Feb. 28, 1956 W. VAN B. ROBERTS 2,736,824

MAGNETOSTRICTIVE FERRITES

Filed Dec. 21, 1950

Fig. 1.

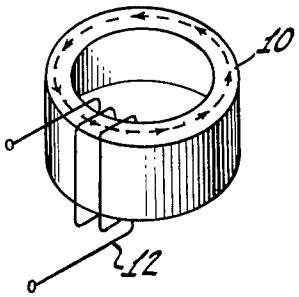


Fig. 2.

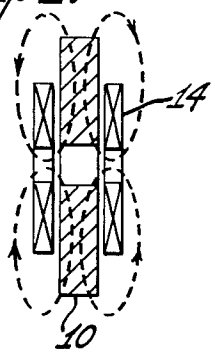
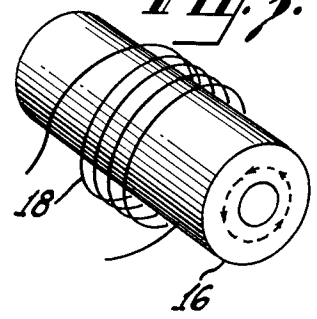


Fig. 3.



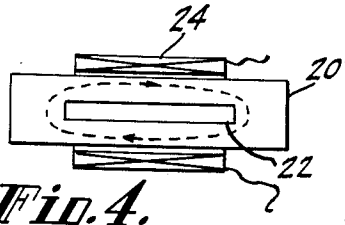


Fig. 4.

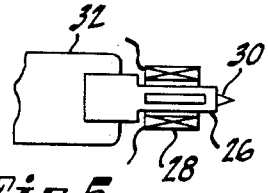


Fig. 5.

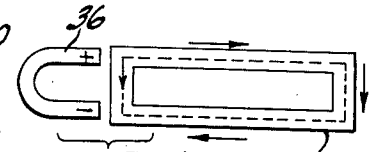


Fig. 6.

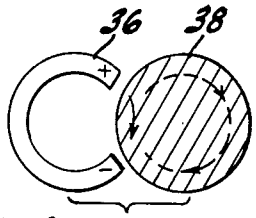


Fig. 7.

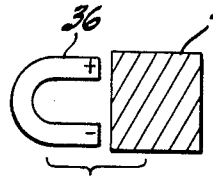


Fig. 8.

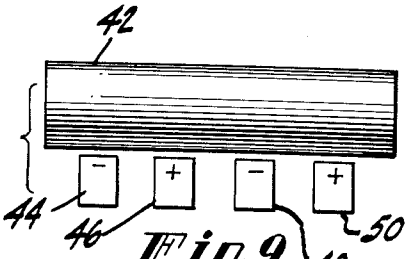


Fig. 9.

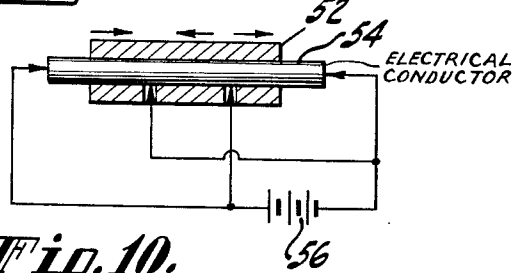


Fig. 10.

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MAGNETOSTRICTIVE FERRITES

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Application December 21, 1950, Serial No. 202,091

1 Claim. (Cl. 310—26)

This invention relates to electromechanical vibrators and more particularly is an improvement in the biasing of electromechanical vibrators for magnetostrictive operation.

The use of ferrite material as a magnetostrictive vibrator for electromechanical conversion is well known. Heretofore, the ferrite vibrator, in order to be utilized with some degree of efficiency, required the use therewith of an auxiliary biasing magnet, since a rod of ferrite does not retain sufficient residual or permanent magnetization to act as a biasing magnetization for efficient magnetostrictive electromechanical conversion. Other metals, such as nickel, which display magnetostrictive characteristics, may be permanently magnetized to act as a self-biasing magnetostrictive electromechanical converter. The advantages of having a self-biased vibrator are obviously a less expensive device, the cost of the biasing magnet is eliminated, also the device may be made more compact since fewer parts are required.

It is therefore an object of the present invention to provide a method of permanently magnetizing a ferrite magnetostrictive vibrator.

It is another object of the present invention to provide a less expensive ferrite magnetostrictive electromechanical conversion system than heretofore available.

It is still another object of the present invention to provide a simpler and more compact ferrite magnetostrictive electromechanical conversion system than heretofore available.

It is yet another object of the present invention to provide a method of biasing a magnetostrictive vibrator with residual flux in closed loops within the vibrator.

These and other objects of the present invention are achieved by magnetizing the vibrator material so that closed loops of magnetic flux are formed entirely inside the material. Under these circumstances a ferrite vibrator retains sufficient residual magnetization to permit efficient magnetostrictive conversion in the case of vibration modes adapted to utilize such closed loops of biasing flux.

The novel features of the invention, as well as the invention itself, both as to its organization and method of operation, will best be understood from the following description, when read in connection with the accompanying drawings in which

Fig. 1 shows a ferrite torus being permanently magnetized in a manner to have closed flux loops disposed around the axis,

Fig. 2 is a sectional view of a permanently magnetized short ferrite torus placed in a driving coil field to produce a shear vibrational mode,

Fig. 3 is a partial sectional view of a permanently magnetized long ferrite torus placed in a driving coil field to produce a torsional vibration mode.

Fig. 4 is a partial sectional view of a permanently magnetized flat strip of ferrite placed in a driving coil field to produce a bending vibrational mode.

Fig. 5 is a partial sectional view of a permanently magnetized ferrite being used as a phonograph transducer,

Fig. 6 shows a ferrite rod being permanently magnetized in a manner to have longitudinal closed flux loops,

Fig. 7 shows a ferrite rod being permanently magnetized in a manner to have closed flux loops disposed around the axis,

Fig. 8 shows a square ferrite rod being permanently magnetized with closed flux loops,

Fig. 9 shows a ferrite rod having adjacent half-wave lengths magnetized with closed flux loops of opposite polarity, and

Fig. 10 shows a ferrite rod with a conductive core having adjacent half-wave lengths magnetized with opposite polarity flux loops, using a direct current source.

It is known that many materials may be permanently magnetized. If a cylinder is magnetized longitudinally it may retain a certain amount of its magnetization even after the magnetizing agent is removed. The cylinder ends then possess magnetic poles, but these poles themselves act to produce a magnetic field within the cylinder which is always in such a direction as to tend to demagnetize it. Thus a good permanent magnet material must be one that is not demagnetized by its own poles. Such a material is said to have a high coercive force. Ferrite has a very low coercive force, so that a rod of ferrite cannot be magnetized permanently to anything like the extent required for practical magnetostriction bias.

I have found, however, that some ferrites have quite large magnetostriction and also retain considerable magnetization if magnetized so that no poles are produced to demagnetize the material. Since poles are produced wherever magnetic flux leaves the material, by magnetizing the material so that the magnetic flux exists within the material in closed loops only, the demagnetizing poles are eliminated.

Referring now to Figure 1, a torus **10**, made of a ferrite material, has a few turns of a coil **12** wound around it. By applying a strong D. C. current to the winding a magnetic field is established which has lines of flux in closed circles entirely within the torus (represented by the dotted line). After the ferrite torus has been so magnetized, the coil or magnetizing means may be removed and a coil carrying an alternating current can be arranged to cause a small alternating flux in the material. According to the direction of the alternating flux, several modes of vibration by the ferrite may be produced.

Fig. 2 shows in section, a ferrite torus **10** having a permanent bias flux which was applied as shown in Fig. 1. A driving coil **14** is disposed on both sides of the torus so that when the coil is electrically excited the driving flux is radial with reference to the torus **10**. Shear vibrations are then produced in which concentric cylindrical shells, each the full length of the torus, rotate, each as a unit, about the common axis, the outer shells rotating opposite to the inner ones. If a driving coil is disposed, as is the magnetizing coil **12** shown in Fig. 1 and then excited with alternating current, the driving flux coincides in direction with the permanent flux and radial vibrations are produced.

Referring now to Fig. 3, a long torus or tube **16**, which has been permanently magnetized in the manner shown in Fig. 1, has a driving coil **18** disposed along its longitudinal axis, so that when the coil is electrically excited it sets up a driving flux which is parallel to the longitudinal axis and therefore at right angles to the closed loop permanent bias flux (represented by the dotted line). The long ferrite torus then vibrates in a torsional mode.

Magnetization in closed loops may be produced in bodies having shapes other than toroidal or cylindrical. Referring to Fig. 4, a long strip of ferrite **20** has a slit

22 extending a part of its length along the center line. By passing a heavy direct current through a conductor (not shown), which passes through the slit, or through a many-turn winding (also not shown), which passes through the slit and around one side of the ferrite strip, closed magnetic flux loops are established which go one way along one edge of the strip around the slit and back along the other edge in the opposite direction and around the slit. The closed flux loops are represented by the dotted line. A driving coil 24 is positioned so that its driving flux is longitudinally distributed in the ferrite strip and adds to the permanent flux along one edge and subtracts from it along the other. This stretches one edge and contracts the other; thereby causing flexual vibrations or bending.

This type of magnetization permits the use of the ferrite strip as a phonograph transducer, since a bending force applied to such a body as by a phonograph needle sets up a voltage in a coil surrounding it. Figure 5 shows a phonograph transducer which consists of a slotted ferrite strip 26 which has been magnetized as above indicated. A pickup coil 28 surrounds the ferrite strip. One end of the strip has a stylus 30 cemented thereon, or the ferrite itself may be ground to act as a stylus. The other end of the ferrite is made large to permit its being gripped in a clamp 32 which is attached to the pickup arm. The stylus 30 traveling in a record groove imparts a bending motion to the ferrite body 26 which sets up voltages which, in the surrounding pickup coil, correspond in amplitude and frequency to the bending amplitude and frequency.

In the foregoing description, "closed loop" magnetization has been produced by a coil winding or by at least a single conductor, carrying large direct current momentarily. However, in some cases this cannot be done. For example, a solid cylinder of ferrite cannot be so magnetized. Nevertheless, I have found a method for magnetizing such bodies. This method depends on the phenomenon of saturation and consists in placing the body in a magnetic field strong enough to produce saturation magnetization in at least part of the body and so arranged that the curl of the flux produced differs from zero. In such a case, after removing the magnetizing field, a residual flux remains in the form of closed loops, i. e., a flux having a curl different from zero. In practice, this magnetization may be produced simply by placing a pair of poles (south and north), against the body and then removing them. The gap between the poles should be considerably smaller than the body dimensions. There is a compromise gap that is optimum for a given magnet and body. If the gap is too large the magnetization is too symmetrical and the curl is small. If the gap is too small, the field, at remote parts of the body, is too weak to produce much magnetization. The optimum gap is readily found by experiment, and in the case of a cylinder is likely to be of the order of the radius.

Referring now to Figure 6, there may be seen a method of permanently magnetizing longitudinally a ferrite rectangle 34. A strong magnet 36 is applied to one end of the rectangle 34. The ferrite is saturated and the directions of the flux lines are as shown by the dotted lines and arrow heads. Thus, when the magnet 36 is removed, the clockwise direction of the flux predominates since there is more length of this flux than of the counterclockwise flux. Figure 7 shows a system for permanently magnetizing a ferrite cylinder 38 with circular flux loops which are around the longitudinal axis. The clockwise flux lines will predominate in the example shown in Figure 7 when the magnet is removed. Figure 8 shows a square ferrite rod 40 being permanently magnetized. A square rod vibrates in torsion at a lower frequency than a round one.

The magnet method, described above, has the disadvantage, compared to magnetizing by a current (where the latter magnetization is possible), of producing less residual flux. On the other hand, it makes possible various expedients in a simple manner that would be difficult or impossible otherwise. For example, suppose it is desired to drive a ferrite cylinder, or tube, in torsion. If the frequency is high, the wavelength is small and a half-wavelength cylinder is so short that a driving coil cannot produce much alternating flux in the material because of the high magnetic reluctance presented by the flux path. The magnetic reluctance can be reduced by making the cylinder several half waves long. But if the cylinder is magnetized so that all the flux loops along the cylinder which are encircling its longitudinal axis circulate in the same direction, the driving effects in adjacent half wavelength sections of the cylinder oppose one another. For a more detailed explanation of this phenomenon one is referred to application Serial No. 84,374, filed March 30, 1949, by Leslie L. Burns, Jr., for "Magnetostriction Devices," now Patent 2,572,313 dated October 23, 1951, which is assigned to this assignee.

Using the magnet method, flux circles can be set up in adjacent half wavelengths of the ferrite cylinder which circulate in opposite directions. This makes the driving effects of the driver coil additive in all parts of the resonator. Referring to Figure 9, there may be seen a ferrite rod 42 which is four half waves long. Each half wavelength has a separate magnet 44, 46, 48, 50 positioned adjacent thereto in the manner shown in Fig. 7, however the polarity of these magnets is alternated over the adjacent half wavelengths. It is to be understood that each of these magnets is similar to the magnets 36 shown in Figures 7 and 8, but, for convenience in representation, in Figure 9, the magnets are shown sidewise. A coil, the full length of the ferrite cylinder, may then be used to drive the ferrite rod 42 at a frequency which has a wavelength one-half the length of the rod.

Referring to Fig. 10, there is shown a system for magnetizing with alternating polarity a hollow ferrite cylinder 52 with a conductive core 54 using electrical currents. Holes may be drilled through a ferrite hollow cylinder wall at the half wavelength points to permit the insertion of contacts to the conductive core 54 extending through the center of the cylinder. This conductive core may be permanently inserted to provide a ferrite rod vibrator with composite characteristics or may be inserted to be removable after permanent magnetization of the ferrite rod. In any event, connection is made to the battery 56 so that a high current flows instantaneously in adjacent half wavelength sectors in opposite directions. Small holes drilled at the half wavelength points have relatively little effect on the electromechanical efficiency of the vibrator since the half wave points are relatively stationary.

The closed loop form of permanent bias flux for magnetostrictive bias can also be produced in materials other than ferrites. In the case of non-magnetic but metallic resonators plated with nickel, the magnet method may be employed, or a large direct current may be passed through the body of the resonator itself. Since most of this current will be enclosed by the nickel plating, the nickel is thereby magnetized in closed loops. Even a resonator of uniform magnetic metal such as NiSpanC alloy can be magnetized by current passing therethrough, although, of course, the field produced in this case varies from zero in the middle of the body (presuming it to be cylindrical) up to a maximum at the surface. A wire of this alloy, so magnetized, makes a torsion resonator requiring no magnet and having practically no frequency variation with temperature. Using a NiSpanC wire as a vibrator, connection for adjacent half wave alternate magnetization may be made in the manner shown for the ferrite hollow cylinder in Fig. 10. Such connection of alternate half wavelength points

of the wire may be made directly to the battery in the manner shown, to obtain opposing currents in adjacent half wave sectors except, of course, no drilling to a center core is required, since the entire wire is a conductor.

It should be noted that while it is possible to obtain sufficient direct current from a storage battery to produce residual magnetization in most cases, yet, since this current need not flow for any appreciable time and since the resistance of its circuit can be very low, sufficient direct current can also be produced by other means, such as the discharge of a condenser, or by the make and break of the primary of a transformer whose secondary furnishes the magnetizing current. I have even found it possible to magnetize a ferrite torus simply by pulling a small magnet out of a closed loop of wire linking the torus.

The type of ferrite best suited to magnetostrictive operation with permanent bias flux is not necessarily the same as the type which works best with a biasing magnet. Presumably a maximum product of residual flux and magnetostrictive coupling at the particular bias used is required, although other factors such as the mechanical Q of the material (and partly determined thereby), are also important in making a selection. No one material may be best for all applications. For example, if the ferrite is employed as the frequency determining element in an oscillator, its mechanical Q would be the paramount factor. If, however, it is used to drive a wideband filter, its electro-mechanical coupling coefficient would be the main factor. As an indication of a suitable material for most purposes, a ferrite formed at 1300° C. from 50% Fe_2O_3, 30% NiO and 20% ZnO has been found to be quite good in every respect.

It should be understood that this invention is not to be limited to any particular application of an electromechanical conversion or even to resonant operation of the converter body. What is shown and described herein is

means for electromechanical conversion without a supplementary bias field using instead permanent bias flux in closed loops.

From the foregoing description, it will be readily apparent that I have provided an improved magnetostrictive electromechanical conversion system wherein the vibrator is self-biased with closed loops of magnetic flux. Further, I have shown methods for permanently magnetizing, for magnetostriction, a ferrite vibrator. Although several embodiments of my invention have been shown and described, it should be apparent that many changes in the embodiments shown and many other embodiments are possible, all within the spirit and scope of my invention. It is therefore desired that the foregoing description shall be taken as illustrative and not as limiting.

What is claimed is:

A torsional mode magnetostrictive vibrator system comprising a substantially tubular ferrite resonator having closed magnetic flux lines disposed around and along the axis of said resonator, and means to establish a driving magnetic flux which is disposed at right angles to said closed magnetic flux lines and parallel with the axis of said resonator.

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