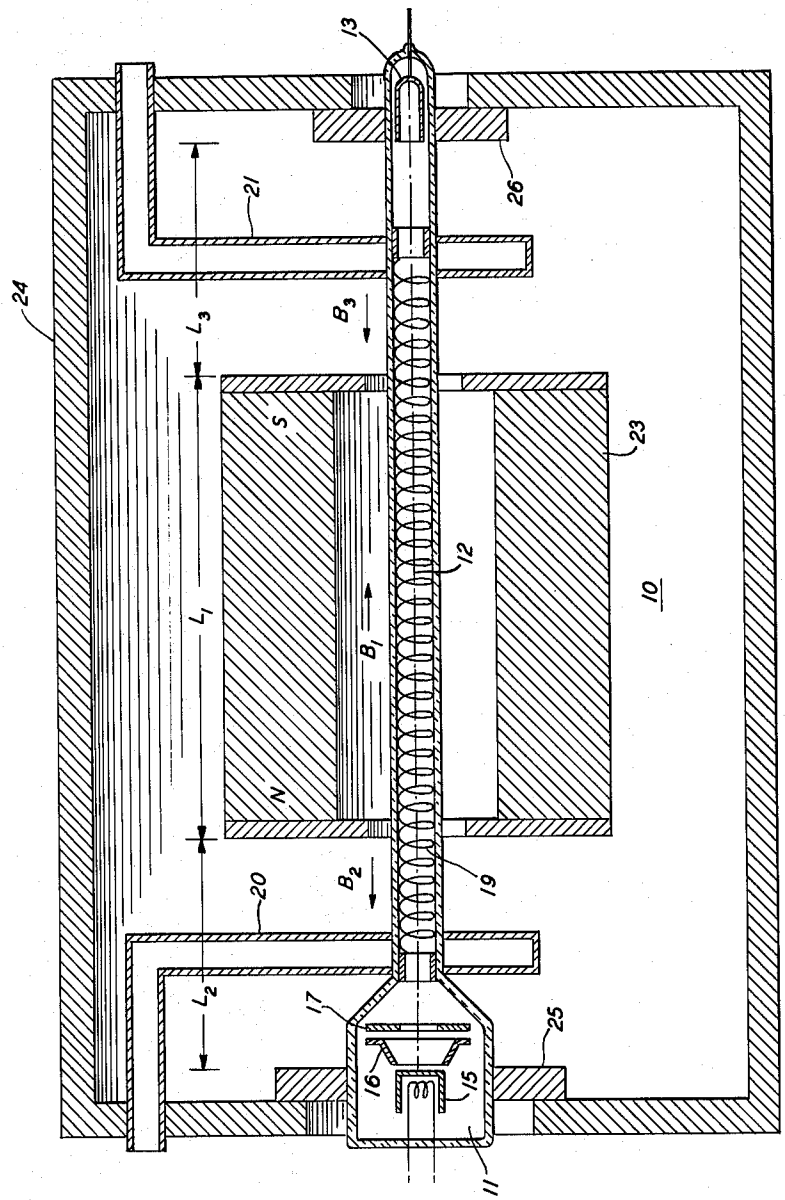
March 29, 1966 M. S. GLASS 3,243,639

MAGNETIC APPARATUS FOR FOCUSING ELECTRON BEAMS

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FIG. 1



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FIG. 2

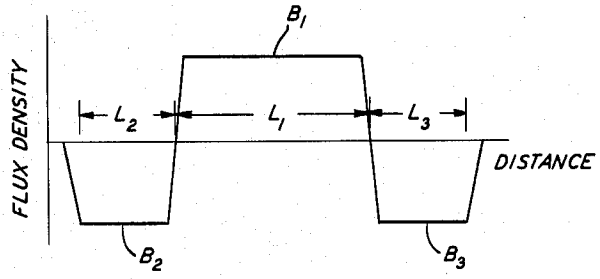


FIG. 3

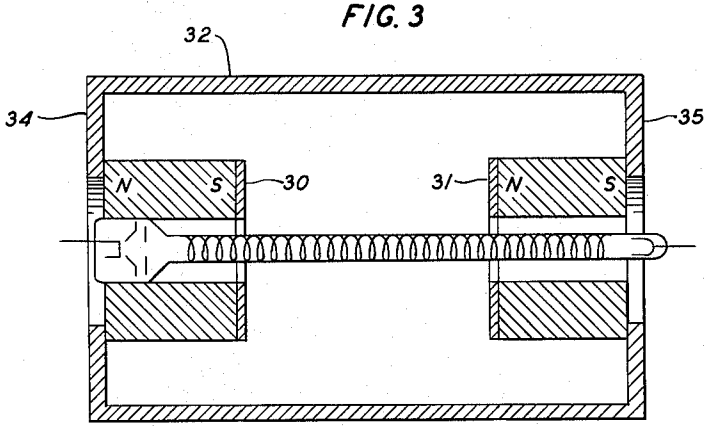
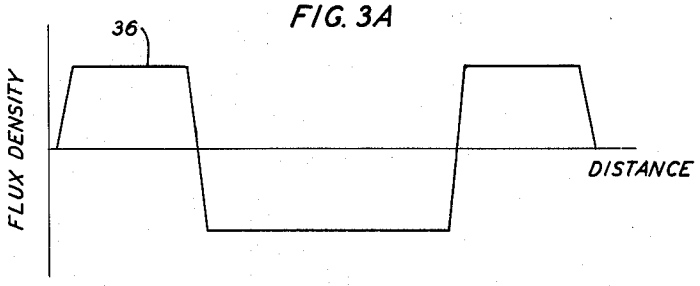


FIG. 3A



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3,243,639

Patented Mar. 29, 1966

3,243,639

MAGNETIC APPARATUS FOR FOCUSING ELECTRON BEAMS

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Filed Oct. 4, 1961, Ser. No. 142,850
12 Claims. (Cl. 315—3.5)

This invention relates to electron beam devices and more particularly to electron beam focusing apparatus.

In electron beam devices such as the traveling wave tube, a magnetic field is normally used to focus the electron beam, that is, constrain the beam to follow a predetermined path and prevent it from diverging. The magnetic field is often produced by a hollow cylindrical permanent magnet that surrounds the tube and is coaxial with the beam path. In the traveling wave tube, movable input and output waveguides must be brought in proximity to the beam through apertures in the permanent magnet, and may thereby interfere with the uniformity of the field while the magnet may interefere with the mobility of the waveguides. Another disadvantage of this type of focusing is the fringing magnetic fields which may extend into adjacent apparatus and disrupt the operation thereof. These fringing fields also evidence the relative inefficiency of the magnet because they are never utilized.

Accordingly, it is an object of this invention to increase the efficiency of magnetic electron beam focusing apparatus by utilizing the fringing fields produced by such apparatus.

It is another object of this invention to provide magnetic electron beam focusing apparatus which produces a magnetic field whose uniformity is unaffected by input and output waveguides in close proximity with the electron beam and which will not interfere with the movability of such input and output waveguides.

These and other objects of my invention are attained in an illustrative embodiment comprising an electron gun for forming an electron beam and projecting it along a path toward a collector. A conductive helix surrounds a portion of the path and transmits a high frequency electromagnetic wave from an input waveguide at one extreme end to an output waveguide on the other end. As the wave propagates along the helix, fields associated therewith interact with the beam to amplify the wave as is well known. Phase adjustments can be made by axially moving the input or output waveguides.

It is a feature of one embodiment of the invention that the electron beam be focused by a hollow cylindrical permanent magnet that surrounds the beam path for approximately one-half the length thereof. An iron encasement surrounds the magnet and affords a low reluctance flux path for the magnetic fringing fields. Pole pieces on the encasement are located at opposite ends of the electron beam path and are displaced from the magnet a distance equal to one-half the length of the magnet. Under this condition the fringing fields are concentrated between the magnet and the pole pieces and a magnetic field of substantially uniform magnitude (but which reverses direction) is produced along the entire length of the electron beam path. As is known, a magnetic focusing field must be of substantially uniform magnitude to prevent beam scalloping. Hence, by efficient use of the fringing fields the effective length of the permanent magnet is doubled. Further, the magnet cannot interfere with the movement of the input and output waveguides which are located at opposite ends of the beam path.

According to a feature of another embodiment of the

invention, two identical permanent magnets are placed at opposite ends of the electron beam path and are separated by a distance equal to their combined lengths. The north pole of one magnet faces the south pole of the other. Under these conditions a substantially uniform flux density is produced along the length of the beam path.

These and other objects and features will be more clearly understood from a consideration of the following detailed description, taken in conjunction with the accompanying drawing, in which:

FIG. 1 is a sectional view of one embodiment of this invention;

FIG. 2 is a graph of flux density versus distance in the device of FIG. 1;

FIG. 3 is a sectional view of another embodiment; and

FIG. 3A is a graph of flux density versus distance in the device of FIG. 3.

Referring now to FIG. 1, there is shown a traveling wave tube **10** comprising an electron gun **11** for forming an electron beam and projecting it along an extended path **12** toward a collector **13**. For purposes of illustration, electron gun **11** is shown as comprising a cathode **15**, a beam forming electrode **16** and an accelerating anode **17**. The electron beam path **12** is surrounded by an evacuated envelope **18** which is of glass or some other suitable non-magnetic material.

Extending along a major portion of path **12** is a conductive helix **19** for transmitting high frequency electromagnetic wave energy from an input waveguide **20** to an output waveguide **21**. As the wave propagates along helix **19**, fields associated therewith interact with the electron beam to amplify the wave in a well known manner. Waveguides **20** and **21** are adapted to move parallel with path **12** to optimize various phase relationships.

In accordance with the invention, the electron beam is focused by the combined action of a cylindrical permanent magnet **23** and a cylindrical ferromagnetic encasement **24** having a pair of pole pieces **25** and **26** which may be of soft iron or some other suitable ferromagnetic material. For illustrative purposes, the left end of magnet **23** is shown as having a north polarity while the right end has a south polarity. A flux density B_1 is then produced along a direct flux path between the two poles. The fringing fields of the magnet follow a low reluctance path through pole piece **25**, encasement **24**, and pole piece **26**; a flux density B_2 is therefore produced in the gap between magnet **23** and pole piece **25** and a flux density B_3 is concentrated between the magnet and pole piece **26**. It is known that if the direction of a magnetic field for focusing an electron beam is abrutply reversed, and if the magnitude of the field immediately upstream and downstream from the reversal is substantially uniform, neither the flow of the beam nor the information carried on it by conventional traveling-wave tube modulation will be disrupted. The use of such magnetic field reversals is known in the art as periodic focusing or strong fousing.

I have found that when the distance between the magnet **23** and each of the pole pieces **25** and **26** is equal to half the length of the magnet **23**, the magnetic flux density, B_1, B_2, and B_3 along path **12** will be uniform in magnitude and will therefore the appropriate for focusing the electron beam without disruption. As shown in the graph of FIG. 2, B_1, B_2, and B_3 are equal and L_1 equals L_2 plus L_3. As a result, the flux produced by magnet **23** focuses an electron beam that is twice as long as would be possible in the absence of the iron encasement **24**. Of course, it can be appreciated that the flux density reverses direction.

The foregoing explanation presupposes the unsaturability of encasement **24** by the magnetic field. Magnetic saturation of the encasement is avoided by making it appropriately thick and of sufficiently large diameter. This is a design consideration that is within the ordinary skill of a worker in the art. It should also be pointed out that since encasement **24** acts as a flux guide for the fringing fields, external elements that are located near the traveling wave tube package will not be effected by the magentic field. Another advantage lies in the fact that waveguides **20** and **21** do not intefere with the magnetic circuit, and the magnetic circuit does not interfere with the movement of the waveguides.

If the last-mentioned advantage is not an important consideration for a particular tube, the design shown in FIG. 3 may be desirable. Magnets **30** and **31** are located on opposite ends of an iron encasement **32** having a pair of end portions **34** and **35**. Because of the low reluctance magnetic circuit through end portion **34**, encasement **32** and end portion **35**, the fringing fields are concentrated in the air gap between magnets **30** and **31**. The distance between the magnets is approximately equal to twice the length of either of the magnets so that the length of the magnetic focusing field is again effectively doubled. Encasement **32** is of sufficient size and diameter to avoid saturation. Under these conditions a magnetic field of substantially uniform magnitude is produced between end portions **34** and **35**, as shown by curve **36** of FIG. 3A. In the embodiments of both FIGS. 1 and 3 a flux density of substantially uniform magnitude is usually necessary to prevent beam scalloping. It shoud also be noted that in both embodiments the magnetic axis of each of the magnets, that is, an imaginary line interconnecting the north and south poles, is parallel to the path of the electron beam.

It is intended that the foregoing embodiments be merely illustrative of my invention. Various other forms and modifications may be used without departing from the spirit and scope of the invention.

What is claimed is:

1. An electron discharge device comprising means for forming and projecting a beam of electrons along a path; means for focusing said beam comprising a cylindrical magnet surrounding a portion of said path; a ferromagnetic cylinder surrounding said magnet and coaxial therewith; and a pole piece at each end of said cylinder; the distance between said magnet and each of said pole pieces being substantially equal to half the axial length of said magnet.

2. A traveling wave tube comprising: an electron gun for forming an electron beam and projecting it along a path toward a collector; a movable input waveguide adjacent the electron gun; a movable output waveguide adjacent the collector; a slow wave structure extending between said input and output waveguides for transmitting an electromagnetic wave in interacting relationship with the beam; a hollow cylindrical magnet surrounding a portion of said slow wave structure and contained completely between said input and output waveguides; and a hollow cylindrical iron encasement surrounding said magnet; said encasement having a first end portion that surrounds part of the electron gun and a second end portion that surrounds part of the collector; said first and second end portions being displaced at substantially equal distances from the magnet, whereby magnetic flux is produced along the entire electron beam path without interfering with input and output waveguide movement.

3. An electron discharge device comprising: an electron gun for forming an electron beam and projecting it along a path to a collector; means for modulating said beam with high frequency electromagnetic wave energy; means for focusing said beam comprising two hollow cylindrical magnets located at opposite ends of said path, each of which surround approximately one-fourth the length of said path; the magnetic axes of the magnets being substantially parallel to the path; and means for concentrating the fringing fields of said magnets along the portion of the path which separates them comprising an encasement which surrounds both magnets and which is in magnetic contact with both magnets.

4. An electron discharge device comprising: an electron gun for forming and projecting an electron beam along a path; a collector which terminates said path for collecting said beam; means for modulating said beam with high frequency electromagnetic wave energy; means for focusing said beam comprising two hollow cylindrical magnets at opposite ends of said path; the magnetic axes of the magnets being substantially parallel to the path; each of said magnets surrounding approximately one-fourth the length of said path; the ends of each cylindrical magnet having a magnetic polarity; the adjacent ends of said magnets being of opposite magnetic polarity; and means for concentrating the magnetic fringing fields of said magnets along the portion of the path which separates them comprising an encasement of predominantly iron material which surrounds both magnets and which is in contact with both magnets.

5. The electron discharge device of claim **4** wherein the encasement is magnetically unsaturable by the magnetic flux of said two magnets.

6. Apparatus for producing a magnetic field along a path which reverses direction but which is of substantially constant magnitude comprising: a magnet adjacent the path having a magnetic axis which is substantially parallel with the path; the length of the magnet being substantially equal to one-half the length of the path and being substantially equidistant from the two ends of the path; and a low reluctance magnetic flux path extending between the two ends of the path.

7. The apparatus of claim **6** wherein said low reluctance flux path comprises a magnetically unsaturated ferromagnetic encasement.

8. Apparatus for producing a magnetic field of substantially uniform magnitude along a path comprising: a plurality of magnets axially arranged along said path; the adjacent ends of the adjacent magnets being of opposite magnetic polarity; the magnetic axes of each of the magnets being substantially parallel with the path; each of the magnets being of substantially equal length; each of the magnets being separated from adjacent magnets by a gap of predetermined length; the combined length of all of the gaps along said path being substantially equal to the combined lengths of all of the magnets along the path; and a low reluctance flux path interconnecting the two extreme ends of the two magnets which are located at opposite ends of said path.

9. The apparatus of claim **8** wherein said low reluctance magnetic flux path comprises a magnetically unsaturated ferromagnetic encasement which surrounds all of said magnets whereby substantially all of the fringing flux of the magnets is concentrated in said gaps.

10. In an electron discharge device, the combination comprising: means for forming and projecting a beam of electrons; magnet apparatus surrounding a portion of the path for focusing the beam and constraining it to follow a predetermined path; said apparatus comprising at least one permanent magnet, the magnetic axis of which is substantially parallel to the path, whereby a main magnetic field is established along the path portion which the magnet apparatus surrounds; and means for concentrating fringing fields of the magnet apparatus along the remainder of the path, the length of the path portion and the remainder being substantially equal, whereby a magnetic flux density of substantially uniform magnitude is produced along the path.

11. In an electron discharge device, the combination comprising: means for forming and projecting a beam of electrons; means for focusing the beam and constraining it to follow a predetermined path of flow; the last-

mentioned means comprising one or more hollow permanent magnets surrounding a portion of the path; the magnetic axis of the magnet or magnets being substantially parallel with the beam path, whereby a main magnetic field or fields is established along the said path portion; and means for concentrating fringing fields of the magnet or magnets along the remainder or the path; the length of the path portion and the remainder being substantially equal whereby a magnetic flux density of substantially uniform magnitude is produced along the path.

12. The combination of claim **11** wherein the concentrating means comprises means for establishing a low reluctance flux path from one end of the electron beam path to the other.

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