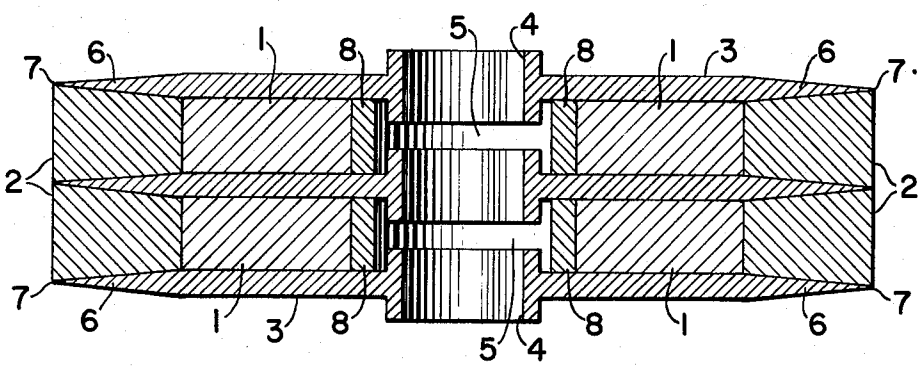
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PERIODIC PERMANENT MAGNET FOCUSING STACK

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PERIODIC PERMANENT MAGNET FOCUSING STACK

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This invention relates to a periodic permanent magnet focusing stack and more particularly to such a stack creating a higher field and a greater degree of temperature compensation for the same weight, volume and beam dimensions than the present conventional design.

There are a number of electronic and nuclear applications requiring magnets which prevent scattering of subatomic particles, i.e., protons, electrons, ions, etc. One of the most common of these is the traveling wave tube in which it is necessary that an electron beam be confined, for a portion of its travel, within a long, narrow, tubular, volume of space. Without a focusing device of some sort, the electron beam would tend to diverge, because of the fact that electrons, being of like charge, tend to repel each other. An electron beam can be bent into a curved path by a magnetic field, undergoing an acceleration normal to the direction of the field. In a traveling wave tube, an electron is made to follow a scalloping path which, if projected onto a plane, would appear sinusoidal. The field alternates in sinusoidal fashion so that the electron will follow a path of reversing curvature. If properly designed, a beam of any charged particles, such as electrons, protons, plasma, etc. can be made to converge toward a point at the end of their travel and it can be continued within a volume of space along their direction of travel.

The electron beam must be confined by some type of focusing system. The approach finding widest application in present-day medium power tubes is the use of a periodic permanent magnet (PPM) array. PPM focusing minimizes size and weight, eliminates the need for external magnet mounts and reduces problems of magnetic field interference. The PPM array consists of a series of magnets stacked with opposing polarity between ferrous pole pieces. The resulting field approximates a series of alternately reversing fields directed parallel to the electron path.

The magnetic bodies used in lightweight PPM structure are relatively temperature-sensitive. One of the more common has a variation of approximately 80 gauss per 100° C. temperature change. A change of this magnitude can degrade performance at extreme temperatures. To overcome this handicap, temperature compensating shunts are added to the assembly. The temperature-dependent magnetic characteristic of the alloys used is opposite in effect to the magnet characteristic. It is often highly desirable that PPM focused traveling wave tubes be able to operate through temperature ranges which vary from about —60° C. to above plus 100° C. without appreciable change in electrical characteristic.

A standard conventional design of PPM array is described and illustrated on pages 272–274 of Permanent Magnets and Their Application, by Rolen J. Parker and Robert J. Studders, published in 1962 by John Wiley and Sons, Inc., New York.

The conventional design of PPM array leaves something to be desired in its overall efficiency, including the strength of its axial field and its degree of temperature compensation.

Accordingly, one object of this invention is to provide a periodic permanent magnet focusing stack creating a higher axial field than conventional designs.

Another object is to provide such a stack having a greater degree of temperature compensation.

A further object is to provide such a stack having a combination of a higher axial field and a greater degree of temperature compensation for the same weight, volume and beam dimensions than for a stack of conventional design.

Other objects and advantages of the invention will be apparent from the following description, taken in conjunction with the accompanying drawings, in which:

The single figure of drawings illustrates an axial cross section of a portion of one embodiment of a PPM focusing stack made in accordance with this invention.

In experimental work, it has been determined that the conventional design of PPM focusing stack did not produce the maximum axial field desired for use with traveling wave tubes. It is important to improve the conventional design so that a higher axial field can be obtained for the same external dimensions of the stack, i.e., overall length, outer diameter, and pole piece hub dimensions.

There are three possible permeance paths in such a stack:

P1, the gap between adjacent hubs of the pole pieces;
P2, the volume circumscribed by the inner diameter of the tube array; and
P3, the whole of space external to the array.

If P3 can be eliminated, the peak axial field would be considerably increased. The path P3 can to some extent be reduced by making the pole pieces of slightly smaller outer diameter, so that the magnets have a slightly larger outer diameter than the pole pieces. This, however, is not ideal because part of the magnet volume is not contributing to the axial field and the external permeance P3 is not eliminated.

An array of magnets having concave conical sides and pole pieces having convex conical sides was considered on the following theory: In a magnetic circuit, if magnetomotive force is kept constant, the magnetic flux is directly proportional to permeance. Flux, however, must also radiate from a conceptual magnetic pole. Poles can exist in a magnetostatic field only where there is a differential in magnetization: (1) in the material itself; (2) at the boundary between a magnetic material and air; or (3) at the boundary between two different magnetic materials. The flux P3 external to the array is largely due to a differential in magnetization at the pole piece-to-air boundary, which is completely eliminated in such a design. Nevertheless, when such a stack was probed, it was found to have a lower axial field, instead of a higher one. From this, a very important design feature was discovered, namely, that a pole can be formed not only at the boundary between the magnetic material and air, but also between two magnetic materials. While the air-to-pole piece surfaces are the significant poles from which flux radiates in the conventional design, there is also a pole of considerable value at the magnet-to-pole piece boundary. That pole is great enough in the neighborhood of the compensator ring here that the magnet is intrinsically demagnetized to a significant extent in that region.

Pole formation in the above-mentioned region will be considerably lessened if the pole piece is made thinner and the magnet thicker at and near their inner peripheries, and there will be considerably less demagnetization during assembly of the stack. It is during assembly that the magnets are subjected to a higher demagnetizing field than they are in their final operating condition. The last-mentioned design still had two effects which it was desirable to eliminate: (1) the stack was considerably demagnetized by exposure to extreme cold and (2) there was no evident compensation due to the presence of the internal temperature compensator rings.

It was found that better temperature compensation could be achieved by increasing the wall thickness of the compensator. It was found that if the compensator rings were placed internally of the array, instead of on the

outside, and if the wall thickness is sufficiently large, the temperature compensation was close to the ideal. Although there was some sacrifice of peak axial field in use of the thicker, internal, temperature compensator rings, there was still some increase in the axial field over the conventional design. Overall, the new design has been shown conclusively to have both superior temperature compensation and superior axial field at the same time, over the conventional design, and the increase in wall thickness and internal location of the compensator rings provides a significant improvement in temperature compensaion, at some sacrifice of axial field.

In the drawing, the ring-shaped magnets are shown as made in two parts for convenience in manufacture, a radially inner magnet ring **1**, having flat, parallel, sides normal to the axis of the array, and a radially outer magnet ring **2** having its sides flared outwardly from the flat, parallel, inner portion of the magnet **1** to a maximum width at its outer periphery. The magnets are permanent ceramic magnets of a material such as a barium ferrite. Each pole piece **3** is preferably made of a soft magnetic steel and has a large hub **4** at its center. There is an air gap **5** between adjacent hubs **4**. Extending radially outwardly from the hub **4**, each pole piece has flat, parallel, sides on its radially inner portion. Near its outer periphery, at **6**, the pole piece has its sides tapered inwardly toward each other from the flat, parallel, inner portion to the minimum practical thickness or width at its outer periphery **7** to complement the sides of the outer portions **2** of the magnets. The outer diameters of the magnets **2** and the pole pieces **3** are the same.

The temperature compensator rings or shunts **8** are located internally of the inner magnet portions **1** and radially outwardly of the hubs **4** of the pole pieces **3**. The compensators **8** are made approximately twice as thick, radially, as the conventional external temperature compensator strips.

A method of calculating peak axial field has previously been devised by a number of physicists and mathematicians. In this method, a single magnet with its pole pieces is treated as a "unit magnetic cell." The total permeance of the circuit is calculated. From this, the permeance coefficient is determined, and then the peak axial field is solved for as a function of the operating demagnetizing force (H_d) and various dimensions of the magnet. This method is used to predict axial fields before the construction of a prototype model. This will corroborate theoretically results given below. Data were tabulated to indicate a comparison between temperature compensations and peak axial fields when stacks were cycled from room temperature to −54° C., back to room temperature and then to plus 85° C., both for stacks with conventional type of compensators and for stacks embodying the present invention. The results of these test runs are tabulated below, in both instances, stacks of 9 magnets having been used:

Stack	−54° C. Corrected for Instrument Temperature Deviation	Room Temperature After Cycle	85° C. Corrected for Instrument Temperature Deviation	Final
New Design	1,255	1,275	1,275	1,275
Conventional Design	1,280	1,200	1,180	1,200

The numbers in the table above are axial field values in gauss. A study of the data in the table shows that the new design achieves both a better degree of temperature compensation and a higher peak axial field than does a stack of the conventional design.

There are a number of advantages of the new design of this invention which, as far as is known, have never been achieved before. With a given desired magnetic field configuration, this design can produce the same field geometry with a lighter, more compact, focusing array or, with the same weight, volume and beam dimensions, it creates a higher axial field than is possible with the conventional design.

This feature has significant consequences. For example, where exceptionally high fields are desired, at present some traveling wave tubes are using platinum-cobalt alloy, which is a superior magnetic material but is extremely expensive. Also, some others are very heavy and bulky.

Another feature of this new design is a broader temperature range over which the field will remain relatively constant. It is a phenomenon which has to be encountered that the induction of a magnet will vary with temperature. A magnet tends to produce more flux at low temperatures than at high temperatures. In barium ferrite magnets, the variation due to temperature is so great that "temperature compensators" are used. The magnetic permeability of the compensator also varies with temperature, so that at low temperature more magnetic flux will be transmitted through the compensator than will be transmitted at room temperature. The effect of compensators is to stabilize the field acting on the electron by shunting more flux through themselves at low temperatures than at high temperatures.

This new design has a larger percentage of the total flux emitted by the magnet going through the compensator, with the result that more temperature compensation is permissible, i.e., the field intensity down the tubular section can be maintained at a more even value over a broad operating range.

Having the pole pieces tapered in their radially outward portions down to a minimum thickness at their outer peripheries and having the magnets correspondingly flared outwardly results in less leakage flux, intensifying the flux along the axis of the stack and thus providing a higher or more intense focusing field for the subatomic particles. Having the temperature compensator rings on the inside of the stack, instead of on the outside, provides a better temperature compensation.

It will be apparent to those skilled in the art that various changes may be made in the invention, without departing from the spirit and scope thereof, and therefore the invention is not limited by that which is shown in the drawings and described in the specification, but only as indicated in the appended claims.

I claim:

A periodic permanent magnet focusing stack comprising

a plurality of annular permanent magnets,

each magnet having sides which are flat and parallel on its radially inner portion and flared outwardly from the flat parallel inner portion to a maximum width at its outer periphery;

a plurality of annular pole pieces of soft magnetic steel of approximately the same outer diameter as the magnets interposed between adjacent magnets and extending to the ends of the stack,

each pole piece having an integral central hub spaced inwardly from the magnets and sides which are flat and parallel on its radially inner portion and tapered inwardly toward each other from the parallel inner portion to a minimum width at its outer periphery to complement the sides of the magnets; and

a plurality of temperature compensating shunts of a magnetic alloy,

each shunt being a ring abutting the inner periphery of a magnet with an air gap between the shunt and the outer surface of the hub of the adjacent pole piece.

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