May 3, 1966 J. R. COHEN 3,249,825

METHOD OF MAGNETIZING A PERMANENT MAGNET

Filed Dec. 2, 1963 2 Sheets-Sheet 1

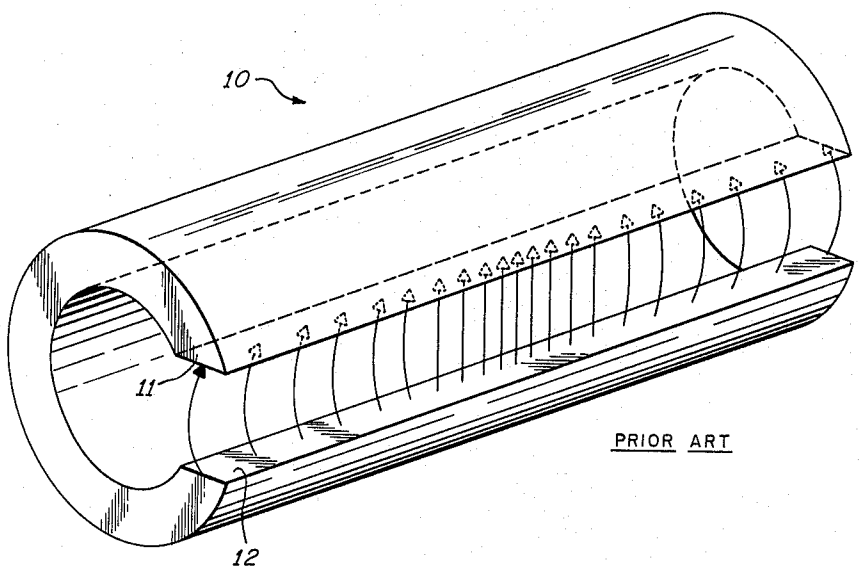


FIG. 1.

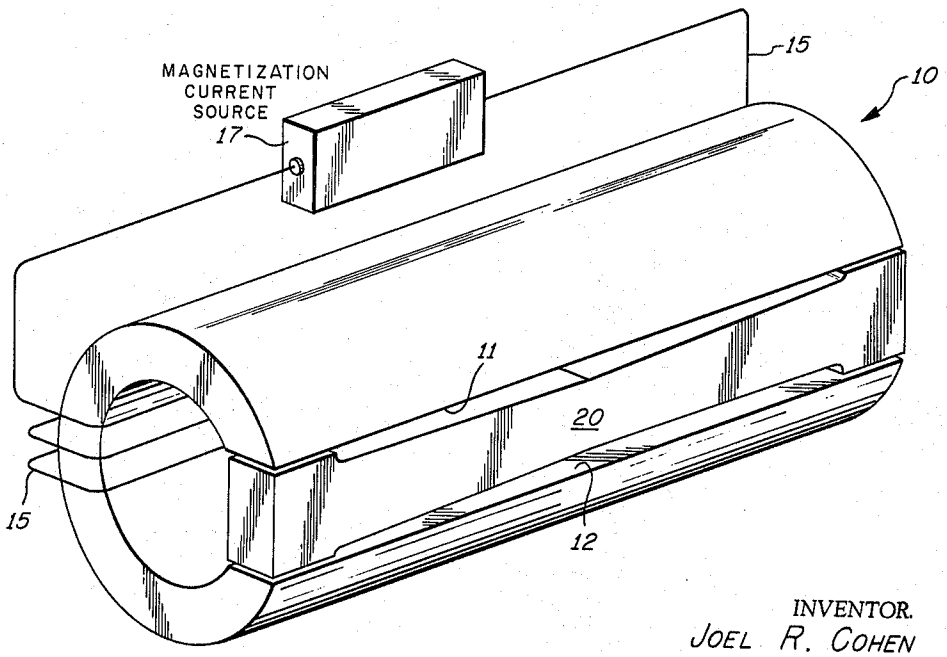


FIG. 2.

INVENTOR.
JOEL R. COHEN

BY

John H. Gallagher
ATTORNEY

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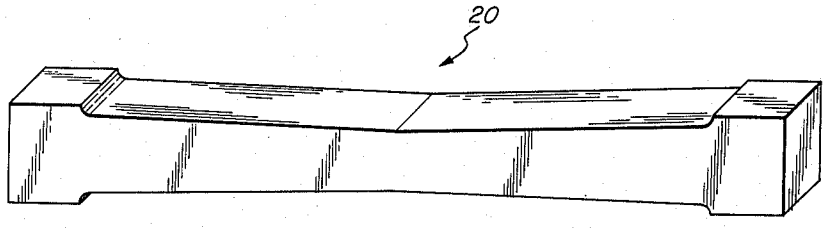


FIG. 3.

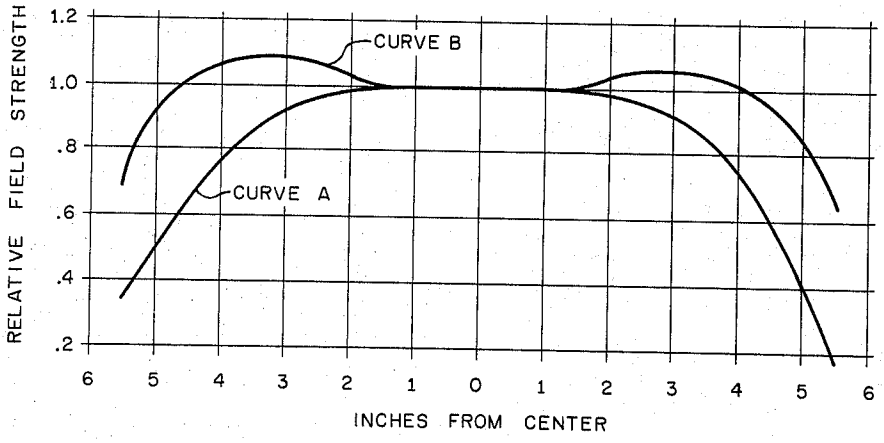


FIG. 4.

INVENTOR.
JOEL R. COHEN

BY

John H. Gallagher
ATTORNEY

United States Patent Office

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METHOD OF MAGNETIZING A PERMANENT MAGNET

Joel R. Cohen, Baltimore, Md., assignor to Sperry Rand Corporation, Great Neck, N.Y., a corporation of Delaware

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This invention relates to a method and apparatus for magnetizing a permanent magnet to obtain a more uniform magnetic field strength along the length of the air space adjacent the pole face of the magnet.

Permanent magnets are used extensively in microwave gyromagnetic devices to supply the magnetic biasing field in which the gyromagnetic material is immersed. Quite often the permanent magnet is a C-type magnet. That is, in cross-section the magnet resembles a capital letter C. In the lower frequency ranges of the microwave spectrum the permanent magnets are relatively long. It has been found that due to magnet end effects and fringing fields the magnetic field strength of the magnet is considerably weaker at the end regions than at the center of the magnet. This nonuniform field along the length of the magnet often is troublesome in the design of microwave gyromagnetic devices because the preliminary design of a device is performed with a large electromagnet whose field strength is adjusted until the desired operating characteristics are obtained. With the electromagnets ordinarily used for this purpose the magnetic field in which the gyromagnetic material is immersed is relatively uniform. When desired operation is achieved, the magnetic field strength of the electromagnet is measured, and then a permanent magnet is made to replace the electromagnet since electromagnets usually are impractical for commercial use. However, because of the aforementioned end effects associated with the permanent magnet, the gyromagnetic material of the device will be immersed in the nonuniform field of the permanent magnet rather than the relatively uniform field of the electromagnet. The microwave gyromagnetic device therefore operates differently from the design model. This is particularly troublesome in the design of rectangular waveguide phase shifters that are employed in conjunction with hybrid junctions to form a duplexer, for example. In these devices the phase shift must be very accurately controlled, and because of the differences between the magnets used in the design model and in the product, the development of such a device can be quite time consuming and expensive.

Further disadvantages resulting from the nonuniform field strength of the permanent C-type magnets is that larger size magnets and/or more gyromagnetic material may be required to obtain the desired result. One expedient that has been used to avoid the deleterious end effects of the permanent magnets has been to use a magnet that is longer than the gyromagnetic member and then position the gyromagnetic member within the central portion of the air gap where the magnetic field is relatively uniform. This, of course, increases the size, weight and cost of the magnet, and therefore is undesirable. Further, a longer specimen of gyromagnetic material may be required to produce a desired result at a given frequency when the magnetic biasing field is nonuniform. This results from the fact that the material is effective for its intended purpose at a given frequency only when immersed in a magnetic field of a given strength. If the magnetic field strength is less than required, a greater

length of gyromagnetic material may be needed to achieve a compensation, since many effects, such as phase shift, is a function of the length of the gyromagnetic material. This increases the losses in the device, and increases its length.

In some microwave gyromagnetic devices that have been designed for use in the lower portion of the microwave spectrum it was found that the magnetic field strength of long C-type magnets was so nonuniform that it was necessary to utilize a plurality of smaller magnets whose field strengths were more controllable. This complicates the manufacturing procedure and creates a problem in mounting the plurality of permanent magnets.

Attempts have been made to shape the pole faces or pole pieces of the magnets to change the magnetic field strength along the length of the air gap. This is undesirable, however, because the materials of the permanent magnets are brittle and machining of the pole faces is difficult.

It therefore is an object of this invention to provide a method of magnetizing a permanent magnet to produce a relatively uniform magnetic field strength in the region adjacent the pole faces of the magnet.

Another object of this invention is to provide a method of magnetizing a C-type permanent magnet to provide a relatively uniform magnetic field strength throughout the length of the air gap between the poles of the magnet.

A further object of this invention is to provide a method of magnetizing a permanent magnet in such a manner that greater magnetizing flux flows through one portion of the magnet than another portion.

In accordance with the illustrated embodiment of the invention, a magnetizing member of soft magnetic material is inserted within the uniform air gap of a C-shaped member of permanent magnet material. The member of soft magnetic material is shaped to have a nonuniform height along the length of the air gap, the maximum height being at the two end regions of the air gap. A current then is passed through a magnetizing winding that is positioned about the C-shaped member. With the member of soft magnetic material in position, the reluctance of the magnetic circuit that includes the C-shaped member, the member of soft magnetic material and the air gap therebetween, is greatest at the central region of the air gap. Therefore, the end regions of the magnet are magnetized more strongly, relative to the central region of the magnet, than they would have been if magnetized in the conventional manner in which the magnetizing tool is of uniform rectangular cross-section throughout its length. This results in a permanent magnet having a more uniform magnetic field strength throughout a greater length of its air gap.

The present invention will be described by referring to the accompanying drawings wherein:

FIG. 1 is a perspective view of a C-type permanent magnet and illustrates the nonuniform magnetic field strength that exists along the length of the air gap of a magnetized permanent magnet that was magnetized in the conventional prior art manner;

FIG. 2 is a simplified illustration of the arrangement for magnetizing a permanent magnet to produce a relatively uniform magnetic field strength along the length of the air gap between pole faces of the magnet;

FIG. 3 is a perspective view of a magnetizing tool that is inserted between the pole faces of a permanent magnet, in accordance with the teachings of this invention; and

FIG. 4 is a graph that contains a series of curves which illustrate the field strength along the length of the air

gap of a magnet, compared to the field strength at the center of the magnet, for a permanent magnet that is magnetized in the conventional prior art manner, and for a magnet that is magnetized in accordance with the teachings of this invention.

Referring now in detail to the drawings, FIG. 1 shows a C-type permanent magnet 10 that commonly is employed with microwave gyromagnetic devices constructed in a rectangular waveguide. As conventionally used, magnet 10 is disposed along the length of a section of rectangular wave guide with the pole faces 11 and 12 disposed on, or extending through, the opposite broad walls of the waveguide section. FIG. 1 illustrates the relative magnetic field strength along the length of the air gap of a C-type permanent magnet that was magnetized according to prior art practices that employed a magnetizing tool of uniform dimensions throughout its length; as illustrated, the magnetic field strength in the air gap is relatively uniform at the central region, but because of magnet end effects and fringing fields, the magnetic field strength decreases at the end regions of the air gap.

The method by which the problem of the decreasing field strength at the end regions of the air gap is overcome is illustrated in FIG. 2. In this arrangement a magnetizing winding 15 of conductive wire is wound about the central portion of C-type permanent magnet 10, and the ends of magnetizing coil 15 are connected to a source of electric current 17. Electric current source 17 may include a bank of capacitors which are charged up and then discharged in unison to provide a large current surge through magnetizing winding 15.

Positioned within the air gap of permanent magnet 10 is a magnetizing tool 20 which is made of soft magnetic material having high permeability and low magnetic reluctance. As illustrated more clearly in FIG. 3, magnetizing tool 20 is an elongated solid rod having substantially rectangular cross-sections at its two ends and then gradually tapering in height to its central region which is of minimum height. Magnetizing tool 20 is of uniform width throughout its length. As seen in FIG. 2, there is but slight clearance between the ends of magnetizing tool 20 and the pole faces 11 and 12 of permanent magnet 10. This clearance increases to a maximum at the central region of permanent magnet 10. Therefore, when magnetizing flux flows around the magnetic circuit that includes the C-type permanent magnet and the magnetizing tool 20, the magnetic reluctance due to the air gap between the pole faces 11, 12 and magnetizing tool 20 will be a minimum at the end regions of the air gap and will taper to a maximum at the central region of the air gap. As a result, more magnetizing flux will flow in the end regions of the magnet and the end regions of the magnet will be more strongly magnetized than they would have been if magnetized by prior art methods. This is illustrated by the curves of FIG. 4 of the drawings. These curves show the relative field strength in the air gap along the length of an 11 inch C-type permanent magnet. These magnetic field strengths are plotted relative to the magnetic field strengths at the central region of the air gap. Curve A illustrates the relative magnetic field strength of a C-type permanent magnet that was magnetized by prior art methods, that is, with a magnetizing tool of uniform cross-section throughout its length. Curve B illustrates the relative magnetic field strength throughout the length of air gap of a substantially identical magnet that was magnetized in accordance with this invention with the use of a magnetizing tool 20. It may be seen from the curves of FIG. 4 that the field strength of a magnet magnetized in accordance with this invention does not fall away as rapidly at the end regions of the magnet, and the field strength of the magnet is more nearly uniform throughout a greater length of the air gap.

It is to be understood that the magnetizing method of this invention is not restricted in its use to magnetizing C-type permanent magnet but may be employed to magnetize other types of permanent magnets as well.

Furthermore, the method of this invention is not restricted to producing a more uniform magnetic field strength throughout the length of the air gap but also may be employed to produce a desired nonuniform tapering magnetic field strength. A nonuniform field sometimes is desired to broadband the operating characteristics of microwave gyromagnetic devices. In the past, this has been done by employing magnetic shunts, or by specially shaping the pole faces of the magnet. The use of magnetic shunts creates a rather cumbersome device, and because the material of the permanent magnet is very brittle, it is difficult to machine. Substantially any desired pattern of magnetic field strength may be achieved by properly shaping the magnetizing tool 20. The exact shape of a magnetizing tool that is required to produce a certain nonuniform magnetic field strength along the air gap is best arrived at by successive trials with different shapes of magnetizing tools.

While the invention has been described in its preferred embodiments, it is to be understood that the words which have been used are words of description rather than limitation and that changes within the purview of the appended claims may be made without departing from the true scope and spirit of the invention in its broader aspects.

What is claimed is:

1. Means for magnetizing a body of permanent magnetic material comprising,

an elongated body of permanent magnet material having a pair of elongated surfaces that extend throughout the length of said body to form pole faces of a magnet,

an elongated solid member of soft magnetic material disposed between the lengths of said surfaces for providing a magnetic flux path therebetween which is of nonuniform reluctance in a direction along the lengths of said surfaces,

said member being shaped throughout its length to have a nonuniform height between said surfaces and a uniform width, and

means for passing a magnetizing flux through said body and said member of soft magnetic material in a direction transverse to said surfaces to form magnetic poles at said surfaces.

2. Means for permanently magnetizing a body of magnetic material comprising,

an elongated body of permanent magnet material having the shape of a letter C in its cross section transverse to its long dimension thereby to form an elongated air gap between opposing surfaces that will serve as pole faces,

an elongated solid member of soft magnetic material disposed throughout the length of said gap for providing nonuniform reluctance in a direction parallel to the length of said gap,

said member of soft magnetic material having a uniform width in said gap and a height that is nonuniform in said air gap, and

means for passing a magnetizing flux through said C-shaped body and across said gap and said member of soft magnetic material thereby to form magnetic poles at said opposing surfaces.

3. The combination claimed in claim 2 wherein said member of soft magnetic material has a height in said air gap that is greatest at its two ends and minimum in its central region.

4. A method of magnetizing an elongated permanent magnet having the shape of a letter C in its cross section transverse to its long dimension, whereby an air gap exists between elongated surfaces that form pole faces of said magnet, said method comprising,

placing a magnetizing winding of conductive wire about said permanent magnet to create a magnetizing flux within the magnet and across said air gap,

placing within said air gap an elongated solid magnetizing tool of soft magnetic material whose width is uniform throughout its length and whose height in the air gap is nonuniform throughout its length, and

passing a magnetizing current through said winding.

5. The method claimed in claim 4 wherein the magnetizing tool that is placed within the air gap is of maximum height at its end regions and tapers to a minimum height at its central region.

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BERNARD A. GILHEANY, *Primary Examiner.*

G. HARRIS, JR., *Assistant Examiner.*