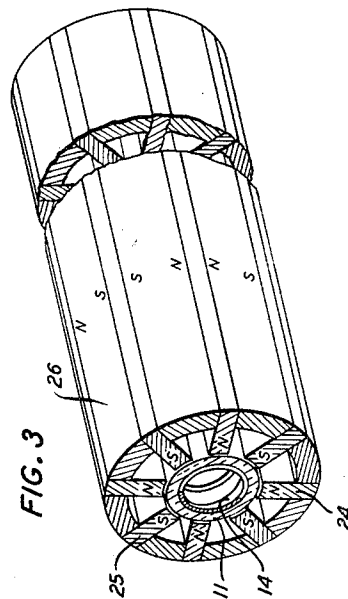
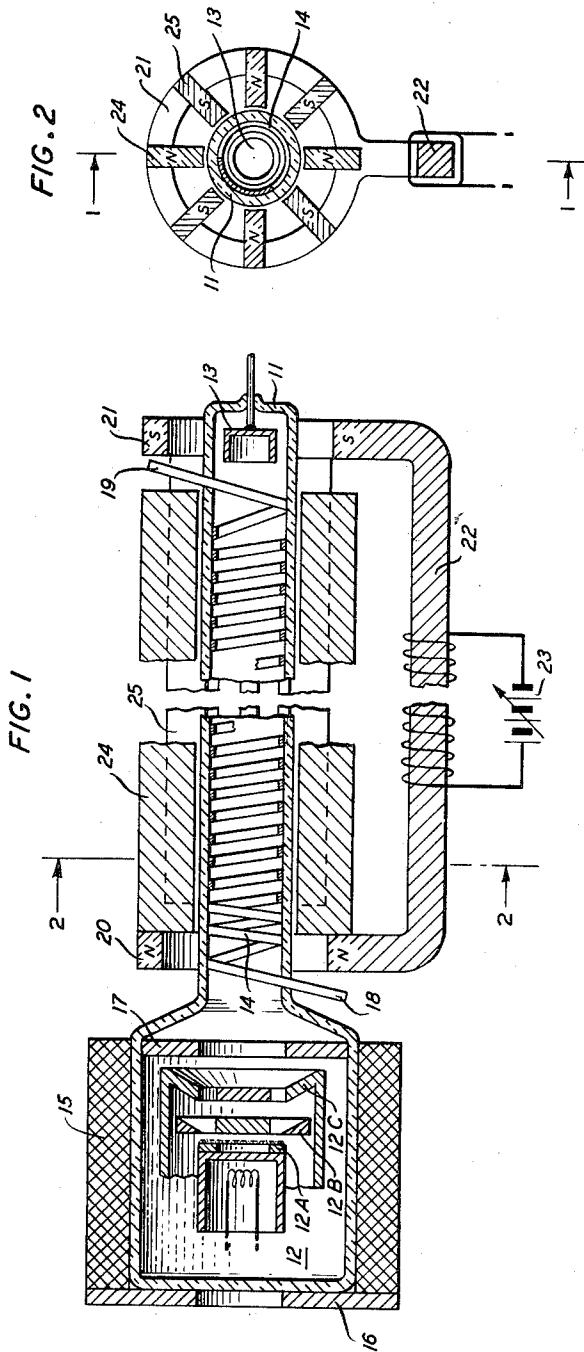


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W. W. RIGROD
BEAM FOCUSING SYSTEM
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BEAM FOCUSING SYSTEM

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This invention relates to electron beam focusing and more particularly to such focusing in traveling wave tubes.

In a traveling wave tube the electromagnetic wave propagates along an interaction circuit past which is projected an electron beam in field coupling relationship. Because of the relatively long length of the electron path and because of the space charge forces acting in an electron beam, it is generally necessary to provide focusing means to keep the electron flow cylindrical during its travel past the interaction circuit. In the past, such focusing generally has been provided by establishing a longitudinal steady magnetic field along the beam path. However, in practice, the high fluxes required in the large gap for such magnetic focusing have necessitated the use of large permanent magnets or solenoids which have added much to the bulk and weight of traveling wave tubes.

Through the use of a periodically varying magnetic field it has been found that the bulk of the magnetic apparatus can be considerably reduced. This is primarily due to better utilization of the magnetic fields. In actuality, it has been found the ratios of maximum fields thereby produced to the longitudinal steady fields for the same magnetic weight may be from 5:1 to 30:1.

In their article, "Focusing of an Electron Beam by Periodic Fields," Journal of Applied Physics, volume 25, pages 436 through 447, April, 1954, A. M. Clogston and H. Heffner discuss various techniques of utilizing the interaction between a periodic transverse magnetic field and the longitudinal velocity of charged particles to provide an inward force acting on the charged particles. One structure suggested in this article is a quadrupolar arrangement of alternating north and south pole faces having hyperbolic profiles. A plurality of such arrangements are placed successively along the length of the electron beam path, successive quadrupoles being rotated 90 degrees such that a spatially periodic field is produced both in the longitudinal and circumferential sense of the electron beam. Each electron traveling along the beam then "sees" an alternating magnetic flux. Although the net result of the force caused by this magnetic flux is in an inward radial direction, the alternating quality of the flux gives rise to fluctuations in the paths of the electrons which is called ripple.

By providing periodic magnetic focusing in the circumferential sense of the beam as described above, the cross-sectional area of the electron beam can theoretically be maintained at a fairly constant value. The quadrupolar arrangement, however, tends to cause the electron beam to assume an elliptical cross-section which effectively rotates as it passes successively rotated quadrupoles. This is an expected manifestation of ripple caused by alternate focusing and defocusing. Because the surfaces of the beam cannot be maintained parallel with the axis thereof, and because of the erratic paths of electrons as a result, optimum interaction with the radio frequency helix is impeded.

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In the device of Clogston and Heffner ripple can be reduced by any one or combination of the following procedures: By increasing the number of pole pieces in an array surrounding the electron beam; increasing the number of arrays per unit length displayed along the path of the electron beam; increasing the abruptness of flux change; and increasing the magnitude of the flux intensity. When, however, one seeks to increase the number of pole pieces or the number of arrays of pole pieces, considerable mechanical difficulties are encountered. Even with the minimum of four pole faces in an array, mass production techniques are impracticable because of the close tolerances necessary in maintaining constant radial distances from the axis of the electron beam and proper angular correlation of the respective pole pieces. The introduction of even the slightest asymmetry may not only cause increased undesirable ripple but may well cause such instability in the electron beam as to result in impingement on the interaction helix by the electrons and hence a degradation of operating efficiency even to the extent of complete inoperativeness. The magnitude of flux intensity which can be introduced is limited by the magnitude of diverging force which the flux force is counter-balancing. In the Clogston and Heffner device this diverging force is due only to the electron beam's space charge. The abruptness of flux change is a function of flux intensity and frequency and is therefore limited for the foregoing reasons. Thus, each of the procedures aimed at reducing beam ripple, while achieving strong focusing, introduces other disadvantages to the extent that the degree of ripple reduction practicably attainable is severely limited.

It is an object of the present invention to achieve strong periodic magnetic focusing with negligible beam ripple.

It is another object of this invention to produce strong focusing with negligible beam ripple with apparatus of quite simple construction having a minimum of critical tolerances.

These and other objects of this invention are attained in one illustrative embodiment of the invention wherein two annular metal members of opposite magnetic polarity are placed at opposite ends of the interaction circuit of a traveling wave tube. Elongated extensions of high permeability protrude from each of these members along the length of the interaction region and are interleaved with one another to form a circular array of elongated magnetized elements of transversely spatially alternating magnetic polarity surrounding the traveling wave tube. Variable magnetic strength is imparted to the annular members and their elongated extensions by connecting the two annular members by electrical solenoid means and by energizing the solenoid with a variable direct current. The electron beam of the traveling wave tube is given a transverse velocity component before entering the focusing region defined by the magnetized members such that each electron therein travels a substantially helical path to a collector electrode.

During its travel to the collector, each electron passes first a north magnetic pole and then a south magnetic pole and hence "sees" a spatially alternating periodic magnetic field. In addition to providing strong focusing, the periodicity of the magnetic field in the circumferential sense of the electron beam maintains a substantially circular cross-sectional area on the electron beam. Rapidly alternating focusing, and thus reduced ripple, can be accomplished in the instant invention by increasing the rotational component or "twist" of the electron beam, whereas such increased rapidity in the Clogston and Heffner device would demand an increased number of successive arrays or quadrupoles. In either device, a more uniformly circular cross-section on the electron beam, and hence, reduced ripple, can be produced by

providing a greater number of pole pieces in each circular array. In the instant invention, however, there is only one array of pole pieces, and an increase in the number of pole pieces in the array not only improves the configuration of the electron beam but also increases the rapidity of alternation of the focusing. In the afore-mentioned device there must necessarily be a large number of arrays, each of which must contain additional pole pieces merely to improve the beam cross-section. In applicant's device not only is there a comparatively small number of elements which must be correctly oriented for proper functioning, but any small increase in that number will both improve the beam cross-section and reduce ripple by the resulting increase in periodicity. The rotating beam of the instant invention also plays a dual role in that, besides permitting periodic focusing, the centrifugal force thereby exhibited permits a stronger focusing force which not only restricts random movement of the electrons, but also increases the abruptness of flux change, thereby further reducing ripple.

From the foregoing description of this embodiment of the invention, it is apparent that, since there are a plurality of members of high permeability extending longitudinally throughout substantially the entire length of the focusing region, each of the members being of substantially constant polarity throughout its length, there will be little or no longitudinal magnetic field in the region of the electron beam. Further, the magnetic intensity of the transverse magnetic field is substantially constant, both as to magnitude and direction, along any line in the interaction region parallel with the axis of the electron beam.

In another embodiment of the invention, the focusing apparatus comprises a circular array of elongated pole pieces connected along their lengths by sectors of permanently magnetized material to form a cylinder which surrounds the tube's interaction region. The permanent magnets are so arranged as to impart a north magnetic polarity on alternate pole pieces and a south magnetic polarity on the other alternate pole pieces. This embodiment is then used in conjunction with a traveling wave tube electron beam having a transverse velocity component as previously described.

It is a feature of this invention that there is established, along the path of flow of an electron beam, a beam focusing field which is longitudinally uniform for substantially the entire length of the beam path and which is spatially alternating transversely to the path of flow.

It is another feature of this invention that the electron beam have imparted thereto a transverse velocity component prior to its entry into the focusing region such that electrons in the beam travel substantially helical paths and encounter periodically alternating magnetic focusing fields.

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

Fig. 1 shows, in longitudinal cross-section, a conventional traveling wave tube of a preferred embodiment of the invention in which a rotating annular electron beam is focused by spatially alternating electromagnets;

Fig. 2 shows a transverse cross-section taken along lines 2-2 of Fig. 1; and

Fig. 3 shows, in transverse cross-section, another embodiment of the invention in which an electron beam is focused by spatially alternating permanent magnets.

Referring now more particularly to the drawing, an evacuated glass envelope 11 houses the various tube elements. At one end of the envelope is an electron gun 12, generally designated as the Pierce-type electron gun, which serves as the electron source for providing a rotating hollow beam of substantially uniform density over its cross-section. This gun 12 is merely exemplary of many types of electron guns which could be used. Indeed, although an annular beam has generally been shown

to give better results, an electron gun generating a solid beam could be used, the only restriction being that said beam must contain a rotational velocity component. The gun illustrated comprises an annular cathode 12A, an annular beam-forming electrode 12B and an annular accelerating anode 12C. Consistent with the well-known principles of the Pierce-type gun, the surfaces of electrode 12B and anode 12C are of such configuration that, in the presence of complete space charge, the electric field component in a direction parallel to the emissive surface of cathode 12A is zero. The electrode 12B and the anode 12C each include a central or inner portion and an outer portion defining annular passages there-through for the electron beam. By the inclusion of such portions, the usual form of Pierce gun may be advantageously modified for providing a hollow cylindrical beam of substantially uniform current density. In operation, the cathode 12A is maintained at reference potential, the electrode 12B at a potential slightly negative thereto, and the anode 12C at a potential positive thereto. In the interest of simplicity, lead-in connections and electrode support means have not been shown.

At the end of the tube opposite the electron gun 12 is a collector 13 which receives the spent electron beam. Intermediate the gun and collector and coaxial with the generated cylindrical electron beam is an interaction helix 14. A radio frequency signal from a source, not shown, is introduced in the helix in any suitable manner well known to workers in the art. For purposes of illustration the tube shown is designed for operation as a forward wave amplifier. To this end, the input wave to be amplified is applied to the electron source end of the helix and the output wave is abstracted at the collector end. Input and output wave coupling means 18 and 19, respectively, are shown schematically for purposes of simplicity. Suitable arrangements for coupling wave guide or transmission line connections to such a traveling wave tube are well known in the art.

A magnetic flux producing means, such as solenoid 15, is positioned adjacent the source of the electron beam current. Such means serves a dual purpose. First, it provides a longitudinal magnetic field in which the electron gun is immersed to confine the beam until it can be focused by the periodic magnetic field. Secondly, it provides a transverse component of magnetic flux on the beam immediately before said beam enters the periodic magnetic field such that a rotational velocity component is imparted thereon. To shape the magnetic flux to the desired configuration, two annular disks 16 and 17, of highly permeable material are positioned transverse to the path of flow, extending as pole pieces from a solenoid 15. In the arrangement shown, the disk 16 is external and the disk 17 internal the tube envelope. By properly positioning these pole pieces, the magnetic flux linking them is longitudinally oriented when it passes through electrodes 12A, 12B and 12C and is transversely oriented where the electron beam passes the disk 17 and enters into the region of alternating field.

In operation, electrons emitted from the cathode 12A are formed into an annular beam by the action of the beam forming electrode 12B and accelerated toward the accelerating anode 12C. The electrons are confined to longitudinal paths through this gun region. As they approach the pole piece 17, where the magnetic flux acquires a transverse direction, they are given a rotational component which sets them spinning with an angular velocity which is determined by the strength of the transverse component of magnetic field. Once beyond the region of transverse magnetic field, the spinning electron beam is focused by a spatially alternating magnetic field to be discussed in detail hereinafter.

This magnetic field is advantageously formed to be spatially alternating in the circumferential sense of the electron beam and of constant uniform strength in the longitudinal sense. The focusing means which produces

the magnetic field in the interaction region of the traveling wave tube comprises solenoid 22 which includes annular pole piece members of high permeability, 20 and 21. Current is supplied through voltage source 23 such that a magnetic polarity is imparted to member 20 and an opposite magnetic polarity is imparted on member 21. In the illustrative embodiment of Figs. 1 and 2, member 20 is of a north magnetic polarity, while member 21 is of a south magnetic polarity. Annular member 20 surrounds the envelope 11 at the electron source end, while annular member 21 surrounds the envelope at the electron collector end. Extending from annular members 20 and 21 and parallel with the electron beam axis are elongated pole pieces of high permeability, 24 and 25. Pole pieces 24 extend from annular member 20, while pole pieces 25 extend from annular member 21. Since the magnetic reluctance along pole pieces 24 and 25 is very small, pole piece 24 is of a substantially uniform north polarity, while pole 25 is of a substantially uniform south polarity. Pole pieces 24 and 25 interleave one another in alternate relationship such as to form a circular array surrounding the envelope 11, as is best seen in Fig. 2. The magnitude of polarization on pole pieces 24 and 25 can be varied by varying the output of direct current voltage supply 23. As can be appreciated from a study of Fig. 1, the magnetic flux intensity along any line in the interaction region parallel with the axis of the electron beam is substantially constant and unvarying, both as to magnitude and direction. Further, the longitudinal component of magnetic flux intensity is substantially zero. As is apparent from Fig. 2, the magnetic flux intensity varies with spatial periodicity in the circumferential sense.

Individual electrons projected from electron gun 12 follow a substantially helical path to collector anode 13 due to the rotational velocity component introduced into the electron beam by the magnetic field in the aperture of member 17. During its traverse, each electron passes, in alternate succession, first a north magnetic pole piece 24, then a south magnetic pole piece 25. Hence, each electron "sees" a spatially alternating magnetic field.

The effect of an alternating magnetic field on any electron is a force thereon which is proportional to the root mean square of the alternating flux intensity. In the instant case, it can be shown that the net inward focusing force on an electron of the beam is proportional to the root mean square of the magnetic flux intensity component in the direction tangential to the path of said electron.

Because of the spiral motion of individual electrons during their traverse, they encounter a relatively large number of polarity reversals. By increasing either or both the rotational velocity components of the beam and the number of pole pieces 24 and 25 in the array, the number of such reversals can be increased such that the ripples caused thereby are so close together and of such small magnitude as to be negligible. The increased number of pole pieces also tends to promote a uniform circular cross-section on the electron beam. Further, centrifugal force caused by the beam rotation tends to make the beam diverge. This permits a stronger converging focusing force which can be applied through voltage supply 23 which reduces random movement of the individual particles. The forces acting on the cylindrical beam are hence quite large and the surfaces of the cylindrical beam become sharply defined. Further, because of increased magnetic intensity, the flux change becomes more abrupt, thereby further reducing ripple.

Fig. 3 illustrates another embodiment of the invention in which alternately polarized pole pieces 24 and 25 are joined by sectors of permanently magnetized material 26 to form a cylinder surrounding the traveling wave tube from its electron source end to its electron collector end. Each pole piece 24 is in contact, throughout

its length, with the north magnetic pole of each adjacent permanently magnetized sector 26, while each pole piece 25 is in contact, throughout its length, with the south magnetic pole of each adjacent sector of permanently magnetized material. Pole pieces 25 and 26 are arranged in alternate relationship to form a circular array around the envelope 14 such as to present a field configuration which is uniform in the longitudinal sense and periodic in the transverse sense.

For the sake of simplicity, only the envelope and helix of a conventional traveling wave tube have been shown in the embodiment of Fig. 3. The tube apparatus is intended to be the same as that shown in the embodiment of Figs. 1 and 2.

As can be readily appreciated from the foregoing description, the focusing apparatus of either of the embodiments is so constructed that it can be conveniently fitted over the envelope of a conventional traveling wave tube. The embodiment of Figs. 1 and 2 is advantageous when a variable flux is desired. The embodiment of Fig. 3 presents the advantage of being even more compact than the embodiment of Figs. 1 and 2.

It is to be understood that the above arrangements are merely illustrative of the application of the principles of the present invention. Numerous other arrangements may be devised by those skilled in the art without departing from the spirit and scope of the invention.

What is claimed is:

1. In an electron discharge device, an electron gun for forming and projecting a cylindrical electron beam having transverse and longitudinal velocity components, a collector for collecting said electron beam, and means for producing a focusing field about said electron beam which is of substantially uniform strength in the longitudinal sense of said electron beam and which is spatially alternating in the circumferential sense of said electron beam, said means surrounding said electron beam and extending substantially the entire distance from said electron gun to said collector.

2. In combination, means for forming and projecting a cylindrical electron beam having a rotational velocity component, means for collecting said electron beam, and means for focusing said electron beam comprising means for producing magnetic flux throughout said electron beam, the intensity of said magnetic flux being substantially uniform along any line parallel with the axis of said cylindrical beam and being spatially alternating with a substantially uniform periodicity in the circumferential sense of said electron beam.

3. An electron discharge device comprising electron gun means for forming and projecting a cylindrical beam of electrons, collector means for collecting said beam of electrons, means included in said electron gun means for forcing said electrons to follow substantially helical paths to said collector means, and means for focussing said beam comprising a circular array of magnetized bars extending substantially the entire length of said cylindrical beam and coaxial therewith, alternate ones of said bars being of like magnetic polarity and adjacent ones of said bars being of opposite magnetic polarity.

4. The combination of elements of claim 3 wherein alternate ones of said bars comprise extensions of one pole piece of an electromagnet, while the remaining ones of said bars comprise extensions of a second pole piece of said electromagnet.

5. The combination of elements of claim 3 wherein alternate ones of said bars are in contact, throughout their length, with permanently magnetized pole faces of like polarity, while adjacent ones of said bars are in contact, throughout their length, with permanently magnetized pole faces of opposite polarity.

6. In an electron discharge device, means for forming and projecting a cylindrical beam of electrons, a collector for collecting said beam, means for imparting to said electrons a transverse velocity component, and means for

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focusing said beam comprising a circular array of elongated members surrounding said beam and extending substantially the entire distance between said beam forming means and said collector and means for establishing a circumferentially spatially alternating focusing field comprising means for maintaining alternate ones of said members at the same polarity and adjacent ones of said members at opposite polarities.

7. An electron discharge device comprising a cylindrical envelope, an electron source at one end of said envelope for projecting a hollow electron beam, means for imparting to the electrons in the beam a transverse velocity component, electron collector means at the end of said envelope opposite said electron source end for collecting said electron beam, a helix surrounding said electron beam for propagating an electromagnetic wave in interacting relationship with said beam, and beam focusing means comprising a circular array of elongated magnetized elements surrounding said envelope and extending from the electron source end of said envelope to the electron collector end of said envelope, alternate ones of said elongated elements being of a uniformly north magnetic polarity and the remaining ones of said elongated elements being of a uniformly south magnetic polarity.

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8. The combination of elements of claim 7 wherein said alternate elongated elements comprise extensions from a first annular pole piece of an electromagnet and said remaining elongated elements comprise extensions from a second annular pole piece of said electromagnet, said first annular pole piece surrounding said envelope at the electron source end and said second annular pole piece surrounding said envelope at the electron collector end.

9. The combination of elements of claim 7 wherein said alternate elongated elements are in contact, throughout their length, with permanently magnetized pole faces of a uniformly north magnetic polarity, while said remaining elongated elements are in contact, throughout their length, with permanently magnetized pole faces of a uniformly south magnetic polarity.

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