 16 threaded through the center of the annular magnetic members 9 and 11 for completing the magnetic circuit of the inner magnet assembly.

The electron gun assembly 1 includes a concave annular cathode emitter button 17. The emitter 17 is heated by a directly heated filamentary heater 18 disposed on the backside of the cathode emitter 17. The cathode emitter 17 and heater 18 are supported from a flared tubular cathode base support 19 via the intermediary of four hollow cylindrical cathode support posts 21 protruding through four openings in a main body transverse header 22. The main body header 22 serves to support the inner central magnet structure disposed within the inner tubular envelope 8.

One end of the heater 18 is electrically connected to

the cathode button 17 and cathode support 19. The other end of the heater element is electrically connected to a centrally disposed heater electrode base support post 24 via the intermediary of a heater lead 25 carried within and insulated from one of the hollow cathode support posts 21. Heater support post 24 is sealed in a vacuum tight manner to a transverse end header 26 thereby closing off one end of the tube envelope. The header 26 is vacuum sealed at its peripheral edge to a cylindrical dielectric ring 27, as of ceramic, which in turn is secured in a vacuum tight manner at its other end to an annular metallic cathode support ring 28 serving to carry therefrom the cathode base support 19 from the inside surface thereof. The cathode support ring 28 in turn is sealed in a vacuum tight manner to a dielectric cathode insulating ring 29 which in turn is sealed at its other end to the main body header 22. The cathode insulator 29 is made of a good dielectric material as of, for example, alumina ceramic and is designed to withstand and hold off the high anode to cathode voltage utilized for accelerating the beam.

An annular accelerating electrode 31 is closely spaced to the annular cathode emitter 17 in overhanging relationship thereto and is provided with an annular opening therein in alignment with the cathode 17 for accelerating the emitted electrons and forming them into an annular beam. The annular accelerating electrode 31 is connected to the inner and outer tubular envelopes 6 and 8 respectively and thus preferably operates at ground potential.

Operating potentials are applied to the heater element 18 via battery 33. The accelerating potential is applied between cathode and anode via battery 32. The positive terminal of battery 32 is preferably grounded such that the body of the tube operates at ground potential.

The operation of the novel focusing structure will now be described with regard to FIGS. 3 and 4. More specifically, a charged particle starting with a longitudinal velocity v_z at $z=0$ and having zero transverse velocity, v_y , will experience, due to passing through half of the transverse dipole magnetic field H_x between the first pair of north and south pole pieces, a certain curvature such that at $z=+a$, the particle will have a certain component of velocity v_2 transverse to the ray axis which is herein defined to mean the direction of mean motion of the particles making up the beam. If the particle is moving in the plane of symmetry of the magnetic structure, the particle will not see any longitudinal magnetic field between $z=a$ and $z=3a$ and therefore will experience no focusing force f_x at right angles to the plane of the beam.

However, if the charged particle is above or below the midplane, $x=0$, it will experience a magnetic focusing effect varying in strength in proportion to its displacement from the midplane. The focusing force tending to move the charged particle back to the midplane will be proportional to $\bar{v}_y \times B_z$ where $\bar{v}_y$ is the transverse velocity of the charged particles and B_z is the strength of the longitudinal component of the magnetic field B . Since the longitudinal magnetic field B_z becomes stronger, the greater the x displacement of the charged particle from the midplane, the stronger will be the focusing effect.

Therefore, the focusing action arises from the cooperation of two components of magnetic field. Firstly, it is proportional to the transverse velocity v_y of the charged particle obtained from beam interaction with the transversely directed component of the magnetic field B_x and it is, secondly, proportional to the strength of the longitudinal component of the magnetic field B_z associated with the fringe field. B_z is off, but near to, the plane of symmetry and is strongest between longitudinally spaced adjacent poles. The strength of B is determined substantially by the configuration and strength of the transverse field B_x at the plane of symmetry.

For a sheet beam of charged particles, the particle trajectories will undulate in the $z-y$ plane about the ray axis, the transverse undulations being in the plane of

the beam. Another variety of the sheet beam is an annular beam as utilized in the traveling wave tube shown and described with regard in FIG. 1. In an annular beam case focused with longitudinal and transverse magnetic fields, the charged particles undulate in an azimuthal direction about the ray axes.

For stable beam conditions, it is desirable that the maximum angle ϕ_0 that the beam particles make with the ray axis in the $y-z$ plane not exceed 0.86 radian or approximately 50 degrees. ϕ_0 is related to the beam parameters as follows:

$$\sin \phi_0 = \sqrt{\frac{e}{2mV_0}} \psi_x$$

where e is the charge on the particle, m is the mass of the particle, V_0 is the beam voltage, and ψ_x is the transverse magnetic flux per unit of beam width due to one-half of any one of the transverse magnetic pole pairs. It would normally be advisable to arrange that the ray axis should be substantially perpendicular to the contours of constant magnetic field intensity, i.e. in the z -direction, but appropriate injection conditions could provide for the ray axis to have a component parallel to these contours, i.e. in the y -direction, if the operation of the tube made this desirable.

One suitable method of injecting the electron beam is shown in FIG. 1. The cathode 17 and accelerating anode 31 are closely spaced to the longitudinal and transverse midpoint of the second pair of transversely disposed opposite magnetic poles 11 and 13 such that as the electron beam issues through the annular opening in the anode 31 it has substantially zero transverse velocity v_y . Also it is desirable to initiate the beam opposite a pair of poles which are removed from end effects of the magnetic focusing structure. It has been found that the second pair of transverse poles are sufficiently removed from end effects to prevent undesired perturbations in the beam. On the other hand, magnetic end effects at the termination end of the beam are not as critical as the beam is soon collected and instabilities of the beam in the collector region are actually desired to prevent localized overheating of the collector.

Referring now to FIG. 5 there is shown another embodiment of the present invention. FIG. 5 is a partial cross-sectional view taken into the center line of a klystron tube apparatus showing primarily the focusing structure. More specifically, the focusing structure of FIG. 5 utilizes a combined transverse dipole magnetic and transverse electric focusing field for focusing the beam. The transverse dipole magnetic field is applied by a plurality of annular magnetic pole pieces 34 as of, for example, soft iron. The pole pieces 34 are disposed circumscribing an outer vacuum tight tubular envelope 35 as of, for example, copper. The pole pieces 34 are energized by annular permanent magnets 36. The permanent magnets 36 are arranged to produce successive poles of opposite polarity spaced longitudinally of an annular beam produced by a suitable electron gun assembly 37. A cylindrical magnetic yoke 38 as of, for example, soft iron terminates the outer magnetic circuit.

An inner cylindrical magnetic pole piece 39 is disposed coaxially of the beam and within a circumscribing inner tubular metallic vacuum envelope 41. The inner pole piece 39 is made of a highly magnetic permeable material as of, for example, soft iron to function as a magnetic mirror for having inducing therein poles of opposite polarity from the outer poles 34 circumscribing the pole piece 39. The inner pole 39 is provided with a plurality of annular recesses 42. The recesses 42 are placed to register with the permanent magnets 36 of the outer magnetic focusing structure. The annular recesses 42 serve to accentuate and more clearly define the induced poles in the pole piece 39.

The magnetic mirror-like effect of the pole piece 39 causes the beam equilibrium point, $x=0$, of purely transverse magnetic focusing to approach very closely to the

surface of the inner magnetic pole 39. A transverse electric field is applied between the inner and outer annular envelopes 41 and 35 respectively to move the stable position of the beam outwardly of the pole piece 39 to a point substantially midway between the transverse magnetic pole pieces 34 and 39 respectively.

The transverse electric field is produced by a positive potential applied to the outside tubular envelope 35 via a voltage source 43 and lead 44 and a negative potential applied to the inner tubular envelope 41 with respect to the beam voltage via a voltage source 45 and lead 46. The inner tubular envelope 41 and outer tubular envelope 35 are insulated from the beam potential and from each other via insulating members 47 disposed at the ends of the magnet assemblies. The insulating members 47 are sealed in a vacuum tight manner and form a portion of the tubes vacuum envelope which also includes the input cavity resonator 48 and output resonator 49. A hollow tubular post 50 is inserted centrally of the output cavity 49 to allow passage therethrough of the insulated lead 46 for applying the operating potential to the pole piece 39. The accelerating electrode 51 of the gun assembly 37 is preferably operated at the same potential as the input cavity 48, beam collector 2, and the output cavity 49. Lead 52 serves to interconnect these equal potential elements.

In operation, the annular electron beam is emitted and formed at a location closely spaced to the beginning of the magnet focusing assembly. The provision of the half strength permanent magnets 30 at the ends of the focusing structure and somewhat less than half-width end pole pieces 40 allows the beam to be initiated with zero transverse velocity at a point such that the beam in crossing the transverse focusing magnetic field B_x produced by the first pair of half strength pole pieces 40 and 39 will pass through substantially one-half of the magnetic field lines ψ_x that it will pass through in the next successive pair of transverse poles 34 and 37. This is another appropriate zero mean deflection beam injection condition. As the beam progresses down the length of the tube, it will be forced radially inwardly of the desired path by the action of the transverse B_x and longitudinal B_z magnetic field components and it will be forced radially outwardly of the desired path by the action of the electric focusing field. By properly balancing the electric and magnetic fields, the beam will be confined to a desired path substantially for its entire length within the magnet structure.

The R.F. energy, it is desired to amplify, is fed into the input cavity 48 to produce velocity modulation of the beam passable therethrough. The velocity modulation is transformed into current density modulation with time. As the beam passes through the output cavity 49, it will excite the cavity 49 in accordance with normal klystron principles to produce a greatly amplified R.F. signal. The amplified R.F. signal is coupled outwardly of the output cavity 49 via output coupling iris 53 and waveguide 54 to a suitable load, not shown. The combined electrostatic and magnetic focusing structure described with regard to FIG. 5 has the advantage that the complexity of the focusing structure disposed inwardly of the inner tubular envelope 41 may be simplified over the focusing structure described with regard to FIG. 1.

Referring now to FIG. 6 there is shown a klystron amplifier embodying the transverse magnetic focusing previously described with regard to the traveling wave tube of FIG. 1. Similar reference numerals will be utilized throughout for describing similar structure. In the apparatus of FIG. 6, R.F. energy which it is desired to amplify is fed to the input cavity 48 via coaxial line 60.

An annular beam formed by the electron gun assembly 37 is projected through the re-entrant portion of the input cavity resonator 48 wherein it interacts with the R.F. electromagnetic fields therewithin to produce velocity modulation of the beam. The beam of electrons is focused by a magnetic field produced in the same manner as the beam focusing field previously described in the structure of FIG. 1. The beam emerges from the end

of the magnet focusing assembly and passes through the output cavity resonator 49 and is collected by a collector assembly 61. In passing through the output cavity 49, the current density modulated beam excites the electromagnetic fields within the cavity 49. R.F. energy is coupled outwardly of cavity 49 through output iris 53, waveguide 54 and vacuum sealed R.F. window 55 to a load, not shown.

Referring now to FIG. 7 there is shown another embodiment of the present invention in which transverse and longitudinal magnetic focusing fields utilized for focusing of an annular electron beam are provided by running high electrical currents through suitably wound coils, described below. More specifically, an electron gun assembly 37 forms and projects an annular electron beam longitudinally of the tube apparatus. The beam is collected at the terminating end of the tube in an annular collector 65. A conducting tape helix 66 is positioned circumscribing the annular beam and closely spaced thereto for electromagnetic interaction between a wave traveling on the helix and the electron beam passable therealong. R.F. energy is applied to the helix 66 via a coaxial line 67, the inner conductor thereof being connected to the helix 66.

The annular beam is focused by passing a high electrical current through a low inductance outer coil 68 disposed within a plurality of suitable annular recesses 69 in an outer annular magnetic pole piece 70. The pole piece 70 is disposed circumscribing and closely spaced to the outer peripheral edge of the annular electron beam. The outer coil 68 includes a plurality of loops spaced longitudinally of the focusing structure. The current is directed through successive loops wound such that successive land portions of the outer pole piece 70, extending between successive current loops, are induced to have opposite magnetic polarities. An inner magnetic pole piece 71 is similarly recessed at 72 to carry therewithin a low inductance coil 73 preferably series connected with the outer coil 68. As in the outside pole piece 69, the inside pole piece 72 has the current directed in the individual loops to produce successive magnetic poles of opposite polarity longitudinally of the tube apparatus and to produce transversely disposed pole pairs of opposite polarities yielding strong dipole magnetic fields transverse to the longitudinal axis of the beam.

The coils 68 and 73 are preferably connected in series with a suitable current pulser 74 for pulsing high currents through the coils to produce a pulsed dipole magnetic focusing field. A pulsed magnetic focusing field has the advantage that a minimum of relatively heavy magnetic material is required and thus the weight and size of the magnet focusing assembly may be minimized for focusing pulsed beams where the focusing field is only required for a small portion of the time. In such a case, the coils 68 and 73 and pulser 74 may be suitably sequenced with operation of the electron gun assembly 37 such that the coils 68 and 73 are energized during the time the beam current is on.

In operation, electromagnetic energy which it is desired to amplify is fed onto the tape helix 66 via coaxial line 67. The wave energy propagates along the helix 66 interacting with the electron beam to produce amplification of the wave, the amplified wave being extracted from the helix at the termination thereof and propagated via waveguide 75 to a suitable load, not shown.

Although the above described current energized magnetic focusing structure has been described having cylindrical symmetry, if desired, the magnet structure could be built with helical symmetry.

Referring now to FIG. 8 there is shown another embodiment of the present invention utilizing transverse magnetic and electric fields for focusing of the beam. More specifically, alternate longitudinally spaced annular permanent magnets 81 and pole pieces 82 are longi-

tudinally arranged within the interior of an inner tubular envelope 83. The permanent magnets 81 are arranged with respect to the annular pole pieces 82 to produce successive longitudinal magnetic poles of opposite polarity. The inner magnet structure is terminated by a tubular yoke 84 having flared ends forming the terminating end pole pieces for minimizing magnetic end effects. An electron gun assembly 37 projects an annular beam over the outer peripheral edge of the inner tubular envelope 83, the beam being collected in an annular collector 85 disposed at the end of the tube apparatus.

An outer cylindrical magnetic pole piece 86 as of, for example, soft iron circumscribes the outer periphery of the annular beam. The pole piece 86 is provided with two annular slots therein forming the beam field interaction gap and the slots are circumscribed by cylindrical re-entrant cavities 87 and 88 forming the input and output cavity resonators respectively. Annular insulators 89 are vacuum sealed to adjoining elements in a vacuum tight manner for insulating the inner tubular envelope 83 and outer pole piece 86 from the collector 85 and electron gun assembly 37.

A transverse electric field is provided by operating the inner tubular envelope 83 at a more positive potential than the outer magnetic pole piece 86 and the collector 85. The more negative operating potential is applied to the outer pole piece 86 via voltage source 91 and lead 92. The more positive potential is applied to the inner tubular envelope 83 via positive voltage source 93 and lead 94. The collector 85 and electron accelerating electrode of the gun assembly 37 are preferably operated at the same potential and thus are interconnected via lead 95.

As it was found with the structure of FIG. 5, the magnetic focusing structure of FIG. 6, alone, will tend to produce a stable beam path which is substantially at the surface of the outer magnetic pole piece 86. Therefore the transverse electric field has been provided to move the beam radially inwardly of the pole piece 86 to a desired stable position to minimize unwanted beam interception by the tube envelope.

In operation input energy, which it is desired to amplify, is fed to the input cavity 87 via coaxial input 67. Electromagnetic fields of the cavity 86 interact with the electron beam to produce velocity modulation thereof. In the time it takes the velocity modulated beam to reach the output cavity 88, the velocity modulation has been transformed into current density modulation which excites the output cavity to produce greatly amplified output signals. The amplified R.F. energy is coupled outwardly of the output cavity 88 via iris 53 and thence propagated to a suitable load, not shown.

In a preferred embodiment of this invention, the beam field interaction gaps are disposed opposite the center of pole pieces 82 to thereby minimize undesired magnetic focusing perturbations produced by the gap in the pole piece 86. This particular embodiment of the present invention has advantage in that there is produced a minimum of physical interference between the focusing structure and the beam field interaction cavities such that a plurality of cavities may be physically disposed about the beam for interaction therewith without seriously physically interfering with the focusing structure.

Referring now to FIG. 9 there is shown an alternative magnetic focusing structure for use in practicing the present invention. In this structure the yoke interconnecting the ends of the structure is dispensed with thereby reducing the weight and size of the magnetic focusing structure. In particular, a plurality of alternately spaced annular concentric inner and outer permanent magnets 101 and 102 respectively are arranged longitudinally of an annular beam. A plurality of annular concentric inner and outer magnetic pole pieces 103 and 104 respectively are disposed between successive permanent magnets 101 and 102 to produce successive poles of opposite polarity

longitudinally of the beam. The magnets 101 and 102 are arranged to produce pairs of magnetic poles transversely of the beam having opposite polarity. In this manner the alternating transverse dipole magnetic focusing field is produced.

The pairs of pole pieces 103 and 104 disposed at the ends of the focusing structure are designed to have approximately twice the reluctance of the interior pole pairs such that only approximately one-half as much magnetic flux passes between the end pairs of poles as passes between centrally disposed pole pairs. The exact dimensions of the end pole pairs are best determined by experiment but are somewhat less than one-half the longitudinal dimensions of the centrally disposed pole pairs. When the focusing structure is as shown in FIG. 9, a zero mean deflection beam injection condition is obtained. Other beam injection conditions are allowable.

Since many changes could be made in the above construction and many apparently widely different embodiments of this invention could be made without departing from the scope thereof, it is intended that all matter contained in the above description or shown in the accompanying drawings shall be interpreted as illustrative and not in a limiting sense.

What is claimed is:

1. The method of focusing a beam of charged particles including the steps of, directing a periodic dipolar magnetic field substantially transversely of the beam, and alternating the polarity of the magnetic field lengthwise of the beam whereby the component of magnetic field transverse to the mean direction of the beam deflects the beam in one direction and the longitudinal fringing component between successive alternate polarities of the magnetic field acting on the deflected particles produces a force on the particles for focusing of the beam.

2. The method according to claim 1 including the step of, directing an electric field transversely of the beam for focusing thereof.

3. The method according to claim 1 including the step of, repetitively pulsing on the magnetic field.

4. In a charged particle discharge device, means forming an evacuable envelope, means for forming a beam of charged particles within said envelope, means for collecting the beam defining a path of particle flow between said beam forming means and said beam collecting means, means for producing a periodic dipole magnetic field of alternating polarity longitudinally of the beam and for directing the dipole magnetic field transversely of the beam path for interacting with the beam to produce focusing thereof.

5. In an apparatus as claimed in claim 4 including, means for providing an electric field directed transversely of the beam for further focusing of the beam.

6. Apparatus according to claim 4 including, means for pulsing the beam, and means for pulsing the periodic magnetic field in synchronism with the beam pulses.

7. Apparatus according to claim 4 wherein said magnetic field producing and directing means includes a plurality of permanent magnets disposed along at least one side of the beam path and wherein said permanent magnets energize opposite polarity poles transversely of the beam path and further provide magnetic fields of alternating polarity on one side of the beam path longitudinally thereof.

8. The apparatus according to claim 4 wherein said magnetic field producing and directing means includes a plurality of permanent magnets disposed straddling the beam path.

9. The apparatus according to claim 7 wherein at least one of said permanent magnets is placed on one side of the beam path and positioned opposite a nonpermanently magnetized pole piece on the other side of the beam

whereby magnetic poles of polarity opposite to the poles of said permanent magnet poles are induced in said pole pieces transversely of the beam path.

10. The apparatus according to claim 9 including means for applying an electric potential difference transversely of the beam to focus the beam away from said nonpermanently magnetized pole piece.

11. The apparatus according to claim 6 wherein said means for pulsing the focusing magnetic field includes a low inductance coil disposed along the beam path at least on one side thereof.

12. The apparatus according to claim 11 including, a highly magnetic permeable member disposed adjacent said low inductance coil for inducing therein the magnetic poles of alternating polarity longitudinally of the beam path.

13. Apparatus according to claim 12 wherein said magnetic permeable member is recessed and carries within the recess said low inductance coil.

14. Apparatus according to claim 13 wherein the recess in said magnetic permeable member is helical.

15. Apparatus according to claim 4 wherein said magnetic field producing and directing means includes, a first set of permanent magnets, a first set of magnetic pole pieces, said first set of permanent magnets and pole pieces being alternately spaced in abutting relationship along the beam path and being disposed at least on one side of the beam path, and said first set of permanent magnets providing magnetic poles of alternating polarity lengthwise of the beam path.

16. Apparatus according to claim 15 including, a second set of permanent magnets, a second set of magnetic pole pieces, said second sets of permanent magnets and pole pieces being alternately spaced in abutting relationship along the beam path on the side thereof opposite from said first permanent magnets and pole pieces, said second set of permanent magnets providing magnetic poles of alternating polarity lengthwise of the beam path, said second sets of permanent magnets and pole pieces being disposed with their magnetic poles in approximate transverse registry with the magnetic poles of said first set of permanent magnets and pole pieces, and said registered poles being of opposite polarity transversely of the beam path.

17. Apparatus according to claim 16 including, terminating magnetic pole pieces disposed at the end of each of said first and second sets of permanent magnets and pole pieces, and wherein the magnetic reluctance of said terminating pole pieces is approximately twice the reluctance of other register pole pieces.

18. The method according to claim 1 wherein said beam is a sheet beam being dimensioned to have an extent transverse to its longitudinal axis greater than twice its thickness.

19. The method according to claim 1 wherein the beam is an annular sheet beam.

20. The apparatus according to claim 4 wherein the beam is a sheet beam being dimensioned to have an extent transverse to its longitudinal axis greater than twice its thickness.

21. The apparatus according to claim 4 wherein the beam is an annular sheet beam.

References Cited in the file of this patent

UNITED STATES PATENTS

2,439,401	Smith	Apr. 13, 1948
2,808,510	Norton	Oct. 1, 1957
2,844,754	Cioffi	July 22, 1958
2,852,715	Rich	Sept. 16, 1958
2,855,537	Mendel	Oct. 7, 1958
2,860,278	Cook et al.	Nov. 11, 1958