Jan. 30, 1968 W. A. BROWN ET AL 3,366,898

SPIRAL RESONATOR

Filed Feb. 26, 1963

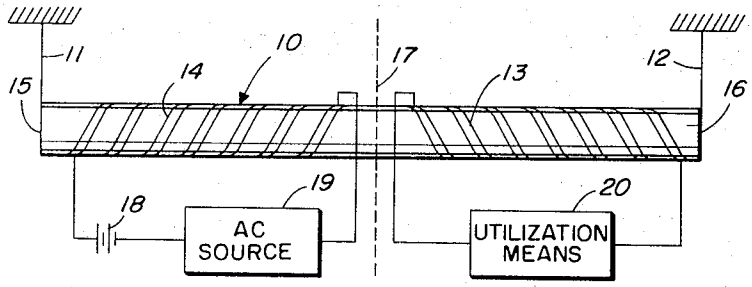


FIG 1

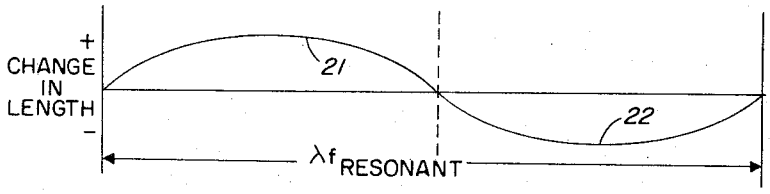


FIG 2

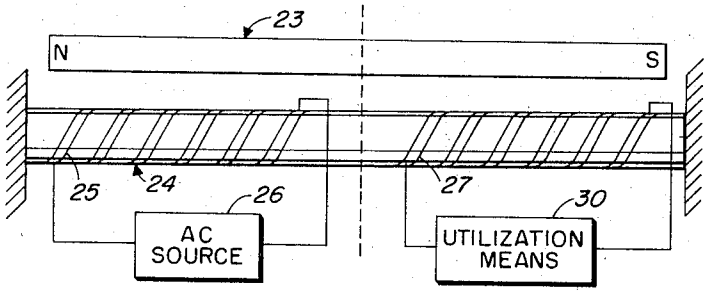
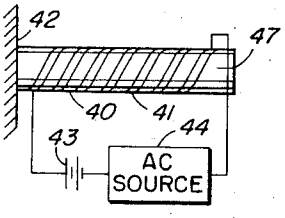


FIG 3

FIG 5



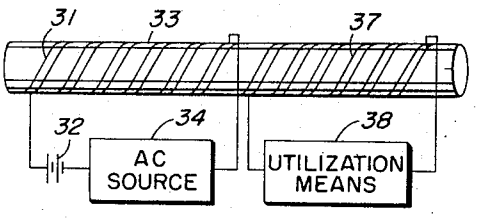


FIG 4

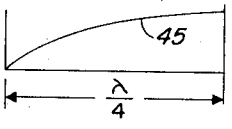


FIG 6

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SPIRAL RESONATOR

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3 Claims. (Cl. 333—71)

This invention relates, generally, to electromagnetically driven mechanical resonators and, more particularly, to mechanical resonators of a type employing a ferrite core with a coil formed thereon by plating means.

There are in the prior art many types of mechanical resonators which are used for a variety of purposes. Generally speaking, mechanical resonators may be employed as elementary filters, or alternatively, as transducers for transforming electric energy into mechanical energy which is then supplied into a more sophisticated filter, such as the mechanical filter described in U.S. Patent 2,829,350 issued Apr. 1, 1958, to L. M. Ibsen, entitled, "Mechanical Flter With Coupling Wires."

Some prior art mechanical resonators employ a core of magnetostrictive material, such as a ferrite core, with a coil wound thereon; the coil being a separate entity from the ferrite core. However, certain difficulties exist with the use of a coil as a component separate from the ferrite core. More specifically, with a separate winding, the inductive coupling of the winding to the ferrite core is impaired since some of the magnetic flux will not pass through the ferrite core, but will instead leak around the individual windings of the coil. A second disadvantage of a separate coil is that the wire of the coil has appreciable thickness, thus presenting a capacitive surface to the adjacent windings. The resonant frequency of the circuit is, of course, equal to $1/2\pi\sqrt{LC}$ where L is the inductance of the coil and C is the interwire capacitance. While the value of L is substantially fixed, C will vary as the amount of surface area existing between adjacent turns. With the use of a separate coil such surface areas can be appreciable. The maximum resonant frequency of the entire assembly is thus limited by the inductance and capacitive values of the input circuit. The core itself can have a natural resonance greater than can be obtained in the input circuit. For optimum performance, however, it is desirable to have the resonances of the input circuit and the core be equal. Assuming that the value of L cannot be reduced any additional amount, the upper frequency level must therefore be increased by reducing the interwire capacitance, which is accomplished in the present invention by reducing the aforementioned surface area.

It is an object of the present invention to provide a means for obtaining a more efficient mechanical resonator comprised of a ferrite core with a winding thereon.

Another object of the invention is to reduce the interwinding capacitance of a mechanical resonator of the type described herein.

A third object of the invention is to increase the coupling of the magnetic flux generated by the coil with the ferrite core.

A fourth purpose of the invention is the improvement of mechanical resonators, generally.

In accordance with the invention there is provided a ferrite core with a coil formed thereon by plating means. In one means for constructing the resonator the entire ferrite core is first plated with silver (or a suitable base, followed by a silver coating) and then a portion of the silver is removed, by a lathe operation for example, to leave a helical configuration of silver plate on the ferrite core, which helical configuration constitutes the winding.

In accordance with a feature of the invention, both an input and an output winding may be so formed on a given ferrite core, thus producing a mechanical resonator with both the input and the output windings formed thereon by means of silver plating, or any other suitable material, such as copper or aluminum.

In accordance with another feature of the invention, a single coil may be formed on a ferrite core having a length equal to a quarter wavelength of the signal frequency to be supplied to the winding. By securing one end firmly to some suitable supporting means, the other end will oscillate longitudinally along the axis of the core, and may be used to drive a mechanical filter of the type described in the above-mentioned U.S. Patent 2,829,350.

In accordance with a third feature of the invention the resonance of the input circuit, including the inductance of the input winding and its inherent capacitance, can be made equal to the natural mechanical resonance of the rod. With such a structure the magnetostrictive effect produced by the input signal and the natural resonance of the rod coact to provide optimum resonance. Alternatively, the natural mechanical resonance of the rod can be caused to be quite far removed from the natural resonant frequency of the input circuit. Under such circumstances the rod is vibrated at the frequency of the input signal, due almost solely to the magnetostrictive characteristics of the rod.

The above-mentioned and other objects and features of the invention will be more fully understood from the following detailed description thereof when read in conjunction with the drawings in which:

FIG. 1 shows a plan view of the mechanical resonator;

FIG. 2 is a graph showing the standing wave produced in the resonator of FIG. 1;

FIG. 3 shows another form of the mechanical resonator employing an external magnetic biasing means;

FIG. 4 shows another embodiment of the mechanical resonator;

FIG. 5 shows another form of the mechanical resonator, which employs only a single winding thereon and which may be used as a transducer since the length of the ferrite core is equal to one quarter of the wavelength of the applied signal; and

FIG. 6 shows a curve of the standing wave produced in the resonator of FIG. 5.

Before discussing the various figures a brief general discussion of mechanical resonators using ferrite cores will be given.

Mechanical resonators employing ferrite cores operate, generally, in the following manner. The ferrite core is composed of a very large number of magnetic dipoles. Further, the ferrite core is not a permanent magnet. In operation, a D-C magnetic bias is applied to the ferrite core and is usually supplied by means of a permanent magnet positioned alongside the ferrite core. Alternatively, a D-C biasing magnetic flux can be created by passing a D-C current through the winding of the ferrite core.

As an A-C signal current is passed through the winding of a ferrite core, two phenomena will occur. One is that the magnetic flux generated by the A-C current will tend to orient the magnetic dipoles of the ferrite core in a given polarity. This polarity may be opposed to or in support of, the orientation of the magnetic dipoles produced by the biasing magnetic flux field. The second phenomena is the fact that the physical length of the ferrite core will change with a change in the magnetic flux therethrough. There is a correlation between the amount of change in length of the ferrite core and the degree of orientation of the magnetic dipoles therein. The fact that the length of the ferrite core changes with the amount and direction of magnetic flux therethrough is well known in the art as the magnetostrictive effect.

For a detailed description of the theory and mathematics of the magnetostrictive properties of ferrite in response to the magnetic field reference is made to Report 6745 of the National Bureau of Standards, dated Feb. 13, 1961, entitled "The Magneto Elastic Properties of Nickel Zinc Ferrite" by Virgil E. Bottom and Bruce Danielson.

For a further discussion of the magnetostrictive properties of ferrite reference is also made to a publication entitled "High Frequency Application of Ferrites" by J. Roberts, published in 1960 by D. Van Nostrand Co., Inc. of Princeton, N.J. The aforementioned publications also discuss the excitation of a ferrite material with respect to the natural resonant frequency of the particular material being excited by a magnetic field.

In addition to the foregoing phenomena, the ferrite core will have a natural resonant frequency due to its physical configuration. If the frequency of the applied signal is equal to the natural resonant frequency of a ferrite core, the changes in length, that is the contraction and expansions of the ferrite core, will be additive and will produce a natural oscillation of the ferrite core. The increased amplitude of vibration of the core will, in turn, cause a correspondingly greater alternate orientation and disorientation of the magnet dipoles within the ferrite core. More specifically, as the length of the ferrite core increases, the degree of orientation of the magnet dipoles therein increases, thus increasing the magnetic flux density within the core. On the other hand, as the length of the core decreases or contracts, the orientation of the magnetic dipoles therein decreases, thus producing a decrease in magnetic flux density. Thus when the frequency applied electrical signal is equal to the natural resonant frequency of the ferrite core, the fluctuations of the magnetic flux in the core will be at its largest value and will induce in the output winding on the ferrite core, the largest possible electrical output signal.

Referring now to FIG. 1, the ferrite core **10**, which may be a solid rod, is supported at either end by support wires **11** and **12**, which permit the ends **15** and **16** of the ferrite rod to move rather freely. It should be noted that while the ends **15** and **16** of the rod **10** represent nodes of the natural resonance of the ferrite core **10**, there remains for all practical purposes, a certain amount of motion at the ends **15** and **16**. Consequently, unless the ends **15** and **16** are freely supported, damping will occur.

On the ferrite core **10** there is formed a coil **14** on the left-hand side in the drawing and a coil **13** on the right-hand side in the drawing. Both of these coils, **14** and **13**, can be formed in the following manner, although other forming means can be employed. The core **10** is first completely plated with a suitable conductive material such as silver, copper, or aluminum. The core **10** is then placed in a lathe-type machine and all of the conductive material, except that shown and represented by reference characters **14** and **13**, is removed from the core, leaving the windings **14** and **13** thereon.

Since the windings **14** and **13** are formed by plating a conductive material upon the core **10**, their thickness will be small relative to the thickness of a separate coil. Thus, the capacitive coupling between adjacent turns of the coils **14** and **13** will be relatively small, with the result that a higher operating frequency can be obtained. Additionally, due to the close contact between the windings **14** and **13** and the ferrite core **10**, the inductive coupling between the windings and the core **10** will be near maximum value, to insure a higher efficiency of operation than can be obtained with a conventional winding. Furthermore, the manufacture of the structure of FIG. 1 is simpler than prior art structures. More specifically, the plating of the ferrite core and the subsequent forming of the spiral winding on the core is a simpler process and a more inexpensive process than winding a coil on the core.

In FIG. 1 the magnetic biasing flux is produced by means of a D-C battery **18** which provides a D-C current through the winding **14**. The A-C exciting signal is supplied from source **19**.

In the manner described hereinbefore, the magnetostrictive effect of the core **10** coupled with the fact that said core is resonating will produce an alternating magnetic flux in the core **10** which will induce a current in the winding **13**. Utilization means **20** employs the signal generated in the winding **13** in a desired manner.

In FIG. 2 there is shown a curve of the standing wave produced in the core **10** of FIG. 1. The length of the standing wave equals the length of the core. A node exists at either end and also in the center of curve **21**. It will be noted that while one-half of the core, say the left-hand half, is expanding, that is increasing in length, the right-hand half of the core **10** will be contracting or decreasing in length as shown by the portion **22** of the curve of FIG. 2.

In FIG. 3 there is shown another form of the invention in which the magnetic bias of the core **24** is produced by permanent magnet **23**, positioned adjacent the core **24** in the manner shown. Two windings, **25** and **27**, are formed on the core in the manner described above with winding **25** being the input winding, and winding **27** being the output winding. Since the biasing magnetic flux is supplied by an external magnet **23**, there is no need for a D-C battery in the structure of FIG. 3, such as the D-C battery **18** of FIG. 1. The utilization means **30** employs the output signal induced in the winding **27** in a desired manner. In FIG. 3 both windings **25** and **27** are wound in the same direction, whereas in FIG. 1 the windings **14** and **13** are wound in opposite directions. Either configuration may be employed, depending upon the polarity of signal desired at the output terminals of the output windings.

Referring to FIG. 4, there is shown another form of the invention, in which both input winding **31** and output winding **37** are wound in the same manner upon the ferrite core **33**. In the configuration of FIG. 4, the biasing magnetic flux is produced by D-C battery **32**, connected in series with the A-C driving source **34**.

In FIG. 5 a somewhat different modification of the invention is shown, in that only one winding, **41**, is formed upon the ferrite core. By providing only a single winding the structure of FIG. 5 can be employed as a transducer with the electrical energy being transformed into mechanical energy which, in turn, can be used to drive a mechanical filter of the type described in the aforementioned U.S. Patent 2,829,350.

In FIG. 5 the left-hand end of the core **40** can be secured to some suitable rigid support. It should be noted that the A-C driving source **44** is constructed to supply a signal having a frequency whose wavelength is four times the wavlength of a natural frequency of the core **40**. Consequently, the right-hand end **47** of the core **40** will have a maximum oscillatory motion along its longitudinal axis, as shown in FIG. 6.

It is to be understood that the forms of the invention shown and described herein are but preferred embodiments thereof and that various changes may be made in the physical configuration of the embodiments and in the materials used therein without departing from the spirit or the scope of the invention.

We claim:

1. Mechanical resonator means comprising:

an elongated rod of magnetostrictive material and having a natural resonance frequency *f*;

first helically shaped winding means comprised of a conductive material coated around a first section of said rod;

second helically shaped winding means comprised of a conductive material coated around a second section of said rod; and

signal source means for energizing said first winding

means with a signal of a frequency bandwidth having a nominal center frequency f;

said rod responsive to energization of said first winding means to alternately elongate and contract magnetostrictively near the said frequency f,

said first and second helically shaped winding means being electrically isolated from each other and said rod but being inductively and magnetostrictively coupled together by said rod.

2. Mechanical resonator means in accordance with claim 1 in which said magnetostrictive material is ferrite.

3. Mechanical resonator means in accordance with claim 2 in which the resonant frequency of a combination of said signal source means and said winding means is equal to f.

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