

Jan. 27, 1959

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2,871,395

MAGNETIC STRUCTURES FOR TRAVELING WAVE TUBES

Filed Oct. 27, 1955

4 Sheets-Sheet 1

FIG. 1

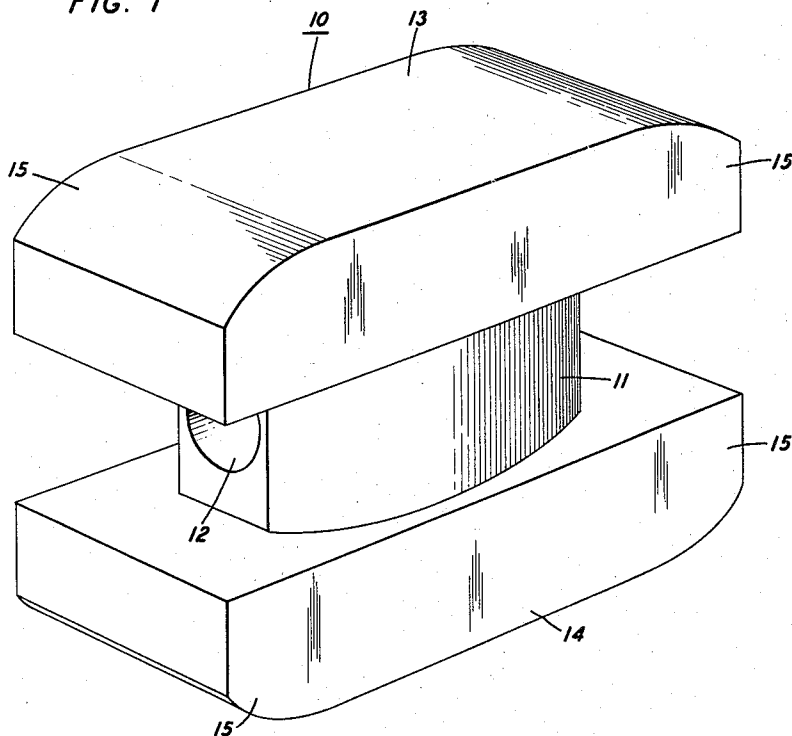
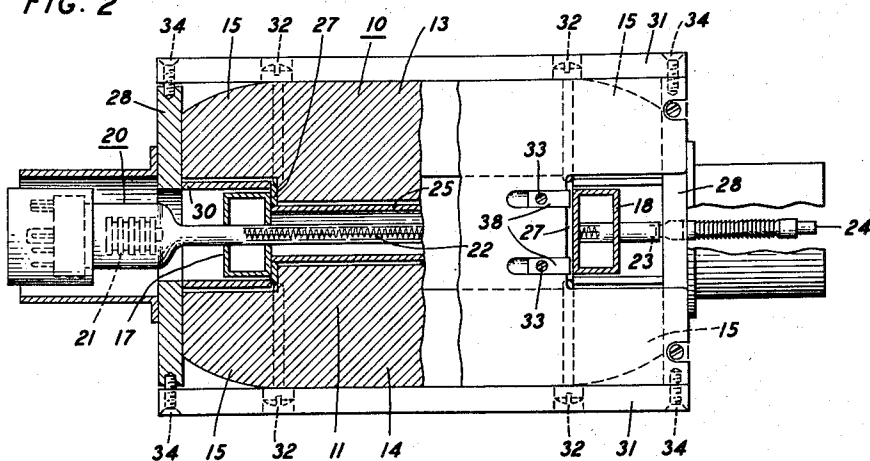


FIG. 2



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FIG. 3

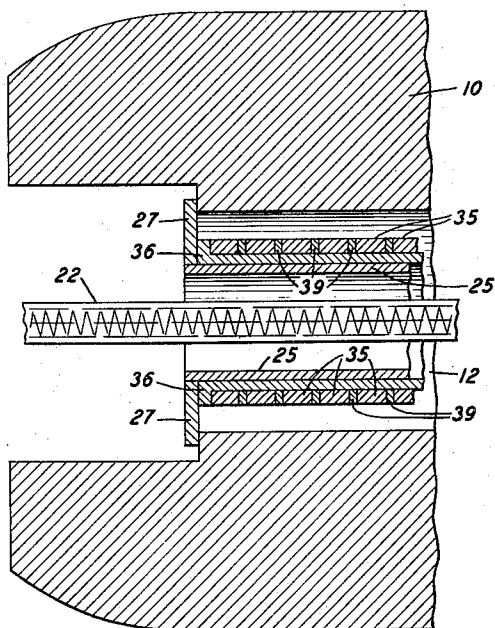
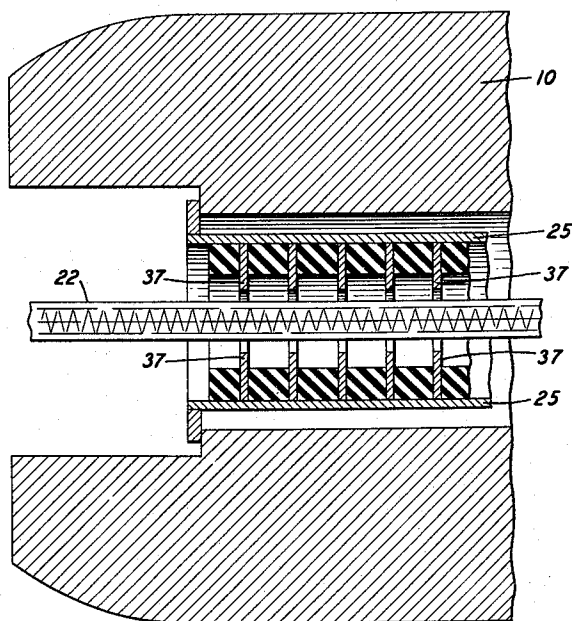


FIG. 4



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FIG. 5

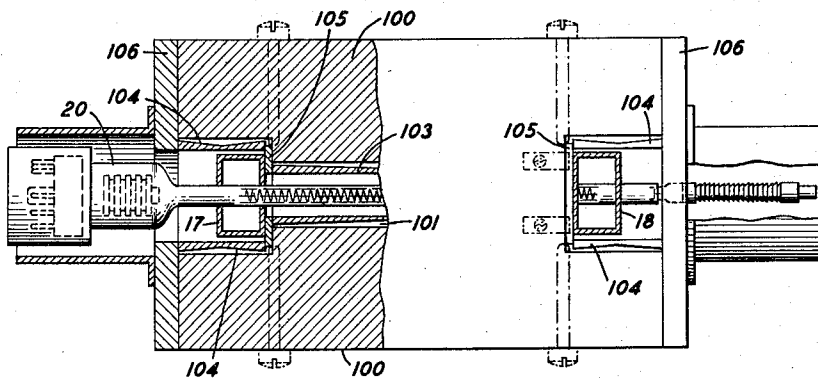
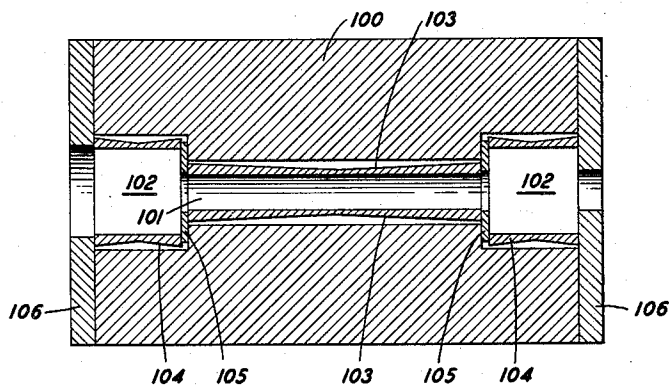


FIG. 6



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FIG. 7

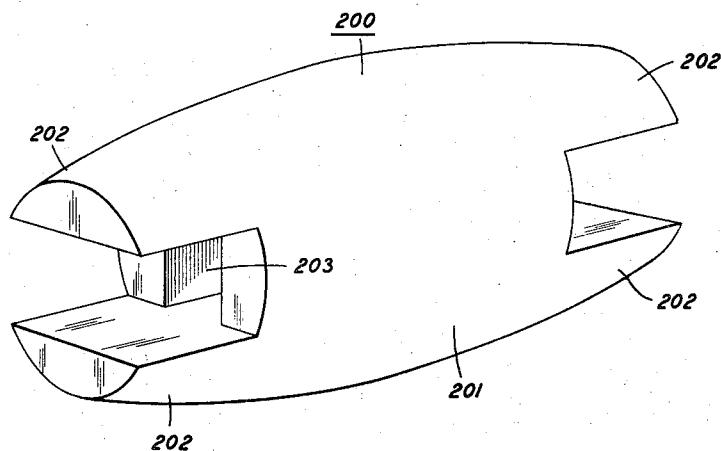
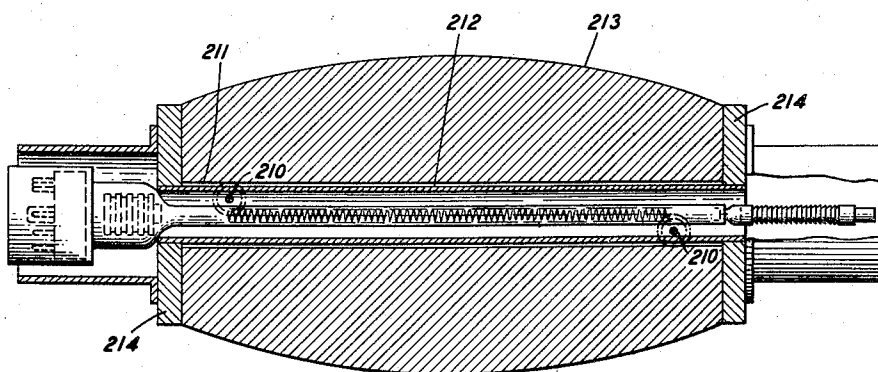


FIG. 8



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MAGNETIC STRUCTURES FOR TRAVELING
WAVE TUBES

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14 Claims. (Cl. 315—3.5)

This invention relates to apparatus including magnetic structures, and more particularly to such apparatus including traveling wave tubes wherein an electron beam is focused by a magnetic field along a relatively long path.

In certain electron discharge devices, such as traveling wave tubes, an electron stream is projected into an interaction space generally defined by a helix, where it is made to interact with an electromagnetic wave traveling along the helix. Optimum operation is achieved when the electron stream is confined to a substantially cylindrical form having electrons at its radial extremities close to but not impinging the helix throughout the interaction space. It has been the practice to establish a longitudinal magnetic field along the path of electron flow to minimize transverse components caused chiefly by space charge effects and thus to confine the beam as desired.

It is an object of this invention to improve the magnetic focusing of electron beams in electron discharge devices such as traveling wave tubes.

More specifically it is an object of this invention to provide a magnetic field which will focus an electron stream over a relatively long path, confining the stream to a uniform shape within narrow limits.

Another object of this invention is to provide a straight magnetic field of sufficient strength to achieve the desired focusing of an electron beam while reducing the size and weight of the focusing equipment.

In the past, Brillouin type focusing has been employed in order to control high density electron beams. In such focusing, the electron gun of the discharge device is enclosed in a magnetic shield, and the electrons are urged in a helical path as they leave the shielded region. A longitudinal field is encountered in the drift space of the device, and electrons entering this field attain an angular velocity proportional to the difference in magnetic flux encountered in going from the shielded region into the field region. The inward or focusing force per charge is proportional to the product of the angular velocity and the longitudinal magnetic field or effectively the square of the magnetic field. This inward force is adjusted to counterbalance exactly the sum of outward mutually repulsive forces of the electrons, generally described as space charge forces, and the outward centrifugal force of the spiraling electrons.

Priorly, in order to provide a uniform longitudinal magnetic field of sufficient strength to offset the large space charge forces existing in an electron stream of high density over a relatively long electron path, the permanent magnets required were many times the weight and size of the device employing this method.

From the standpoints of expense, compactness and portability, among others, it is desirable, therefore, to reduce the size and weight of the focusing equipment.

In order to attain the precise degree of focusing desired without the need for employing large and cumbersome magnets, there has been suggested a system of periodic focusing to overcome the difficulties encountered in

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straight field focusing. In such a system, as described in my Patent No. 2,844,754, issued July 22, 1958, a series of pole pieces having successively opposite polarity is deployed along the path of electron flow to establish a succession of axially symmetric regions of longitudinal magnetic field. Concentration of the field in such a succession of relatively short regions rather than a uniform field over a relatively long region, as in conventional straight field permanent magnets, permits a reduction in total magnet size and weight while maintaining the desired field distribution.

I have discovered, however, that the straight field air gap volume may be reduced in dimensions, in accordance with this invention, to those obtainable with periodic field structures for the same focusing requirements and that the straight field magnet weight and volume is then comparable to that of the periodic field structure. In so doing, the benefits of a straight field can be achieved without the encumbering weight and volume of prior straight magnetic field devices.

The present invention achieves this objective, among others, by employing a single permanent magnet extending over the length of the interaction space of the traveling wave tube and having an axial cylindrical hole through the magnetic material concentric with the longitudinal axis of the magnet, in which axial hole the helical conductor of the traveling wave tube is positioned. The required volume of uniform air gap field can be developed within this hole.

In one specific illustrative embodiment of this invention, the permanent magnet has a generally elliptical contour. The magnetization of an ellipsoid is uniform throughout, and the lines of force therein are straight and parallel to the major axis. Since the flux density, B , is constant over the entire length of the ellipsoid, the field intensity or magnetizing force, H , is also constant. As is well known, the field through an aperture in a magnetic material is the same as the field in the magnetic material. Thus the field intensity through an aperture concentric with the major axis of the ellipsoid is constant and equal to the field intensity in the permanent magnetic material of the ellipsoid.

For any given (B , H) point of operation on the magnetization curve, the ellipsoid, in contradistinction to other configurations, has the minimum possible magnet weight to satisfy uniform field requirements. An aperture through the ellipsoid increases its permeance and consequently requires an increase in its weight, but only by a negligible amount. In traveling wave tube applications it may be desirable to attain a magnetic field intensity of 600 oersteds for example. A suitable permanent magnet material for Brillouin fields of 600 oersteds is Alnico VI, an iron alloy containing aluminum, nickel, cobalt, copper and titanium, since it develops its optimum energy-product at a point having coordinates of flux density and field intensity of 6000 gauss and 600 oersteds, respectively. I have found that in specific illustrative embodiments of this invention wherein the permanent magnet member is an ellipsoid of Alnico VI, for a length of aperture concentric with the major axis of 7.5 inches, the required diameter of the minor axes is 2.5 inches to produce the desired field within the aperture. The resultant volume of magnetic material to produce the desired straight magnetic field in the aperture is comparable to the total volume of periodic field magnetic materials and is considerably less than the volume of prior straight field magnets. The weight, of course, is reduced proportionately. A cylindrical flux guide encompasses the interaction circuit within the aperture to provide for field rectilinearity adjustments of the flux guide position.

Alternatively, in another specific illustrative embodi-

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ment of this invention, the ellipsoidal shape may be approximated by employing a rectangular permanent magnet and by shaping the flux guide to compensate for leakage flux, thereby attaining the desired magnetic field uniformity.

It is one feature of this invention that traveling wave tube apparatus comprise an elongated permanent magnet having an aperture concentric with the longitudinal axis of the magnet to provide a uniform magnetic field in the aperture for guidance of an electron stream there-through, the elongated electrical conductor of the tube being positioned in the aperture.

It is another feature of certain specific illustrative embodiments of this invention that the permanent magnet be shaped to insure uniformity of the magnetic field through the aperture. More specifically, in accordance with this feature of the invention, the single magnet in which the tube is positioned may be of an elliptical cross section.

It is a further feature of this invention that a flux guide be provided within the aperture to provide for field rectilinearity adjustments.

It is still another feature of certain specific illustrative embodiments of this invention that the flux guide be shaped to insure uniformity of the magnetic field through the aperture.

A complete understanding of this invention and of the various features thereof may be gained from consideration of the following detailed description and the accompanying drawing, in which:

Fig. 1 is a perspective view of a permanent magnet utilized in one specific embodiment of this invention;

Fig. 2 is a side view partly in section of apparatus utilized in one specific illustrative embodiment of this invention, employing the permanent magnet of Fig. 1;

Fig. 3 is an enlarged partial view in section showing additional apparatus which may be utilized in the aperture of the permanent magnet in accordance with one specific illustrative embodiment of this invention;

Fig. 4 is another enlarged partial view in section showing additional apparatus in accordance with another specific illustrative embodiment of this invention;

Fig. 5 is a side view partly in section of apparatus utilized in accordance with another specific embodiment of this invention;

Fig. 6 is a side view in section illustrating the shape of the flux guides utilized in the embodiment shown in Fig. 5;

Fig. 7 is a perspective view illustrating a variation in contour of the permanent magnet of Fig. 1 as utilized in another specific illustrative embodiment of this invention; and

Fig. 8 is a side view in section of apparatus including a form of the permanent magnet of Fig. 7.

One specific illustrative embodiment of this invention is depicted in Fig. 2 and comprises a permanent magnet body 10, best seen in the perspective view of Fig. 1. As seen in Fig. 1 the permanent magnet member 10 comprises a center section 11 having an elliptical cross section and a central aperture 12 axially therethrough. An upper section 13 and a lower section 14 are positioned on the center section 10, the upper and lower sections 13 and 14 having planar sides which extend beyond the elliptically shaped sides of the center section 11 and having flat top and bottom portions adjacent the center section 10. Additionally the upper and lower sections 13 and 14 have portions 15 extending beyond the ends of the center section and having elliptically shaped outer surfaces; the portions 15 define bridging extensions for the magnetic member 10. The magnetic member 10 may advantageously be a single integral unit, two equal sections divided by a plane through the major axis of center section 11, or each of the center, upper, and lower sections may be distinct, the three sections being joined

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together to define the member 10. The magnetic member may advantageously be of a magnetic material having a high optimum energy product such as the materials known in the art as Alnico V or Alnico VI.

The traveling wave tube 20, which may be of any type known in the art, is inserted into the aperture 12 of magnetic member 10 and extends across the air gap formed by the aperture 12 and the bridging extensions 15. The traveling wave tube essentially comprises an electron gun assembly 21, a helix transmission circuit 22, and an electron collector assembly 23 adjacent to which may be positioned a heat radiator 24.

Input and output wave guides 17 and 18 are positioned within the bridging extensions 15 transverse to the axis of the traveling wave tube 20 in energy coupling relation with the input and output ends of the helix transmission circuit 22.

The helix 22 extends within the aperture 12 from the input wave guide 17 between one set of bridging extensions 15 to the output wave guide 18 between the other set of bridging extensions 15. A cylindrical flux guide 25 is also positioned within the aperture 12 around the envelope of the traveling wave tube 20, and rectangular pole pieces 27 are fitted around the flux guide 25 adjacent each end thereof. The pole pieces 27 advantageously abut directly against the ends of the center section 11 of the magnet member 10. A second pair of pole pieces 28 abut the ends of the upper and lower sections 13 and 14 of the magnet member 10 and enclose the space between bridging portions 15. The pole piece 28, adjacent the input wave guide 17, has an aperture therein of sufficient size to accommodate the enlarged portion of the envelope of the traveling wave tube 20, which enlarged portion encompasses the electron gun 21. Similarly, the pole piece 28 adjacent the output wave guide 18 has an aperture therein to accommodate the heat radiator portion 24 of the traveling wave tube 20 adjacent the electron collector 23.

In the specific illustrative embodiment of my invention depicted in Fig. 2, the flux guide 25 advantageously may be a thin-walled seamless iron tube which is mounted coaxially within the aperture 12 and provides for field rectilinearity adjustments. The magnet 10 is enclosed in a framework 31 through which extend adjustment screws 32, 33 and 34. In accordance with one aspect of this invention, a mechanical adjustment at screws 32, the ends of which abut the pole pieces 27, positions the pole pieces and the flux guide 25 in the aperture 12 to provide coincidence of the magnetic and mechanical axes in one coordinate. Adjustment of screws 33 and their associated spring fingers 38 performs a similar function in the other coordinate. Pole pieces 28 may also be positioned for additional correction, if necessary, through adjustment of screws 34. I have found that uniformity of the magnetic field in the aperture is assured by shaping of the magnet member 10 to have an elliptical cross section so that shaping of the flux guide 25 is not required in this embodiment. Proper shaping of the magnet member 10 in accordance with my invention, results in the aperture 12 having the same uniformity of flux distribution as that within the magnetic material.

Inhomogeneities in the material of the permanent magnet 10 and its close proximity to the magnetic field axis may cause field components transverse to the axis which disturb the uniform longitudinal field set up in the aperture 12. Such transverse fields may be offset by magnetic shielding of the flux guide tube 25 or by utilizing magnetic equipotential planes within the tube 25.

The shielding means may comprise spaced apart coaxial rings 35, Fig. 3, of high permeability material located between the flux guide 25 and the walls defining the aperture 12. Such rings would be supported by supports 36 and 39 of nonmagnetic material in such a manner as not to be in magnetic contact with the pole pieces 27, flux guide 25, or the walls defining the air gap 12. A

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concentric tube may be utilized in place of the shielding rings with suitable supports of nonmagnetic material again provided. As an alternative, or in addition to such shielding rings or tube, equipotential planes across the aperture may be enhanced to intercept transverse fields by affixing spaced-apart, apertured plates or discs 37, as seen in Fig. 4, to the inner wall of the flux guide tube 25 extending inward equal distances toward the axis of the tube in parallel planes perpendicular to the axis of the flux guide tube 25. Such discs of high permeability material would serve to intercept transverse fields before they can reach the path of electron flow close to the magnetic axis.

The open or bridging sections 15 of the magnet 10 adjacent each end of the aperture 12 are necessary to accommodate a coupling arrangement for the traveling wave tube 20. As shown in Fig. 2 the coupling arrangement utilized to illustrate this embodiment of the invention comprises input and output wave guide sections 17 and 18. The bridging sections 15 are effective to extend the magnetic field of the magnet 10 to include the area occupied by the wave guides 17 and 18 and are elliptically tapered on their outer surfaces to provide the necessary field uniformity and distribution in these areas. I have found that the shaping of the magnetic material in the bridging sections 15 is sufficient without flux guides to realize the desired field uniformity in the bridged areas as established between the pole pieces 28 abutting the ends of the upper and lower magnet sections 13 and 14.

It may be expedient, however, to employ flux guides in the bridged areas for field rectilinearity adjustment and to assure magnetic uniformity therein if the bridging sections 15 are not shaped elliptically as is the case in other embodiments of this invention to be described hereinafter. Flux guides, if utilized in the bridging areas, may advantageously be rectangular plates, such as 30 in Fig. 2, rather than a tubular guide as 25 in the inner aperture 12. If employed in this embodiment, the flux guide plates 31 need not be shaped, since the shape of bridging sections 15 adequately provides for field uniformity.

Comparable results are achieved in another specific illustrative embodiment of this invention wherein a rectangular permanent magnet 100, Figs. 5 and 6, is employed. Magnet 100 may advantageously be a single unit having an inner axially bored aperture 101 of a diameter sufficient to accommodate the helix of the traveling wave tube 20, which may be identical to that shown in Fig. 1. Adjacent the ends of the aperture 101, rectangular openings 102 are provided, which openings are sufficient to accommodate the input and output wave guides 17 and 18.

A uniform field distribution is attained in the air gaps defined by the inner aperture 101 and the outer openings 102, in accordance with this embodiment of this invention, by utilizing a shaped flux guide tube 103 in the inner aperture 101 and shaped flux guide plates 104 in the outer openings 102. A pair of pole pieces 105 abut the inner faces of the magnet 100 formed at the junctures of inner aperture 101 with outer openings 102 and are joined to the ends of flux guide 103. A second pair of pole pieces 106 abut the ends of the magnet 100 and enclose the outer openings 102 of the magnet member 100. Flux guides 104 are joined to the pole pieces 105 and 106 so that each flux guide 104 is suspended in an outer aperture 102 between a pole piece 105 and a pole piece 106.

The uniform field distribution in the inner aperture 101 is attained in accordance with this embodiment of my invention, by shaping of the flux guide 103 connected between pole pieces 105 so that it will be uniformly magnetized. The flux guide 103 is advantageously a hollow cylinder of magnetic material.

Uniform magnetization in the flux guide 103 is obtained by sectional area compensation for the leakage flux. The potential drop along the cylindrical flux guide 103 is then the same as at the axis of the cylinder, thus forming equipotential parallel planes mutually perpendicular to the

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axis of the cylinder. Flux lines spanning the aperture necessarily intersect these equipotential parallel planes at right angles and are thus parallel to the axis of the cylinder. Stated another way, as the magnetic potential distribution in the flux guide 103 is uniform throughout, the equipotential surfaces between the pole pieces 105 extend through the air gap inside the flux guide 103 as parallel planes rather than the contours normally encountered in the air gap between opposed magnetic poles. Since the magnetic flux lines make orthogonal intersections with these parallel equipotential planes, a uniformly straight magnetic field is attained.

The flux guide 103, as utilized in this embodiment of my invention, is advantageously shaped so that the thickness varies linearly from a minimum thickness at the point midway between the pole pieces 105 to a maximum thickness adjacent the pole pieces 105. The shape corresponds to the variation of flux distribution along the helix and comprises a uniform section sufficiently thick at the mid-section to provide adequate mechanical strength and a leakage shell varying from maximum thickness at the ends to zero thickness at the midpoint. A more detailed account of the flux guide shaping and calculations for the dimensions can be found in my Patent No. 2,807,743, issued September 24, 1957.

The flux guides 104 are connected between pole pieces 106 and 105 in the outer apertures 102 abutting the upper and lower bridging sections of magnet 100 and are shaped in similar fashion to flux guide 103 to provide uniform fields in the outer apertures 102; viz., thinnest at the midpoint and thickest adjacent the pole pieces.

This arrangement permits establishment of the desired uniform field in the outer apertures 102, thereby assisting the uniform field of the inner aperture 101, as described hereinbefore, in maintaining the electron beam of the traveling wave tube 20 in a uniformly straight part throughout its travel. Either or both of the shielding devices depicted in Figs. 3 and 4 may be utilized to advantage in the specific illustrative embodiment of Figs. 5 and 6 to offset transverse fields in the aperture 101.

In the specific illustrative embodiments of this invention depicted in Figs. 7 and 8, the desired results are obtained by provision of permanent magnets 200 in Fig. 7 and 213 in Fig. 8 having ellipsoidal configurations. Bridging sections 202 are formed at each end of the magnet 200, Fig. 7, and retain the elliptical contour of the magnet 200. The space enclosed by the bridging sections 202 provides for input and output wave guides, and in the event that this type of coupling is employed, the aperture 203 is given a square or rectangular contour as shown in Fig. 7. In this event flat rectangular flux guide plates are positioned adjacent the upper and lower walls of the aperture 203 and extend the full length of the magnet abutting pole pieces placed against the end portion of magnet 200.

Rather than input and output wave guides, the couplings may consist of coaxial lines such as input and output lines 210 in Fig. 8. With this arrangement, the aperture 211 may advantageously be of circular cross section with a cylindrical flux guide 212 extending the full length of the ellipsoidal shaped magnet 213 and abutting the pole pieces 214.

As the magnets 200 and 213 are shaped to provide for field uniformity, the flux guides may be flat plates positioned on opposite sides of the square or rectangular aperture of Fig. 7 or a uniform thickness cylinder in the circular aperture of Fig. 8, with adjustment screws at the pole pieces to provide for field rectilinearity adjustments. Again, either or both of the shielding devices depicted in Figs. 3 and 4 may be utilized to advantage in the specific illustrative embodiments of Figs. 7 and 8 to offset transverse fields in the aperture.

It is to be understood that the above-described arrangements are illustrative of the application of the principles of the invention. Numerous other arrangements

may be devised by those skilled in the art without departing from the spirit and scope of this invention.

What is claimed is:

1. An electron discharge device comprising an electrical conductor defining an elongated electromagnetic wave transmission system, an input and an output coupling means for said transmission system, said coupling means being spaced apart from each other along said conductor, electron gun means adjacent one end of said conductor for projecting an electron stream lengthwise of an in coupled relationship to said conductor, electron receiving means adjacent the other end of said conductor, and means applying a magnetic field along said conductor to focus said electron stream, said last-mentioned means including a permanent magnet member having an elongated central aperture therein through which the portion of said conductor between said coupling means extends and having a pair of outer apertures coaxial with and larger than said central aperture in which said coupling means are positioned, pole pieces across the ends of each of said apertures, and flux guide means extending between said pole pieces.

2. An electron discharge device in accordance with claim 1 and further comprising means for aligning the axis of said flux guide means with the axis of said conductor.

3. An electron discharge device in accordance with claim 1 wherein one of said flux guide means and permanent magnet member is shaped along said conductor to compensate for leakage flux whereby the magnetic flux within said apertures is parallel and axial along the entire length of said apertures.

4. An electron discharge device in accordance with claim 1 wherein said permanent magnet member has elliptical contours.

5. An electron discharge device in accordance with claim 1 and further comprising shielding means adjacent said flux guide means in said central aperture, said shielding means operative to intercept magnetic fields transverse to the length of said central aperture.

6. An electron discharge device in accordance with claim 5 wherein said shielding means includes a cylindrical magnetic member positioned between said flux guide and the surface of said permanent magnet member in said central aperture.

7. An electron discharge device in accordance with claim 5 wherein said shielding means includes a plurality of spaced-apart magnetic members extending inward of said central aperture from said flux guide means.

8. An electron discharge device comprising an electrical conductor defining an elongated electromagnetic wave transmission system, an input and an output coupling means for said transmission system, said coupling means being spaced apart from each other along said conductor, electron gun means adjacent one end of said conductor for projecting an electron stream lengthwise of and in coupled relationship to said conductor, electron receiving means adjacent the other end of said conductor, and means applying a magnetic field along said conductor to focus said electron stream, said last-mentioned means including a permanent magnet member having an elongated central aperture therein through which the portion of said conductor between said coupling means extends and having a pair of larger outer apertures coaxial with said central aperture in which said coupling means are positioned, a cylindrical magnetic member positioned in said central aperture and defining a flux guide, a first pair of pole pieces across the ends of said central aperture, and a second pair of pole pieces across the ends of said outer apertures.

9. An electron discharge device in accordance with

claim 8 wherein said cylindrical magnetic member is of smallest internal diameter adjacent its mid-portion and of largest internal diameter adjacent its ends.

10. An electron discharge device comprising an electrical conductor defining an elongated electromagnetic wave transmission system, an input and an output wave guide for said transmission system, said wave guides being spaced apart from each other along said conductor, electron gun means adjacent one end of said conductor for projecting an electron stream lengthwise of and in coupled relationship to said conductor, electron receiving means adjacent the other end of said conductor, and means applying a magnetic field along said conductor to focus said electron stream, said last-mentioned means including a first permanent magnet member having an elongated central aperture therein through which the portion of said conductor between said wave guides extends, flux guide means within said central aperture, second permanent magnet members abutting the ends of said first magnet member and encompassing said wave guides, second flux guide means positioned within said second magnet members and around said wave guides, a first pair of pole pieces across the ends of said first magnet member and a second pair of pole pieces across the ends of said second magnet members.

11. An electron discharge device comprising an electrical conductor defining an elongated electromagnetic wave transmission system, input and output coupling means for said transmission system, said coupling means being spaced apart from each other along said conductor, electron gun means adjacent one end of said conductor for projecting an electron stream lengthwise of and in coupled relationship to said conductor, electron receiving means adjacent the other end of said conductor, and means applying a longitudinal magnetic field along said conductor to focus said electron stream, said last-mentioned means including a permanent magnet member having an elongated central aperture through which the portion of said conductor between said coupling means extends and having a pair of outer apertures coaxial with and of greater cross section than said central aperture in which said coupling means are positioned, flux guide means within said central aperture, said flux guide means being of varying thickness along its length to compensate for leakage flux whereby the lines of force within said central aperture follow a predetermined path, a first pair of pole pieces across the ends of said central aperture and a second pair of pole pieces abutting said magnetic member and across said outer apertures.

12. An electron discharge device in accordance with claim 11 wherein said flux guide means comprises a cylindrical flux guide member encompassing said helical conductor.

13. An electron discharge device in accordance with claim 12 wherein said flux guide member is thinnest adjacent its middle and thickest adjacent its ends.

14. An electron discharge device in accordance with claim 12 and further comprising a pair of pole pieces secured to said flux guide member at its opposite ends and means for determining the position of said pole pieces relative to said aperture to align the axes of said flux guide member and said helical conductor.

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