

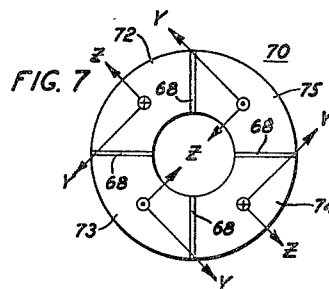
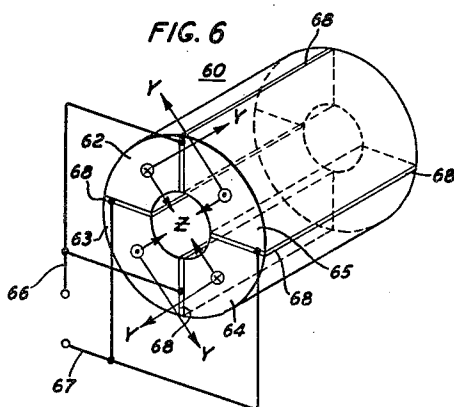
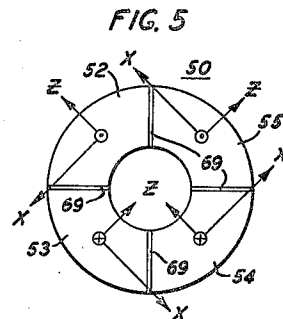
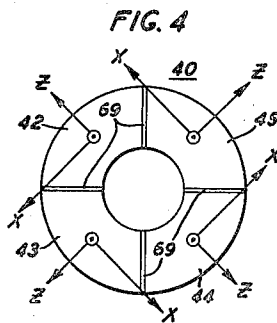
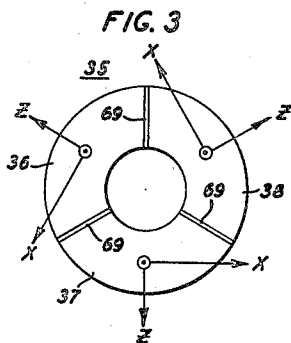
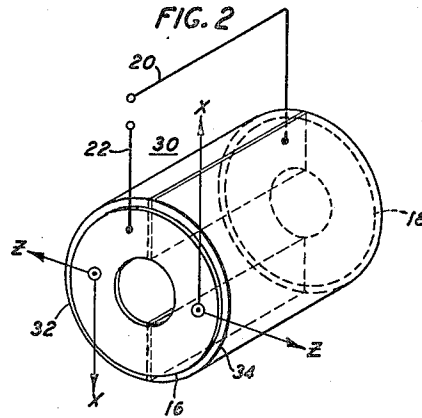
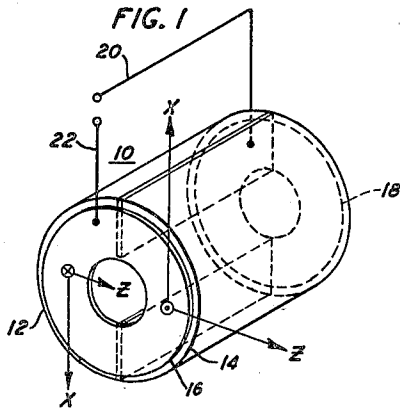
June 10, 1958

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2,838,695

MULTI-SECTION QUARTZ TORSIONAL TRANSDUCERS

Filed Aug. 15, 1955



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2,838,695

MULTI-SECTION QUARTZ TORSIONAL TRANSDUCERS

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Application August 15, 1955, Serial No. 528,461

10 Claims. (Cl. 310—8.1)

This invention relates to piezoelectric quartz torsional transducers. More particularly, it relates to quartz transducers comprising two or more similar sections assembled to form a complete transducer, each section being cut from a quartz crystal at a specific orientation with respect to the crystallographic axes, the assembly being provided with driving means, i. e., electrodes, so that a signal voltage can induce torsional vibration of the assembly and vice versa.

A principal object of the invention is to provide simple economical torsional quartz transducers having increased electromechanical coupling coefficients.

Other and further objects will become apparent during the course of the following description of illustrative embodiments of the invention and from the appended claims.

In general, transducers of the invention, in a preferred form, comprise circular cylindrical assemblies, which may conveniently be of annular form, although in most instances they could be solid, each cylindrical assembly comprising two or more cylindrical sections. The sections are each cut from a single quartz crystal but, in general, are differently oriented with respect to the crystallographic axes of the crystal, so that when assembled to form the complete cylinder, the Z axes of all sections will be radially directed with respect to the longitudinal axis of the cylinder, two of the crystallographic axes of each section will be at angles of at least 90 degrees with respect to the corresponding axes of the other sections; and all sections will have the same crystallographic axis (either the Y or the X axis) parallel to the longitudinal axis of the completed cylinder. Electrodes are then applied to the composite cylinder in such manner that torsional vibration is induced in the cylinder when signal voltage is applied to the electrodes, or vice versa. In general, for quartz transducers of the invention, the driving field is applied substantially along the Y axis to produce the shear S_{xy} through the piezoelectric constant d_{26} . For a comprehensive treatise relative to the analysis of piezoelectric phenomena, reference may be had to the book entitled "Piezoelectric Crystals and Their Application to Ultrasonics" by W. P. Mason, published by D. Van Nostrand Co., Inc., New York City, 1950. With respect to the above-mentioned shear and piezoelectric constant, for example, see equation 3.58 on page 39 of Mason's book.

The transducers of the invention, by way of example, are well adapted, as will be apparent to those skilled in the art, for use either as individual electromechanical filter units or as the sending and receiving transducers at the input and output ends, respectively, of a complex electromechanical wave filter or an electromechanical delay line designed for use in conjunction with electrical circuits.

Related transducers of ethylene diamine tartrate (EDT) or dipotassium tartrate (DKT), requiring somewhat different orientation of the crystallographic axes of the component sections, are disclosed and claimed in applicant's copending application Serial No. 528,462, filed August 15, 1955, concurrently with the present application.

The principles, objects, features and advantages of the

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present invention will become apparent during the course of the following detailed description of a number of embodiments of the invention shown, by way of illustration, in the accompanying drawings, in which:

5 Fig. 1 is a two-piece, or two-section, assembly in accordance with the invention in which the X and Y crystallographic axes of the two components are oppositely directed, the Y axis of each section being parallel to the longitudinal axis of the cylinder;

10 Fig. 2 is similar to Fig. 1 except that the X and Z axes of the two components are oppositely directed;

Fig. 3 is a three-piece, or three-section, assembly, the X and Z axes of each component being at 120 degree angles with respect to the corresponding axes of each of the other components; and

Figs. 4 through 7, inclusive, illustrate various arrangements of four-piece, or four-section, assemblies of the invention.

In more detail in Fig. 1, the transducer 10 includes an annular cylindrical member consisting of two hemi-cylindrical quartz portions, or sections, 12 and 14, cemented together. Each of the portions 12 and 14 is cut from a single crystal of quartz at a particular orientation with respect to the crystallographic axes X, Y and Z of the crystal. These are the electrical, mechanical and optic axes, respectively, of the crystal as defined, for example, in the above-mentioned book by W. P. Mason (see particularly Fig. 6.3 on page 83 of the book).

As shown in Fig. 1 of the accompanying drawings, the Z axes of both portions 12 and 14 are horizontal and, at the center of each portion, are directed radially, with respect to the longitudinal axis of the complete cylinder, toward the right. Similarly, the X axes are both vertical but are oppositely directed. The third, or Y, axes of the two portions 12 and 14 are represented by the small centrally positioned circles on the end surfaces of the portions. A small circle with a dot in the center indicates that the Y axis of portion 14 is directed perpendicularly to the end surface (i. e., parallel to the longitudinal axis of cylinder 10) and emerging from the surface. A small circle with a cross or x therein indicates, similarly, that for portion 12 the Y axis is perpendicular to its end surface but is directed inwardly. In other words, the Y axes of both portions 12 and 14 are parallel to the longitudinal axis of cylinder 10 but are oppositely directed.

Electrodes 16 and 18, with associated conductors 20, 22 complete the transducer. The electrodes may comprise, for example, conductive coatings of a metallized paint covering the complete front and rear annular surfaces of the overall assembly, respectively. Conductors 20, 22 may be cemented or soldered to their respective electrodes. Alternatively, metal plate electrodes may be cemented or soldered to a silver coating which has been fired onto each end of the assembly. The electrodes may be given sufficient inertia to mechanically load the transducer to reduce its resonant frequency of torsional vibration.

The device of Fig. 2 can be the same as that of Fig. 1 except that the left-hand hemi-cylinder is cut from its crystal with the Z axis extending (radially) toward the left and its Y axis extending toward, rather than away from, the front surface. Accordingly, in the device of Fig. 2, the X and Z axes of hemi-cylindrical piece 32 are both directed in opposite directions with respect to the corresponding axes of piece 34, and the Y axes of both pieces are parallel to the longitudinal axis of the overall assembly and directed in the same direction (outwardly).

To complete the assembly of Fig. 2, electrodes 16 and 18 and associated lead conductors 20, 22 are provided, as described for Fig. 1.

In Fig. 3 a simple front end view of a cylindrical assembly 35 of the invention comprising three 120 degree

sections 36 through 38, inclusive, is illustrated. The X and Z axes of each section make angles exceeding 90 degrees (actually 120 degrees) with the corresponding

following table indicates two arrangements in which each of the above listed piezoelectric constants can be used to provide duplex torsional transducers.

Table I

Illustrative Material	Transducer Axis=Axis Along Which Electric Field is Applied	Shear Components for Torsion about Transducer Axis	Associated Piezo-electric Constant	Possible Axes for the 180° Rotation	Axis Which Maintains a Consistent Clockwise (or Counter-clockwise) Sense
EDT-----	$x \sim 1$	$S_{xy} \sim S_6$	d_{16}	x, z	y
Tourmaline-----		$S_{xz} \sim S_5$	d_{15}	x, y	z
Do-----	$y \sim 2$	$S_{yz} \sim S_4$	d_{24}	y, x	z
Quartz-----		$S_{zy} \sim S_6$	d_{26}	y, z	x
Ammonium-ethyl-ethanolamine Hydrogen Tartrate-----	$z \sim 3$	$S_{zx} \sim S_5$	d_{35}	z, y	x
EDT or DKT-----		$S_{yx} \sim S_4$	d_{34}	z, x	y

axes of each of the other two sections. The Z axes are directed radially outward. The Y axes of all three sections are parallel to the longitudinal axis of the assembly and all are directed toward the front face of the assembly (outwardly).

The electrodes, the conductive leads connecting thereto and a perspective showing of the whole transducer have been omitted in the cases of the arrangements illustrated in Figs. 3 through 5, inclusive, to simplify the drawings, since the end views suffice to adequately illustrate the differences between the several species shown. As to details so omitted, it is to be understood that they can be identical with the corresponding details as shown in Figs. 1 and 2 and described above in full for the devices of Figs. 1 and 2.

In Fig. 4 a simple front end view of a cylindrical assembly 40 comprising four 90 degree sections 42 through 45, inclusive, is illustrated. The Y axes of all four sections are parallel to the longitudinal axis of the assembly and directed toward the front end of the assembly. The X and Z axes of each section are at angles of 90 degrees with respect to the corresponding axes of immediately adjacent sections and oppositely directed with respect to the corresponding axes of the diametrically located section. The Z axes are directed radially outward, as viewed from the center of each portion.

In Fig. 5 a still further permissible arrangement of the invention is illustrated by the simple front end view of a cylindrical assembly 40 comprising four 90 degree sections 52 through 55, inclusive, as illustrated. The directions of the respective axes of the sections are as indicated on the drawing, i. e., the Y axes of all sections are parallel to the longitudinal axis of the cylinder, the Y axes of the lower two sections being directed inwardly, those of the upper two sections being directed outwardly, the Z axes are directed radially, the two upper section Z axes being directed outwardly and the two lower section Z axes being directed inwardly, and each X axis is at an angle of 90 degrees with respect to the Z axis of its section, all as shown in Fig. 5.

In all of the above arrangements of Figs. 1 through 5, inclusive, the Y axis of every section is parallel to the longitudinal axis of the assembly, the Z axis is radially directed and the assemblies are all adapted to be driven by electrodes placed on the front and rear ends, as described in detail in connection with Figs. 1 and 2. The several sections of any of these transducers can be cemented together by a thin film of any strong nonconductive adhesive but if sufficiently rigid end-plate electrodes are used, it is preferable to merely cement each section to the end plates only since smaller mechanical dissipation can then be realized.

In general, similar torsional transducers can be made from any piezoelectric material having at least one of the piezoelectric constants d_{35} , d_{34} , d_{16} , d_{15} , d_{26} or d_{24} (see W. P. Mason's book, page 39) greater than zero. The

It should be understood that for each of the example materials in the table the piezoelectric constant listed is referred to the conventional axes, as defined, for example, in Mason's above-mentioned book. The possibility of obtaining equivalent constants in other materials by reference to different sets of axes will be apparent to those skilled in the art.

In Figs. 6 and 7, two arrangements of the invention, each comprising four 90 degree sections, are illustrated in which the X axis of every section is parallel to the longitudinal axis of the assembly, the Z axes are directed radially, and the electrodes are interposed between the interfaces of the consecutive sections. In a preferred form, a conductive or a metallized cement may perform the dual function of holding the sections together mechanically and serving as the driving electrodes, diametrically opposite pairs of electrodes being connected together and to appropriate conductive leads, as shown in Fig. 6.

In more detail in Fig. 6, an annular cylindrical assembly 60, comprising four 90 degree sections 62 through 65, inclusive, is shown. The X axis of each of the four sections is parallel to the longitudinal axis of the assembly, the direction of the X axes of sections 62 and 64 being toward the rear end and that of the X axes of sections 63 and 65 being toward the front end, as shown. All the Z axes are radially directed inwardly. The Z and Y axes of adjacent sections are mutually perpendicular and the Z and Y axes of diametrically opposite sections are oppositely directed, as shown. The quarter sections 62 through 65 are bound together by cement 68 at their interfaces, the cement preferably being conductive and thereby serving as driving electrodes as well as cementing the sections together. Diametrically opposite pairs of the electrodes 68 are connected together and to electrical conductors 66, 67, respectively, as shown, to complete the transducer.

In Fig. 7, a simple front end view of an arrangement 70 of the invention is illustrated, comprising four quarter sections 72 through 75, inclusive. This arrangement is identical with that of Fig. 6, as described in detail above, except that sections 72 and 74 have their Y and Z axes turned through 180 degrees with respect to the corresponding axes of sections 62 and 64 of Fig. 6. Electrodes and connections thereto should be identical with the corresponding features of the device illustrated in Fig. 6 but are omitted from Fig. 7 to simplify the drawing.

In general, four-piece torsional transducers of the types illustrated by Figs. 4 through 7, inclusive, described hereinabove, can be made from any piezoelectric material having at least one of the piezoelectric constants d_{15} , d_{16} , d_{24} , d_{26} , d_{34} or d_{35} greater than zero (see W. P. Mason's book, page 39). The following table indicates how this may be done.

Table II

Illustrative Material	Axis Along Which Electric Field is to be Applied	Shear Component Used	Associated Piezo-electric Constant	Axis Which Must Be Reversed in Adjacent Pieces—Axis about Which Torsion Takes Place
EDT-----	$x \sim 1$	$S_{xy} \sim S_0$	d_{16}	y
Tourmaline-----		$S_{xz} \sim S_5$	d_{15}	z
Quartz-----	$y \sim 2$	$S_{xy} \sim S_0$	d_{26}	x
Tourmaline-----		$S_{yz} \sim S_4$	d_{24}	z
Ammonoethyl - ethanalamine Hydrogen Tartrate-----	$z \sim 3$	$S_{xz} \sim S_5$	d_{35}	x
EDT or DKT-----		$S_{yz} \sim S_4$	d_{34}	y

The transducers of Figs. 6 and 7 may be compared, as follows, with those of Figs. 1 through 5, which latter require nonconducting bonds between the sectors and use an axial driving field. The electromechanical coupling is approximately the same for the two types. If it is easier to make a good nonconducting bond, the type using the axial field will be easier to construct. On the other hand, if a good conducting bond is more easily realized, as is likely to be the case for quartz, then the type described in connection with Figs. 6 and 7 will be easier to construct. For very short (high-frequency) transducers of relatively large diameter, the type of Figs. 1 through 5 will have the larger interelectrode capacity, whereas for more slender transducers, the type of Figs. 6 and 7 will have the larger interelectrode capacity. We note in passing that the interelectrode capacity of the type using radial electrodes, as shown in Figs. 6 and 7, can be increased by increasing the number of sectors (and electrodes) used, and the capacity of the other type can be increased by making them shorter and/or of larger diameter, while maintaining the frequency by adjustment of the loading introduced by inertia discs on the ends, as previously described.

All of the above arrangements, as illustrated in Figs. 1 through 7, inclusive, and described in detail above, are operative electromechanical torsional quartz transducers.

From the above, it is obvious that numerous and varied other arrangements within the spirit and scope of the invention can be readily devised by those skilled in the art. Accordingly, the above-described arrangements are to be understood to be illustrative only.

What is claimed is:

1. A piezoelectric quartz torsional transducer comprising a plurality of cylindrical sections of quartz assembled to form a complete quartz cylinder, each section being cut from a single quartz crystal with predetermined orientation with respect to the crystallographic axes of the crystal, said sections when assembled in the complete cylinder having two of the three crystallographic axes of each section at an angle of at least 90 degrees with respect to the corresponding crystallographic axes of each of the other sections, the Z axes of all sections being radially directed with respect to the longitudinal axis of the complete cylinder, all sections having the same crystallographic axis parallel to the longitudinal axis of the completed cylinder, and means for applying signal voltage to each section of said cylinder in a direction substantially parallel to the Y axis of said section to induce torsional vibration of said cylinder.

2. A transducer as defined in claim 1, the cylindrical element thereof comprising two hemi-cylindrical sections.

3. A transducer as defined in claim 2, said means for applying signal voltage comprising a pair of electrodes, each electrode consisting of a layer of conductive material substantially coextensive with and adhering to an end of the cylindrical element of said transducer.

4. A transducer as defined in claim 1, the cylindrical element thereof comprising three 120 degree cylindrical sections.

5. A transducer as defined in claim 1, the cylindrical element thereof comprising four 90 degree cylindrical sections.

6. A transducer as defined in claim 5, said means for applying signal voltage comprising a pair of electrodes, each electrode consisting of a layer of conductive material substantially coextensive with and adhering to an end of the cylindrical element of said transducer.

7. A transducer as defined in claim 5, said means for applying signal voltage comprising conductive electrodes interposed between the interfaces of adjacent 90 degree cylindrical sections of the cylindrical element of said transducer, diametrically opposite electrodes being electrically interconnected.

8. A transducer comprising a cylindrical element of quartz, said element consisting of two hemi-cylindrical sections, each section being cut from a single crystal of quartz, the Y axes of both sections being parallel to the longitudinal axis of said element but oppositely directed, the Z axes of both sections being parallel and directed in the same direction, the X axes being parallel but oppositely directed, and a conductive electrode covering each end of said cylindrical element.

9. A transducer comprising a cylindrical element of quartz, said element consisting of four 90 degree cylindrical sections, each section being cut from a single crystal of quartz, the Y axes of all four sections being parallel to the longitudinal axis of said element, two of the three crystallographic axes of each of said 90 degree sections making an angle of at least 90 degrees with respect to the corresponding axes of each of said other sections, and a conductive electrode covering each end of said cylindrical element.

10. A transducer comprising a cylindrical element of quartz, said element consisting of four 90 degree cylindrical sections, each section being cut from a single crystal of quartz, the X axes of all four sections being parallel to the longitudinal axis of said element, two of the three crystallographic axes of each of said 90 degree sections making an angle of at least 90 degrees with respect to the corresponding axes of each of said other sections, and a conductive electrode interposed between two adjacent sections of said cylindrical element, diametrically opposite electrodes being electrically interconnected.

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