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E. E. BLISS

2,964,670

TRAVELING WAVE TUBE

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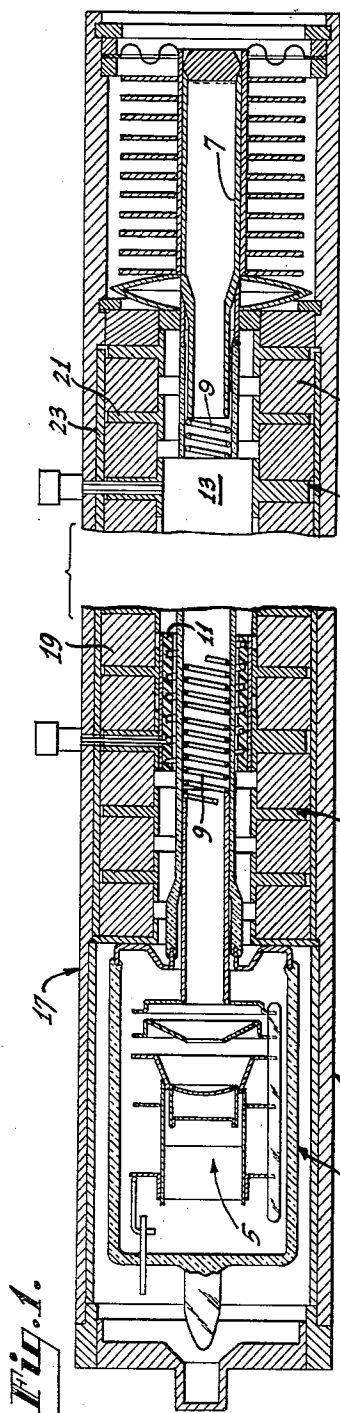


Fig. 1.

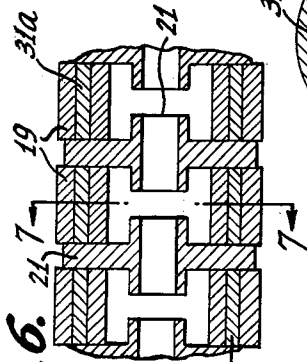


Fig. 2.

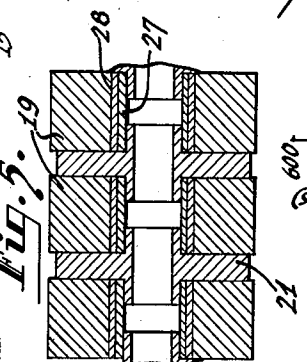


Fig. 3.

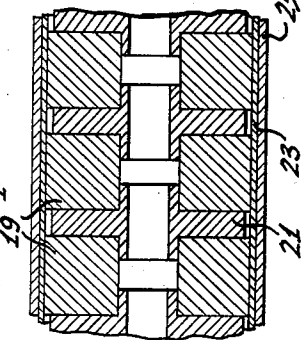


Fig. 4.

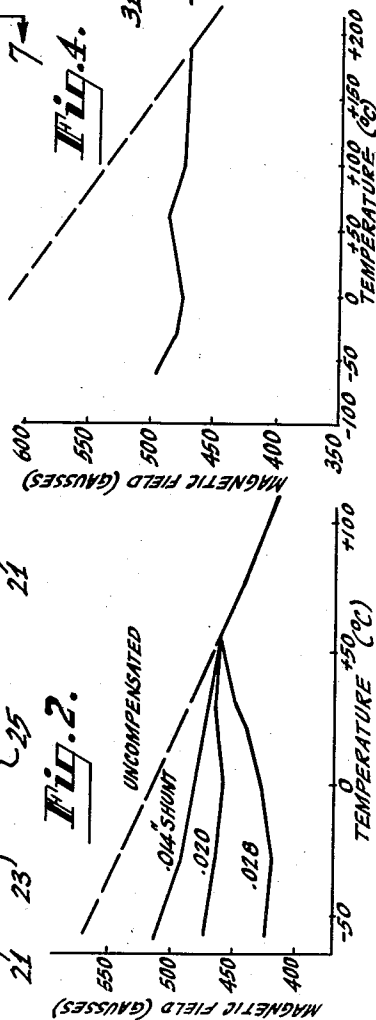


Fig. 5.

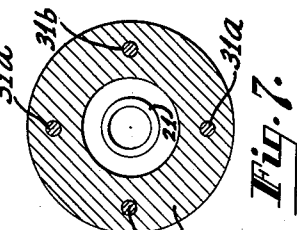


Fig. 6.

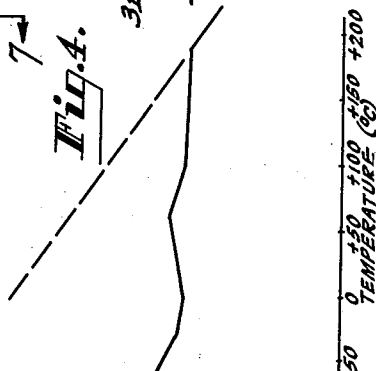


Fig. 7.

INVENTOR.
EDWARD E. BLISS

BY

Thomas R. Webb
AGENT

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TRAVELING WAVE TUBE

Edward E. Bliss, Parsippany, N.J., assignor to Radio Corporation of America, a corporation of Delaware

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12 Claims. (Cl. 315—3.5)

The present invention relates to an improvement in periodic magnetic focusing structures, and particularly, to traveling wave tubes incorporating periodic magnetic beam focusing fields.

In traveling wave tubes in which an electron beam is projected along an extended path for interaction with traveling electric fields associated with a helix, or other elongated slow wave structure, it is necessary to provide suitable focusing means to prevent excessive interception of beam current by the helix. Early traveling wave tubes were provided with electromagnets or solenoids coaxially surrounding the beam path to establish an axial unidirectional magnetic focusing field. For many applications the bulk, weight and power consumption of such solenoids are prohibitive. The comparatively recent development of periodic (spatially-alternating) permanent magnet focusing stacks as a means for maintaining a coherent electron beam of substantially uniform diameter in traveling wave tubes effected a great reduction in bulk and weight and eliminated the power consumption entirely (after the initial magnetization of the magnets). However, most traveling wave tubes that are focused by periodic permanent magnets are limited in the range of ambient temperatures in which they can be operated satisfactorily. Only certain ceramic-type magnets can be used for periodic focusing because of the high coercive force required by the geometry involved. These magnet materials, usually of the barium ferrite variety, have high change in magnetic properties with changes in temperature. For example, a typical magnet assembly producing a peak axial magnetic field of 475 gauss at room temperature changes as much as 30 percent in magnetic field over a temperature range of 200° C. While very low power tubes can tolerate the change of field strength produced by temperature changes up to 100° C., because of their ability to dissipate large percentages of their beam current on the helix without causing overheating and gassing, the practical limit is about 25 to 50° C. for most tubes. For high power tubes the limit is still lower.

The principal object of the present invention is to provide traveling wave tubes with improved periodic permanent magnet beam focusing means capable of producing substantially constant peak magnetic field along the beam path over a substantial range of ambient temperatures.

This object is accomplished in accordance with the present invention by partially shunting each of the permanent magnets of a periodic permanent magnet structure by one or more elements of temperature-compensating magnetic material, the magnetic permeability of which changes with temperature in the same direction as the permanent magnets. Substantial compensation is obtained over a temperature range up to about 100° C. by means of a single shunting element. To obtain compensation over larger temperature ranges, two shunts of materials having Curie points about 100° C. apart are used.

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Other objects and advantages of the invention will be apparent from the following detailed description.

In the accompanying drawing:

Fig. 1 is an axial sectional view of a traveling wave tube embodying one form of the present invention;

Fig. 2 is a graph showing the effect of temperature-compensating magnetic shunts on the variation of peak magnetic field strength of a permanent magnet with temperature;

Fig. 3 is a fragmentary axial section view of a portion of the magnetic focusing structure of Fig. 1 modified by the addition of a second shunt of different material;

Fig. 4 is a graph showing the effect of the two shunts of Fig. 3 on the peak magnetic field;

Figs. 5 and 6 are views similar to Fig. 3 of two other forms of the invention; and

Fig. 7 is a transverse sectional view taken on the line 7—7 of Fig. 6.

Referring to Fig. 1, there is shown, for example, a traveling wave tube 1 comprising: an elongated evacuated envelope 3, containing a convergent electron gun 5 and a collector 7 at opposite ends thereof and an intermediate elongated helix 9; helical input and output couplers 11 and 13 coupled to the input and output ends of helix 9; an elongated periodic permanent magnet focusing stack 15 surrounding the envelope 3, couplers 11 and 13 and helix 9; and a tubular aluminum capsule casing completely enclosing all of the other parts.

The magnetic focusing stack 15 is made up of a series of axially-polarized, annular, permanent magnets 19 stacked alternately with a series of magnetic shims of pole pieces 21. The ring magnets 19, which are preferably of a ceramic type magnetic material, such as barium ferrite, are arranged with like poles adjacent to each other to establish a periodic magnetic focusing field that alternates in axial direction from gap to gap along the beam path. Preferably, the pole pieces 21 are soft iron rings having a T-shaped cross-section with the heads of adjacent pole pieces axially spaced apart by a gap distance that is small compared to the length of the heads, as shown. Two of the pole pieces 21 surrounding the input and output couplers 11 and 13 are made thicker than the others to provide room for passage of coaxial coupling lines therethrough to the coupler helices. The slight asymmetries thus introduced do not appreciably affect the focusing of the beam.

In accordance with the invention, all of the ring magnets 19 are partially shunted by a tubular element 23 of temperature-compensating magnetic material closely surrounding the magnets and coextensive with the stack 15.

Without the temperature-compensating shunt 23, the peak strength of the periodic magnetic field produced by the ring magnets 19 along the central beam axis by the focusing stack 15 may decrease as much as 30 percent with an ambient temperature increase of 200° C., as shown by the dashed curve in Fig. 2. In order to compensate for the change in magnetic field strength of the magnets 19 with temperature change, the element 23 is made of a magnetic material, such as an alloy of iron and nickel containing about 30 percent nickel and having a Curie point in the range of temperatures from 30° C. to 200° C. The permeability of such an alloy changes with temperature below the Curie point in the same direction as the change of strength of the magnets. Thus, as the ambient temperature decreases and the magnetic strength of the magnets increase, the shunting capacity of the element 23 also increases, thereby reducing the portion of the total magnetic flux that reaches the beam path, and at least partially compensating for the change in magnet strength with temperature.

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By a proper choice of temperature-compensating material and of thickness of the shunting element 23, for a given temperature range, substantially perfect compensation can be obtained over a temperature range of over 100° C. with a single shunt.

The solid curves in Fig. 2 show the peak magnetic field produced along the beam path in a 10 watt, C.W., S-band traveling wave amplifier tube as shown in Fig. 1. The magnet stack was designed to provide sufficient reserve field in the magnets to supply the extra amount required by the temperature-compensating shunt. An assembly containing ten ring magnets was magnetized to about 475 gauss and surrounded by a sheet of 30 percent nickel-iron alloy. The Curie point of this alloy was about 60° C. Curves obtained by using three different thicknesses of the alloy sheet are shown. The intermediate shunt, having a thickness of .020 inch, provided almost perfect compensation, reducing the change in peak magnetic field along the beam path from over 110 gauss to less than 20 gauss from -65° C. to +60° C.

If the tubular shunt 23 of Fig. 1 is made of a temperature-compensating alloy such as a 32 percent nickel-iron alloy having a Curie point about 190° C. compensation is obtained over a range of more than 100° C. below the Curie point.

In order to compensate the magnets over a wider range than 100° C., two magnetic shunts with different Curie points are used in combination, as shown in Figs. 3 and 5 to 7.

In Fig. 3 a second magnetic shunt 25 is shown surrounding and coextensive with the shunt 23. For example, the two shunts 23 and 25 may be nickel-iron alloys having 30 percent and 32 percent nickel. The solid line curve of Fig. 4 shows the peak magnetic field obtained by use of these two alloys. Over an ambient temperature range of -65° C. to +190° C., the magnetic field along the beam path varied only about 25 gauss.

Fig. 5 shows an embodiment of the invention wherein temperature compensating shunts in the form of short tubes 27 and 28 are positioned inside each ring magnet with the ends in contact with the adjacent pole pieces 21. It will be understood one of the shunts may be omitted, if compensation over a shorter temperature range is required.

In the embodiment shown in Fig. 6 a plurality of axial holes are formed in each ring magnet 19 to receive temperature-compensating magnetic rods 31a and 31b. The rods may be of a single nickel-iron alloy, or the alternate rods 31a may be of 30 percent nickel alloy and the other alternate rods 31b may be of 32 percent nickel alloy.

What is claimed is:

1. A traveling wave tube adapted to operate over a substantial ambient temperature range comprising: an electron gun for producing an electron beam along an extended beam path within said tube; means, including a series of axially-polarized permanent magnets disposed along said beam path with like poles adjacent to each other, for establishing a periodic spatially-alternating beam focusing magnetic field along said path; and means, including temperature-compensating magnetic material partially shunting each of said magnets, for at least partially compensating for the variation of the peak strength of said periodic magnetic field along said path over said temperature range.

2. A traveling wave tube adapted to operate over a substantial ambient temperature range comprising: an electron gun for producing an electron beam along an extended beam path; within said tube means, including a series of magnetic pole pieces alternating with a series of axially-polarized permanent magnets disposed along

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said beam path with like poles adjacent to each other, for establishing a periodic spatially-alternating beam focusing magnetic field along said path; and means, including at least one element of temperature-compensating magnetic material partially shunting each of said magnets, for maintaining the peak strength of said periodic magnetic field along said path substantially constant over said temperature range.

3. A traveling wave tube as in claim 2, wherein said pole pieces are centrally-apertured discs of soft iron, and said magnets are ceramic rings having a high rate of change of magnetic field strength with temperature extending between peripheral portions of adjacent pole pieces.

4. A traveling wave tube as in claim 3, wherein said element comprises a tubular member of said material surrounding and extending along said ring magnets.

5. A traveling wave tube as in claim 4, further including a second tubular member of said materials surrounding and coextensive with said first named tubular member and having a Curie point substantially different from said first named tubular member.

6. A traveling wave tube as in claim 3, wherein said element comprises a tubular member of said material within each of said ring magnets and extending between and contacting the two adjacent pole pieces.

7. A traveling wave tube as in claim 6, further including a second tubular member of said material within and coextensive with said first named tubular member and having a Curie point substantially different from said first named tubular member.

8. A traveling wave tube as in claim 3, wherein said elements comprise a plurality of rods of said material extending through a corresponding number of axial holes in each of said ring magnets and contacting the two adjacent pole pieces.

9. A traveling wave tube as in claim 8, wherein said rods comprise two sets having substantially different Curie points.

10. A traveling wave tube as in claim 2, wherein said element is made of a nickel-iron alloy steel having about 30% nickel and having a Curie point in the range of temperatures from 30° C. to 200° C.

11. A traveling wave tube as in claim 10, wherein said last-named means comprises two of said elements having Curie points about 100° C. apart.

12. A traveling wave tube adapted to operate over an ambient temperature range of at least 100° C. comprising: an evacuated envelope containing an electron gun for producing an electron beam along an extended beam path within said envelope and a slow wave structure extending along the major portion of said beam path within said envelope for propagating a slow wave in coupling relation with said beam; means for confining said beam to substantially uniform transverse dimensions in its travel along said structure, comprising a series of pole pieces of magnetic material alternating with a series of axially-polarized permanent magnets disposed along said structure external to said envelope with like poles adjacent to each other for establishing a periodic spatially-alternating magnetic field along said path; and means, including at least one element of temperature-compensating magnetic material partially shunting each of said magnets, for maintaining the peak strength of said periodic magnetic field along said path substantially constant over said temperature range.

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