Oct. 29, 1968 J. ADAMIETZ ETAL 3,408,514

ELECTROMECHANICAL TRANSDUCER OF THE ELECTROSTRICTIVE TYPE

Original Filed May 19, 1964 2 Sheets-Sheet 1

Fig. 1

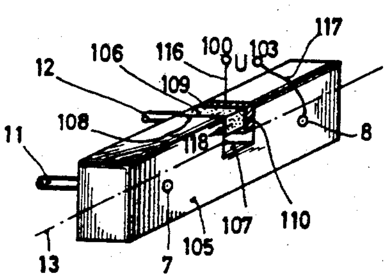


Fig. 2

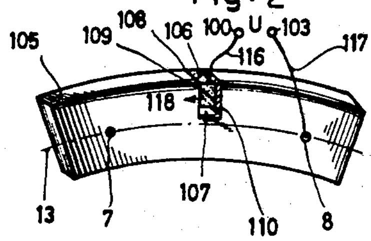


Fig. 3

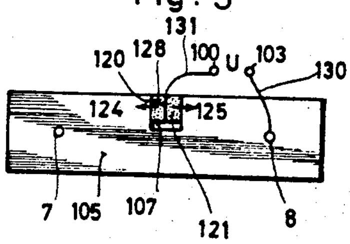


Fig. 4

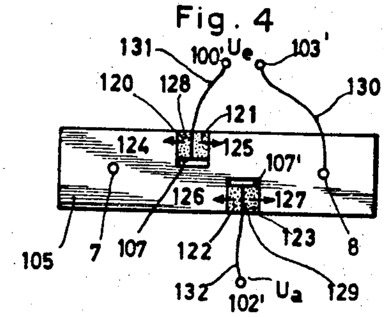


Fig. 5

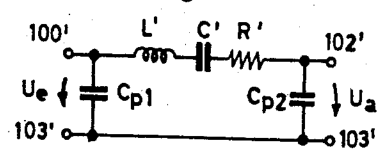


Fig. 6

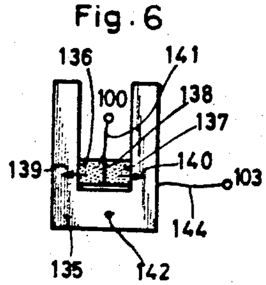
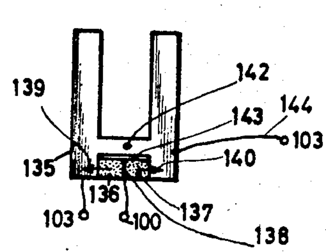


Fig. 7



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ELECTROMECHANICAL TRANSDUCER OF THE ELECTROSTRICTIVE TYPE

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Fig. 8

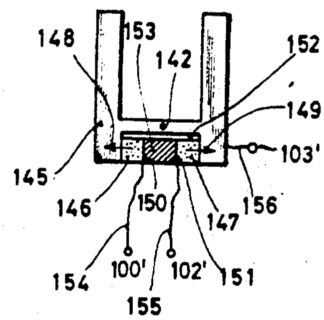


Fig. 9

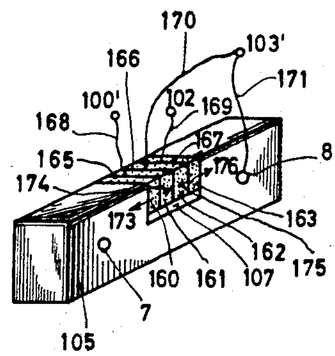
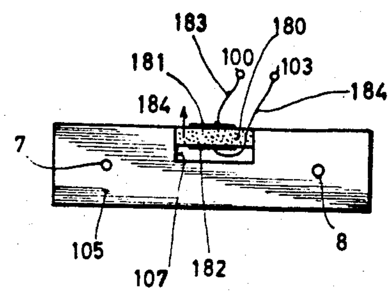


Fig. 10



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ELECTROMECHANICAL TRANSDUCER OF THE ELECTROSTRICTIVE TYPE

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Original application May 19, 1964, Ser. No. 368,716. Divided and this application Sept. 18, 1967, Ser. No. 675,269

Claims priority, application Germany, May 21, 1963, S 85,316

15 Claims. (Cl. 310—8.2)

ABSTRACT OF THE DISCLOSURE

A transducer for translating electrical oscillations into mechanical bending vibrations or vice versa comprises essentially a bar, tuning fork or other elastic structure capable of bending vibrations at a natural frequency and defining a neutral fiber or axis between the compressing and tensioning forces due to the bending motions. The structure forms a slot, preferably on a lateral side of the straight bar, or on opposite sides of the bar, or between the tines of the tuning fork. One or more electrostrictive members with respective electrode coatings are disposed in the slots in transversely spaced relation to the neutral axis and are firmly joined at both sides with the elastic vibrator structure. Electric conductor means are connected with the electrode coatings to supply excitation voltage to, or take generated voltage from, the transducer. Since the bendable structure is constituted by a single integral piece which is not fully subdivided by the slots or the electrostrictive insertions, the transducer has increased mechanical strength.

Specification

Our invention relates to an electromechanical transducer which, through small plates or blocks of electrostrictive material provided with electrically conducting coatings, is designed as a transducer for translating electrical oscillations into mechanical bending vibrations and vice versa, such transducer being applicable, for example, as an end vibrator of a multipart electromechanical filter, and in one of its more specific although not exclusive aspects the invention relates to improvements of electromechanical bending vibrators as described and claimed in the copending application Ser. No. 368,716, filed May 19, 1964, of which the present application is a division, claiming the original U.S. filing priority of May 19, 1964, and a German priority of May 21, 1963.

According to the invention described in the copending application, at least one plate or block member of electrostrictive material is disposed between the neutral fiber or axis of a bending vibrator structure and its outer perimetric surface, and an electric polarization is impressed on the electrostrictive member in a direction perpendicular to the planes of the conductive coatings. The bending vibrator structure proper, consisting for example of steel or quartz glass, is interrupted and thus subdivided by the electrostrictive member consisting, as a rule, of a ceramic material.

It is an object of the present invention to provide a transducer of the bending type that is particularly resistant to mechanical jarring or shock loads.

Another object of the invention is to improve electromechanical transducers, generally of the type briefly described above, so as to greatly increase the mechanical strength of the vibrator.

To achieve these objects, and in accordance with a feature of the present invention, we provide the bending vibrator structure of an electromechanical transducer with a lateral slot and we dispose at least one block or plate member of electrostrictive material, provided with excitation electrodes, between the neutral axis of the structure and its outer perimetric surface, an electrically insulating layer being interposed between at least one of the excitation electrodes and the bending vibrator structure.

According to another feature of the invention, we dispose two opposingly polarized plate or block members of electrostrictive material separated by an electrically conducting layer in the lateral slot of the bending vibrator structure.

According to a further feature of the invention, a favorable design of electromechanical bending vibrators is obtained by providing the vibrator structure with two slots located at only one side of the neutral axis and disposing the electrostrictive members with their excitation electrodes in the slots, or by providing the bending vibrator structure with respective slots on both sides of the neutral axis and disposing respective electrostrictive members with the appertaining excitation electrodes in the two slots.

According to still another feature of the invention, the bending vibrator structure is constructed as a tuning fork resonator. In this case, the blocks or other members of electrostrictive material with their excitation electrodes are disposed between the two fork tines, or they are disposed in a slot located in the base portion of the fork which interconnects the two fork tines.

In such tuning fork resonators, it is of advantage to dispose a plurality of electrostrictive members in the slot and to separate them by a spacer piece of electrically insulating material preferably quartz glass.

Electrical multipoles can be constituted with such electromechanical bending vibrators by subdividing the electrostrictive block or plate members with the aid of electrically conducting interlayers.

The plate or block members of electrostrictive material can be rigidly attached in the slot of the vibrator structure simply by placing the members under mechanical prestress between the slot walls, thus applying a holding force of suitable magnitude.

The invention will be further described with reference to the accompanying drawings illustrating embodiments of electromechanical transducer according to the invention by way of example. On the drawing:

FIG. 1 shows schematically a perspective view of a bar-type transducer;

FIG. 2 is an elevational view of the same transducer with a voltage applied thereto;

FIGS. 3 and 4 are elevational views of two other embodiments of transducers according to the invention;

FIG. 5 is an electrical equivalent circuit diagram relating to the transducer illustrated in FIG. 4;

FIGS. 6, 7 and 8 illustrate additional modifications of the invention as applied to tuning fork resonators;

FIG. 9 is a bar-type transducer, similar to that of FIG. 1 and illustrating a further modification; and

FIG. 10 is an elevational view of still another embodiment illustrating the application of the invention to a vibrator utilizing the so-called transverse piezoelectric effect.

Referring to FIG. 1, there is shown a mechanical bending vibrator which comprises a continuous bar **105** of steel provided with a slot **107** in which there is disposed a block or plate member **106** of an electrostriceive ceramic, for example lead zirconate. The axial end faces of member **106** have metal coatings **108** and **109**, preferably of silver. One of the silver coatings is bonded to the adjacent slot face of the steel bar **105**. A plate **110** of electrically non-conducting material, such as quartz glass, is interposed between the other silver coating and the bar **105** and fused or otherwise bonded to both. In the vibration nodes **7** and **8** there are attached rigid metal wires or rods **11** and **12** which may serve for coupling the vibrator with other bending vibrators such as those of a multipart filter, or for anchoring of the vibrator in a casing (not illustrated). A conductor wire **116** is soldered to the silver coating **109** and extends to a terminal **100**. Another wire **117** is attached to the bar **105** at the vibration node **8** and extends to a terminal **103**. To eliminate undesirable effects on the electrical quality of the vibrator, the wires **116** and **117** are made of light and flexible material. A dot-and-dash line **13** indicates the so-called neutral axis of the vibrator, which locates the plane between the compressive and tensile forces arising from the vibration.

FIG. 2 is an elevational view of the vibrator of FIG. 1, when an alternating voltage U is applied to terminals **100** and **103**. The arrow **118** indicates an electric polarization impressed on the electrostrictive member **106**. This polarization, for example in the positive half-wave of the electric alternating potential, is oriented in the same direction as the electric field, and in the negative half-wave of the voltage, is oriented in opposition to the field direction. Corresponding to this polarization, the electrostrictive member **106** expands under the influence of the electric field. Since the vibrator consists of a continuous steel body, the expansion of the block **106** causes bending forces to be exerted on the vibrator, which is thereby bent in the manner schematically shown in FIG. 2. When the polarity of the alternating voltage U, applied to the terminals **100** and **103**, reverses, the member **106** contracts, whereby the vibrator is bent in the opposite direction, which vibration state is not represented by FIG. 2. If the frequency of the alternating voltage U substantially agrees with the natural frequency of the vibrator, the latter executes intensive bending vibrations in rhythm with the applied alternating voltage, which are symmetrical to a plane containing the vibration nodes **7** and **8**.

The electrostrictive member **106** and also the plate **110** of quartz glass, can be secured in the vibrator by soldering. For this purpose, the quartz glass plate **110** as well as the ceramic member **106** are provided with metal coatings. It is also possible to attach the members **106** and **110** by shrinkage in the steel bar **105**, in which process the contraction in length occurring during cooling of the steel bar **105** places both members **106** and **110** under mechanical compression which is expediently so selected that an intimate connection of the members **106** and **110** with the steel part is effected.

FIGS. 3 and 4 illustrate examples of vibrators in which the quartz glass or other electrostrictively inactive material used for the separation of the excitation electrodes, is substituted by an electrostrictively active material.

The vibrator according to FIG. 3 consists of a continuous steel bar **105** into which a slot **107** is milled. Rods attached to bar **105** in the vibration nodes **7** and **8** may serve for supporting the vibrator in its casing, these rods and casing being ommited in the drawing. In the slot **107** there are soldered two blocks **120** of electrostrictive material separated by a silver coating **128**. A conductor wire **131** connected to the silver layers extends to a terminal **100**. Another conductor wire **130** is attached to the steel bar **105** in the vibration node **8** and extends to a terminal **103**. The polarization of block **120** is parallel to the axis of the steel bar and opposed to that of the block **121**, as indicated by arrows **124** and **125**. When an alternating voltage U is applied to terminals **100** and **103** then, for example in the positive halfwave, both blocks **120** and **121** expand under the effect of the electric field, while in the negative half-wave they contract, whereby the vibrator is excited to bending vibrations.

The example according to FIG. 4 is a further development of the vibrator illustrated in FIG. 3. In addition to the excitation system formed by the ceramic blocks **120** and **121** described above, the vibrator of FIG. 4 is provided with a further electrostrictively active system which consists of ceramic blocks **122** and **123**. These are mounted in another slot **107′** formed in the steel bar **105**. The polarization of each block **122** and **123** is parallel to the bar structure and opposed to that of the other block as is indicated by arrows **126** and **127**. Between the blocks **122** and **123** there is disposed a silver coating **129** to which is soldered a connecting wire **132** leading to a terminal **102′**. The silver coating **128** likewise is provided with a connecting wire **131** extending to a terminal **100′**; and an additional connecting wire **130** extends from the vibration node **8** of the steel bar to a terminal **103′**. When an input alternating voltage U_e is applied to the terminals **100′** and **103′**, the vibrator is excited to bending vibrations in the manner previously described. By reason of these bending vibrations, the blocks **122** and **123** are subjected to expansions and contractions, and as a result of the piezoelectric effect between the silver layer **129** and the steel bar **105** there is produced an alternating voltage whose frequency agrees with the frequency of the exciting voltage and which can be obtained at the terminals **102′** and **103′** as an output voltage U_2.

In the embodiment of FIG. 4, the two electrostrictively active systems are disposed in offset relation to each other on laterally opposite sides of the neutral axis of the vibrator structure. Practically the same electrical properties can be achieved if the electrostrictively active systems are arranged exactly opposite each other or if they are arranged only on one side of the neutral axis and spaced a suitable distance apart.

If the vibrator is operated as a bipole, as in FIGS. 1 to 3, its electrical behavior corresponds to that of an equivalent circuit in which the impedance condition between the terminals **100** and **103** is represented by a series resonant circuit formed of an inductance L, a capacitance C and a loss resistance R, another capacitance being connected in parallel to this series circuit.

The electrical equivalent circuit diagram of a vibrator operated as a quadrupole (according to FIG. 4) is illustrated in FIG. 5. A shunt capacitance C_{p1} is connected across the input terminals **100′** and **103′**; in the longitudinal branch there is disposed a series resonant circuit comprising the inductane L′, the capacitance C′ and the loss resistance R′; and a shunt capacitance C_{p2} is connected between the output terminals **102′** and **103′**. There occurs between the terminals **102′** and **103′** an output alternating voltage U_2, if the natural frequency of the vibrator agrees at least approximately with the frequency of the input alternating voltage U_e.

FIGS. 6 to 8 show bending vibrators in the shape of tuning forks. These are especially useful at relatively low frequencies at which the greater constructional length of a bar-shaped bending vibrator of equal frequency may be undesirable.

The embodiment of FIG. 6 comprises two blocks **136** and **137** of an electrostrictive ceramic between the tines of a tuning fork bending vibrator **135**, as indicated by arrows **139** and **140**. Each block is polarized in opposition to the polarization of the other. A silver layer **138** separates the blocks **136** and **137**, and a connecting wire **141** extends from the layer to a terminal **100**. Another connecting wire **144** is attached directly to the steel body of the tuning fork and extends to a terminal **103**. Since there is a point in the tuning fork base in which virtually no movement occurs, a supporting rod **142** for anchoring the tuning fork in a casing (not illustrated) is attached to the fork base at this point. When an alternating voltage is applied to the terminals **100** and **103**, the electrostrictively active blocks **136** and **137** are subjected to expansions and contractions which, due to the rigid connection of the blocks with the tuning fork tines, are transmitted to the entire tuning fork. Thus the tuning fork is excited to vibrations when its natural frequency agrees at least approximately with the frequency of the voltage applied at the terminals **100** and **103**.

The tuning fork resonator illustrated in FIG. 7 corresponds generally to that illustrated in FIG. 6, except that the electrostrictively active system is disposed in a slot **143** provided in the base or bight piece which interconnects the two fork tines.

Tuning fork resonators as illustrated in FIGS. 6 and 7 can be operated only as bipoles. A quadrupole characteristic, however, can be achieved with a tuning fork resonator as illustrated in FIG. 8.

The base portion of the tuning fork **145** has a slot **152** in which two electrostrictive systems are accommodated. These comprise two blocks of electrostrictive material between which a spacer piece **153** of electrically non-conducting material, for example quartz glass, is disposed. The mutually opposed polarization of the blocks may correspond to the directions of respective arrows **148** and **149**. From a silver coating **150** applied to the block **146** a connecting wire **154** extends to a terminal **100'**, and from the silver coating **151** applied to the block **147** a connecting wire **155** extends to a terminal **102'**. Another connecting wire **156** is attached directly to the steel part and extends to a terminal **103'**. A supporting rod **142** is attached to the neutral point of the tuning fork **145**.

When an input alternating voltage U_e whose frequency agrees substantially with the natural frequency of the tuning fork is applied to terminals **100'** and **103'**, the latter executes bending vibrations in the rhythm of the applied alternating voltage. These vibrations cause the electrostrictive block **147** to expand and contract. As a result, an alternating voltage appears between the silver coating **151** and the steel structure **145** and can be taken as output voltage from the terminals **102'** and **103'**. The tuning fork resonator illustrated in FIG. 8 thus operates in accordance with the equivalent circuit diagram of FIG. 5. Virtually the same electrical relations are achieved if the electrostrictively active systems and the spacer piece **153** are arranged between the two fork tines similar to those of FIG. 6.

The embodiment of FIG. 9 comprises a straight steel bar **105** with a slot **107** in which there are mounted four successively disposed electrostrictive plate members **160, 161, 162** and **163** separated from each other by respective silver coatings **165, 166** and **167**. A connecting wire **168** extends from the silver coating **165** to a terminal **100'**. From silver coating **167** a connecting wire **169** extends to a terminal **102'** and from silver coating **166** a connecting wire **170** extends to a terminal **103'** to which also connected another wire **171** which extends from the steel bar **105**. As a rule, the connecting wire **171** is soldered to the steel bar at one of the vibration nodes **7** or **8**. Due to the connection through wires **170** and **171**, the silver coating **166** lies on the same electrical potential as the steel bar **105** of the vibrator. Each two adjacent ones of the magnetostrictive plates are opposingly polarized as is indicated, for example by the arrows **173** to **176**. An input alternating voltage applied to terminals **100'** and **103'** generates between terminals **102'** and **103'**, in the manner previously described, an output alternating voltage whenever the frequency of the input alternating voltage is substantially tuned to the natural frequency of the bending vibrator.

A virbrator constructed according to FIG. 9 has the advantage, among others, that the steel bar requires only one slot, whereby the mechanical strength of the vibrator is increased. Its electrical equivalent circuit diagram corresponds to the one represented in FIG. 5. In a further development of the vibrator illustrated in FIG. 9, there can be arranged in the slot **107** an additional pair of electrostrictive plates separated by a metal interlayer, whose electromechanical coupling factor differs from that of the other plates. Such an arrangement permits in a simple manner to obtain an additional signal voltage which can be used for the control of other devices.

The vibration excitation of the bending vibrator illustrated in FIG. 10 is effected by the so-called transverse piezoelectric effect. The steel bar **105** is provided with a slot **107** into which there is soldered an electrostrictively active plate **180**. The plate carries excitation electrodes **181** and **182** in the form of silver coatings which are connected by wires **183** and **182** to respective terminals **100** and **103**.

The polarization of the electrostrictive plate **180** is indicated by the arrow **184**. The application of an alternating voltage to the terminals **100** and **103** causes the plate **180** to expand and contract. This movement, because of the transverse effect, results in expansions and contractions of the electrostrictive ceramic **180** in the direction of the mechanical expansion of the vibrator bar **105** and thus excites the bar to bending vibrations. The embodiment illustrated in FIG. 10 corresponds to a bipole vibrator and can be extended by another system of the same type into a vibrator operating as an electrical quadrupole. Analogously, this excitation system can also be used in tuning fork type vibrators as exemplified by FIGS. 6 to 8 and is preferably employed when only narrow filter band widths are required.

Changes may be made within the scope and spirit of the appended claims which define what is believed to be new and desired to have protected by Letters Patent.

We claim:

1. An electromechanical transducer comprising an elastic vibrator structure capable of bending vibrations at a natural frequency and having a neutral bending axis, said structure having a slot which has a dimension of depth extending transversely of said axis, an electrostrictive member having opposite faces and respective electrodes on said faces, said member being disposed in said slot in transversely spaced relation to said axis and firmly joined with both sides of said slot in said structure, at least one of said electrodes being insulated from said structure, and electric conductor means in electrically conducting connection with said electrodes.

2. In a transducer according to claim **1**, said vibrator structure being formed substantially of a single integral piece of elastic material and having an elongated shape, said slot being located generally in the middle portion of said shape and extending inwardly from a lateral side of said shape.

3. In a transducer according to claim **1**, said vibrator structure being formed substantially as a straight and elongated bar and having two longitudinally spaced vibration nodes, said slot being located between said nodes in longitudinally spaced relation to each of said nodes and extending inwardly into said bar from a longitudinal side thereof.

4. In a transducer according to claim **1**, said vibrator structure being formed substantially as a tuning fork having a base portion and two tines integral with said base portion, said slot being adjacent and parallel to said base portion.

5. In a transducer according to claim **4**, said slot being constituted by the space between said two tines.

6. In a transducer according to claim **4**, said slot being disposed in said base portion at the side thereof facing away from said tines.

7. In a transducer according to claim **2**, said two faces and electrodes of said electrostrictive member being substantially planar and extending substantially in planes perpendicular to said neutral axis.

8. In a transducer according to claim **7**, one of said electrodes being conductively joined in said slot with said structure, and an electrically insulating layer interposed in said slot between said other electrode and said structure.

9. In a transducer according to claim 7, one of said electrodes being conductively joined in said slot with said structure, and another electrostrictive plate member joined face-to-face with said other electrode and interposed in said slot between said other electrode and said structure, said two members having electrical polarizations in respective mutually opposed directions parallel to said axis.

10. In a transducer according to claim 2, said structure having two slots in opposite sides of said shape respectively, two of said electrostrictive members being disposed in said respective slots and electrically polarized in mutually opposed directions.

11. In a transducer according to claim 1, comprising a plurality of said electrostrictive members disposed in said slot in a sequence direction parallel to said axis, a spacer of electrically insulating material being interposed between the respective electrodes of two sequentially adjacent ones of said members.

12. In a transducer according to claim 11, said spacer consisting of quartz glass.

13. In a transducer according to claim 1, said two faces and electrodes extending substantially parallel to

said axis, whereby the excitation of the electrostrictive member is perpendicular to the resulting vibrating elongation of said structure.

14. In a transducer according to claim 1, said electrostrictive member being subdivided by conductive layers extending parallel to said electrode-coated faces.

15. In a transducer according to claim 1, said electrostrictive member being in pressure engagement with the transversal walls formed by said slot and being thereby compressively prestressed in the unexcited state of said structure.

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