Feb. 4, 1958 J. H. BRYANT 2,822,500

TRAVELING WAVE ELECTRON DISCHARGE DEVICES

Filed Oct. 31, 1952

2 Sheets-Sheet 1

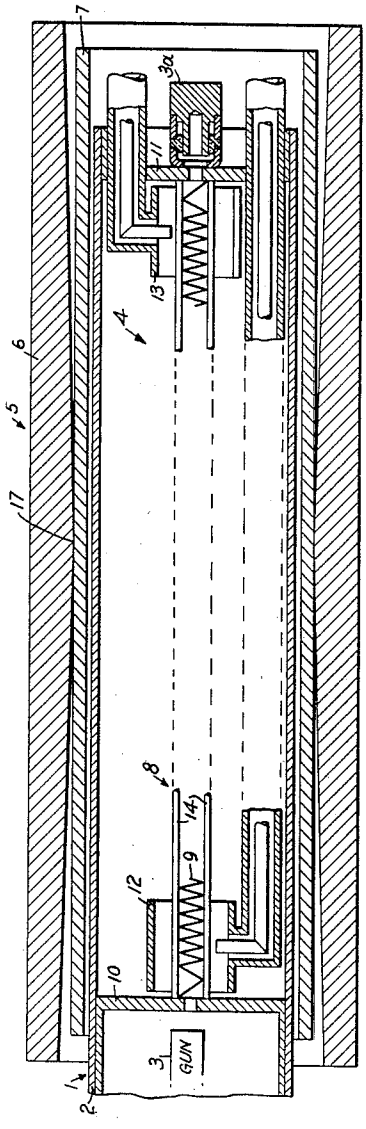


Fig. 1

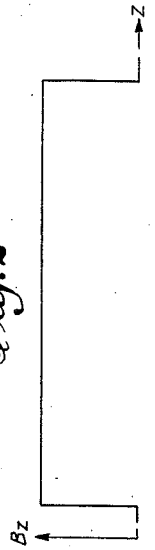


Fig. 2

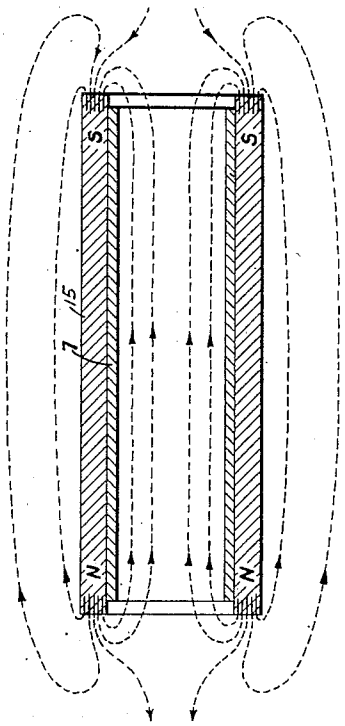


Fig. 3

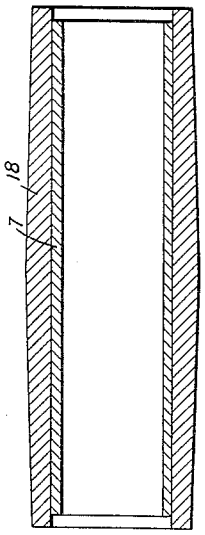


Fig. 4

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Filed Oct. 31, 1952 2 Sheets-Sheet 2

Fig. 5

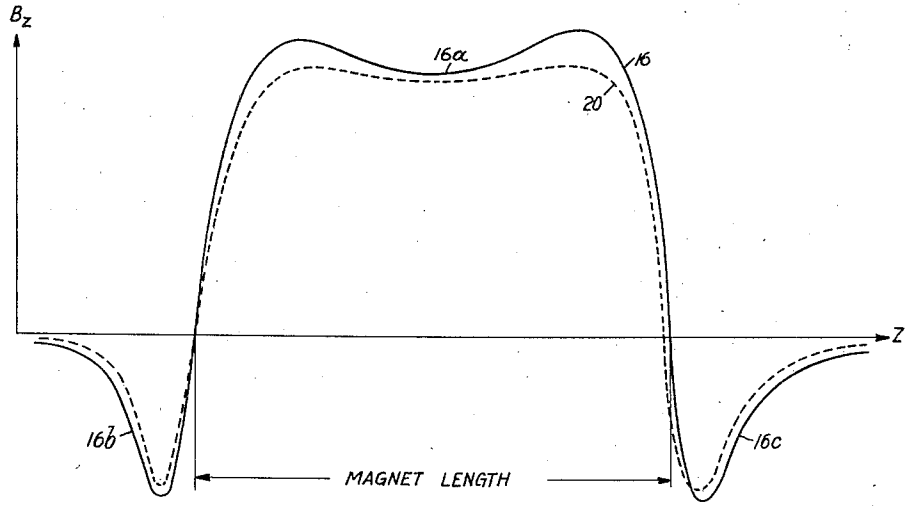
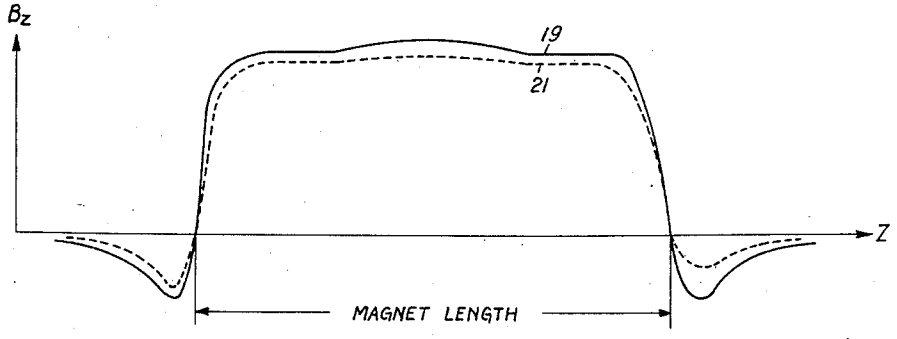


Fig. 6



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TRAVELING WAVE ELECTRON DISCHARGE DEVICES

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Application October 31, 1952, Serial No. 318,060

9 Claims. (Cl. 315—3.5)

This invention relates to traveling wave electron discharge devices and more particularly to electron-optical systems of a permanent magnet type applicable to such devices.

The traveling wave type of tube is particularly useful in wideband microwave systems since it is capable of amplifying radio frequency energy over an unusual wideband of frequencies. The tube includes a form of transmission line, usually a helix, for transmission of microwave energy for interaction with an electron beam closely associated with the line. The helical characteristic of the transmission line is such that the axial velocity of microwave signals conducted along the helical path is approximately the same as or slightly slower than the velocity of the electrons of the beam whereby the electrical field of the microwave signals interact with the electron beam for amplification of the microwave signals.

In the passage of the electron beam from an electron gun along the length of the transmission line, there is a tendency for the electrons of the beam to deviate from a desired electron beam path and as a result causes an increased electron beam cross-section which eventually will become greater than the diameter of the helical transmission line. This deviation of the beam is caused by the natural spaced-charge repulsion of electrons along the path of the helix, as well as by some types of electron guns which naturally projects a convergent electron beam. In becoming larger than the diameter of the helical transmission line, the electron beam will transfer electron beam current to the helical line which is a feature undesired for maximum amplification as well as requiring power dissipation on the helical structure. The use of magnetic fields to maintain electron beams uniform in diameter is substantially well understood, which is to say that the required magnetic field for any given application can be predicted. Heretofore the solution to this problem has been solved by employing electromagnets comprising a number of solenoid coils, ranging from one to four separate coils, coaxial of the electron beam path and extending substantially the entire length of the traveling wave propagating structure. These solenoids with their associated current supplying devices are arranged to produce a substantially uniform magnetic field whose lines of flux extend axially of the helical conductor for substantially its entire length to insure a pencil-like beam throughout the entire length of the transmission line.

In a number of traveling wave device applications these electromagnets, with the number of coils employed and the circuitry required to establish the regulated current to flow therethrough to produce a desired magnetic field, become cumbersome. Further, even with all the current regulating circuitry, the magnetic field produced by the electromagnets often varies enough to produce an undesired effect of beam expansion and thus yielding undesired power operating characteristics. In these applications where the known electromagnet type electron-optical systems become cumbersome, it may become desirable to employ a permanent magnet to produce the required magnetic field distribution. From the viewpoint of economy of the magnetizing force, consideration must be given to the D.-C. power when a solenoid is employed and the weight of the magnet when a permanent magnet is employed, as well as the quality of the result. It is required for use in electron-optical system that the magnetic field be uniform over the axial extent of the electron beam in the helical propagating structure. In many of these applications it has been found preferable and more economical to employ permanent magnet type of electron-optical systems.

It is an object of this invention, therefore, to provide an improved electron-optical system of the permanently magnetized type to provide a substantially uniform axial magnetic field; and another object is to provide such an electron-optical system in combination with a traveling wave type of electron discharge device.

Still another object of this invention is the provision of a hollow cylindrical magnetic system capable of providing a substantially axial magnetic field throughout substantially the entire length thereof.

A feature of this invention is the tapering of the interior wall of a hollow cylindrical permanent magnet in a manner to obtain a uniform axial magnetic field over a substantial portion of the axial extent of the permanent magnet.

Another feature of this invention is the employment of a shell of saturable magnetic material coaxially of and within a hollow cylindrical permanent magnet to assist in aligning the axis of the magnetic field with the mechanical axis of the permanent magnet, and where such magnet is used in conjunction with a traveling wave electron discharge device to assist in making the axis of the magnetic field coincide with the electron path of such device.

Additional features of this invention include the combination of a shell of saturable magnetic material and a cylindrical shell permanent magnet of uniform cross-section; a shell of saturable magnetic material and a cylindrical shell permanent magnet having a tapered interior wall; and a shell of saturable magnetic material and a cylindrical shell permanent magnet having a tapered exterior wall; each combination producing a substantially uniform magnetic field in substantial coincidence with the mechanical axis of the permanent magnet.

The above-mentioned and other features and objects of this invention will become more apparent by reference to the following description taken in conjunction with the accompanying drawings, in which:

Fig. 1 is a longitudinal section illustrating an application of an embodiment of this invention;

Fig. 2 is a curve illustrating the ideal magnetic field distribution for application with a traveling wave tube which the embodiments of this invention attempt to approach;

Figs. 3 and 4 are longitudinal sections illustrating other embodiments of this invention; and

Figs. 5 and 6 are graphical representations of the axial magnetic field distribution for the various embodiments of this invention with and without the shell of the saturable magnetic material.

Referring to Fig. 1, a traveling wave type of electron discharge device 1 is shown to comprise a cylindrical housing 2 containing at one end thereof an electron gun unit 3, at the opposite end thereof an electron collector 3a and intermediate thereof a radio frequency interaction section 4. The housing 2 has mounted thereon and concentric thereto an embodiment of an electron-optical system 5 in accordance with the principles of this invention.

For application with a traveling wave type it is desirable to have a magnetic field distribution as illustrated in Fig. 2 or as close as may be practically attainable. The

embodiments of the electron-optical system 5 shown herein produce a practical magnetic field distribution which closely approximates that shown in Fig. 2. The form shown in Fig. 1 comprises a cylindrical shell of saturable magnetic material 7 and a cylindrical permanent magnet 6, the latter having a tapered inner surface for production of an axial magnetic field to maintain a substantially uniform electron beam throughout the length of section 4.

Housing 2 may be composed of ceramic or non-magnetic metallic material as desired. The internal structure of the electron gun unit 3 may follow any of the conventional structures presently known in the art. Preferably the device 1 employed with the electron-optical system 5 should follow generally the teachings of the copending application of J. H. Bryant and T. J. Marchese, Serial No. 221,862, filed April 19, 1951, now Patent No. 2,788,465. Disclosed therein is the structural arrangement of a traveling wave tube with the terminals for the electrodes of the gun unit at one end of the tube and the terminals for the radio frequency input and output connections at the other end of the tube. The input and output radio frequency connections disclosed therein are of the coaxial type, but may be adapted to function with waveguide coupling lines as disclosed in the copending application of J. H. Bryant, A. G. Peifer, and R. W. Wilmarth, Serial No. 305,538, filed August 21, 1952. It is desirable for the structure of the traveling wave tube employed with the electron-optical system of this invention to have radio frequency input and output connections carried longitudinally by the tube so that the electron-optical system is not physically distributed by carrying such connections at right angles to the devices.

Referring more particularly to interaction section 4, a radio frequency transmission line 8 preferably in the form of a helix 9 may be supported in a ceramic tubing positioned axially by the magnetic barrier members 10 and 11 and the matching transformer sections 12 and 13 located respectively at the input and output ends of section 4. It is preferred, however, to support helix 9 in a plurality of dielectric support rods 14 substantially as disclosed in the copending application of R. W. Wilmarth and B. D. McNary, Serial No. 305,228, filed August 19, 1952. Disclosed therein are means and methods for manufacturing a rigid transmission line or propagating structure while maintaining close mechanical tolerances with every turn of the helical conductor being bonded to the dielectric support rods. Preferably, transmission line 8 should be coated for substantially the first half or a selected portion thereof of its length with aquadag or other lossy material to minimize flow of reverse radio frequency waves along the conductor 9 and the electric field thereof. The propagating structure is not necessarily limited to the helical conductor type but may assume other configurations such as a plurality of annular discs or plates, whereby the axial velocity of the radio frequency energy is preferably slightly slower than the velocity of the beam of the electrons projected from the unit 3.

The major advantage in an electron-optical system employing a hollow cylindrical permanent magnet is the economical value where the weight of such a magnet is not very great, the D.-C. supply for a solenoid is eliminated, and a magnetic field distribution is obtained which approaches more closely the ideal magnetic distribution illustrated in Fig. 2. However, it must be remembered that the electron beams used in traveling wave tubes assume two different types of geometry. The magnetic field requirements for each geometry differ only in the field distribution requirements at the ends of the magnet. The first, which shall be referred to as type 1, relates to tubes with rectilinear electron flow from cathode to collector, the beam diameter being essentially the same as the cathode diameter. For this application one requires a uniform magnetic field over a given interval without regard of what occurs outside that interval. This is true since the cathode may be operated within the uniform field region. The second, referred to as type 2, relates to tubes using electron guns with converging electron beams. For this application it is essential that the magnetic field be eliminated from the cathode-anode region. Also, for maximum efficient utilization of a magnetic field, a type of focusing that has been referred to generally as "Brillouin" focusing should be used. For "Brillouin" focusing the magnetic field must rise abruptly from zero to the uniform value at a point where the electron beam ceases converging and becomes parallel to the axis. Such a magnetic field distribution may be fairly well obtained with iron-encased solenoids, but such a field, although obtainable by special care and manipulation in the construction of traveling wave tube particularly in the cathode-anode region, is much more difficult to obtain with permanent magnets.

Uniform cylindrical shell permanent magnets may be and are preferably employed from an economy standpoint for type 1 applications and also for some of the type 2 applications where the cathode-anode region is specifically constructed to provide a shielding from magnetic fields and arranged such that the point where the electron beam ceases converging and becomes parallel to the axis occurs just outside the shielded cathode-anode region. A longitudinal section of this type of magnet is illustrated in Fig. 3 wherein shell 15 is magnetized longitudinally resulting in an axial magnetic field distribution. The resulting axial magnetic field distribution illustrated by curve 16 of Fig. 5 indicates a drop in magnetic field strength at the central portion 16*a* of the magnet which is objectionable in the application to a traveling wave tube. The reversals 16*b* and 16*c* of the magnetic field at the ends of the cylindrical shell magnet are peculiar to permanent magnets and are shown by flux lines in Fig. 3. As can be seen the direction of the magnetic field actually reverses at or near the end of the magnet. This reversal of field is not objectionable for type 1 applications but is objectionable for type 2 applications unless arranged in a manner such that the reversal occurs in the shielded portion of the cathode-anode region.

It was discovered that tapering the wall of the magnet from the center outward as illustrated in Fig. 1, results in an axial magnetic field substantially as shown in Fig. 6, curve 19, substantially eliminating the drop in magnetic field strength over the central portion of the permanent magnet of Fig. 3, see curve 16 of Fig. 5. As can be seen, the field is quite uniform except for the slight rise in the center of the magnet. This raise can be eliminated by judicial grinding away of the sharp discontinuity at point 17 of magnet 6 wherein the inner magnet wall is tapered from the center outward.

In Fig. 4 the outer diameter of the magnet 18 is shown tapered from the center to the ends. It was found that the magnetic field distribution for magnet 18 is similar to the uniform diameter cylindrical permanent magnet as illustrated by curve 16 of Fig. 5.

Experiments with sample magnets of the type shown in Fig. 1 demonstrated that the alignment of the magnetic field axis with the mechanical axis of the magnet did not always agree. A further difficulty encounted was that the direction of the magnetic field at one end of the magnet sometimes varied from that at the opposite end by a degree or more. It has been discovered that this magnetic field misalignment could be overcome by placing a thin cylinder of saturable magnetic material such as shell 7, Fig. 1, inside the cylindrical shell magnet 6 and concentric with the envelope 2 of traveling wave 1. It is important that the shell 7 saturates magnetically at magnetic field strengths equal to or less than the minimum field which one wishes to control. The employment of such a thin shell of saturable magnetic material not only aids in the alignment but also renders the field strength more uniform in all

embodiments of cylindrical shell magnets illustrated in Figs. 1, 3, and 4. Reference to Figs. 5 and 6 and curves **20** and **21**, respectively, illustrate the behavior of the axial magnetic field when the shell **17** is employed in conjunction with the embodiments of the cylindrical shell magnet shown in Fig. 1 and Figs. 3 and 4, the curves **16** and **20** being typical for both forms of magnets shown in Figs. 3 and 4. Such a magnetic field distribution as illustrated herein for each of the separate embodiments illustrates that the various embodiments may be interchanged to function as a portion of the electron-optical system as shown in Fig. 1 with equivalent practical advantages. However, it can be readily seen by those skilled in the art that it would be preferable to employ the embodiment shown in Fig. 1 for an application wherein the magnetic field distribution is required to rigidly maintain the electron beam uniform throughout the length of interaction section **4**.

While I have described above the principles of my invention in connection with specific apparatus, it is to be clearly understood that this description is made only by way of example and not as a limitation to the scope of my invention as set forth in the objects thereof and in the accompanying claims.

I claim:

1. In a device of the traveling wave tube type which includes means for producing an electron beam for flow along a given path and a radio frequency propagating structure disposed adjacent said path to enable interaction between the electrons of said beam and radio frequency energy propagated along said structure; an electron-optical system disposed concentrically of said path comprising a hollow cylindrical permanent magnet magnetized longitudinally in a manner to produce oppositely polarized poles substantially at the ends of the cylindrical form of said magnet and a thin cylinder of saturable magnetic material disposed concentrically within said magnet and about said path to orient the axis of the developed magnetic field with the path of said beam, said permanent magnet comprising a cylindrical shell having a cross-section tapering from the center toward its ends.

2. In a device according to claim 1, wherein the inner diameter of said cylindrical shell is constant and the outer diameter thereof varies in a manner along its length such that the outer surface is tapered from the center to the ends.

3. In a device according to claim 1, wherein the inner diameter of said cylindrical shell varies in a manner along its length such that the inner surface is tapered from the center to the ends.

4. In a device according to claim 3, wherein the central portion of said inner surface is slightly rounded to reduce the abrupt change of the contour of said inner surfare.

5. In a device of the traveling wave tube type which includes means for producing an electron beam for flow along a given path and a radio frequency propagating structure disposed adjacent said path to enable interaction between the electrons of said beam and radio frequency energy propagated along said structure; an electron-optical system disposed concentrically of said path comprising a hollow cylindrical permanent magnet magnetized longitudinally in a manner to produce oppositely polarized poles substantially at the ends of the cylindrical form of said magnet and a thin cylinder of saturable magnetic material disposed concentrically within said magnet and about said path to orient the axis of the developed magnetic field with the path of said beam, said permanent magnet being tapered in cross-section toward at least one end thereof.

6. In a device of the traveling wave tube type which includes means for producing an electron beam for flow along a given path and a radio frequency propagating structure disposed adjacent said path to enable interaction between the electrons of said beam and radio frequency energy propagated along said structure; an electron-optical system disposed concentrically of said path comprising a hollow cylindrical permanent magnet magnetized to produce oppositely polarized poles substantially at the ends of said magnet having the cross-section of a portion thereof tapering toward at least one of its ends.

7. In a device according to claim 6, wherein the inner diameter of said magnet varies in a manner along its length such that the inner surface is tapered from the center portion thereof toward its ends.

8. A permanent magnet comprising a hollow cylinder having a cross section tapering from the center towards its ends magnetized longitudinally to produce oppositely polarized poles substantially at the ends of said cylinder and a saturable magnetic shell of uniform cross section disposed to be concentrically within said cylinder, substantially coextensive of said cylinder and in contact with at least the central portion of said cylinder for cooperation therewith to produce a substantially uniformly distributed magnetic field axially of said cylinder.

9. A magnet according to claim 8, wherein the inner diameter of said cylinder varies in a manner along its length such that the inner surface is tapered from the center portion toward its ends.

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