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RADIAL MAGNET BEAM FOCUSING SYSTEM

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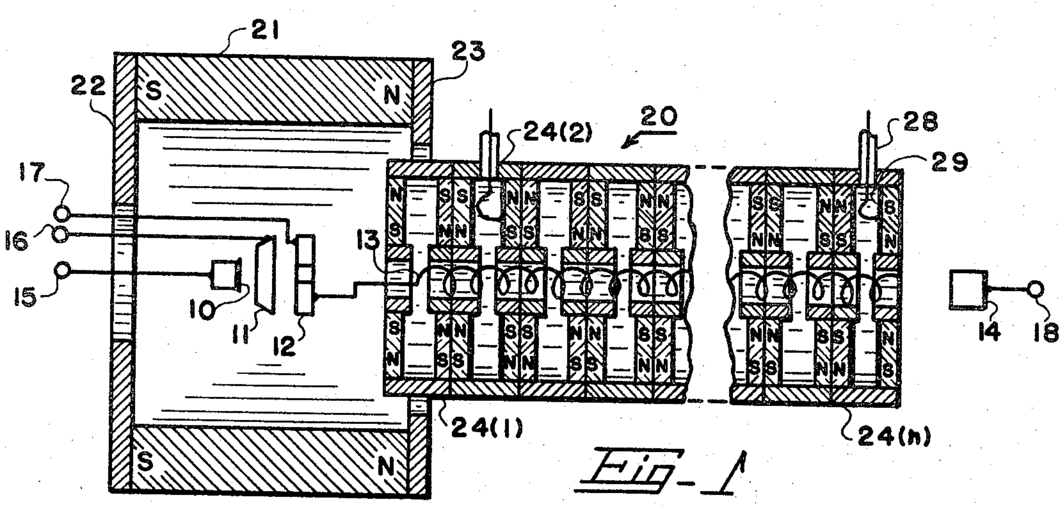
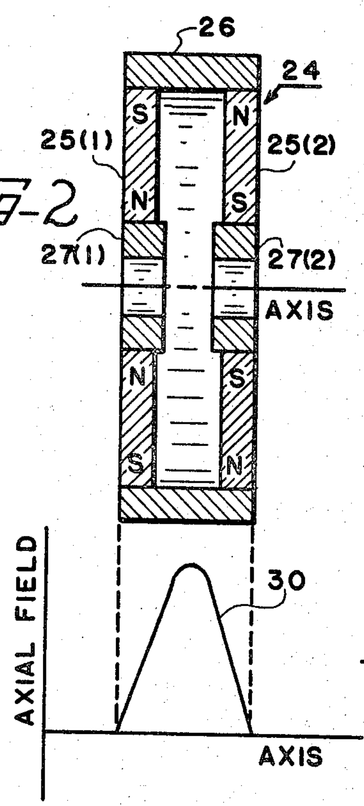


Fig-1

Fig-2



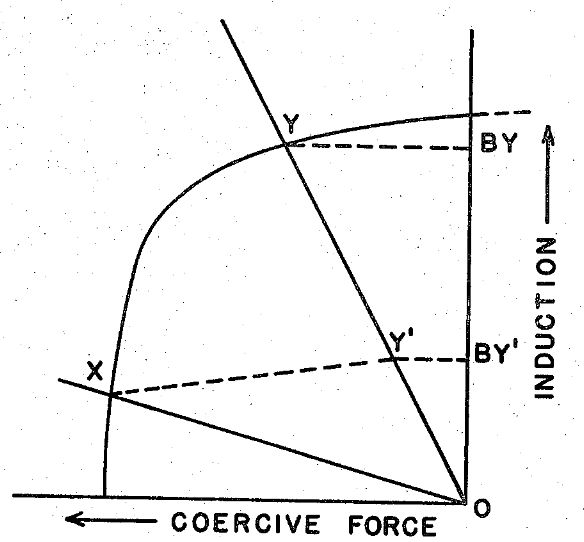


Fig-3

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RADIAL MAGNET BEAM FOCUSING SYSTEM

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ABSTRACT OF THE DISCLOSURE

A magnetic system for a traveling wave tube comprising a series of abutting cells of alternating magnetic polarity wherein each cell includes a pair of annular magnets of opposite magnetic polarity.

This invention relates to a magnet system of relatively small size and light weight for focusing the electron beam of a traveling wave tube or the like. More particularly the invention relates to a focusing system employing radially magnetized magnets to provide a periodic or spatially alternating focusing field, the magnetic structure being arranged to make efficient use of the magnetic material and to allow ready adjustment of the field strength of individual portions of the structure whereby uniformity of field can be obtained.

In a typical traveling wave tube, a beam of electrons is projected by an electron gun closely past an interaction circuit along which an electromagnetic wave is propagated, the beam eventually being intercepted by a collector electrode. To prevent dispersion of the electrons of the beam, to prevent the electrons from striking the interaction circuit, and to confine the electrons to regions of high signal fields, an axial or longitudinal magnet field is ordinarily provided to focus the beam.

It is now well-known that the weight of a beam focusing magnet system can be substantially reduced by the use of a periodic magnetic field as compared to a uniform field. Such periodic magnetic fields have been discussed, for example, by J. T. Mendel et al. in an article entitled, "Electron Beam Focusing With Periodic Permanent Magnet Fields," Proc. of I.R.E., vol. 42, pp. 800–810, May 1954.

Practical focusing systems using periodic magnetic fields are now known, for example, as shown by William Hershyn in a U.S. patent application S.N. 362,359, filed Apr. 24, 1964, now Patent No. 3,353,056, entitled "Electron Beam Focusing System" and assigned to the same assignee as the present invention. In that application a periodic focusing field is provided by an array of annular permanent magnets which are axially magnetized with alternating polarity.

In a periodic focusing system it is desirable to provide a relatively short magnetic period. A short magnetic period minimizes the ripple in the electron beam diameter, maximizes beam transmission efficiency, and allows minimization of size and weight of the focusing structure. Thus in axially magnetized arrays, magnets of relatively short length must necessarily be employed to provide the desired short magnetic period. However, the efficiency of short permanent magnets is relatively low which follows from the principle that the rise of the magnetic potential from one end of a magnet to the other equals the fall of the magnetic potential through the external circuit as shown by the following expression:

$$H_g = \frac{L_m H_m}{L_g}$$

where:

H_g is the field strength through the external circuit;
L_m is the length of the magnet;

H_m is the coercive force of the magnet; and
L_g is the length of the external circuit.

In a practical circuit H_g provides the focusing field through an air gap between pole pieces bridged by the magnet. Therefore the focusing field strength is directly proportional to the length of the magnet and inversely proportional to the length of the air gap.

The use of radially magnetized permanent magnets to provide the periodic focusing field has been proposed, for example, by Kompfner in U.S. Patent No. 2,867,744. Because the length of a radially magnetized magnet extends in the radial direction the strength of the focusing field can be increased by increasing the diameter of the magnets while still maintaining the desired short magnetic period.

To achieve minimum weight of the focusing system, as is necessary for air-borne use of traveling wave tubes for example, it is necessary to maximize the utilization of the magnetic material. To maximize the utilization of the magnetic material it is necessary to provide a focusing structure wherein the magnets can be magnetized and the structure assembled in such a way as to maintain a maximum magnetic energy product, $B \times H$, of the magnets.

It is therefore an object of the invention to maximize the utilization of the magnetic material of radially magnetized magnets in a periodic beam focusing structure.

To maintain a maximum magnetic energy product in a radial magnet focusing structure it is necessary that the magnets be magnetized in the magnetic circuit in which they are to operate or are maintained in a magnetic circuit of equal or lower reluctance than the operating circuit. In other words, if after being magnetized a permanent magnet is exposed to a magnetic circuit of higher reluctance, such as by being open-circuited in air, the maximum energy product is not maintained.

Desirably the magnets should be magnetized after assembly of the focusing structure when the magnets, pole pieces, etc., are in place. As a practical matter this presents a very difficult problem in view of the alternating polarity of the magnets and the relative inaccessibility thereof. For example, to construct the system shown in the previously mentioned Kompfner Patent No. 2,867,744 it would appear necessary to magnetize the magnets before assembly into the system whereby they would be exposed to an open-circuit condition at some step in the assembly process with consequent loss of magnetic energy product.

It is therefore a further object of the invention to provide a periodic focusing structure wherein the magnets thereof can be radially magnetized substantially within their operating magnet circuits.

It is further desirable that the field strength of incremental portions of the focusing circuit be selectively adjustable without substantial influence on adjacent portions of the circuit. This is desirable, for example, to compensate for variations in materials and for ready adjustment of the magnetic field in regions influenced by the gun magnet and in regions of the input and output couplers.

It is therefore a further object of the invention to provide a periodic focusing structure wherein incremental portions of the magnetic circuit can be separately magnetized to provide a desired field strength without substantial influence on adjacent portions of the circuit.

A further problem in the design of periodic focusing structures is the problem of discontinuities of the focusing field due to the input and output couplers to the R.F. circuit.

It is thus a further object of the invention to provide a simplified coupler arrangement providing minimum disturbance of the magnetic focusing circuit.

The foregoing and other objects are achieved according to the invention by dividing the radial magnet array into a plurality of individual units or cells, each magnet of the array being divided so that it is formed by a pair of similar magnets in abutting relation. Each individual unit is formed of a pair of spaced magnets with associated pole pieces. Thus each unit forms a closed-circuit half-period cell which is essentially magnetically independent of other cells.

With this construction the magnets of a cell can be magnetized separate from the magnets of other cells to provide a selected value of magnetic field strength and the magnets are magnetized and maintained within the magnetic circuit in which they operate so that the magnetic energy product is retained.

A simplified R.F. coupler is provided by utilizing the space between the radial magnets of a selected cell, that is, the interior space of the cell, as a coupling cavity.

The invention is described more specifically with reference to the accompanying drawings in which:

FIGURE 1 is a longitudinal section view of a beam focusing structure according to the invention with a traveling wave tube structure shown schematically;

FIGURE 2 is a longitudinal section view of a half-period radial magnet cell with a curve of the axial magnetic field provided thereby; and

FIGURE 3 is a typical demagnetization curve useful in illustrating the advantage of maintaining a magnet in its operating circuit as provided by the present invention.

Illustrated in FIG. 1 in longitudinal section view, is a magnet system according to the invention as adapted to focus the electron beam of a traveling wave tube.

A traveling wave tube of well-known type is illustrated schematically in FIG. 1. The elements of such a tube comprise an electron gun, including a cathode **10** and a plurality of focusing and accelerating electrodes **11** and **12** for projecting a beam of electrons along the axis of a slow-wave circuit, illustrated as a helix **13**, to a collector electrode **14**. These elements of the traveling wave tube are enclosed in an evacuated envelope (not shown) and appropriate operating voltages are applied to a plurality of terminals **15**, **16**, **17** and **18** connected to respective tube elements.

In the system illustrated in FIG. 1, the electron gun is immersed in a substantially uniform magnetic field provided by an annular, or barrel-shaped, axially magnetized permanent magnet **21**, sometimes called the gun magnet, which is fitted with a pair of pole pieces **22** and **23**. Thus, the magnet **21** provides an axial magnetic field for focusing the electron beam along the initial portion of its path of travel from the cathode **10** to the collector electrode **14**.

For focusing the electron beam along the remainder of its path a spatially alternating focusing field is provided according to the invention by a periodic structure **20** comprising an array of half-period radial magnet cells illustrated as a plurality of cells **24(1)**–**24(*n*)**.

A representative one of the half-period cells **24(1)**–**24(*n*)** is illustrated in FIG. 2 as a cell **24** together with a curve illustrating the half-period axial magnetic field provided by the cell. The cell **24** includes a pair of spaced annular disk-shaped permanent magnets **25(1)** and **25(2)** which are axially magnetized with opposite magnetic polarity. The operating magnetic circuit for the magnets **25(1)** and **25(2)** is formed of an outer cylindrical pole piece **26** bridging the magnets **25(1)** and **25(2)** and a pair of inner annular pole pieces **27(1)** and **27(2)** which are fitted in the apertures of the magnets **25(1)** and **25(2)** and are spaced to provide a gap across which the half-period axial focusing field is developed. The pole pieces are preferably formed of high permeability material.

As illustrated in FIG. 1, the cells of the periodic focusing structure **20** are positioned such that the abutting magnets of adjacent cells are of like magnetic polarity. Thus adjacent cells produce axial fields of opposite direction whereby the alternating focusing field is provided.

As mentioned hereinbefore, an outstanding advantage of the present periodic structure is that each half-period cell **24** is substantially independent of the other cells of the structure **20** both mechanically and magnetically. Because the axial magnetic field is zero at the junctions between cells (that is, at the edges of each cell as shown in FIG. 2), the magnetic field of each cell is substantially independent of the fields of other cells.

As is believed clear from consideration of FIG. 2, each cell may be separately assembled in its operating magnetic circuit comprising the pole pieces **26**, **27(1)** and **27(2)** and the magnets **25(1)** and **25(2)** of the cell are readily accessible for selective magnetization before the cell is assembled in the focusing structure **20**. (For example, a pair of magnetizing electromagnets, not shown, may be positioned at opposite sides of the cell **24**, the magnetizing electromagnets having center pole pieces which fit within the apertures of the pole pieces **27(1)** and **27(2)** and having cylindrical outer pole pieces which abut the edges of pole piece **26**.) In this way, the magnets of each cell are magnetized after assembly in their operating circuits and they are retained in their operating circuits so that the magnetic energy product is maintained whereby efficient utilization of magnetic material is achieved.

The necessity of magnetizing a magnet in its operating magnetic circuit and maintaining it therein to maximize the magnetic energy product is illustrated by the demagnetization curve of FIG. 3 which is typical of a magnetic material such as Alnico 5. The line OX is a typical operating line of a radial magnet alone, that is in an open circuit condition. Thus after magnetization such a magnet operates at the point X in this open circuit condition.

The line OY is a typical operating line of a magnetized radial magnet assembled with its pole pieces in its operating circuit. If such a magnet is magnetized alone, before assembly, and is then inserted in its operating circuit, its operating point recoils along the dashed line XY′ to the point Y′ on the operating line OY and the induction provided by the magnet in this case is BY′.

On the other hand, if the magnet is magnetized within and retained within its operating circuit the magnet operates at point Y and the induction provided in this case is BY. The substantial increase in energy product in this latter case and the consequent efficient utilization of the magnets is readily apparent.

In addition to the advantage of enabling magnetization and retention of the magnets within their operating circuits, the present invention allows the separate magnetization of each half-period cell to a value appropriate to its position in the focusing structure whereby the amplitudes of the magnetic field can be readily equalized. For example, as discussed in the previously mentioned patent application No. 362,359, the gun magnet **21** (FIG. 1) produces a minor lobe of magnetic flux in the transition region between the gun magnet **21** and the periodic structure **20**. The cells of the periodic structure in this transition region, including cell **24(1)** in particular, may be magnetized to a value that will compensate for the effect of this minor lobe of the gun magnet.

Another problem in the design of periodic focusing systems is the discontinuities caused by input and output R.F. coupling structures to the slow-wave circuit. Such problems are discussed, for example, by Yasuda in U.S. Patent No. 2,991,382.

Frequently the desired magnet spacing, to achieve the desired short magnetic period, is less than the axial length required for the coupling structure. Also, in the case of a waveguide coupler, the waveguide displaces a significant amount of the magnetic circuit. The individual cell nature of the present invention enables ready compensation for such discontinuities by magnetizing the cells adjacent such discontinuities to appropriate values.

Furthermore, the half-period cell of the present invention lends itself well to the construction of a simplified form of coupler which causes little discontinuity of the magnetic field and in which the effect of any such discontinuity is readily overcome.

As illustrated in FIG. 1, the cell **24(2)** has incorporated therein an input R.F. coupler while the cell **24**(*n*) has incorporated therein a similar coupler used as an output R.F. coupler. Having reference to cell **24**(*n*) by way of illustration, the coupler includes a coaxial line **28**, the outer conductor of which is fitted in an aperture through the outer pole piece of the cell. As opposed to a waveguide, the coaxial line displaces little of the magnetic circuit. The inner conductor of the coaxial line **28** is extended into the interior of the cell in the form of a coupling loop, the end thereof being attached to an inner wall **29** of the cell. The interior of the cell thus forms a coupling cavity for coupling R.F. energy from the slow-wave circuit **12** to the coaxial line **28**. The interior walls of the cell, such as the wall **29**, may be plated or coated with a material of good electrical conductivity, such as copper, for reduced losses.

The size of the coupling cell may be altered to provide the required dimensions for the coupling cavity. For example, the cell can be made longer with increased spacing of the magnets thereof to increase the interior volume. In any case, the magnets of the cell can be magnetized to provide a magnetic field compatible with the fields of adjacent cells.

Thus what has been described is a periodic beam focusing structure comprised of individual half-period magnetic cells wherein the magnets thereof can be conveniently magnetized within their magnetic circuits and wherein the magnetic field of each cell can be individually adjusted to a selected value, the individual cell construction being further utilized to provide simplified input and output R.F. couplers.

While the principles of the invention have been made clear in the illustrative embodiments, there will be obvious to those skilled in the art many modifications in structure, arrangement, proportions, the elements, materials and components used in the practice of the invention, and otherwise, which are adapted for specific environments and operating requirements, without departing from these principles. The appended claims are therefore intended to cover and embrace any such modifications within the limits only of the true spirit and scope of the invention.

What is claimed is:

1. A periodic magnet system for providing an alternating magnetic field along an axis, comprising: a series of abutting magnetic cells of alternating magnetic polarity, each cell including a pair of spaced apertured magnets with the apertures thereof in alignment with said axis, said pair of magnets being radially magnetized with opposite

magnetic polarity, each cell further including an outer pole piece bridging the outer edges of said pair of magnets, adjacent magnets of said series of abutting cells being of like magnetic polarity.

2. The magnet system of claim **1** wherein each said cell further includes a pair of spaced annular pole pieces each fitted within the aperture of a respective one of said pair of magnets.

3. In a device for projecting a beam of electrons closely past a slow-wave circuit and including a periodic magnet structure providing an alternating magnetic field for focusing said beam, a combined magnetic cell and coupler in said structure for coupling R.F. energy between a coaxial line and said slow-wave circuit comprising: a pair of spaced apertured magnets, said slow-wave circuit passing through the apertures of said magnets; a pole piece bridging the outer edges of said magnets and defining with said magnets a coupling cavity, the outer conductor of said coaxial line being fitted in an aperture in said pole piece, the inner conductor of said coaxial line extended within the interior of said cell and terminating at an interior surface thereof.

4. A device according to claim **3** wherein a substantial portion of the interior surface of said cell is covered with a relatively thin film of high electrical conductivity material.

5. A periodic magnet system for providing an alternating magnetic field along an axis, comprising: a series of individual magnetic cells positioned in abutting relation along said axis, each cell comprising a separate magnetic circuit for providing a half period of said alternating magnetic field along said axis, each cell including a pair of axially aligned and spaced magnetically permeable annular pole pieces, a pair of permanent magnets each extending radially from a respective one of said pole pieces, and a magnetically permeable member bridging the outer ends of said pair of magnets, said pair of magnets being radially magnetized with opposite magnetic polarity to a selected magnetic strength within said magnetic circuit for retention of maximum magnetic energy product, adjacent magnets of abutting cells being of like magnetic polarity.

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