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3,004,176

ELECTROMECHANICAL TRANSDUCERS

Filed March 30, 1959

2 Sheets-Sheet 1

FIG. 1

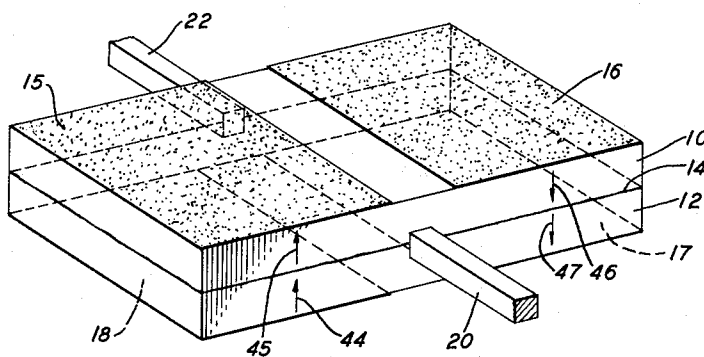


FIG. 2

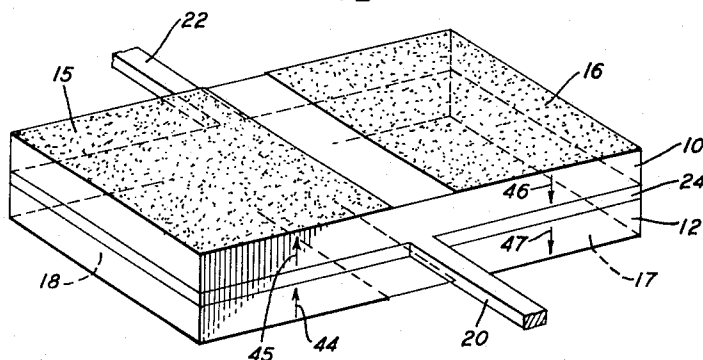
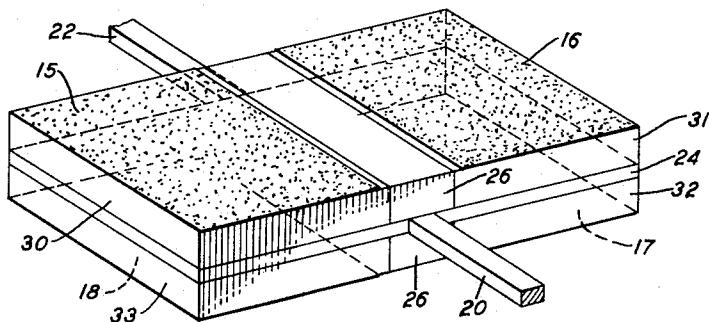


FIG. 3



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FIG. 4

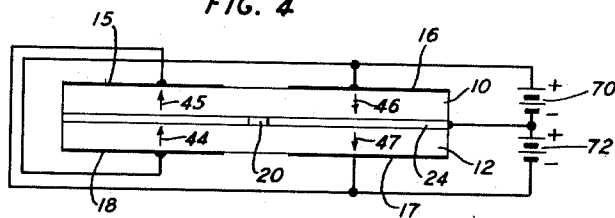


FIG. 5

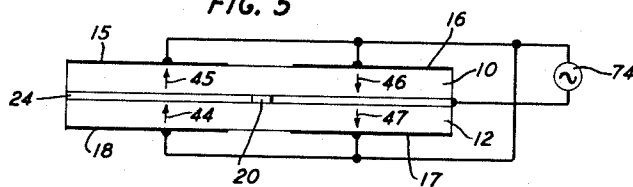


FIG. 6

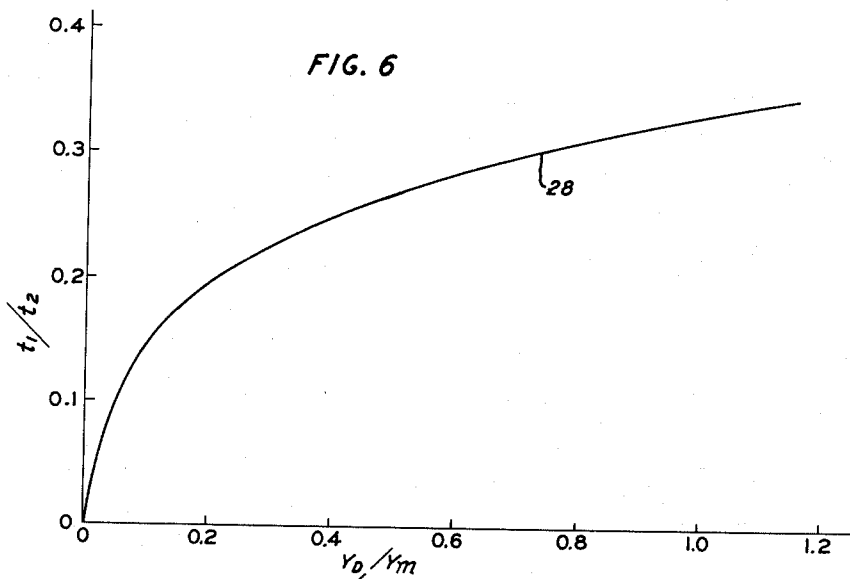
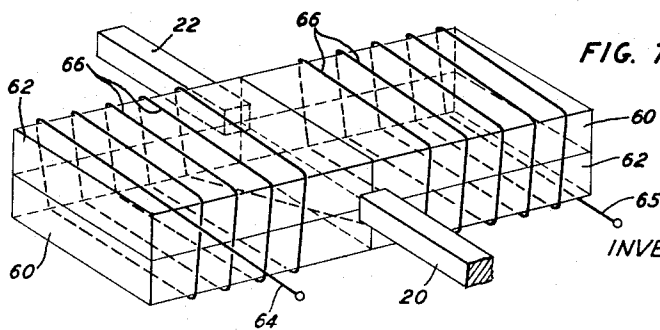


FIG. 7



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ELECTROMECHANICAL TRANSDUCERS

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13 Claims. (Cl. 310-9.1)

This invention relates to electromechanical transducers. More particularly, it relates to transducers for converting electrical wave energy to torsionally vibratory mechanical wave energy and vice versa.

Numerous and varied forms of transducers of the above-mentioned type are well known in the art but it is, in general, feasible to employ them only at frequencies within the range of approximately 30 to 150 kilocycles per second. At lower frequencies, and particularly within a major portion of the audible range of frequencies, i.e. within a range of substantially 100 cycles per second to 18 kilocycles per second, the majority of prior art transducers of the above-mentioned type require structures too large for convenient and economical use.

It is, accordingly, a principal object of the invention to overcome the above indicated difficulties in the application of torsionally vibratory electromechanical transducers of the prior art at lower frequencies.

Other objects are to reduce the size and cost of torsionally vibratory electromechanical transducers for use at lower frequencies and to simplify the fabrication of these transducers.

The above and other objects of the invention are achieved by employing antisymmetric flexural vibration of the two halves of an elongated composite bar transducer structure supported at its transverse bisecting axis. The vibrations are induced in the respective halves of the bar by a composite type of construction for each half of the bar. The composite type of construction employed at each end of the bar is closely related to specific arrangements which deform by simple longitudinal flexure and are known to those skilled in the art under the trademark "Bimorph." This type of construction, as is well known to those skilled in the art, involves the combination of two elongated members of similar dimensions, the two members being firmly secured to each other at all points along a common major surface of the members. The materials of which the members are made are chosen so that one member will expand along a particular axis in response to a specific force while the other member will contract along its corresponding axis in response to the same force, so that the combination tends to flex or bend toward the side of the member which contracts. In the specific illustrative embodiments of the invention described hereinbelow, piezoelectric or magnetostrictive materials are employed and the Bimorph structures respond to alternating current electrical signals by flexural vibration about the axis of support. The composite bar of the invention, therefore, is essentially a double Bimorph structure, as will presently become apparent. The Bimorph structures are arranged in antisymmetric fashion, that is they are adapted to flex their respective halves of the composite bar in phase opposition in response to applied alternating current electrical wave energy thereby imparting a vibrating torsional drive to the axial supporting members. Conversely, the structures of the invention generate corresponding electrical signals when

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the axial supporting members are subjected to torsional vibrations.

Other objects, features and advantages of the invention will become apparent from a perusal of the following detailed description of structures specifically illustrative of the invention taken in conjunction with the accompanying drawings, in which:

FIG. 1 represents a simple structure of the invention;

FIG. 2 represents an improved form of structure of the invention;

FIG. 3 represents a further modification of the improved form of structure of the invention;

FIG. 4 illustrates a circuit which can be employed for polarizing certain structures of the invention;

FIG. 5 illustrates a circuit which can be employed for driving certain structures of the invention;

FIG. 6 is a curve for use in designing certain structures of the invention; and

FIG. 7 represents a magnetostrictive structure operating in accordance with the invention.

In more detail in FIG. 1, the two elongated rectangular pieces 10 and 12 are of a material having strong piezoelectric or electrostrictive properties. By way of example, among the suitable materials are the ceramics, barium titanate, or a mixture of titanates such, for example, as one comprising 80 percent barium titanate, 12 percent lead titanate and 8 percent calcium titanate or a mixture of substantially equal quantities of lead zirconate and lead titanate. Other suitable ternary mixtures of titanates having outstandingly stable frequency versus temperature characteristics are disclosed and claimed in application W. P. Mason's copending application, Serial No. 351,843, filed April 29, 1953, which matured as Patent 2,906,973 granted September 29, 1959. Pieces 10 and 12 are securely fastened together with a thin layer 14 of a conductive binder such as solder to form a unitary composite bar. Corresponding opposite portions of the outer surfaces of pieces 10 and 12 are equipped with conductive electrodes 15 through 18, respectively, on each half of the bar, as shown. The opposite halves of pieces 10 and 12 are oppositely poled, as indicated by the arrows 44 through 47, inclusive, respectively. Poling can be effected, for example, in a circuit and manner to be described in detail in connection with FIG. 4, hereinafter. The assembly is supported for rotation about its transverse bisecting axis by shaft members 20 and 22, as shown, which should be firmly secured to the sides of the composite bar.

When the four electrodes 15 through 18, inclusive, are connected together and to one terminal of a source of alternating electrical wave energy and the solder layer 14 is connected to the other terminal of the source, in the manner illustrated in FIG. 5, each half of the composite bar, i.e. each of the two portions on opposite sides of the transverse axis, obviously comprises two members of ceramic polarized in the same direction but driven by alternating currents which are in phase opposition. Accordingly, one member will expand while the other contracts, and vice versa, producing flexural vibration about the axis of support. In other words, the Bimorph character of each of the half portions of the composite bar obviously will cause the half portions to vibrate in flexure. Since the halves are oppositely poled, as indicated by arrows 44 through 47, inclusive, the flexural vibrations of the two halves will be in phase opposition, i.e. antisymmetric, and a vibratory torsional force will be exerted

on the shaft members 20, 22. Such structures can therefore clearly be employed as electromechanical transducers to convert electrical wave energy into vibratory torsional mechanical energy and vice versa.

The structure of FIG. 2 is in the majority of its features substantially identical to that of FIG. 1, as indicated by the parts bearing corresponding designation numbers in both figures. The structure of FIG. 2 does differ from that of FIG. 1, however, in that a thin plate 24 of a strong resilient metal is interposed between members 10 and 12 in place of the thin layer 14 of solder. The members 10 and 12 should be firmly attached to the opposite faces of plate 24 by any suitably strong adhesive conductive material such, for example, as a solder bond. Plate 24 may be, for example, of steel. Alternatively, it may be of any strong resilient metal such as brass or bronze having mechanical properties approximating those of steel.

The optimum thickness ratio t_1/t_2 where t_1 is the thickness of the plate 24 and t_2 is the total thickness of the composite structure of FIG. 2 is dependent upon the ratio of Young's modulus Y_D for the material of pieces 10 and 12 to Young's modulus for the central metal plate Y_m and varies in accordance with curve 28 of FIG. 6. Values derived from curve 28 are not critical but it is safer to err on the side of using a somewhat too thin rather than a somewhat too thick metal plate 24, since too thick a plate can substantially reduce the electromechanical coupling of the transducer.

The introduction of the plate 24 has the effect of increasing the ratio of flexural to longitudinal coupling and when of optimum or nearly optimum thickness as determined from curve 28 of FIG. 6 can improve the electromechanical coupling of the transducer between 5 to 10 percent. Plate 24, of course, can serve as the common electrode between the adjacent faces of the members 10 and 12 and the over-all device obviously can be poled and driven exactly as described above for the assembly of FIG. 1 and further illustrated in FIGS. 4 and 5, respectively, to be described in more detail presently.

In FIG. 3 a further modification of a device in accordance with the invention is illustrated. In FIG. 3 the more central portions of the pieces 10 and 12 of FIGS. 1 and 2 are in effect removed leaving portions 30 through 33, inclusive, with electrode platings 15 through 18, inclusive, upon the free surfaces of the four portions. Portions 30 through 33, inclusive, are firmly secured to plate 24 as by solder bonds. As shown, the platings 15 through 18, inclusive, terminate a short distance from the more central edge of each of the portions 30 through 33. The gaps left between portions 30 and 31 and between portions 33 and 32 may be filled by rectangular pieces 26, as shown, which may be of the same material as plate 24 and should be firmly secured to plate 24. They serve to stiffen the central portion of plate 24 thus more clearly defining the parts of the assembly which take part in the antisymmetric flexural vibrations. Alternatively, they can be omitted or plate 24 and pieces 26 obviously can be milled as an integral member from a bar of appropriate size.

Members 30 through 33 may be of piezoelectric or electrostrictive ceramic material and can be polarized as were the corresponding portions of the members 10 and 12 of FIGS. 1 and 2 as illustrated in FIG. 4. The assembly can then be driven in the same manner as described for the previous figures in a circuit such as that illustrated in FIG. 5.

Alternatively, members 30 through 33 can be piezoelectric crystals such as crystals of quartz, Rochelle salt, or the like, the pairs 31, 32 and 30, 33 being arranged to provide Bimorph characteristics antisymmetric with respect to each other. The requirements for obtaining Bimorph pairs of piezoelectric crystals are given, for example, in applicant W. P. Mason's book entitled "Electromechanical Transducers and Wave Filters," second edition, published by D. Van Nostrand Co., New York,

1948, at pages 199, 209 and 210. Such crystals, of course, do not require polarization as do the ceramic materials discussed hereinabove. However, they can be driven by the circuit arrangements of FIG. 5 precisely as for the devices of FIGS. 1 and 2. They should be assembled, of course, so as to be antisymmetrical with respect to the transverse axis of the composite bar in their flexural vibrational response to the applied alternating current signals.

In FIG. 4 a convenient circuit is shown for effecting the polarization of the ends of the ceramic elements of FIGS. 1 and 2 and the four ceramic elements of FIG. 3, if the latter assembly is provided with elements 30 through 33 of ceramic material. The circuit comprises a source of direct current voltage having the two equal sections 70 and 72 connected in series aiding. The center point between sections 70 and 72 is connected to member 24, or for the device of FIG. 1 to solder layer 14.

The positive terminal of section 70 is connected to electrode platings 16 and 18. The negative terminal of section 72 is connected to electrode platings 15 and 17. The total voltage of each of the section 70 and 72 should be sufficient to provide 30 to 100 volts per mil between each of the electrode platings and the common center electrode 24 (or 14 for FIG. 1).

In FIG. 5, a convenient circuit is shown for driving devices of any of the forms illustrated in FIGS. 1, 2 and 3 as described in detail hereinabove. All four electrode platings 15 through 18, inclusive, are connected together and to one terminal of the alternating current source 74. The other terminal of source 74 is connected to the plate 24 (or coating 14 of FIG. 1).

Alternatively, if the polarizing source 70, 72 of FIG. 4 is interchanged with the alternating current source 74 of FIG. 5 then the circuit of FIG. 5 may be used to polarize the composite bars of the invention and the circuit of FIG. 4 may be used to drive bars so polarized. Such an interchange would, of course, involve, in connecting source 74 into the circuit of FIG. 4, connecting all of electrodes 15 through 18 to one terminal of source 74 and the plate 24 (or solder layer 14 of FIG. 1) to the other terminal of source 74. Similarly, in connecting source 70, 72 into the circuit of FIG. 5, the positive terminal of portion 70 should be connected to electrodes 15 and 16 and the negative terminal of portion 72 should be connected to electrodes 17 and 18, the junction between portions 70 and 72 being connected to plate 24.

By the principle of reciprocity, if torsional vibratory energy is supplied to the supporting shafts 20, 22, electrical signals corresponding to the torsional vibrations will be generated by the piezoelectric or electrostrictive elements of the devices of FIGS. 1, 2 and 3 described above.

A magnetostrictive form of the double Bimorph, antisymmetric flexurally vibrating composite bar type of electromechanical transducer for torsional vibratory wave energy of the present invention is illustrated in FIG. 7. It comprises two elements 60 of a magnetostrictive material having a positive coefficient and two elements 62 of a magnetostrictive material having a negative coefficient assembled and firmly secured together in antisymmetric fashion to form a composite bar as shown. The bar is supported along its transverse bisecting axis by shaft members 20 and 22. An electrical winding 66 having leads 64 and 65 is wound around corresponding portions of the composite bar on each side of the axis of support. Since the two materials have inversely related magnetostrictive properties, the composite bar is obviously a double Bimorph structure antisymmetric with respect to the axis of support. It will, therefore, respond to electrical signals applied to its winding by antisymmetric flexural vibrations of its ends thus providing vibratory torsional wave energy to the supporting shaft members 20, 22. Conversely, vibratory torsional wave energy applied to shaft members 20, 22 will result in the genera-

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tion of corresponding electrical signals in the winding 66 of the structure. The magnetostrictive coefficients of a large number of materials are given in tabular form in applicant W. P. Mason's book entitled "Physical and Acoustical Properties of Solids," published by D. Van Nostrand Co., Princeton, New Jersey, 1958. Materials having substantial positive coefficients, by way of example, are the alloys consisting essentially of 50 percent cobalt, one-half percent chromium and 49.5 percent iron or of 35 percent cobalt, one-half percent chromium and 64.5 percent iron. Materials having substantial negative coefficients, by way of example, are nickel and nickel zinc ferrite, the latter consisting essentially of 18 percent nickel oxide, 32 percent zinc oxide and 50 percent of the iron oxide Fe_2O_3 .

The transducers of the invention obviously can be employed to drive torsional wave delay lines and filters of the types disclosed and claimed in applicants' copending joint application, Serial No. 564,682, filed February 10, 1956, which matured as Patent 2,906,971 granted September 29, 1959, as well as other torsional wave delay lines and wave filters.

Numerous and varied modifications and rearrangements of the above-described specific illustrative embodiments clearly within the spirit and scope of the principles of the invention will readily occur to those skilled in the art.

What is claimed is:

1. An electromechanical transducer comprising an elongated composite bar supported by supporting members solely at its transverse bisecting axis, each half of the bar as divided by the axis comprising an electromechanical structure, the structure comprising two subportions mechanically bound into a unitary structure, means for electrically coupling to the two subportions, one subportion expanding, the other contracting, and vice versa, for alternate half cycles of an applied alternating current potential, the structures on opposite sides of the transverse axis being in antisymmetrical relation to each other, whereby the transducer responds to an alternating current potential to produce antisymmetrical flexural vibrations of the halves of the bar and a purely torsional force is produced at the axial supports.

2. The transducer of claim 1 in which the Bimorph structure on each side of the transverse axis comprises a pair of electrostrictively active ceramic members, the ceramic members on one side of the transverse axis being polarized in phase opposition to those on the other side, and electrical means for driving the members of each Bimorph pair in phase opposition.

3. The transducer of claim 1 in which the structure on each side of the transverse axis comprises a pair of piezoelectric crystals, the pairs of crystals being arranged in antisymmetric relation with respect to each other, and electrical means for driving the members of each pair in phase opposition.

4. The transducer of claim 1 in which the structure on each side of the transverse axis comprises a pair of magnetostrictive elements having magnetostrictive coefficients of opposite signs, the pair on one side of the transverse axis being in antisymmetric order with respect to the pair on the other side of the axis, and electromagnetic means for driving the structures in antisymmetrical flexural vibration.

5. An electromechanical transducer comprising an elongated resilient metallic member supported solely at its transverse bisecting axis, a pair of like piezoelectric ceramic members, the metallic member being sandwiched between the two ceramic members, the ceramic members being firmly attached to opposite surfaces of the metallic member, the portions of the ceramic members on opposite sides of the axis being polarized in phase opposition, and electrical driving means for driving the portions of the ceramic members in phase opposition to produce anti-

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symmetric flexural vibrations of the halves of the bar with respect to the axis of support.

6. An electromechanical transducer for producing torsional vibrations about a central transverse axis, the transducer comprising a thin elongated metallic member, four piezoelectric elements symmetrically disposed and secured in paired relation to opposite sides of the metallic member and on opposite sides of the central axis, each pair of elements covering a corresponding portion of its half of the member, the elements having a longitudinal dimension of less than half that of the member, each element having a conductive electrode substantially covering the surface of the element opposite its surface in contact with the member, electrical circuit means for driving each pair of elements in longitudinal vibration and in opposed phase with respect to each other and antisymmetrically with respect to the elements of the other pair, and means for supporting the transducer solely at its transverse bisecting axis whereby torsional vibratory energy is imparted to the supporting means.

7. An electromechanical transducer comprising an elongated metallic member supported solely at its transverse bisecting axis and piezoelectric elements disposed and secured in paired relation to opposite sides of the member at each end of the member and having conductive electrodes on their surfaces opposite the surfaces secured to the member, and electrical circuit means for driving the piezoelectric elements to produce antisymmetric flexural vibrations of the halves of the member about its transverse axis whereby torsional vibratory energy is imparted to the supporting means.

8. An electromechanical transducer comprising a composite elongated member, the member being supported by supporting members supporting the elongated member solely about its central transverse axis, the portions of the elongated member on each side of the transverse axis including two subportions mechanically bound together, a first electromechanical means for vibrating the two subportions of the elongated member on one side of the transverse axis longitudinally and in phase opposition to produce flexural vibration of that portion of the member, and a second electromechanical means for vibrating the two subportions of the elongated member on the other side of the transverse axis longitudinally and in phase opposition to produce flexural vibration of that portion of the member, and in phase opposition with the flexural vibrations of the portion of the member on the opposite side of the central transverse axis.

9. The transducer of claim 8 in which the means for flexurally vibrating each of the portions of the elongated member on opposite sides of the transverse axis comprises two transversely polarized like ceramic subportions included in each driven portion and electrical means for driving the two subportions of each driven portion in longitudinal vibration and in phase opposition, the polarization of the two subportions in the portion on one side of the transverse axis being opposite in direction with respect to that of the two polarized subportions in the portion on the other side of the transverse axis.

10. The transducer of claim 9 in which the elongated member includes a centrally located metallic plate extending throughout the member.

11. The transducer of claim 8 in which the means for flexurally vibrating each of the portions of the elongated member on opposite sides of the transverse axis comprises two subportions of magnetostrictive material, the subportions having magnetostrictive coefficients of opposite signs, the subportions on one side of the transverse axis being antisymmetrically arranged with respect to the subportions on the other side of the axis, and electromagnetic means for driving the four subportions.

12. The transducer of claim 8 in which the means for flexurally vibrating each of the portions of the elongated member on opposite sides of the transverse axis comprises a pair of piezoelectric crystals and electrical means for driving the crystals longitudinally in phase opposition,

the pair of crystals on one side of the transverse axis being antisymmetrically arranged with respect to the crystals of the pair on the other side of the axis.

13. The transducer of claim 12 in which the elongated member includes a centrally located metallic plate extending throughout the member. 5

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