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MAGNETOSTRICTIVE TUNING OF THE MAGNETIC PARAMETERS OF
GYROMAGNETIC MATERIALS USED IN WAVE
TRANSMISSION DEVICES

3,316,507

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FIG. 1

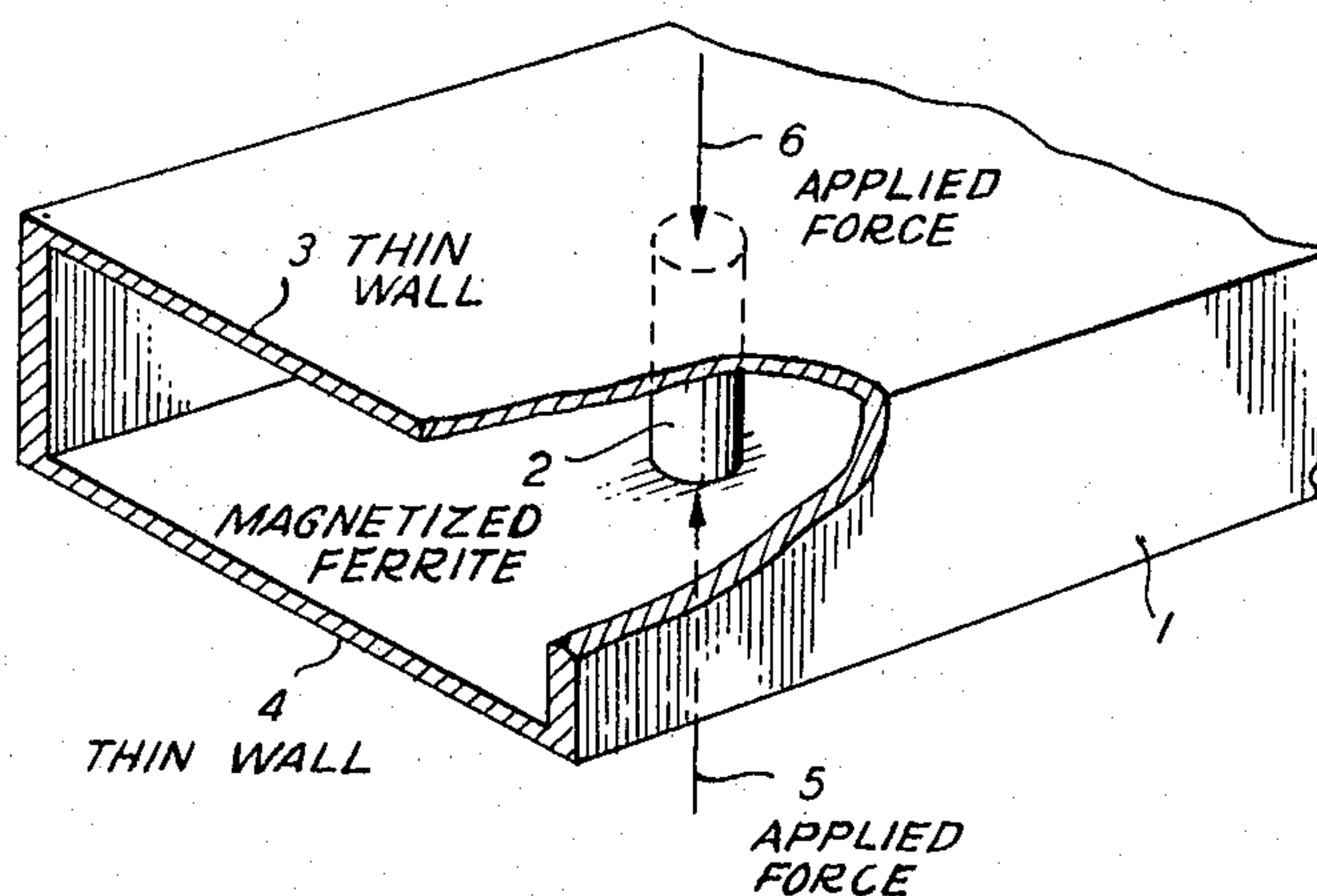


FIG. 1A

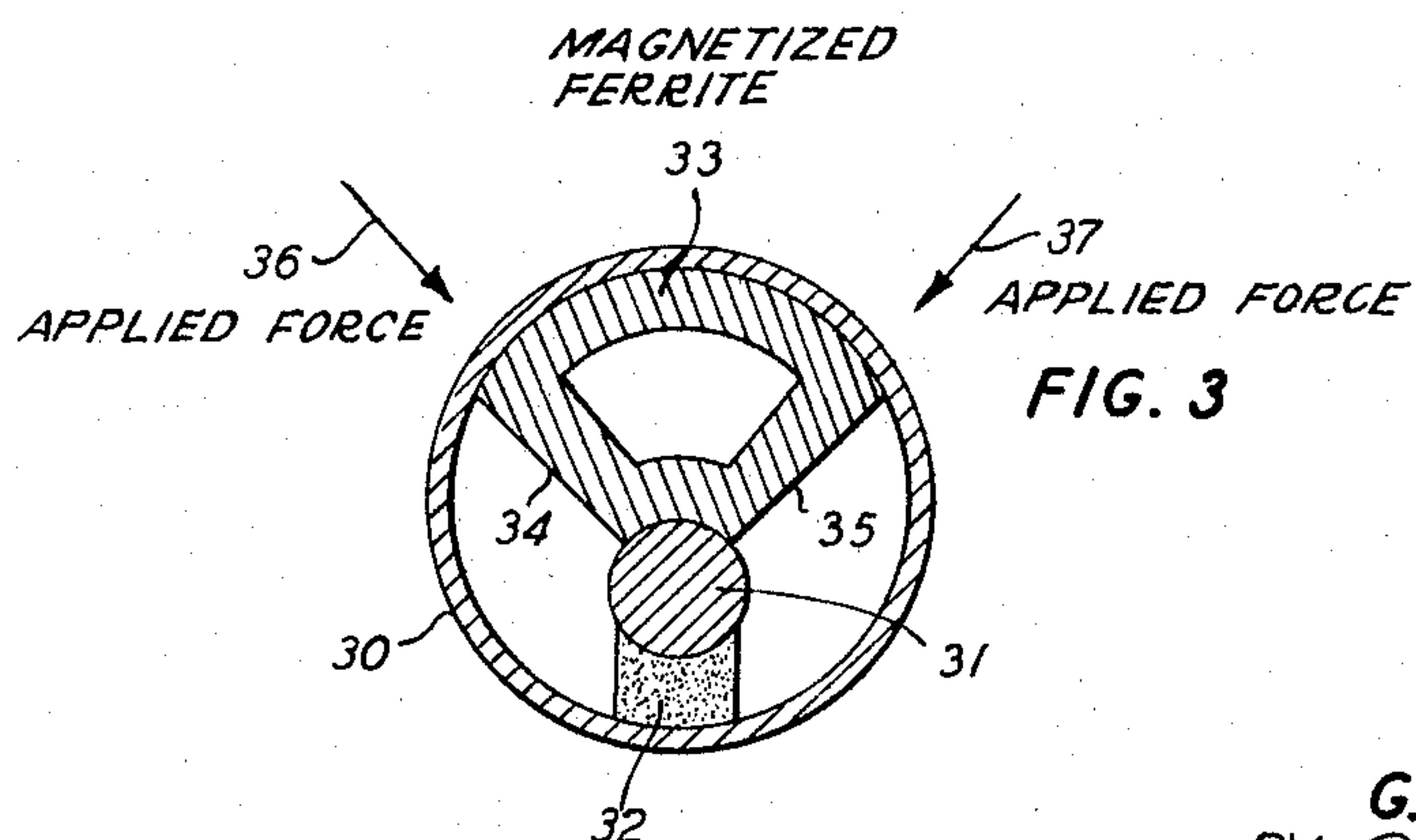
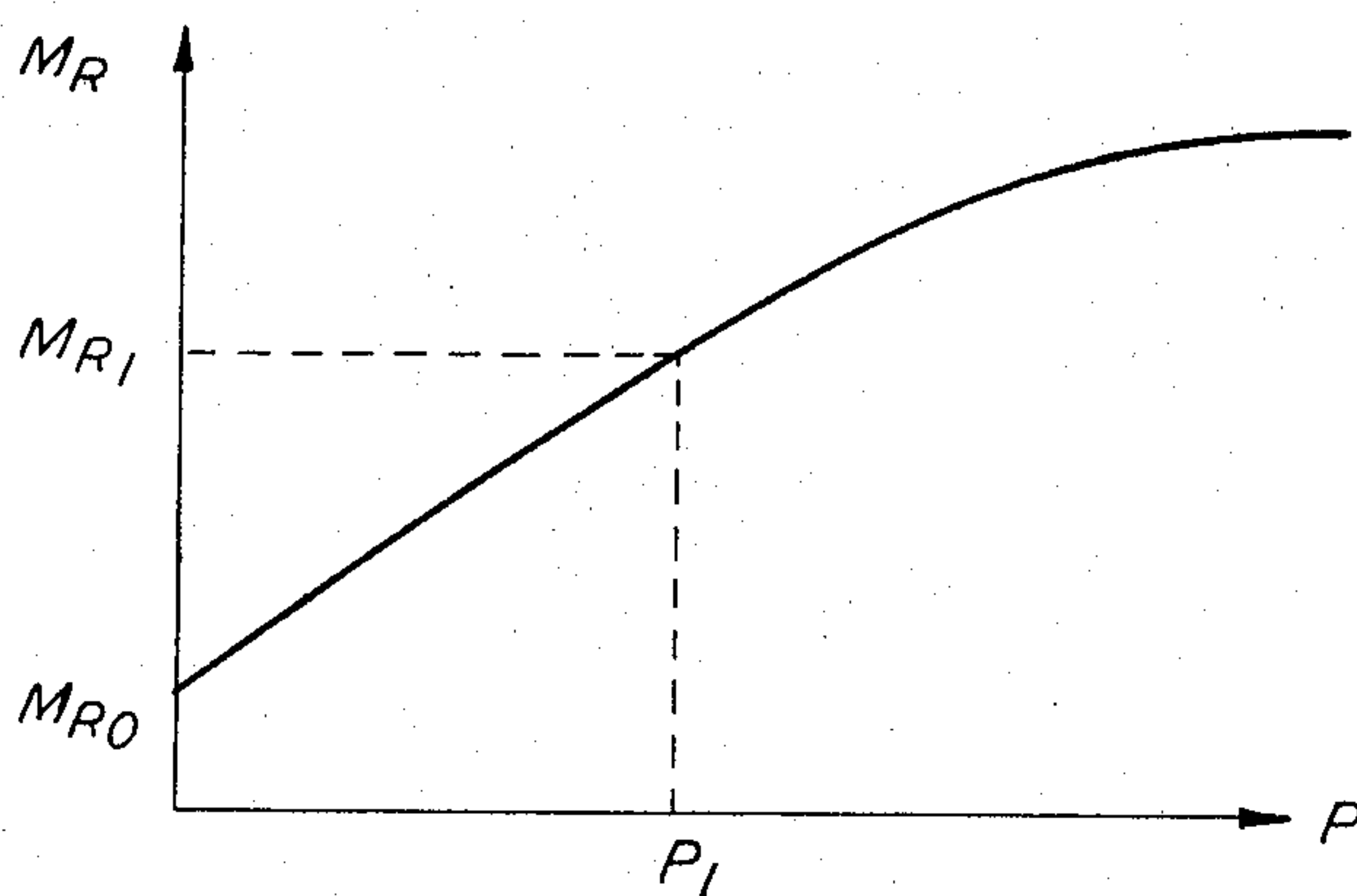


FIG. 3

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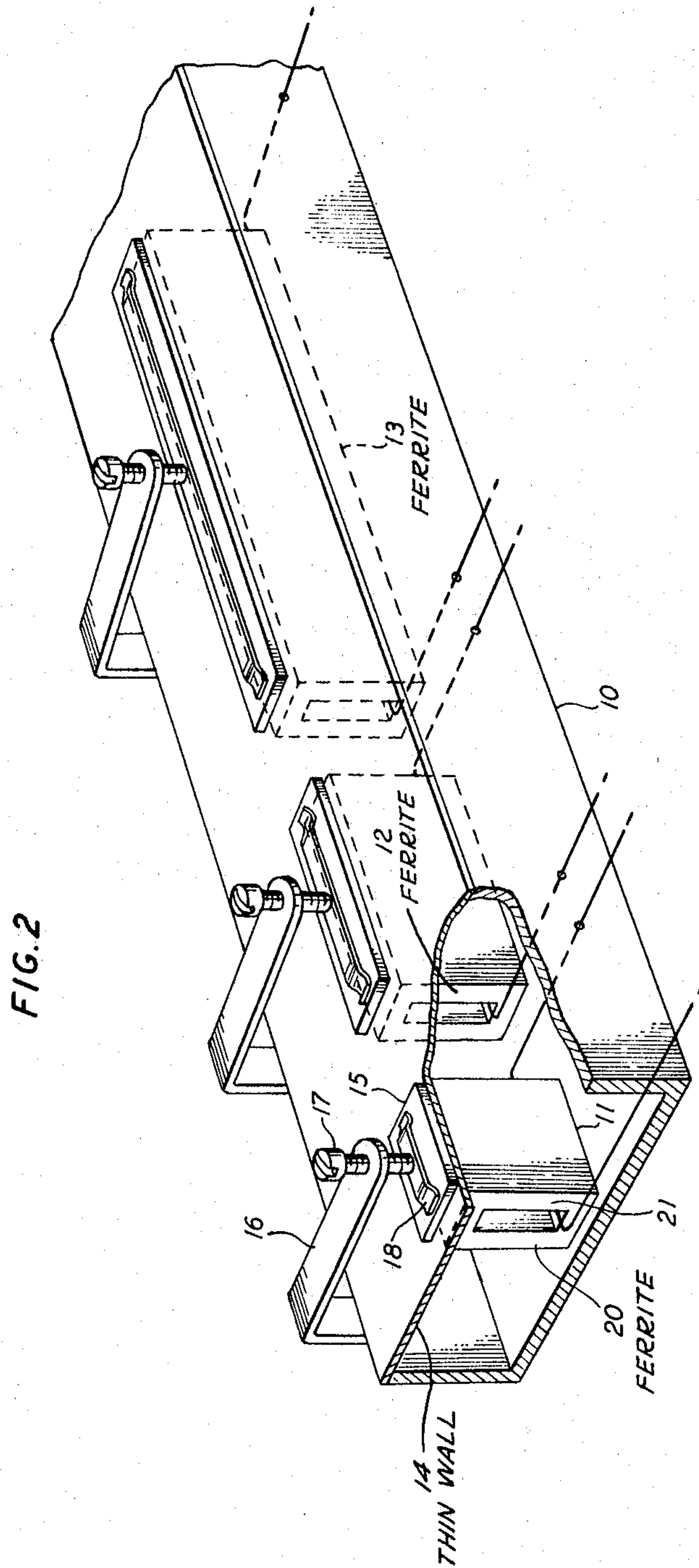
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MAGNETOSTRICTIVE TUNING OF THE MAGNETIC PARAMETERS OF GYROMAGNETIC MATERIALS USED IN WAVE TRANSMISSION DEVICES

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7 Claims. (Cl. 333-24.1)

This invention relates to electromagnetic wave transmission structures and more particularly to electromagnetic wave transmission structures having magnetic members with magnetostrictive properties.

Ferrimagnetic materials such as ferites and garnets, and to a lesser extent ferromagnetic materials, have grown in importance in conjunction with their usage in transmission devices such as phase shifters, circulators, isolators, filters and limiters. These materials are useful for their gyromagnetic properties. For example, when a magnetic field is directed through a ferrite member placed in an electromagnetic wave transmission structure so that a component of this field is perpendicular to a transmitted circularly polarized electromagnetic wave, the transmission properties of the structure are altered by the gyromagnetic effects produced. This is generally attributed to the resulting interaction between the circularly polarized electromagnetic field that is propagated within the structure and the field resulting from the spinning motion of the electrons within the crystalline structure of the gyromagnetic material employed. As a result of this interaction, electrons are made to precess about the axis of the directed magnetic field. The magnitude of the directed field within the gyromagnetic material determines the frequency of precession and consequently controls the extent of the gyromagnetic interaction.

Clearly, an important property of such gyromagnetic materials is the magnetization. The magnetization may be established from an external source or it may be due to the remanence of the material as it is for a large number of transmission devices. One of the factors influencing the magnitude of the magnetic field internal to a core structure composed of such materials is the effect of magnetostriction. Magnetostrictive materials exhibit a change in magnetization with a change in crystalline dimensions and vice versa and are conventionally characterized by a quantity designated as the magnetostrictive constant. This quantity is a measure of the change in internal magnetization with pressure and materials having either positive or negative values of this parameter are known to exist. The magnetic properties of magnetostrictive materials result from the alignment of electron spins associated with the magnetic atoms in the crystalline lattice structure. In response to applied pressures the crystalline structure is altered to effect interatomic interactions. For example, as the applied forces are increased, certain distances between lattice points are decreased. Since atomic interaction varies inversely with interatomic distance a resulting increase in electron spin alignments is observed for a given magnetizing field directed parallel to the applied force and consequently an increase in the internal magnetic field results.

A problem which frequently occurs when gyromagnetic materials are employed in wave transmission structures arises out of the difficulty in producing cores that meet the specified electrical and mechanical manufacturing tolerances. It is a frequent occurrence to find during the manufacture of transmission devices that the desired magnetic properties of the gyromagnetic elements integral thereto are outside a permissible tolerance range about a specified nominal value. Illustratively,

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this frequently occurs because of variations in mechanical dimensions and/or the arrangement of crystalline lattices during a molding process. Furthermore, since materials exhibiting gyromagnetic properties also exhibit magnetostrictive properties, a core material having magnetic parameters adjusted to nominal value before assembly within a transmission device may have its parameters altered beyond the permissible tolerance range by pressure within the device after assembly. It therefore appears to be extremely desirable to be able to employ and utilize, instead of attempting to neutralize or eliminate, the magnetostrictive properties of such materials in wave transmission structures.

Accordingly, it is an object of this invention to utilize magnetostrictive properties of magnetic materials employed in wave transmission devices.

It is another object of this invention to provide an arrangement for adjusting the magnetic parameters of gyromagnetic materials used in wave transmission devices.

It is still another object of this invention to provide in a multicore waveguide transmission device a means for trimming the magnetic parameters of each core.

In accordance with the principle features of the invention, these and other objects are achieved by providing in a wave transmission structure employing magnetic materials with magnetostrictive properties a means for applying an adjustable pressure to such materials to adjust to nominal value the magnetic parameters thereof. In an illustrative embodiment, the magnetostrictive properties of core materials are utilized to advantage in a multibit latching type phase shifter. Each of a plurality of cores is manufactured so that it contains a remanent magnetic field magnitude within a permissibly wide tolerance range. The particular side of nominal value on which the tolerance range is selected is dependent on the sign of the magnetostrictive constant of the material used. Assuming a negative constant, the tolerance range is selected below nominal value so that after assembly, the magnitude of the remanent magnetic field existing within each core may be increased to nominal value by adjusting a positive pressure applicator individual to each core.

The invention may be better understood if reference is had to the drawing in which:

FIG. 1 is a perspective view of a portion of a waveguide transmission device having a gyromagnetic element with magnetostrictive properties adjusted in accordance with the present invention;

FIG. 1A is a typical graph indicating the relationship between remanent magnetization and pressure for a material exhibiting magnetostrictive properties;

FIG. 2 is a perspective view of a multibit latching type phase shifter with provision for magnetostrictively tuning each core; and

FIG. 3 is a cross-sectional diagram of a nonreciprocal phase shifter for coaxial lines which employs the principles of the present invention.

Shown in FIG. 1 is a portion of a rectangular waveguide structure 1 with a rod of gyromagnetic material 2 judiciously placed within the waveguide. The illustrative portion of the structure shown is representative of any one of the many commonly used gyromagnetic waveguide transmission devices. The rod of gyromagnetic material 2 is placed so that its upper and lower circular surfaces abut opposite membranaceous walls 3 and 4 of the waveguide. The thickness of walls 3 and 4 is decreased in comparison with the other waveguide walls so that they may perform as diaphragms in transmitting externally applied pressure to rod 2. It may be assumed that a magnetic field exists within rod 2 in the direction parallel to its length by virtue of either an externally applied field or by virtue of its own remanent magnetization. If now a varying pressure is applied to walls 3 and

4 in a direction to compress rod 2 as indicated by arrows 5 and 6, a graphical relationship of remanent magnetization, M_R , versus pressure, P , may be obtained as shown in FIGURE 1A. For the material selected (having a negative magnetostrictive constant) the magnitude of remanent magnetization increases from its initial value in an approximately linear relationship with increasing pressure until a saturation point is reached. It may be noted that while the remanent magnetization M_R and the flux density B are distinct and different quantities, it is possible for both to reach their respective saturation values together as pressure is increased. While the curve shown has a positive slope, material having a positive magnetostrictive constant could be utilized to produce a curve with a corresponding negative sloping portion.

While, for illustrative purposes, a rod of gyromagnetic material is shown in the transmission device illustrated in FIG. 1, the principles of the invention apply equally well to any shape of core and any number of core members used in any of the commonly known gyromagnetic devices. So, for example, magnetostrictive tuning may be employed in the manner illustrated in FIG. 1 to alter the frequency band of operation in a circulator or isolator by widening, narrowing or shifting the band. Similarly, when gyromagnetic elements are utilized in filter structures and limiters, it is possible to respectively tune to the desired band of operation and to adjust to the desired power level. Thus, the operating characteristics of gyromagnetic devices may be tuned to those desired by a controlled adjustment of pressure rather than through a variation of an externally applied magnetic field.

In the specific illustrative embodiment disclosed in FIG. 2, a multibit latching type phase shifter is magnetostriictively tuned by utilizing an external pressure applicator individual to each core. A rectangular waveguide 10 is here provided with three ferrite cores, 11, 12, and 13, in an arrangement for producing discrete incremental phase shifts. Because of the closed magnetic circuit of each core, coils wound individually through each core may be pulse operated to produce latching type operation. A properly poled current pulse is used to switch the direction of the lines of remanent magnetic field within each core and therefore to change by discrete amounts the phase shift experienced by an electromagnetic wave being propagated through waveguide 10. If it is assumed that a single core is placed within waveguide 10 and that an electromagnetic wave is propagated within the waveguide past the core, the phase shift introduced will be dependent upon the longitudinal length of the core and the magnitude and direction of the magnetic field contained within the core. Therefore if core 11 is selected to have a unit length and cores 12 and 13 are selected respectively to have double and quadruple the unit length, with all other things being equal, a latching type phase shifter having incremental phase shifts of 45° is produced. Thus if all cores are identical and have the same value of magnetization and core 11 has a length sufficient to introduce a 45° phase shift when properly switched, cores 12 and 13 will have capacities to introduce phase shifts of 90° and 180° , respectively, and the device can introduce phase shifts of up to 360° in 45° increments. To the extent the cores differ in cross-sectional dimensions and composition the remanent magnetization within each can be adjusted so that each tuned core delivers an integral multiple of a 45° phase shift when properly switched.

A core material having remanent magnetization versus pressure characteristics similar to that shown in FIG. 1A is selected for each of cores 11, 12 and 13. Core 11 is manufactured so that it has a remanent magnetization corresponding to M_{R0} (or any value within a substantial tolerance band about M_{R0}) significantly less than the value of the remanent magnetization M_{R1} necessary to provide the incremental phase shifts desired. Wall 14

of waveguide 10 is constructed thinner than the other three in order that it may function as a diaphragm. A pressure bar 15 is placed on top of wall 14 directly over the abutting surface of core 11. Pressure bar 15 is used to apply a uniform pressure to core 11 much in the same fashion as that described in connection with FIG. 1. This is accomplished with the aid of a C-clamp 16 having a tuning screw 17 threaded through one of a pair of extended arms of the clamp (the other arm not being visible in the figure as drawn), and bearing upon a pressure spring 18 which is in contact with pressure bar 15. By adjusting tuning screw 17 to increase the pressure in transverse members 20 and 21 of core 11, the remanent magnetization within core 11 increases until a value M_{R1} is reached at a pressure P_1 shown in FIG. 1A.

In a similar fashion, cores 12 and 13 are manufactured so that the remanent magnetization existing in each at atmospheric pressure is a value substantially below the nominal value required for their respective phase shifting capacities. By adjusting the tuning screw associated with each of the respective cores, the remanent magnetization within each is likewise brought up to the required nominal value. Thus each core can be manufactured so that its atmospheric remanent magnetization can be within a substantially large tolerance range beneath the nominal value and adjusted to nominal value after each core is assembled within the waveguide.

It will be recognized by those versed in the art that other techniques for applying pressures are possible and completely within the scope of the invention. For example, pressure may be hydraulically applied if individually sealed chambers are adapted to the structure.

FIG. 3 illustrates in cross section still another embodiment of the invention wherein a nonreciprocal latching type phase shifter for coaxial transmission lines as described in my copending application Ser. No. 403,729, filed Oct. 14, 1964, employs magnetostrictive tuning in accordance with the principles of this invention. Shown in the cross-sectional view of FIG. 3 is an outer conductor 30 and a center conductor 31 having an axis colinear with, but offset from, the axis of outer conductor 30. A wedge of dielectric material 32 provides a support between conductors 30 and 31 to maintain equilibrium in the presence of applied tuning forces, and a closed loop core of gyromagnetic material 33 is placed in the region of maximum cross-sectional space between the conductors. An external force is applied along radial members 34 and 35 of core 33 as indicated by arrows 36 and 37. By adjusting the magnitude of this pressure, the remanent magnetization within members 34 and 35 may be adjusted to the value required for the incremental phase shifter desired. As described in my above identified copending application, a plurality of cores with judiciously chosen respective lengths may be longitudinally placed between conductors 30 and 31 to provide digital operation and arbitrarily small incremental phase shifts. In accordance with the principles of this invention, each core may be individually tuned by pressure applicators running the length of each core to provide uniformly distributed pressures to the radial members (e.g., members 34 and 35) of each core. As with the rectangular phase shifter described in FIG. 2, the remanent magnetization of each core is adjusted after assembly.

It is to be understood that the above-described arrangements are illustrative of the application of the principles of the invention. Numerous other arrangements may be devised by those skilled in the art without departing from the spirit and scope of the invention.

What is claimed is:

1. In an electromagnetic energy transmission device having a member of material exhibiting magnetostrictive properties positioned within said device for gyromagnetic interaction with electromagnetic energy propagating in said device and requiring a defined nominal value of magnetic field directed through said member to render said

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device operational, means for directing through said member a magnetic field having a value different from said nominal value and means for magnetostrictively tuning said directed magnetic field through said member to said nominal value.

2. An electromagnetic energy transmission device in accordance with claim 1 wherein said tuning means includes means for applying to said member mechanical forces codirectional with said directed field.

3. An electromagnetic energy transmission device comprising a plurality of magnetostrictive members positioned within said device for gyromagnetic interaction with electromagnetic energy propagating in said device, each of said members requiring a defined value of magnetization to render said device operational, means for magnetizing each of said members to values different from said operational value and means for adjusting the magnetization within each of said members to render said device operational including an adjustable mechanical force applicator individual to each of said members.

4. In a multibit electromagnetic energy phase shifter including a radio frequency transmission line and a plurality of cores of gyromagnetic material exhibiting magnetostrictive properties disposed within said line for incrementally varying the phase shift, the improvement comprising means for varying the magnitude of said incremental phase shift including an adjustable mechanical pressure applicator individually bearing on each of said cores to tune the quantum of phase shift contributed by each of said cores to said incremental phase shift.

5. A latching type phase shifter comprising a radio frequency transmission line, a plurality of magnetized cores having a closed magnetic loop structure of gyromagnetic material disposed within said waveguide to incrementally shift the phase of energy propagated through said waveguide, and means for altering the magnitude of said incremental phase shift including adjustable mechanical pressure applicator means for transmitting to said cores forces colinear with the magnetic field direction within a portion of said cores.

6. A latching type phase shifter in accordance with

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claim 5 wherein said radio frequency transmission line is a modified coaxial line having eccentrically positioned center and outer conductors, a dielectric slab positioned between said conductors in a region of minimum spacing to support said inner conductor, said core structures have a pair of radially positioned members interconnected by a pair of members positioned on the periphery of each of said conductors in a region of maximum spacing between said conductors, and wherein said pressure applicator means includes means for applying radial forces of adjustable magnitude to said radial members to tune the magnitude of phase shift introduced.

7. A latching type phase shifter in accordance with claim 5 wherein said radio frequency transmission line is a rectangular structure having at least one membranaceous broad wall, said cores have a rectangular cross section with a first pair of members internally abutting each broad wall of said waveguide and a second pair of members interconnecting said first pair, and wherein said pressure applicator means includes a pressure plate individual to each of said cores externally abutting each membranaceous broad wall so that a membranaceous wall separates a plate and corresponding one of said first pair of core members, a pressure spring bearing on each of said pressure plates, a rigid clamp enveloping said waveguide and a tuning screw threaded through said clamp bearing on each of said pressure springs for applying an adjustable uniform force to each of said pair of second core members.

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