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TRAVELING-WAVE TUBE FOCUSING FIELD STRAIGHTENER

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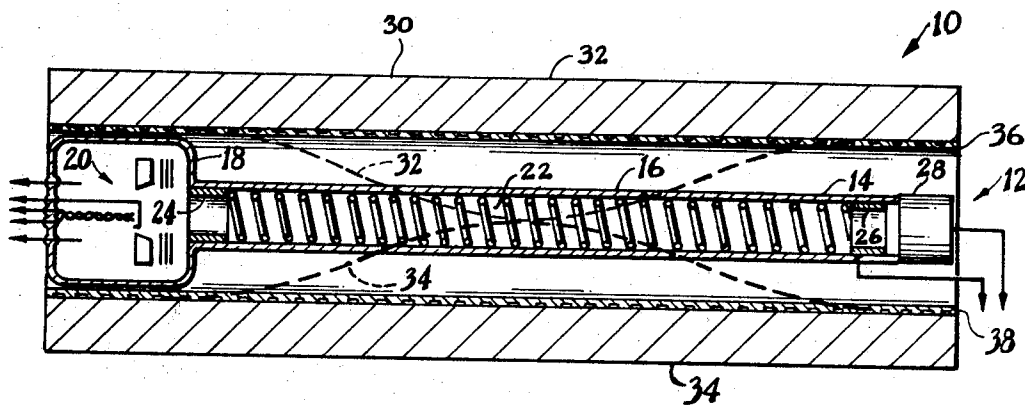


FIG. 1

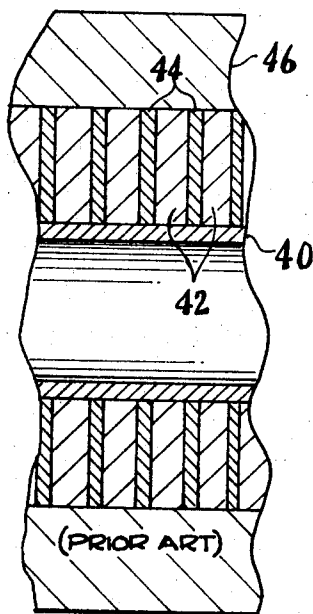


FIG. 2

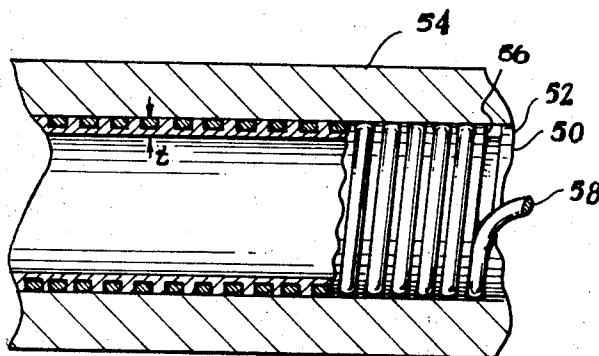


FIG. 3

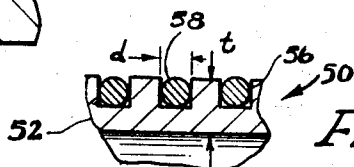


FIG. 4

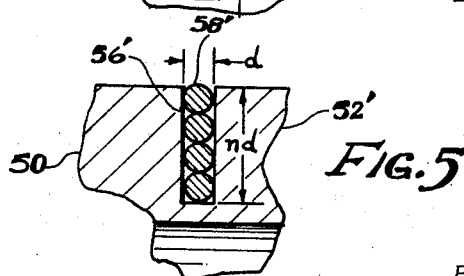


FIG. 5

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TRAVELING-WAVE TUBE FOCUSING FIELD STRAIGHTENER

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This invention relates to traveling-wave type amplifiers and oscillators and more particularly to field straighteners for straight field type focusing systems thereof.

Although the present invention finds particularly useful application in the field of traveling-wave tube amplifiers of the forward wave variety and backward wave oscillators, and although in the cause of clarity and brevity of presentation much of the following discussion and description of examples relate thereto, it is to be understood that the advantages of the invention are equally well manifest in other devices of this general character wherever any critically accurate and lineal magnetic field is desired. The principles of the present invention are also useful in providing improved focusing in other charged particle devices, such as, for example, orbital and linear accelerators.

Such a traveling-wave device of the character mentioned above generally includes an electron gun for developing an electron stream and directing it along an axial path within an elongated slow-wave structure such as a helix. The slow-wave structure is typically placed within a glass vacuum envelope and as closely as possible to the electron stream in order to maximize the electromagnetic energy exchange relationship between the microwave signals on the slow-wave structure and the space charge waves associated with the traveling electron stream.

In order to achieve a useful length of region for such interaction and to maximize both its effective length as well as its overall energy interchange effectiveness, which requires that the stream pass as closely as possible to the slow-wave structure without undue electron interception thereby, a strong axial focusing magnetic field is generally utilized for the purposes of correcting for the aberrations and other imperfections of the electron gun as well as to counteract electrostatic defocusing effects experienced by the stream as it traverses the length of the slow-wave structure.

This focusing and confining field may be achieved by a large overall permanent magnet or solenoid which is placed about the traveling-wave tube structure and which extends for the length thereof with the electron stream disposed within and parallel along the axis of the central magnetic field of the focusing magnet. Alternatively, periodic focusing techniques may be employed which involve the utilization of a long series of small, annular or ring magnets which are stacked along and about the glass vacuum envelope about the slow-wave structure. The annular magnets are axially polarized and, when properly stacked and spaced, form effectively a series of focusing lenses seen by the electron stream as it traverses the length of the slow-wave structure.

Periodic focusing has heretofore enjoyed the advantage of providing, for a total magnet weight, more focusing effect for a given weight of permanent magnet material because, in part, of its close proximity to the electron stream and because of its lower overall reluctance between its terminal pole pieces. However, it does suffer other disadvantages, e.g., it is difficult to provide satisfactorily for waveguide coupling through the magnet structure to the ends of the slow-wave structure, and it is often more difficult to provide cooling for the slow-wave structure through the periodic focusing structure which is placed closely thereabout. Furthermore, it has been confirmed

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in recent work that with careful and thorough design, straight field, i.e., non-periodic focusing, can be achieved without the inherent requirement of a magnet structure which is significantly heavier than a periodic structure would be for the same tube.

This careful and thorough design usually results in a structure which provides a strong axial magnetic field having the necessary length and diameter for immersing the traveling-wave tube therein. However, such magnets typically provide focusing fields having transverse components in the critical region of 30 to 100 gauss. The best of such magnets can presently be produced which provide a transverse field component as low as approximately 20 gauss. In this connection it should be recognized that most traveling-wave tube amplifiers in which power and gain are to be optimized with respect to other parameters such as tube life, noise figure, and the like, must have focusing fields without transverse components of more than 2 to 3 gauss. In backward wave oscillators and in certain other traveling-wave tube devices, the permissible magnitude of cross component for operation at currently desired specifications is less than one gauss.

In order to utilize these magnets to provide the necessary purity of axial field, focusing field straighteners have been developed which, in the past, have consisted of a stack of a large number of paramagnetic rings or discs exceedingly carefully stacked with nonmagnetic or diamagnetic spacers therebetween along the length of the tube. The rings, being axially short and circumferentially continuous and uniform, effectively short out any angular or transverse components while not appreciably and not deleteriously affecting the axial components of the focusing field.

In accordance with the best known prior art practice, the magnetic rings or discs and non-magnetic spacers are stacked along the outer cylindrical surface of a thin-walled brass tube which slips snugly over the traveling-wave tube and within the focusing magnet. However, the stacking process is an exceedingly difficult one requiring subtle skills on the part of hand craftsmen. Factories which produce these field straighteners currently report that even with skilled and experienced labor the rate of units which appear to be perfect but which are rejected upon dynamic testing is 30-50%. Furthermore, the cost of providing such field straighteners, exclusive of amortization of the expensive dies for stamping the rings and discs, is approximately \$150.00 each. Furthermore, the minimum radial thickness of the annular rings or discs requires the utilization of a magnet with internal clearance great enough to clear the traveling-wave tube with the tubular field straightener in place thereover. Thus the magnet is larger and therefore heavier and more costly than if a thinner field straightener were provided.

Accordingly, it is an object of the present invention to provide a straight field magnetic focusing system for a traveling-wave tube or other such device which is not subject to these and other disadvantages and limitations of the prior art.

It is another object to provide a magnetic focusing field straightener which has a weight of the order of less than $\frac{1}{10}$ that of conventional field straighteners.

It is another object to provide such a field straightener which is radially extremely thin, being of the order typically of $\frac{1}{16}$ of an inch in total annular thickness.

It is another object to provide such a field straightener which permits the design of an overall traveling-wave tube package which is less than one-half the weight of a conventional traveling-wave tube package of like magnetic performance.

It is another object to provide such a traveling-wave tube field straightener which is exceedingly easy and inexpensive to manufacture with substantially perfect repeat-

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ability and one hundred percent acceptance yield by relatively unskilled persons.

It is another object to provide such a field straightener which provides cross-field purity of the order of less than one gauss.

Briefly, these and other objects are achieved in accordance with the structural aspects of one example of the invention which includes a thin-walled, nonmagnetic or diamagnetic metal tube having a length equal to the desired length of focusing region and which fits snugly over the traveling-wave tube to be focused. A close pitched spiral channel is then milled into the outer surface of the tube over its entire length. A magnetic wire having approximately the cross dimensions of the milled channel is then laid therein over the length of the tubular field straightener body.

Thusly a structure is formed which eliminates all radial and angular fields and yet does not appreciably affect the axial field because, in the axial direction, the turns of the spiral magnetic wire are effectively isolated by high reluctance gaps.

The critical parameters of the field straightener, including the depth and pitch of the spiral channel and the continuity of the composition and cross section of the magnetic wire, are easily maintained by conventional machines operated by persons of ordinary skill. It may furthermore be appreciated that the field straightener structure readily lends itself to mass production techniques whereby long lengths of the finished field straightener stock may be manufactured and then cut to required lengths as desired for particular utilizations.

Further details of these and other novel features and their principles of operation as well as additional objects and advantages of the invention will become apparent and be best understood from a consideration of the following description taken in connection with the accompanying drawings which are presented by way of an illustrative example only and in which:

FIGURE 1 is a longitudinally sectioned view shown partially in schematic form of a traveling-wave tube focusing system constructed in accordance with the principles of the present invention;

FIGURE 2 is a cross-sectional view of a portion of magnetic focusing field straightener constructed in accordance with prior art techniques;

FIGURE 3 is an enlarged sectional view of a portion of the structure shown in FIGURE 1;

FIGURE 4 is a still further enlarged sectional view of a portion of the structure shown in FIGURES 1 and 3; and

FIGURE 5 is a view, like that of FIGURE 4, of an alternative example of the invention.

Referring to the particular figures in detail, it is stressed that the particulars shown are by way of example and for purposes of illustrative discussion only and are presented in the cause of providing what is believed to be the most useful and readily understood description of the principles and structural concepts of the invention. In this regard, no attempt is made herein to show structural details of the apparatus in more detail than is necessary for a fundamental understanding of the invention, the description taken with the drawing making apparent to those skilled in the arts of traveling-wave tube and magnetic circuit design how the several forms of the invention may be embodied in practice. Specifically, the details shown are not to be taken as a limitation upon the scope of the invention which is defined by the appended claims forming, along with the drawing, a part of this specification.

In FIGURE 1 an example of a traveling-wave tube focusing field straightener which is embodied with a traveling-wave tube assembly 10 is illustrated. The assembly includes a traveling-wave tube 12 having a glass vacuum envelope 14 with an elongate reduced diameter portion 16 joined integrally with an enlarged diameter portion 18 within which is supported and housed an electron gun 20. The gun is provided for producing an

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electron stream and directing it along an axial path concentrically disposed with respect to the vacuum envelope 14 and particularly its reduced diameter portion 16. Supported in precision alignment within the glass envelope portion 16 is, in this example, a microwave slow-wave structure in the form of a helix 22. The helical slow-wave structure extends for a substantial portion of the length of the reduced diameter portion 16 of the envelope and is terminated at its opposite ends by a matching ferrule 24, 26. Disposed axially contiguously to the matching ferrule 26 at the downstream end of the traveling-wave tube is a collector electrode 28 which receives and dissipates the kinetic energy of the electron stream generated by the electron gun 20 after it has traversed the helix 22 in electromagnetic energy exchange relationship therewith. A number of reference leads are indicated in the figure as being coupled appropriately and conventionally to the various electrode portions of the traveling-wave tube 10.

A focusing magnet assembly 30 which, in this example, is a permanent magnet in two symmetrical, split halves 32, 34 in a substantially conventional manner, more or less surround the traveling-wave tube 12 and provide a substantially axially straight focusing field along the axis of the assembly 10 about which the traveling-wave tube slow-wave structure helix 22 is concentrically disposed. Interposed snugly between the focusing magnet 30 and the enlarged diameter portion 18 of the vacuum envelope 14 and disposed concentrically about the axis of the traveling-wave tube 12 is the tubular field straightener 36. As may be seen clearly from the drawing the field straightener 36 in this example includes a thin-walled cylindrical body member 38 having a substantially constant cross section along its length which is approximately equal to the overall axial length of the traveling-wave tube 12. The body member 38 is formed of a rigid nonmagnetic substance and in a presently preferred embodiment the fabricating substance is chosen to be aluminum. Other nonmagnetic or diamagnetic materials may be chosen as desired such as brass, or plastics for example. Further details of the structure of the field straightener 36 are considered to be more clearly shown in subsequent figures wherein certain aspects of the invention are illustrated in more enlarged detail.

In FIGURE 2 a typical example of a prior art magnet and field straightener assembly is illustrated. The prior art assembly typically includes an inner brass supporting tube 40 which is surrounded by a stack of annular magnets 42 interposed alternately along the stack with nonmagnetic spacer discs 44. The field straightener assembly is then surrounded by the focusing permanent magnet 46 as shown. Such field straightener assemblies not including the focusing magnet itself typically weigh 710 grams and, because of the required greater radial distance of the magnet 46 from the system axis, a larger weight is required in addition for the magnet itself. Such prior art structures have the additional disadvantages discussed earlier hereinabove.

Referring to FIGURE 3 an example of a field straightener 50 constructed in accordance with the principles of the present invention is illustrated for use with a traveling-wave tube having the same dimensions and other parameters as that for which the prior art field straightener and magnet assembly shown in FIGURE 2 was designed. In FIGURE 3 however it is seen that the field straightener body member 52 has a radial wall thickness which is much thinner than that of the illustrated prior art field straightener. In a practical example the total wall thickness is $\frac{1}{16}$ of an inch. Accordingly the focusing magnet 54 may be made considerably smaller, as indicated, whereby the total magnet package while providing better focusing at lower cost weighs less than half that required for prior art field straighteners. In this connection it may be noted that field straighteners constructed in accordance with the example of FIGURE 3 weigh approxi-

mately 50 grams as opposed to the 710 grams for the analogous structure illustrated in FIGURE 2.

In the manufacture of the field straightener 50 a helical strand receiving channel 56 is milled from the outer cylindrical surface of the body member 52. In a practical example the channel 56 may be approximately .010 inch deep and .010 inch wide. The inter-turn spacing of the helical channel 56 is in this example .030 inch in the axial direction.

When the body member 52 of the field straightener assembly has been thusly prepared, a length of magnetic wire of typically but not necessarily circular cross section is wound about the body member 52 within the channel 56, the diameter of the magnetic wire 58 may also be .010 inch to insure a snug or press fit of the wire within the wire receiving channel 56. In the drawing the right hand end of the wire 58 is shown displaced outwardly and to the right from the portion of the channel 56 into which it would otherwise be fitted, the presentation being for purposes of illustrating the resulting structure and the assembly step of winding the wire within the milled channel.

The composition of the magnetic wire or strand 58 may be iron or nickel or a nickel-molybdenum-iron alloy or of other appropriate magnetic metal composition suitable for a particular application.

Referring to FIGURE 4, a portion of the field straightener assembly 50 is illustrated in enlarged detail. In this view a portion of the body member 52 is shown broken away with the 10 mil channel 56 shown milled away in a continuous spiral fashion along the axial length of the body member 52. Again it may be pointed out that the total thickness of the body member 52 is, in this example, $\frac{1}{16}$ of an inch while the strand receiving channel 56 is 10 mils by 10 mils and the turns of the resulting helix are spaced by 30 mils in the axial direction. The width of the channel 56 as well as the diameter of the magnetic wire 58 is indicated in the FIGURE as "d."

In FIGURE 5 an alternative example of the invention is illustrated in which the body member 52' of the field straightener assembly 50 is shown provided with a strand receiving channel which is d in width and nd in depth where n is a small integer. The strand receiving channel 56' may then receive and hold a plurality of magnetic strand windings 58' as shown. Furthermore it may be noted that when the field straightener is formed in this manner, it may be desirable and appropriate to increase the spacings slightly between the strand receiving channels 56'.

In operation, the examples of the invention illustrated in either FIGURE 4 or FIGURE 5 are substantially similar. The helical turns of the magnetic wire are, in an exceedingly precise manner, held by the strand receiving channels to form what may be considered a series of a large number of annular lens-forming turns of magnetic material spaced by a nonmagnetic material represented by the inter-turn spacings between the milled strand receiving channels in the body member 52. Thusly although, as seen by the focusing magnetic field within the field straightener assembly 50, the effect of the turns of the magnetic wire is that of a series of annular lenses aligned axially along the length of the permanent wave tube, the structure actually is a single continuous strand, in the case of FIGURE 4; and the tedious, critical stacking of magnetic and nonmagnetic materials has been eliminated.

There has thus been disclosed and described a number of examples of a traveling-wave tube magnetic focusing field straightener system which achieves the objects and exhibits the advantages set forth hereinabove.

What is claimed is:

1. For a traveling-wave tube of the character including an electron gun for emitting a stream of electrons and directing it along a predetermined lineal path and having an elongated slow wave structure disposed about said stream and along said path in electromagnetic energy exchange relationship with said stream and having a straight field focusing magnet for providing an axial focusing and confining field along said path and in which said slow wave structure is immersed, a focusing magnetic field straightener comprising:

hollow tubular body member adapted to be disposed over said traveling-wave tube concentrically with said path and within said focusing field;

said tubular body being composed of substantially nonmagnetic rigid material and having an inner diameter substantially equal to the outer diameter of the traveling-wave tube, plus clearance tolerances, and having an outer diameter to permit its disposition within said focusing magnet,

said hollow tubular body member being further formed to define a spiral, strand receiving channel in the outer cylindrical surface thereof,

said channel having a predetermined depth and width and being of relatively close pitch compared to said inner diameter of said tubular body, and

magnetic strand material having a substantially constant cross dimension approximately equal to said predetermined width,

said strand material being disposed continuously and evenly along and within said strand receiving channel.

2. The invention according to claim 1 in which said hollow tubular body member is fabricated of aluminum.

3. The invention according to claim 1 in which the cross section of said spiral strand receiving channel is substantially rectangular.

4. The invention according to claim 3 in which the depth and width of said strand receiving channel is approximately of the order of .01 inch.

5. The invention according to claim 4 in which said magnetic strand material is circular in cross section with a cross sectional diameter approximately equal to said channel depth and width.

6. The invention according to claim 5 in which said magnetic strand material is wire of substantially nickel composition.

7. The invention according to claim 5 in which said magnetic strand material is wire of substantially nickel, molybdenum and iron alloy.

8. The invention according to claim 1 in which said channel has a predetermined width d and a depth nd where n is small integer number.

9. The invention according to claim 8 which includes a plurality of n said strands of magnetic material disposed in substantially continuous contact with each other along their spiral length within said strand receiving channel.

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