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Tsubouchi

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[54] **RESONATOR FOR TORSIONAL VIBRATION**

[75] Inventor: **Norio Tsubouchi**, Tokyo, Japan

[73] Assignee: **Nippon Electric Company, Limited**, Minato-ku, Tokyo, Japan

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[30] **Foreign Application Priority Data**

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[52] **U.S. Cl.** **310/9.5**, 310/9.6, 310/8.5, 333/72

[51] **Int. Cl.** **H04r 17/00**

[58] **Field of Search** 310/9.5, 9.6; 333/72, 71

[56] **References Cited**

UNITED STATES PATENTS

3,396,327	8/1968	Nakazawa	310/9.4 X
3,284,727	11/1966	Carlson et al.	310/9.6 X
2,928,069	3/1960	Petermann	310/9.6 X
3,020,424	2/1962	Bechmann	310/9.6 X
3,405,289	10/1968	Gikow	310/9.6 X
3,074,034	1/1963	Crownover	310/9.6 X

OTHER PUBLICATIONS

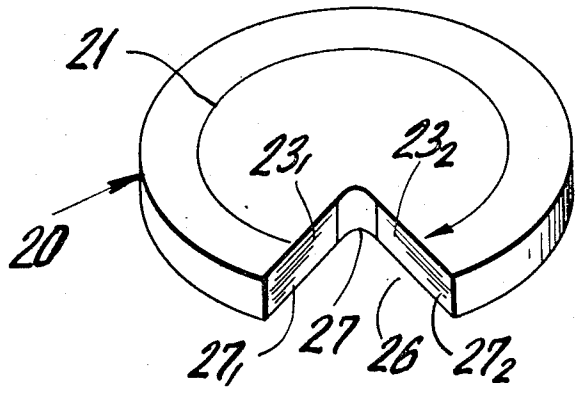
IBM Technical Disclosure Bulletin, Piezoelectric Transducer, by W. V. Vilkelis, Vol. 6, No. 8, Jan. 1964.

Primary Examiner—Mark O. Budd
Attorney—Nichol M. Sandoe et al.

[57] **ABSTRACT**

A generally disc-shaped ferroelectric ceramic piece is provided with at least one recess inwardly extending from the peripheral surface and is poled along the azimuthal direction so as to adapt the piece to torsional vibration. A pair of electrodes are attached to the principal surfaces of the piece, respectively. During manufacture, a pair of electrodes for poling the piece are attached to the face of the piece provided by the recess and are removed after poling.

11 Claims, 13 Drawing Figures



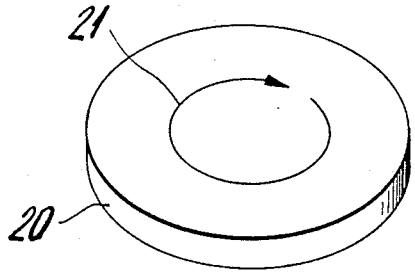
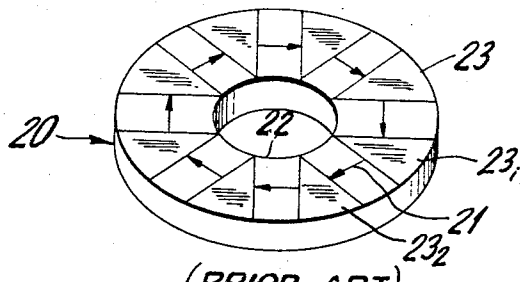


FIG. 1



(PRIOR ART)

FIG. 2

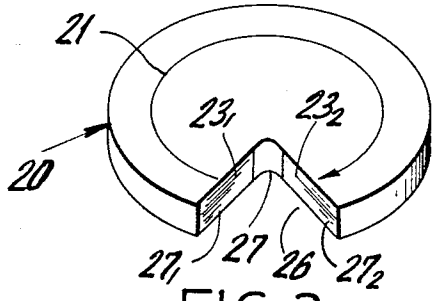


FIG. 3

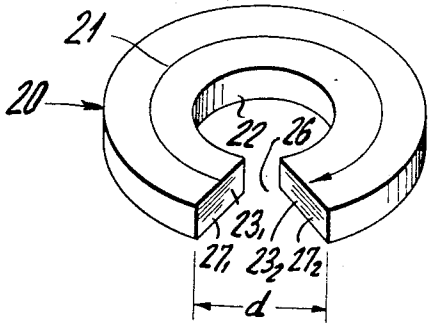


FIG. 5

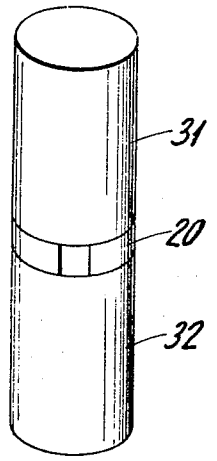


FIG. 4

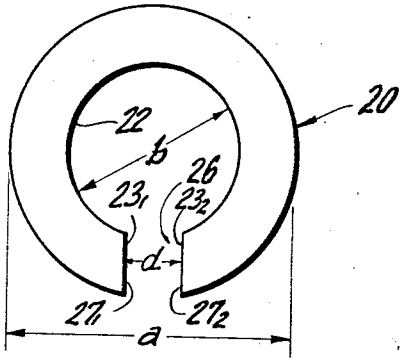


FIG. 6.

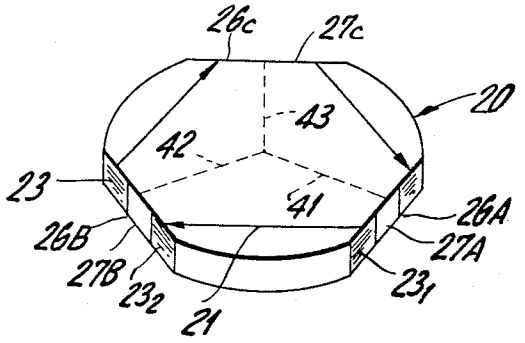


FIG. 7

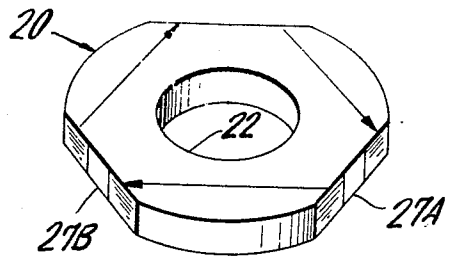


FIG. 8

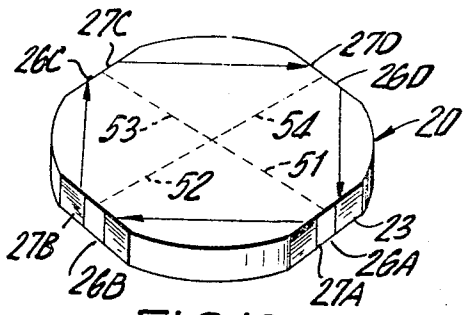


FIG. 10

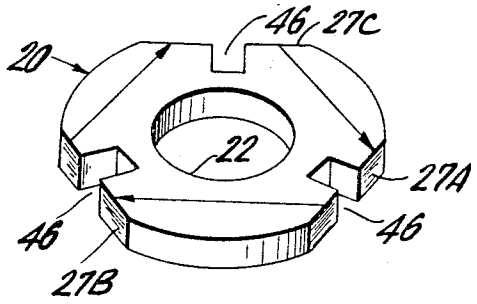


FIG. 9

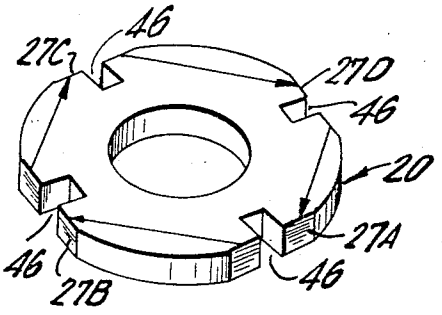


FIG. 11

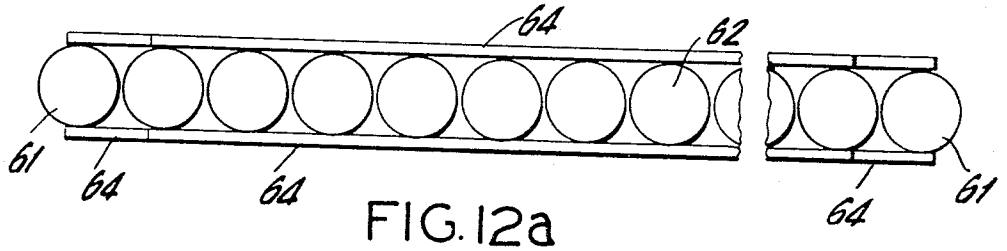


FIG. 12a

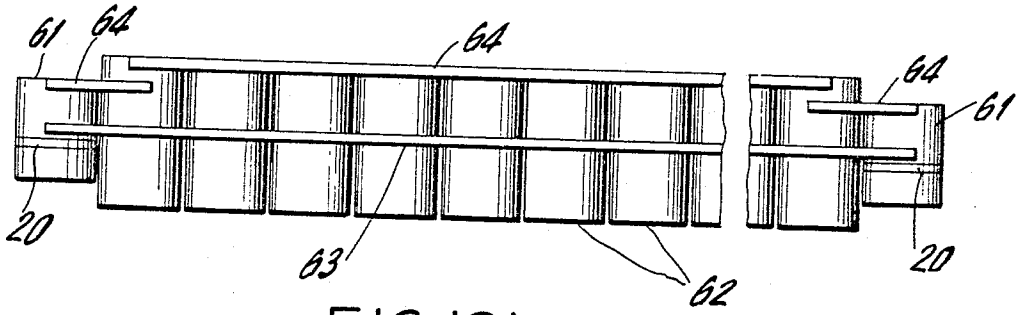


FIG. 12b

RESONATOR FOR TORSIONAL VIBRATION

BACKGROUND OF THE INVENTION

This invention relates to a ferroelectric or piezoelectric ceramic resonator to be put into torsional vibration and a method of making the same.

Piezoelectric ceramic resonators for the longitudinal vibration or thickness shear vibration have been used as the transducers in mechanical filters which are widely in use in telecommunication apparatus. With such ceramic resonators, it is possible to use the electrodes used to pole the ceramic pieces as the electrodes for excitation and vibration. This makes it possible to assemble a piezoelectric ceramic resonator and has provided a wider use thereof.

With the progress of the telecommunication technique, it is strongly desired to reduce the dimensions of the mechanical filters and to widen the band width thereof. It is, however, difficult to satisfy these requirements with conventional piezoelectric ceramic resonators. More particularly, a conventional piezoelectric ceramic resonator has poor electromechanical conversion efficiency and a high propagation speed of sonic waves. The poor electromechanical conversion efficiency makes it difficult to provide the filter with a wide band width. The high propagation speed makes it difficult to miniaturize the piezoelectric resonator.

Access has therefore been desired towards a piezoelectric ceramic resonator having excellent electromechanical conversion efficiency and a moderately slow propagation speed. This has drawn attention to piezoelectric ceramic resonators to be used in the torsional mode of vibration, which satisfies, in theory, the desires. It is, however, to be noted that the direction of the electric fields for poling must be varied from place to place, in the manner later explained with reference to one of the accompanying drawings, in order to manufacture a piezoelectric ceramic resonator to be put in the torsional mode of vibration. This imposes difficulties on the manner of furnishing the piezoelectric ceramic piece with the electrodes for poling. An attempt has therefore been made to remove the difficulties as will be described with reference to another of the accompanying drawings. The attempt, however, is still incapable of attaining the satisfactory poling and results in the survival of unpoled portions and in the consequent reduction of the piezoelectric activities.

SUMMARY OF THE INVENTION

It is therefore an object of the present invention to provide a piezoelectric ceramic resonator of the shape with which it is easy to provide the electrodes for poling the piezoelectric ceramic piece so as to adapt the piece to the torsional mode of vibration.

Another object of this invention is to provide a piezoelectric ceramic resonator of the shape with which it is easy to miniaturize the resonator.

Still another object of this invention is to provide a piezoelectric ceramic resonator by which application to the piezoelectric ceramic piece of the electric field for poling will not leave unpoled portions in the piece.

Yet another object of this invention is to provide a piezoelectric ceramic resonator which shows excellent piezoelectric activities.

A further object of this invention is to provide a method of making a piezoelectric ceramic resonator of any of the types described.

According to the instant invention there is provided a ceramic resonator comprising a ferroelectric ceramic piece of a generally disc shape having two parallel principal surfaces, a cylindrical peripheral surface joining said principal surfaces, and a pair of electrodes attached to said principal surfaces, respectively. The piece is poled along the paths between and substantially parallel to the principal surface so as to adapt said resonator to the torsional mode of vibration. The improvement comprises at least one recess inwardly extending from said peripheral surface into the body of said disc, the face of said piece provided by said recess being substantially perpendicular to said principal surfaces.

According to this invention there is also provided a method of making a ceramic resonator comprising the steps of forming a ferroelectric ceramic piece of a generally disc shape having two parallel principal surfaces and a cylindrical peripheral surface joining said principal surfaces, providing at least a pair of first electrodes to said piece, applying an electric field between said pair of said first electrodes to pole said piece and adapt said piece to the torsional mode of vibration whereby its principal surfaces move in opposite directions, removing said first electrodes, and then attaching a pair of second electrodes to said principal surfaces, respectively, characterized in that said piece is formed at least one recess inwardly extending from said peripheral surface into the body of said disc, the face of said piece provided by said recess being substantially perpendicular to said principal surfaces, and that said first electrodes are attached to said face of said piece provided by said recess so as to allow application of said electric field.

BRIEF DESCRIPTION OF THE DRAWINGS

FIG. **1** is a perspective view of a piezoelectric ceramic piece which illustrates the principles of the present invention;

FIG. **2** is a perspective view of a piezoelectric ceramic piece produced during the manufacture of a conventional piezoelectric ceramic resonator adapted to the torsional mode of vibration;

FIG. **3** is a perspective view of a first example of a piezoelectric ceramic piece for use in an embodiment of this invention;

FIG. **4** is a perspective view of an embodiment of this invention;

FIG. **5** is a perspective view of a second example of a piezoelectric ceramic piece;

FIG. **6** is a plan view of a third example of a piezoelectric ceramic piece;

FIG. **7** is a perspective view of a fourth example of a piezoelectric ceramic piece;

FIG. **8** is a perspective view of a fifth example of a piezoelectric ceramic piece;

FIG. **9** is a perspective view of a sixth example of a piezoelectric ceramic piece;

FIG. **10** is a perspective view of a seventh example of a piezoelectric ceramic piece;

FIG. **11** is a perspective view of an eighth example of a piezoelectric ceramic piece;

FIG. **12***a* is a plan view of a mechanical filter comprising an embodiment of this invention; and

FIG. **12***b* is an elevational view of the mechanical filter.

DESCRIPTION OF THE PREFERRED EMBODIMENTS

Referring to FIG. **1**, it is necessary in order to provide a piezoelectric ceramic piece **20** adapted to the torsional mode of vibration to subject the piece **20** to an electric field **21** whose direction varies along the azimuth of the piece **20**. It has, however, been impossible to realize this ideal distribution of the field **21**.

Referring to FIG. **2**, a conventional method of making a piezoelectric ceramic resonator adapted to the torsional mode of vibration comprises the steps of providing a piezoelectric ceramic piece **20** having a bore **22** at the center, providing a plurality of electrodes **23** on both principal surfaces of the piece **20** in the manner depicted in the drawing, and applying an electric field **21** between each pair of the neighbouring electrodes, such as 23_1 and 23_2, for poling the piece **20**. This method not only leaves unpoled portions at the sections where the electrodes **23** are attached to the principal surfaces but also restricts the poled portions to the adjacencies of the principal surfaces. This further gives rise, on exciting the piezoelectric torsional vibration, to unwanted additional load and to the consequent reduction in the piezoelectric activities.

Referring to FIG. **3**, a first example of the piezoelectric ceramic piece **20** of a generally disc shape for use in an embodiment of the instant invention has two substantially parallel principal surfaces and a substantially circular cylindrical peripheral surface joining the principal surfaces. The piece **20** further has a recess **26** extending inwardly from the peripheral surface into the body of the disc. The face **27** of the piece **20** provided by the recess **26** is substantially perpendicular to the principal surfaces. The recess **26** is generally V-shaped so that the face **27** is divided into two face portions 27_1 and 27_2, each forming a selected angle with a radius of the disc. During manufacture, a pair of electrodes 23_1 and 23_2 are attached to the face portions 27_1 and 27_2, respectively. An electric potential is applied between the electrodes 23_1 and 23_2, which produces an electric field **21** in the piece **20** varying along the azimuthal direction for poling the piece **20** in the known manner so as to adapt the piece **20** to the torsional mode of vibration. Thus, the piece **20** is poled along paths between and substantially parallel to its principal surfaces. Subsequently, the electrodes 23_1 and 23_2 are removed.

Referring to FIG. **4**, an embodiment of this invention comprises a piezoelectric ceramic piece **20** manufactured either in the manner described above with reference to FIG. **1** or in the manner to be later described with reference to any one of FIGS. **5** through **11**. A pair of metal pieces **31** and **32** are attached to the principal surfaces of the piece **20**, respectively, to complete a resonator of the Langevin type. These metal pieces **31** and **32** may be fixed to the piece **20** by means of an electroconductive binding agent and used as the electrodes for exciting the desired torsional vibration.

Referring to FIG. **5**, a second example of the piezoelectric ceramic piece **20** has a shape similar to that of the first example but has a generally cylindrical bore **22** substantially at the center of the piece **20**, in substantially concentric relation to the peripheral surface and in communicating relation to the recess **26**. The face **27** of the piece **20** is thus divided into two face portions 27_1 and 27_2. The electrodes 23_1 and 23_2 are attached preferably to the whole face portions 27_1 and 27_2, respectively. Also preferably, the face portions 27_1 and 27_2 are substantially planes respectively, and the largest distance d between such two face portions 27_1 and 27_2 is not greater than 0.9 times the diameter of the peripheral surface. The smallest distance between these two face portions 27_1 and 27_2 may be zero. In other words, the central bore **22** need not necessarily be in communicating relation to the recess **26**. It is, however, to be noted that the communicating relation facilitates the application and removal of the electrodes 23_1 and 23_2 to and from the ceramic piece **20**. Furthermore, the central bore **22** and the recess **26** may be of configuration such that the bore **22** has the shape of a semicircle and the recess **26** has the shape of a triangle that has a base coincident with the circle-dividing diameter and is truncated by the circle of the peripheral surface.

Referring further to FIG. **5**, it has been confirmed by a series of experiments carried out with piezoelectric ceramic resonators, each comprising a piezoelectric ceramic piece **20** described above with reference to FIG. **5**, that the best results are obtained when the diameter of the central bore **22** is within a range between 0.2 through 0.9 times that of the peripheral surface.

Referring to FIG. **6**, a third example of the piezoelectric ceramic piece **20** is a variation of the second example and has a central bore **22** and a communicating recess **26** bounded by a pair of substantially parallel plane face portions 27_1 and 27_2. The electrodes 23_1 and 23_2 for poling are attached to the face portions 27_1 and 27_2 and subsequently removed after poling. The piece is thus poled along paths that are arcuate and concentric with respect to the peripheral cylindrical surface of the disc. The diameters a and b of the peripheral surface and the bore **22** and the distance d of the face portions 27_1 and 27_2 will be referred to later.

Referring to FIG. **7**, a fourth example of the piezoelectric ceramic piece **20** has three recesses **27A**, **27B**, and **27C**. The faces **27A**, **27B**, and **27C** provided by the respective recesses **26A**, **26B**, and **26C** are substantially perpendicular to the respective radii **41**, **42**, and **43** of the disc which substantially trisect the disc. A pair of electrodes 23_1 and 23_2 is attached to one of the faces **27A** at a portion offset to left in the drawing and to an adjacent face **27B** at a portion reversely offset to right in the drawing respectively. In this manner, three pairs of electrodes **23** are attached to the piece **20** for production of the electric fields **21** for poling the piece **20** in the desired manner along paths that are cordal with respect to the cylinder defined by the peripheral surface of the disc.

Referring to FIG. **8**, a fifth example of the piezoelectric ceramic piece **20** is similar to the fourth example but has a central bore **22**.

Referring to FIG. **9**, a sixth example of the piezoelectric ceramic piece **20** is similar to the fifth example but has a further recess **46** inwardly extending from each of the faces **27A**, **27B**, and **27C** into the body of the disc, starting in the vicinity of a line which is perpendicular to the principal surfaces and substantially bisects the area of one face **27A**, **27B**, or **27C**. The further recesses **46** serve to define the offset portions of the faces **27A**, **27B**, and **27C**, respectively.

Referring to FIG. **10**, a seventh example of the piezoelectric ceramic piece **20** has four recesses **26A**, **26B**, **26C**, and **26D**. The faces **27A**, **27B**, **27C**, and **27D** provided by the recesses **26A**, **26B**, **26C**, and **26D**, respectively, are substantially perpendicular to the respective

radii **51, 52, 53,** and **54** of the disc which are in substantially quadrature relation to one another. Four pairs of electrodes **23** are attached to the piece **20** for poling the piece **20** in a manner similar to the electrodes **23** of the fourth and the fifth examples.

Referring to FIG. **11,** an eighth example of the piezoelectric ceramic piece **20** is similar to the seventh example but has a further recess **46** inwardly extending from each of the faces **27A, 27B, 27C,** and **27D** like the sixth example.

EXAMPLES

Lead zirconate-titanate ceramic pieces **20** of disc shape, 5 mm in diameter and 1 mm in thickness, and of annular disc shape having a central bore **22** of 1.23 mm in diameter, were provided. The electromechanical coupling coefficient K_r under the radial mode of vibration was 42 percent, and the mechanical quality factor Q_m under the same condition was 1,500. Each piece **20** was provided with at least one recess **26** in the manner illustrated with reference to FIG. **3** and FIGS. **5** through **11.** As is known in the art of the piezoelectric ceramic materials, the piece **20** may be made directly into either the disc shape or the annular shape having at least one recess **26.** At least one pair of first, silver electrodes **23** for poling the piece **20** was attached to the face or faces **27** provided by the (at least one) recess **26.** Poling was carried out under a D.C. electric field **21** between 2 and 3 kV/mm at a temperature of 100°C for 30 minutes. Subsequently, the first electrodes **23** were removed. So prepared piece **20** was placed between a pair of second electrodes **31** and **32** for exciting the vibration. The second electrodes **31** and **32** or the metal pieces **31** and **32** may be 5 mm in diameter and 7 mm in length and made of an iron-nickel-chromium alloy called "Elinvar."

TABLE 1

Shape of Piece **20**	Resonant Freq. F_o (kHz)	Capacitance Ratio r	Mech. Quality Factor Q_m
FIG. 5	77.87	18	570
FIG. 7	72.50	29	220
FIG. 9	67.51	19	170
FIG. 11	72.66	32	230

Table 1 shows the results obtained for thus manufactured piezoelectric ceramic resonators for the resonant frequencies F_o, the capacitance ratios r, and the mechanical quality factors Q_m. From Table 1, it is obvious that the piecoelectric ceramic resonators have moderately low resonant frequencies F_o, which is due to the fact that the torsional vibration has a relatively low propagation speed for sonic waves. It is also clear that the capacitance ratios r are sufficiently small and consequently that the piezoelectric activities are much improved. Furthermore, it is apparent that the piezoelectric ceramic resonator including the piezoelectric ceramic piece **20** of the shape depicted in FIG. **5** exhibits a remarkably high mechanical quality factor Q_m.

TABLE 2

a	b	Resonant Freq. F_o (kHz)	Capacitance Ratio r	Mech. Quality Factor Q_m
4	2	106.72	25	840
5	2	108.20	24	870
7	2	108.47	22	810
7	3	108.02	26	1050
7	4	105.23	23	830

Of a piezoelectric ceramic material whose electromechanical coupling coefficient K_r and mechanical quality factor Q_m in the radial mode were 64 percent and 900, respectively, piezoelectric ceramic pieces **20** were made into the configuration shown in FIG. **6.** Table 2 shows the resonant frequencies F_o, the capacitance ratios r, and the mechanical quality factors Q_m for the torsional vibration. The pieces **20** were 1 mm thick. The distance d between the parallel plane surfaces was 1.2 mm. Examples of the diameter of the piece a and the bore b are given in Table 2. The lengths of a pair of "Elinvar" pieces **31** and **32** were 6.4 mm and 4.0 mm, respectively.

Referring to FIGS. **12***a* and **12***b*, a mechanical filter includes a pair of transducers **61,** each having the piezoelectric ceramic piece **20,** and a plurality of metal pieces **62.** The transducers **61** and the metal pieces **62** are welded to a pair of supporting rods **63** and to several coupling rods **64.**

It will be obvious to those skilled in the art that the embodiment described above is meant to be merely exemplary and that the specific structure of the apparatus and steps of the method are susceptible of modification and variation without departing from the spirit and scope of the invention. Therefore, the invention is not deemed to be limited except as defined by the appended claims.

What is claimed is:

1. A ceramic resonator comprising a ferro-electric ceramic piece that is generally disc shaped having two parallel principal surfaces, a cylindrical peripheral surface joining said principal surfaces, and a pair of electrodes attached to said principal surfaces, respectively, said piece being poled along paths between and substantially parallel to said principal surfaces so as to adapt said resonator to the torsional mode of vibration with its principal surfaces moving in opposite directions, wherein the improvement comprises at least one recess extending inwardly from the circle defined by said peripheral surface, the face of said piece formed by said recess being substantially perpendicular to said principal surfaces.

2. A resonator as set forth in claim **1,** wherein there is only one recess and said face of said piece provided by said recess comprises two face portions, each portion forming a plane, said paths along which said piece is poled being arcuate and concentric with said peripheral surface.

3. A resonator as set forth in claim **1,** wherein the greatest distance between said two face portions is not more than 0.9 times the diameter of said peripheral surface.

4. A resonator as set forth in claim **2,** wherein said two face portions form a pair of substantially parallel planes, the distance between said planes, and the diameter of the piece being in the proportions 1.2, 2.0 and not more than 7.0, respectively.

5. A resonator as set forth in claim **1,** wherein said recesses are three in number and each face of said piece which forms a recess is substantially perpendicular to one of three radii of said disc, said three radii trisecting said disc and said paths along which said piece is poled being cordal with respect to the cylinder defined by said peripheral surface.

6. A resonator as set forth in claim **5,** wherein a further recess extends inwardly from each of said faces of

said piece starting in the vicinity of a line which is perpendicular to said principal surfaces and which substantially bisects the area of one of said faces.

7. A resonator as set forth in claim **1**, wherein said recesses are four in number and said faces of said piece formed by the respective recesses are substantially perpendicular to four radii of said disc which are in quadrature relation to one another.

8. A resonator as set forth in claim **7**, wherein a further recess extends inwardly from each of said four faces of said piece starting in the vicinity of a line which is perpendicular to a principal surface and which substantially bisects the area of one of said faces.

9. The resonator as set forth in claim **2**, wherein each face portion forms an angle of 0° to 90° with an intersecting radius of said disc.

10. The resonator as set forth in claim **1**, further comprising a substantially cylindrical bore centrally disposed in said disc, said recess extending into said bore.

11. A resonator as set forth in claim **10**, wherein the diameter of said bore is within a range between 0.2 and 0.9 times the diameter of said peripheral surface.

* * * * *