

Feb. 16, 1960

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2,925,508

ELECTRON BEAM FOCUSING STRUCTURE

Filed July 28, 1955

3 Sheets-Sheet 1

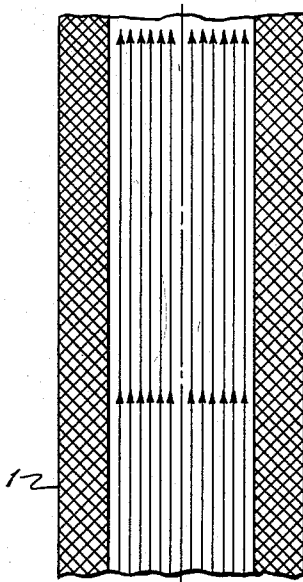


Fig. 1.

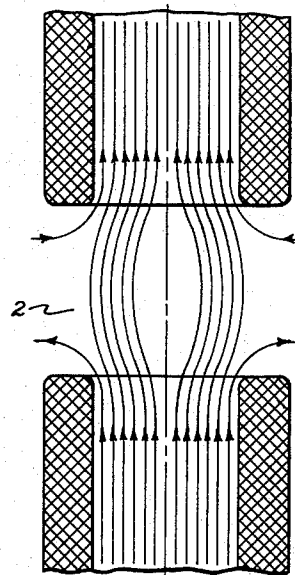


Fig. 2.

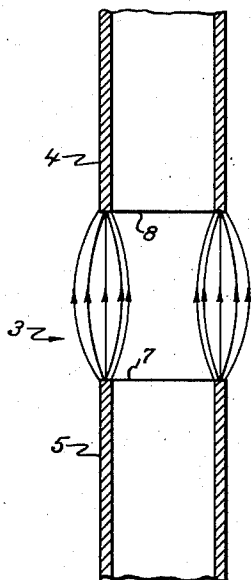


Fig. 3.

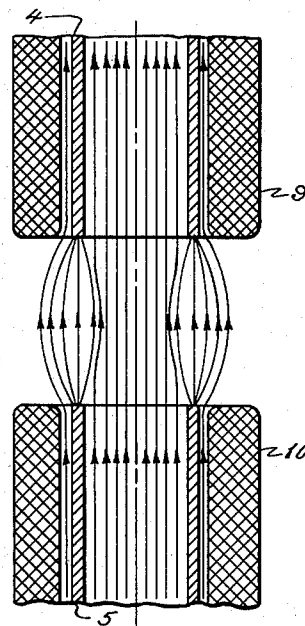


Fig. 4.

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3 Sheets-Sheet 2

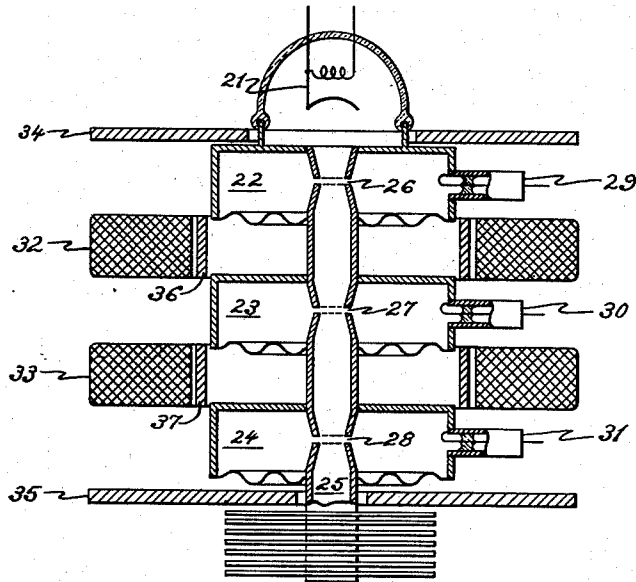


FIG. 5.

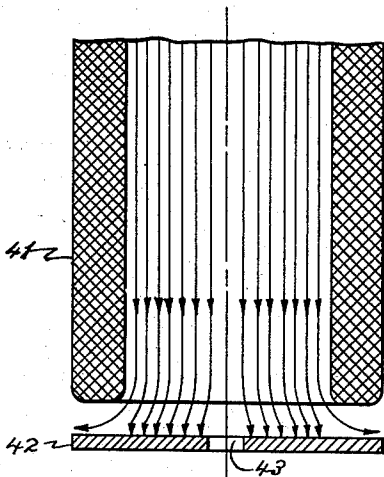


FIG. 6.

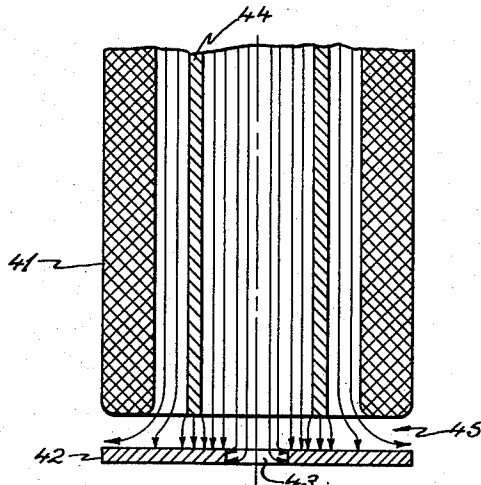


FIG. 7.

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ELECTRON BEAM FOCUSING STRUCTURE

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3 Sheets-Sheet 3

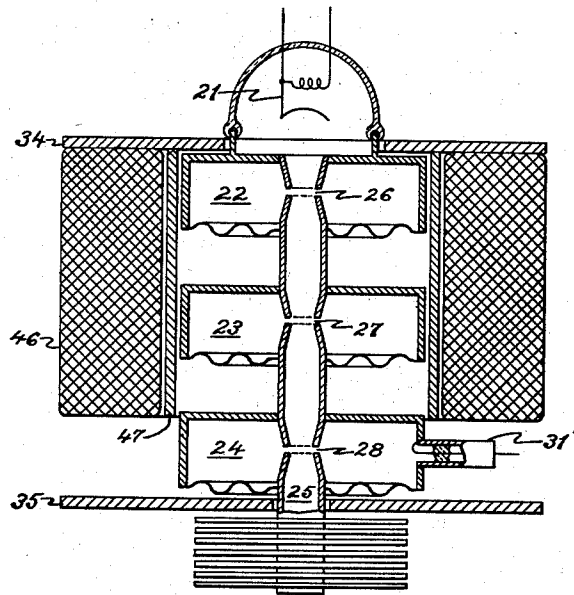


FIG. 8.

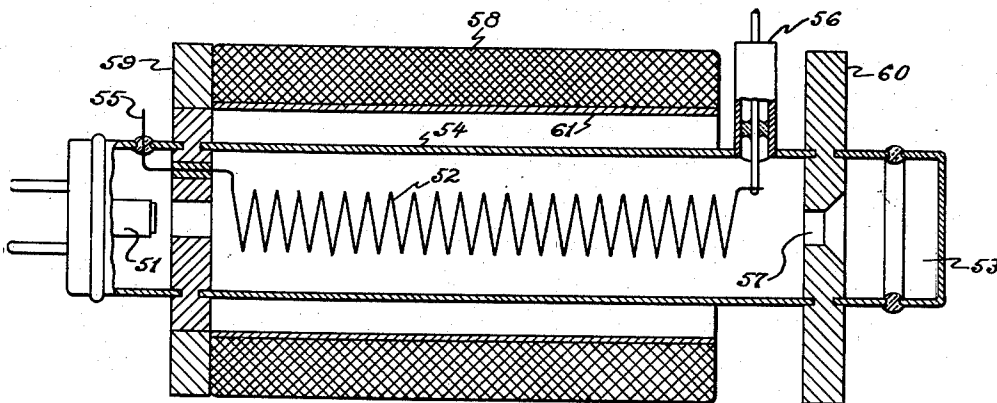


FIG. 9.

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ELECTRON BEAM FOCUSING STRUCTURE

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2 Claims. (Cl. 313-84)

This invention pertains to magnetic field shaping apparatus and more particularly to a device for compensating for the reduction of magnetic field that occurs at gaps in solenoid magnets.

In electron beam tubes, such as klystrons and traveling wave amplifiers, it is necessary to project a stream of electrons along the axis of the tube for a considerable distance. To confine the beam of electrons to a given cross-section by preventing its radial dispersion, it is necessary to employ an axial magnetic field. The axial magnetic field tends to convert any radial motion of the electrons in the beam into a rotational motion about the tube axis and thereby prevents spreading of the beam. This field is frequently provided by a solenoid external to the electron tube structure. To provide a uniform axial magnetic field and to prevent any fluctuations in the electron beam along its path, it is desirable that the solenoid be uniform and coextensive with the path length traveled by the electron stream along the tube axis. In the construction of tubes of this type it is often necessary to couple energy into or out of the tube by means of radially disposed transmission line or waveguide structures intermediate the ends of the tube. These coupling structures prevent the use of a uniform continuous solenoid surrounding the length of the electron beam path, but instead the solenoid must be constructed in segments, the segments terminating at the coupling devices and thereby defining a gap. The axial magnetic field in the vicinity of these gaps tends to fringe outwardly and become weakened. Such non-uniformity in the axial magnetic field interferes with the beam focusing and the efficient operation of these electron tubes.

It is therefore an object of this invention to provide means for overcoming the reduction of magnetic field that occurs at gaps in electron beam focusing structures.

It is a further object of this invention to provide means for shaping axially symmetric magnetic fields in the vicinity of solenoid gaps.

It is a further object of this invention to provide for a uniform axial magnetic field despite gaps in the magnetic structure.

It is a further object of this invention to minimize the fringing of magnetic fields near the ends of long solenoids.

In this invention means is provided to compensate for the reduction of the axial magnetic field at gaps in the solenoid. Compensation means is used in cooperation with the existing solenoid structure and consists of paramagnetic shells substantially concentric and coextensive with the solenoid elements. The shells are employed inside the solenoid and surrounding the electron beam. The shells become saturated in the fields of the solenoid and set up their own magnetic field, which when superimposed on the existing fringing magnetic field due to the gap of the solenoid effectively straightens the flux lines and results in a uniform axial magnetic field at the gap.

Other objects and advantages of the present invention

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will become apparent from the specification taken in connection with the accompanying drawings, wherein,

Fig. 1 is a cross-sectional view of a solenoid;

Fig. 2 is a cross-sectional view of a solenoid having a gap;

Fig. 3 is a cross-sectional view of a saturated paramagnetic shell having a gap;

Fig. 4 is a cross-sectional view of the magnetic gap compensating structure of this invention;

Fig. 5 is a cross-sectional view of a klystron amplifier tube employing the compensating structure of this invention;

Fig. 6 is a cross-sectional view of a solenoid adjacent a pole piece;

Fig. 7 is a cross-sectional view of the compensating structure of this invention employed in connection with the structure of Fig. 6;

Fig. 8 is a cross-sectional view of a klystron amplifier tube employing the structure of Fig. 7; and

Fig. 9 is a cross-sectional view of a traveling wave amplifier employing the compensating structure of this invention.

Referring now to Fig. 1, there is shown in cross-section a segment of a long current carrying coil or solenoid 1. If the solenoid is uniformly wound the magnetic flux lines near the center of the length of the solenoid are substantially parallel to the axis of the solenoid, as shown in the figure. If now an electron beam is projected along this axis, the cross-sectional area of the beam will tend to remain constant due to the uniform focusing effect of the axial magnetic field. Any electrons in the beam having components of velocity which are perpendicular to the axis or beam path will be caused to describe helical paths having a small radius of curvature, this radius remaining constant so long as the axially directed magnetic field remains constant.

If the gap 2 is introduced in the solenoid, as in Fig. 2, or if two solenoids having common axes are placed close together so that both windings produce aiding magnetic flux, a fringing magnetic field will exist in the vicinity of the gap. The axially-directed field near the axis will be reduced in the gap region. An electron beam traveling along the axis and being focused by the axial magnetic field will tend to diverge or be defocused as it crosses the gap defining the decreased axial magnetic field. The original cross-sectional area of the beam will not in general be restored after crossing the gap.

In order to overcome the defocusing effect on an axial beam of electrons by a gap in a solenoid the compensating structure of Fig. 3 is employed. The compensating structure consists of a magnetized shell having a gap 3 corresponding to the gap of the solenoid structure. The shell may be composed of any paramagnetic material, such as cold-rolled steel. The portions 4 and 5 of the shell must be so magnetized that their respective ends 7 and 8 nearest the gap are unlike magnetic poles in order that fringing magnetic fields as shown are introduced at the gap. The fringing fields in the vicinity of the gap 3 of the magnetic shell are of such shape that they tend to compensate for the fringing fields in the vicinity of the gap 2 of the solenoid when the solenoid and shell structures of Figs. 2 and 3 are properly oriented with respect to each other.

Fig. 4 shows the compensating magnetic shell portions 4 and 5 introduced in the structure of Fig. 2 in accordance with this invention. The shell portions 4 and 5 are concentrically mounted within respective solenoid portions 9 and 10 arranged to be coextensive with these solenoid portions. The magnetomotive force generated by the solenoid portions saturates the shell material thereby inducing magnetic fields in the shell which have the desired configuration of Fig. 3. When the shell

fields of Fig. 3 are superimposed on the fields due to the solenoid portions of Fig. 2, magnetic field compensation is achieved. In the area surrounded by the shell, the outwardly fringing flux lines of the solenoid gap are straightened or corrected by the inwardly fringing flux lines of the shell structure. As shown in Fig. 4, the flux lines are materially straightened in the vicinity of the gap, and an electron beam will remain focused as it traverses the gap of the solenoid along its axis.

The value of axial magnetic field in the area of the path surrounded by the shell remains substantially the same as before, since the magnetomotive force is unchanged. The effect of the reduction in path reluctance on the magnetomotive force is overcome by the increased flux in the shell. It has been found that the number of flux lines inside the shell should be about twice the number of lines threading the area of the path surrounded by the shell. The saturated iron cylinder normally would have a flux density of about 137,000 lines per square inch. Equating the total flux within the cylinder to twice the flux threading the area surrounded by the shell, the following simplified relationship expresses the approximate design value for the thickness t of the shell to the radius R of the shell,

$$\frac{t}{R} = 4.71 \times 10^{-6} B$$

where B is the axial flux density in gauss.

A particular application of this invention is disclosed in Fig. 5 in which there is shown in cross-section a three resonator klystron amplifier tube employing a magnetically focused electron beam, the beam being focused according to the principles of this invention. The klystron comprises an electron gun 21 for projecting a cylindrical stream of electrons through the successive toroidal cavity resonators 22, 23 and 24. The beam is terminated in a collector 25. The resonant cavities 22, 23 and 24 are of the doubly reentrant type, their reentrant portions defining the respective interaction gaps 26, 27 and 28. Connected to the cavity resonators for coupling in or extracting energy therefrom are the coaxial line coupling elements 29, 30 and 31, which project radially from the respective cavity resonators to which they are connected. It is necessary for efficient operation of this tube that the diameter of the interaction gaps be kept as small as possible. In order to confine the electron beam to a sufficiently small cross-sectional area that it may pass through the three successive interaction gaps, it is necessary to supply a magnetic focusing field along the axis of the tube. The magnetomotive force to supply the field is provided by the cylindrical solenoid sections 32 and 33. The solenoid cannot be formed as one continuous cylindrical element because of the radial coupling elements 29, 30 and 31. Paramagnetic pole pieces 34 and 35 abutting the ends of the solenoid complete the magnetic path. In order to prevent fringing of the magnetic field at the central interaction gap 27, the paramagnetic shell portions 36 and 37 are provided so as to be concentric and coextensive with the solenoid portions 32 and 33. These shell portions 36 and 37 further act to correct the fringing magnetic field opposite the gaps defined by pole pieces 34 and 35 and respective solenoid sections 32 and 33, as will be explained later.

This invention is also useful for shaping or correcting the axial magnetic field near the ends of a solenoid.

Fig. 6 shows in cross-section the magnetic field existing within a solenoid 41 which is disposed adjacent to but not in contact with an apertured paramagnetic pole piece 42 located near one end of the solenoid. Since the pole piece 42 is not in contact with the end of solenoid 41, the flux lines tend to fringe before they enter the pole piece from the solenoid. An electron beam projected along the axis of this device and requiring the axial magnetic field for focusing will tend to diverge before it reaches an outlet aperture 43 in pole piece 42. Instead

of passing through the aperture 43, the beam will strike the edges of the aperture and cause undue overheating and undesirable secondary emission electrons.

The magnetic field near the end of the solenoid may be corrected by the compensating paramagnetic shell 44 of this invention, as shown in Fig. 7. The magnetic flux induced in the shell tends to bow or fringe inwardly near the axis of the solenoid at the gap 45 and thereby compensates or straightens the lines of flux in the vicinity of the gap. These straightened lines of magnetic flux permit passage of a greater portion of the electron beam through aperture 43.

Referring once more to Fig. 5, the shell portions 36 and 37 tend to correct the axial focusing field in the respective gaps defined by the ends of solenoid sections 32 and 33 and pole pieces 34 and 35 in accordance with the principles described in connection with Figs. 6 and 7.

A modified version of the klystron amplifier of Fig. 5 is shown in Fig. 8, in which only one resonant cavity has a radially extending coupling element 31'. Thus the axial focusing solenoid 46 may extend for the full length of the tube with the exception of a gap in the vicinity of coupling element 31'. Consequently, a single saturable shell 47 may be inserted within the solenoid to provide the compensation required at interaction gap 28 for passage of the electron beam.

A further embodiment of this invention is shown in Fig. 9, wherein the electron beam of a traveling wave amplifier is focused. The traveling wave amplifier essentially comprises an electron gun 51, a slow wave structure 52, such as a helix, a collector 53 and a vacuum envelope 54. An R.-F. input connector 55 and an R.-F. output connector 56 respectively introduce signal energy onto the slow wave structure and extract amplified energy therefrom. The electron gun 51 projects a stream of electrons along the axis of the slow wave structure, where the electron beam interacts with the electromagnetic wave traveling on the structure and causes amplification of the wave. The beam then passes through an aperture 57 to collector 53. The electron beam is focused throughout its travel along the tube axis by means of an axial magnetic field provided by a solenoid 58 in cooperation with paramagnetic pole pieces 59 and 60. The R.-F. output connector 56 which projects radially from the vacuum envelope prevents the solenoid 58 from abutting pole piece 60, the resulting gap between the end of solenoid 58 and pole piece 60 causing a fringing or reduced axial magnetic field in the vicinity of aperture 57. Compensation or correction of the fringing field in the vicinity of the aperture is provided by the paramagnetic shell or insert 61, which is coextensive with solenoid 58 along the axis of the tube. As discussed in connection with Figs. 6 and 7 this magnetic insert corrects the axial flux lines in the vicinity of the magnetic gap thereby permitting a greater portion of the electron beam to pass through the aperture 57 to the collector 53.

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

What is claimed is:

1. The combination of means for producing and directing an electron stream along a predetermined axis, first and second apertured solenoid sections disposed in coaxial relationship with said axis for producing an axial magnetic field that confines said stream to a given cross section, the adjacent ends of said solenoid sections being separated by an air gap, a thin-walled shell positioned coaxially within the aperture of each of said solenoid sections, each shell being in substantially coextensive relationship with its surrounding solenoid section and sepa-

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rated from the other shell by an air gap, each of said shells being of a magnetically permeable material that is saturated by the magnetic field which is produced for confining said beam to its given cross section, the saturated flux density of each shell being of the order of 137,000 lines per square inch, the thickness t and the radius R of each shell having an approximate relationship of

$$\frac{t}{R} = 4.71 \times 10^{-5} B$$

where B is the axial flux density in gauss of the flux lines threading the area surrounded by the shell.

2. The combination of means for producing and directing an electron stream along a predetermined axis, at least one apertured solenoid section and at least one apertured pole piece disposed in coaxial relationship with said axis for producing a magnetic field that confines said stream to a given cross section, one end of said solenoid section being separated from said pole piece by an air gap, a thin-walled shell positioned coaxially within the aperture of said solenoid section in substantially coextensive relationship therewith, the shell being separated from said pole piece by an air gap, said shell being of a magnetically permeable material that is saturated by the magnetic field which is produced for confining said stream to its given cross section, the saturated flux density of said

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shell being of the order of 137,000 lines per square inch, the thickness t and radius R of said shell having an approximate relationship of

$$\frac{t}{R} = 4.71 \times 10^{-5} B$$

where B is the axial flux density in gauss of the flux lines threading the area surrounded by the shell.

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