Sept. 5, 1950 F. MASSA 2,521,642

TRANSDUCER MEANS

Filed Nov. 29, 1945 4 Sheets-Sheet 1

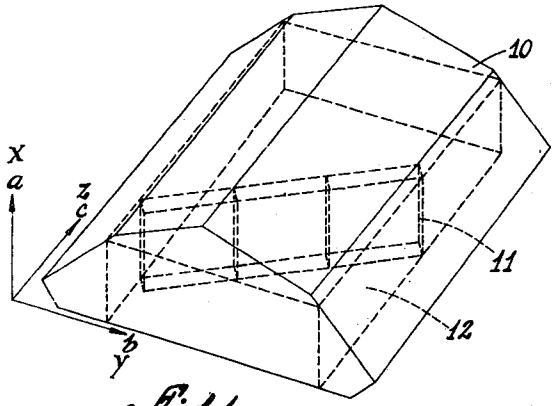


Fig 1.

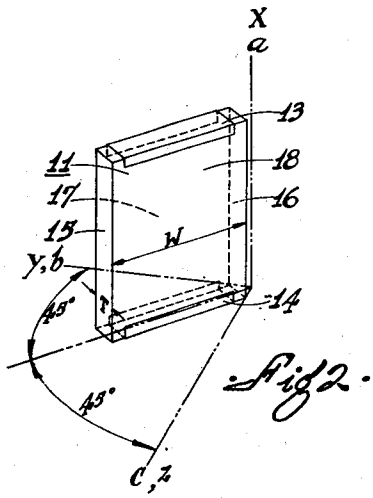


Fig 2.

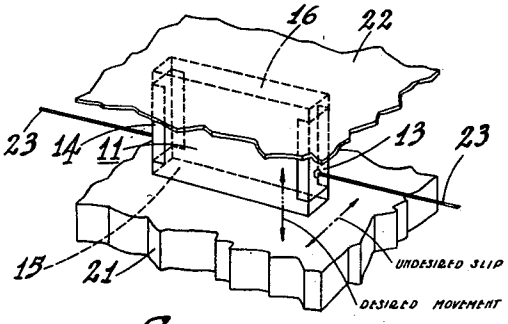


Fig 3.

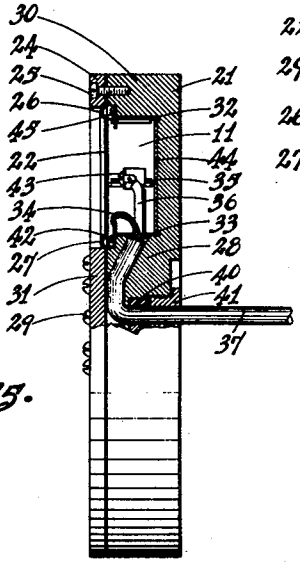


Fig 5.

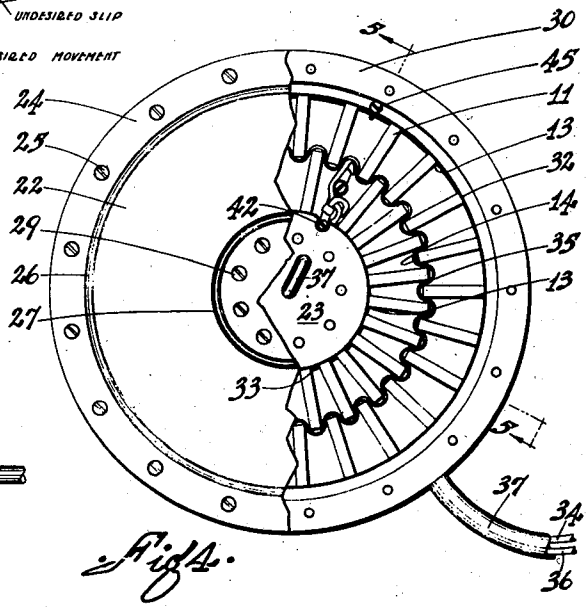


Fig 4.

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TRANSDUCER MEANS

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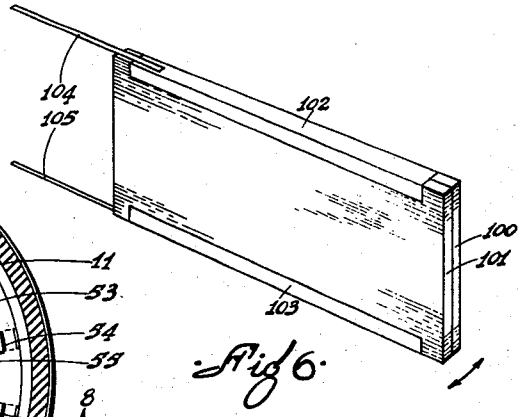


Fig 6.

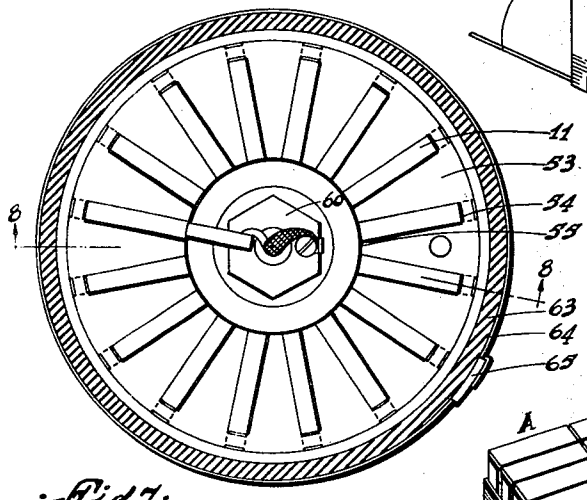


Fig 7.

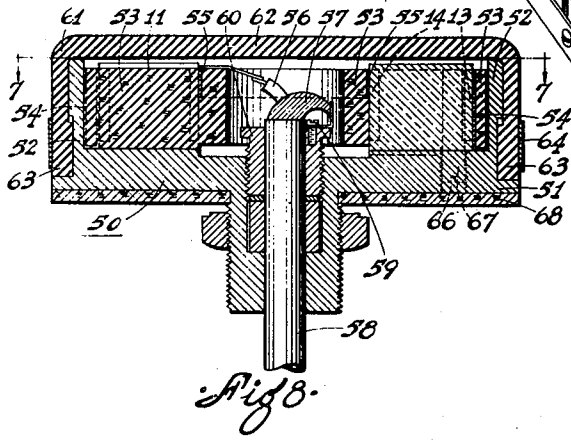


Fig 8.

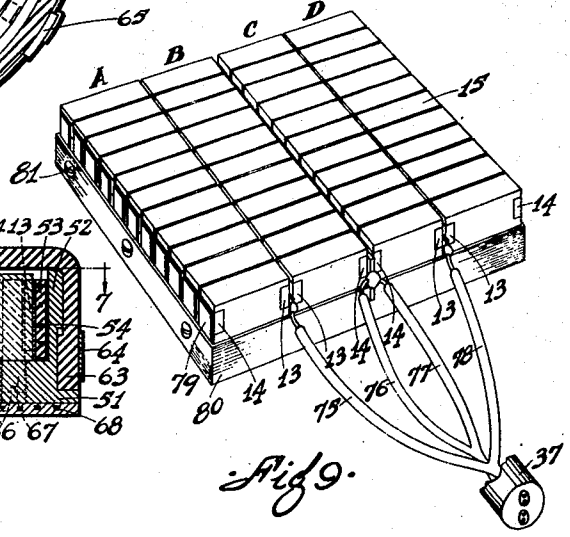


Fig 9.

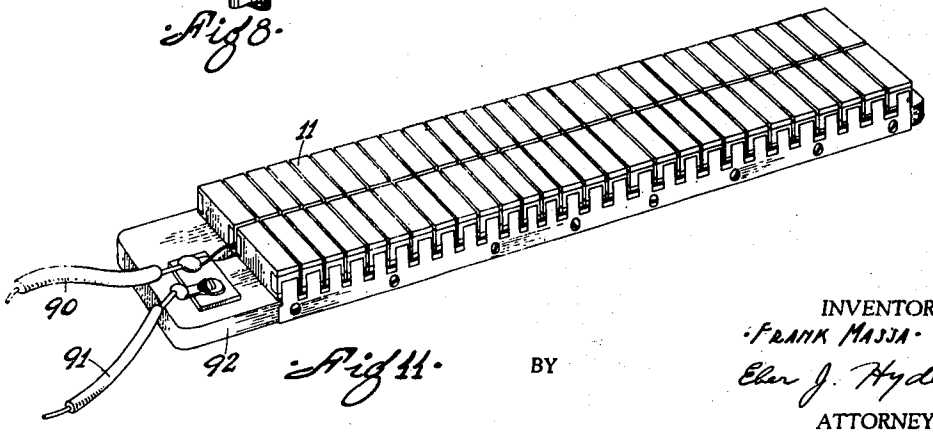


Fig 11.

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TRANSDUCER MEANS

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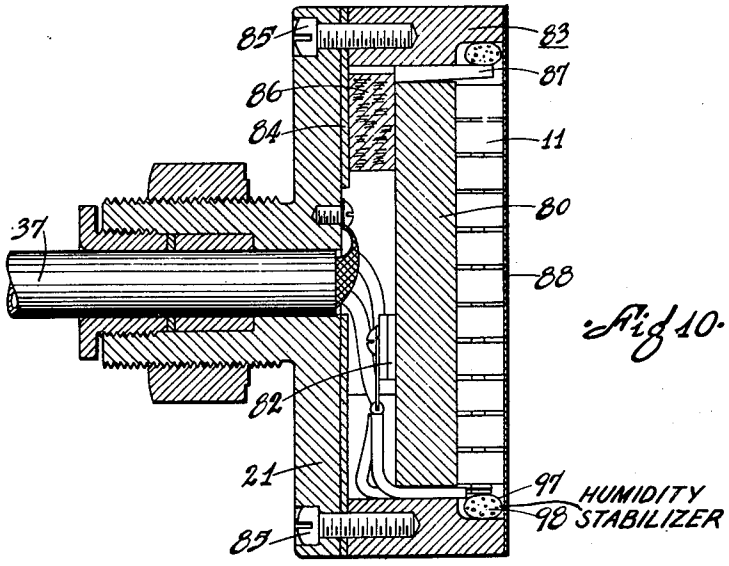


Fig 10.

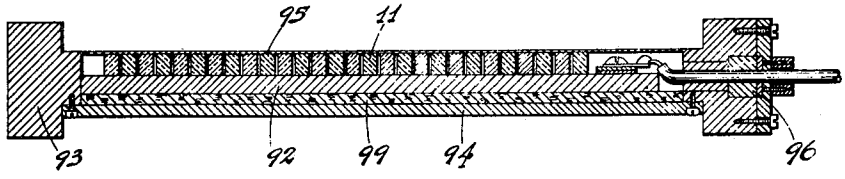


Fig 12.

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TRANSDUCER MEANS

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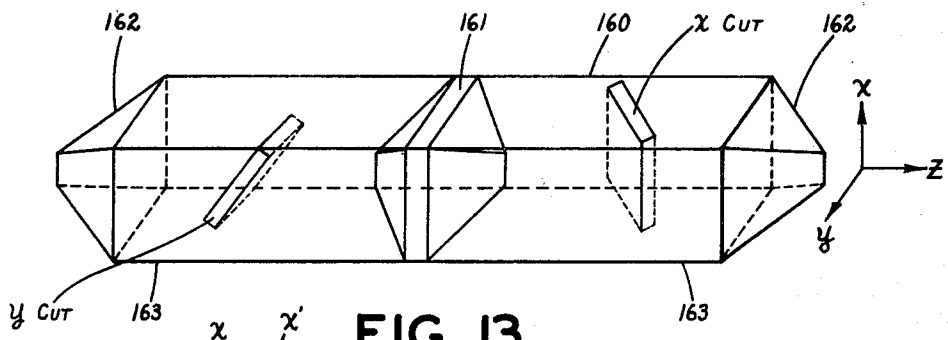


FIG. 13

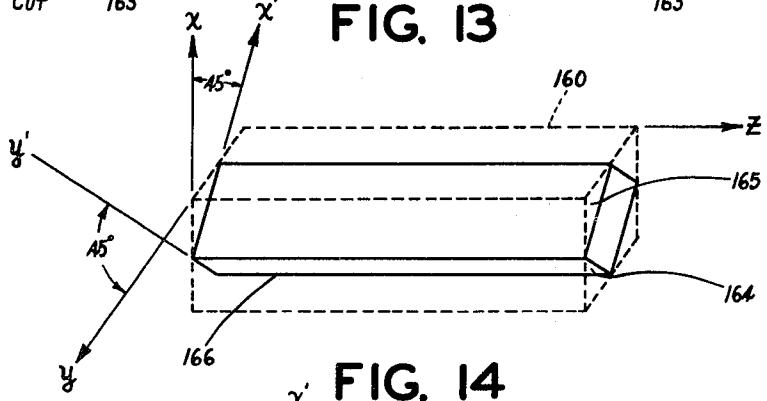


FIG. 14

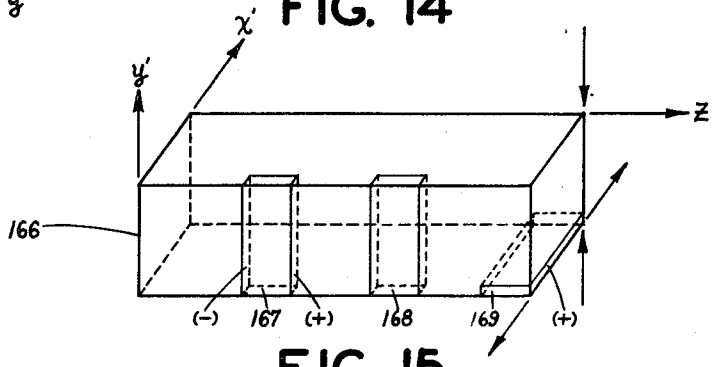


FIG. 15

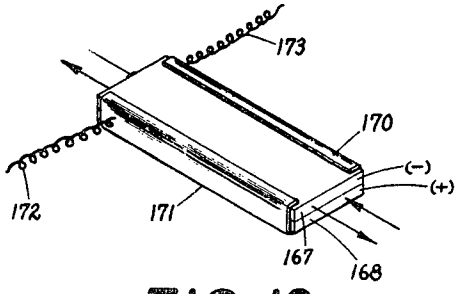


FIG. 16

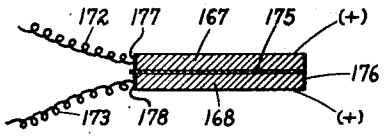


FIG. 17

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Patented Sept. 5, 1950

2,521,642

UNITED STATES PATENT OFFICE

2,521,642

TRANSDUCER MEANS

Frank Massa, Cleveland Heights, Ohio, assignor to The Brush Development Company, Cleveland, Ohio, a corporation of Ohio

Application November 29, 1945, Serial No. 631,667

3 Claims. (Cl. 177—386)

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My invention pertains to piezoelectric crystals of a particular orientation and dimension and their mounting in piezoelectric devices.

This invention is a continuation-in-part of Serial No. 431,429, now abandoned and is related to my copending application Serial No. 564,138, now Patent No. 2,451,966, which is a continuation-in-part of Serial No. 452,908, now abandoned.

Rochelle salt is an isomorphous substance belonging to the rhombic hemihedral class V of crystals and exhibits a piezoelectric effect when subject to an electric field in certain directions or when subject to mechanical pressure in certain directions. Other isomorphous substances belonging to the rhombic hemihedral class of crystals exhibit the piezoelectric effect and accordingly may be spoken of as Rochelle salt type crystals although they may not have the Rochelle salt chemical formula.

Rochelle salt type crystals have three orthogonal crystallographic axes sometimes called A, B and C and sometimes called X, Y and Z, and the smaller crystal elements which are cut from the larger virgin crystals may have different orientation with respect to the orthogonal axes and different dimensions along the axes to bring out various characteristics of the crystal material.

My invention is not restricted to the V class of crystals as it is also applicable to piezoelectric crystals in classes D_4, V_d, D_8, T and T_d; or, in other words, it is applicable to all piezoelectric crystal classes whose symmetry contains V as a sub-group.

My invention relates to a crystal element cut from a virgin crystal from any one of a limited number of crystal classes with a particular orientation and relative dimensions to effect, when mounted, a new result, and is illustrated in connection with a high frequency underwater energy radiator although it is not to be limited to speaker, high frequency, or underwater use.

An object of my invention is to provide a piezoelectric crystal device of greater efficiency.

Another object of my invention is to reduce heating due to friction between a piezoelectric crystal element and its supporting base.

A further object of my invention is to provide an electro-acoustic transducer primarily adapted for use in a liquid.

A further object of my invention is to reduce undesired modes of vibration in a restrained piezoelectric crystal element.

Still another object of my invention is to provide a more powerful and efficient high frequency speaker primarily adapted for operation in a heavy fluid.

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Another object of my invention is to provide a directional microphone.

Another object of my invention is to provide a directional speaker.

It is a further object of my invention to provide a speaker which is easily and economically assembled.

Other objects and a fuller understanding of my invention may be had by referring to the following specification and the accompanying drawings in which:

Figure 1 is an isometric view of a portion of a Rochelle salt-type crystal.

Figure 2 is an isometric view of a crystal element cut from the Rochelle salt-type crystal and showing the orientation with respect to the three crystallographic axes.

Figure 3 is a schematic drawing of one of my crystal elements between a base and a diaphragm and showing the directions of desired and undesired piezoelectric movement and their relation to the dimension of the element.

Figure 4 is a partially broken-away plan view of a speaker utilizing my new crystal element.

Figure 5 is a partially broken-away side view taken along line 5—5 of Figure 4.

Figure 6 is a multiplate flexing element made from my new crystal element.

Figure 7 is a sectional plan view of a form of my invention, and taken along line 7—7 of Fig. 8.

Figure 8 is a sectional view taken along lines 8—8 of Figure 7.

Figure 9 is an isometric view of a crystal subassembly of one form of my invention.

Figure 10 is a sectional view through the subassembly of Figure 9 after it has been mounted in its housing.

Figure 11 is an isometric view of a crystal subassembly of another form of my invention.

Figure 12 is a sectional view through the subassembly of Figure 11 after it has been mounted in its housing.

Figure 13 illustrates a typical crystal of class V_d and showing how plates may be cut from it.

Figure 14 shows a bar cut from the crystal of Figure 13.

Figure 15 shows the orientation and dimensional relationship of the new plates cut from the bar of Figure 14.

Figure 16 shows a multiplate flexing element comprised of the plates shown in Figure 15, and

Figure 17 is a cross-sectional view of a series connected multiplate flexing element.

Referring to the drawings Figure 1 is a perspective representation of a portion of a virgin crystal 10 of class V (Rochelle salt) showing the direction of the orthogonal crystallographic axes X, Y and Z, and showing in construction lines the orientation and approximate relative dimensions of a crystal slab 12 and a crystal element 11 which may be cut from the crystal 10. For most efficient production the size of the crystal element 11 may be such that substantially a whole number (such as 3 or 4) elements may be obtained from one cut at 45° across the slab 12.

Figure 2 illustrates the crystal element 11 as cut from the crystal 10 and after the electrodes 13 and 14 have been applied. The electrodes are applied to the only pair of crystal element faces which are perpendicular to the X orthogonal axis, and the dimension of the crystal element between the electrodes may be large compared to the other two dimensions of the element. It will be seen that each of the four unelectroded faces is at an angle of substantially 45 degrees to the Y and Z axes. The element, therefore, is an X-cut 45 degree element. The four unelectroded faces may be said to comprise two pair of faces, the first pair 15—16 being of small area, and the second pair 17—18 being of greater area. The dimensions of the element 11 may be such that it is long between the electrodes 13 and 14, and that its width is substantially greater than its thickness. For convenience the width and thickness are designated in Figure 2.

It is known that an alternating field applied to a 45 degree X-cut crystal produces stresses in two directions each substantially perpendicular to the direction of the application of the field (that is, perpendicular to the X-axis) and substantially perpendicular to each other. It is also known that relatively little or no stress is produced in the direction of the application of the field. Heretofore 45 degree X-cut crystals were made with a short dimension along the direction of the application of the field and with longer dimensions along two directions each substantially perpendicular to the direction of the field. For ordinary applications, stresses along the two longer dimensions caused no trouble. However, in high frequency speakers where one of the crystal faces having one of the longer stressed dimensions is in close frictional engagement with a substantially rigid base, the use of ordinary 45 degree X-cut crystals causes frictional heating between the crystal and the base. This heating sometimes is sufficient to impair the heat sensitive crystal element and causes undesired restraining forces to be applied to the crystal element thereby reducing its effectiveness.

Figure 3 diagrammatically illustrates the use of my crystal in association with a portion of a fixed base 21 and a portion of a diaphragm 22. The crystal element 11 is positioned between the base 21 and the diaphragm 22 in engagement with each, and with the electrodes 13 and 14 in electrical engagement with an electrical circuit 23 through which a signal current is adapted to flow. One direction of stress in the crystal element due to an electric field along the X-axis is substantially normal to the base 21 and to the diaphragm 22 and is indicated in Figure 3 as the direction of "Desired Movement." Another direction of stress in the crystal element due to an electric field along the X-axis, is substantially normal to the X-axis and to the first direction of stress, and is indicated in Figure 3 as the direction of "Undesired Slip." In the direction along

the X-axis there is relatively little movement due to the piezoelectric action of the element. The first motion is desired because it actuates the diaphragm 22 with respect to the base 21, and the second motion is undesired because it causes frictional heating between the crystal face 15 and the base 21 and between the crystal face 16 and the diaphragm 22. Further it causes undesired modes of vibration in the speaker.

In the description of Figure 3 the term "piezoelectric action" is used. This means that upon a charge of one polarity being applied to the electrodes of the plate, the plate expands in a first direction and contracts in a second direction; and that upon a charge of the opposite polarity being applied to the electrodes of the plate, the plate contracts in the first direction and expands in the second direction. Broadly speaking, therefore, it may mean a change in dimension due to an applied charge. The crystal action is also reversible. Upon the application of a strain between two surfaces to deform the crystal along a particular direction, there is developed a voltage across the electrodes. The term "piezoelectric action," therefore, may also mean the establishment of a charge due to change in the dimensions of a crystal.

It is in order to reduce this frictional heating and the undesired modes of vibration which accompany it that I cut and mount my crystal as disclosed. The crystal element 11 is cut from the virgin crystal 10 with such orientation and relative dimensions and mounted between the base 21 and the diaphragm 22 in such a position that expansion and contraction in the desired direction is relatively large and the expansion and contraction in the undesired direction is relatively small, thereby reducing to a minimum the amount of friction due to slippage between the crystal element face 15 and the fixed base 21, and between the crystal element face 16 and the diaphragm 22. The most effective manner of cutting the crystal is with a long dimension in a direction along the X-axis and with a short dimension in a direction at 90 degrees to the X-axis and at 45 degrees to the Y and Z axes. This establishes a pair of opposed crystal faces such as 15 and 16 which are of substantial area for contact with the base 21 and the diaphragm 22. The large area of those two faces may be defined by a long dimension and a short dimension, the long dimension being along the X orthogonal axis and therefore not subject to expansion and contraction due to the piezoelectric effect, and the short dimension being at 45 degrees to the Y and Z orthogonal axes and therefore subject to expansion and contraction due to the piezoelectric effect. However, due to the fact that the changeable dimension is very small the amplitude of movement due to the piezoelectric effect is relatively small and the frictional heat developed is not excessive.

An ordinary 45 degree X-cut crystal mounted between base 21 and diaphragm 22 would have faces defined by two changeable dimensions and the longer would be in contact with the base and the diaphragm. Operation of the device would result in relative movement between the crystal and the base 21 and between the crystal and the diaphragm 22, and the amplitude of movement would be large. This would establish several undesired modes of vibration in the crystal and would be apt to cause excessive heating. In the crystal of my invention the undesired modes of vibration are reduced and the frictional heating

is practically negligible. This is because the amplitude of movement between the crystal and the diaphragm or base has been reduced to a negligible amount. For some devices, particularly underwater speakers having a desired directional pattern, the ordinary 45 degree X-cut crystal is not satisfactory while the new crystal gives highly satisfactory results. Such devices are shown in Figures 4, 5, 7, 8, 9, 10, 11, and 12.

Figures 4 and 5 illustrate respectively a partially cut-away plan view and a partially cut-away side view of a loudspeaker adapted to operate under water and utilizing a plurality of crystals 11 according to my invention.

The loudspeaker comprises a base portion 21 having a raised edge portion 30 and a center portion 28. Between the edge 30 and the center 28 there are a plurality of crystals 11. The crystals may be arranged concentrically in an inner and an outer ring as illustrated in the cut-away portion of Figure 4, with one of the unelectroded narrow faces 15 or 16 in engagement with the base 21, and the other in engagement with a diaphragm 22. The diaphragm 22 is connected at its outside edge to the raised edge portion 30 of the base by means of a ring 24 and a plurality of screws 25. Gasket means may be used between the diaphragm 22 and the edge 30 to prevent the ingress of water into the speaker. The central portion of the diaphragm is connected to the raised central portion 28 of the base 21 by means of a block 31 and a plurality of screws 29. The width of the crystal units 11 is such that they fit tightly between the base 21 and the diaphram 22 and upon an alternating signal being applied to the crystals the diaphragm 22 is driven with respect to the base 21. In order that the effective or radiating area of the diaphragm may move as nearly like a piston as possible, two raised annuli are provided in the diaphragm. The outer annulus 26 is near the ring 24 and the inner annulus 27 is near the block 31.

A cable 37 is brought into the speaker through the base 21 at the raised central portion 28, and waterproof connection means comprised of packing 40 and a nut 41 are provided for effecting a waterproof seal around the cable 37. The cable contains two leads 34 and 36. The lead 34 is connected to the central portion 28 of the base 21 by means of screw 42, and the lead 36 is connected to a central conductor spring 35 by means of a screw 43. The central conductor spring 35 is woven between the ends of the crystals in the inner and outer concentric circles of crystals and makes electrical contact with each of the electrodes 14. An insulating mat 44 is positioned against the inside surface of the base 21 and prevents the conductor spring 35 from making an electrical contact with the speaker housing. The mat 44 is cut away to allow the crystals 11 to extend through it and directly engage the base 21. Accordingly, there is no compressible material between the crystals 11 and the base 21. An inside conductor spring 33 is provided in electrical engagement with the lead 34 through the screw 42, and in electrical engagement with the electrodes 13 of the outer circle of crystals 11 through an outer conductor spring 32 and a screw 45 which connects the spring 32 to the base 21. The inside surface of the housing is coated with an insulating paint or lacquer to prevent undesired circuits. Accordingly, connections are made by means of screws threaded into the housing; such as screw 45 which effects an electrical contact between spring 32 and the base 21, and the screw 42 which effects an electrical contact between base 21 and the lead 34. The electrical path is, therefore, from the lead 34 to screw 42 where it splits into two paths, the first path being to the housing 21, to the screw 45, to the conductor spring 32, to the electrodes 13 of the outside circle of crystals, and then to the crystals; the second path is from the screw 42 to the inside conductor spring 33, to the electrodes 13 of the inside circle of crystals 11, and then to the crystals. The electrical path from lead 36 is to the screw 43, to the central conductor spring 35, to the electrodes 14 of both rings of crystals and then to the crystals. An alternating voltage on the circuit through the crystals causes the crystals to expand and contract and drive the diaphragm 22 with respect to the base 21. Due to the orientation of the faces of the crystals there will be substantially no movement of the crystals in a direction between the electrodes 13 and 14, but there will be a slight movement due to the piezoelectric effect in a direction substantially normal to the large faces 17 and 18 of the crystals. Due to the dimensions and orientation of the crystal unit with respect to the virgin crystal from which it was cut. the amplitude of movement of the portions of the crystal units which are in engagement with the diaphragm 22 or the base 21 will be very small. This results in very little heating due to friction, and materially reduces undesired modes of vibration compared to the modes present when standard 45 degree X-cut crystals are used.

Figures 7 and 8 illustrate another form of my invention in which a plurality of crystal units 11 are placed in a single circle in a metal housing 50. The housing has a base portion 51 to which one of the faces 15 and 16 is connected, and has an upstanding peripheral edge portion 52. Positioned within the upstanding circular edge portion 52 and with its bottom side against the base 51 of the housing 50 is a composition spider 53 which has a plurality of slots into which the plurality of crystal units 11 fit. The spider material should possess a relatively low bulk modulus of elasticity as compared to Rochelle salt crystal and may be made of sponge-rubber, cork, a combination of rubber and cork, or of some of the synthetic rubbers. It should not deteriorate in oil and should be slightly compressible. The crystal units 11 are positioned in the slots in the spider with their electrodes 13 toward the outside of the circular speaker, and with their electrodes 14 toward the inside of the speaker. Each of the electrodes 13 engages one leg of a substantially U-shaped contactor clip 54, and the other leg of the clip 54 engages the upstanding edge portion 52 of the housing 50 thereby making an electrical contact from the crystal electrode 13 to the housing 50. A contactor clip 54 is provided for each of the crystal units 11. The electrode 14 of each crystal unit 11 is in electrical contact with a single conductor strip 55 which fits in a slot in the spider 53, and the conductor strip 55 is connected to a lead 56. The housing 50, which is connected to the electrodes 13 of the crystal units, is electrically connected to a lead 57 by means of a screw 59, thereby establishing an electrical circuit through each of the crystal units 11. The leads 56 and 57 are encased into a cable 58 and are brought out of the housing 50. Waterproof connection means comprising packing and a threaded nut 60 are provided to prevent water from entering the speaker. A cover 61 made of a fairly thick rubber having a specific acoustic

resistance substantially equal to that of water is provided for the speaker, and comprises a top portion 62 and downwardly extending edge portions 63. The downwardly extending edge portions 63 are adapted to fit outside of the upwardly extending edge portions 52 of the housing 50, and a metal band 64 presses the edge of the cover against the edge of the housing. A clip 65 is provided to anchor the ends of the band 64 after it has been drawn tight. This prevents the ingress of water into the speaker. After the speaker has been assembled and all of the connections made water tight, the air is evacuated from the enclosure through the outlet 66, after which oil having a specific acoustic resistance substantially equal to that of water is sucked into the inside of the speaker through the threaded opening 66. Castor oil is one type of oil which may be used. With the cover 61 of the speaker in a downward position and the threaded opening 66 in an upward position, the process of evacuating the air from the speaker and filling with castor oil is continued until all of the space is completely filled with castor oil. During the filling of the unit with castor oil, the cover 61 is allowed to bulge slightly outward, and while the cover is held in this bulging position, a threaded plug 67 is screwed into the threaded opening 66 to effect a seal. The partial vacuum on the outside of the cover 61 may then be released leaving a slight pressure inside the speaker. When an alternating signal is applied through leads 56 and 57 to the electrodes 14 and 13 of the crystal units 11, the units expand and contract due to the piezoelectric effect in a first direction which is substantially normal to the base 51. Due to this expansion and contraction of the crystal units 11, an alternating pressure is established in the oil in the speaker, above and below the normal pressure. This alternating pressure in the oil is transmitted through the cover 61 into the fluid outside of the cover. These alternating pressures represent the signal to be transmitted. The piezoelectric effect also causes a contraction and expansion of the crystal units 11 in a second direction which is substantially normal to the large faces of the crystals. This contraction and expansion in the second direction is complementary to the expansion and contraction in the first direction and except for the presence of the spider 53 against the large faces of the crystal units would substantially cancel out the desired changes in the pressure in the oil. However, due to the presence of the spider against the large faces of the crystal units 11, the movement of the large faces in the second direction is taken up in the material of the spider and accordingly does not materially affect the signal presures sent out by the speaker. Each of the speaker devices illustrated may also be used as a high frequency directional microphone as the piezoelectric effect is reversible. The microphone illustrated in Figures 4, 5, 7 and 8 would have a symmetrical polar directional characteristic, and the microphone illustrated in Figure 12 would have a "fan shaped" directional characteristic. That is, it would be broadly directional along its length, and would be sharply directional across its width.

As is shown in Figure 8, a layer of cork or air filled rubber 68 may be connected to the base 51 of the housing to improve the directional characteristics of the device.

Figures 9 and 10 illustrate a form of my invention in which a plurality of my new crystals are connected in parallel. The row A and the row B of crystals are connected in parallel between the leads 75 and 76, and the row C and the row D of crystals are connected in parallel between leads 77 and 78. Leads 76 and 77 are then connected as one common lead. Each of the crystals 11 has an electrode 13 and an electrode 14. The electrodes 13 of rows A and B are electrically connected to lead 75 and the electrodes 13 of rows C and D are electrically connected to lead 78. Leads 75 and 78 are connected together at terminal block 82 (Fig. 10). The electrodes 14 of rows A and D are in electrical contact with the base 80 through a plurality of connected fingers 79 and screws 81, and the electrodes 14 of rows B and C are in electrical contact with leads 76 and 77 respectively. Lead 76 is connected to lead 77 at terminal block 82. A housing 83 is provided into which the base 80 and the crystals 11 are mounted. The housing comprises a base portion 21 and waterproof cable connection means (somewhat similar to those of Figure 8) through which a cable 37 enters the housing. A gasket 84 and screws 85 are provided for effecting a waterproof seal between the base 21 and the side walls of the housing. A sheet of packing material 86 such as cork or the like is positioned between the gasket 84 and the base 80 of the crystal assembly, and a plurality of wedges 87 are provided between the crystal assembly and the walls of the housing. A diaphragm 88 of metal or other suitable material is connected to the housing 83 to effect a waterproof seal.

The preferred form of assembling the device is to sweat-solder or otherwise affix the diaphragm 88 to the side walls of the housing 83 before the base 21 is connected. A crystal sub-assembly consisting of crystals 11 cemented to the base 80 is provided and all of the crystal faces which are to be against the diaphragm 88 are in one plane. Cement is then applied to each of the crystal faces which is to be in contact with the diaphragm 88. The sub-assembly is then positioned between the side walls of the housing 83 with the cement covered crystal facing against the diaphragm 88. Wedges 87 hold the sub-assembly in place. The packing 86 and the gasket 84 are put into the housing and then the base 21 is screwed tightly to the sidewalls of housing. This assures that the crystals 11 will be in good driving engagement with the diaphragm 88. Leads 75 and 78 which were connected together are also brought out through cable 37, and leads 76 and 77 which were connected together are also brought out through cable 37. A flexible tube 97 containing a humidity stabilizing chemical such as silica gel 98 may be positioned in the speaker to regulate the humidity therein during variations in temperature within the sealed housing.

Figures 11 and 12 illustrate another form of my invention in which a plurality of crystals 11 are connected in parallel across leads 90 and 91, and are cemented to a base 92 to establish a sub-assembly. The sub-assembly is mounted in a housing 93 between a base 94 and a diaphragm 95, and the leads are brought out through waterproof connection means 96 in the housing. Packing 99 is positioned between the sub-assembly base 92 and the base 94. This establishes a long thin speaker having desired directional characteristics, and in which all of the individual crystals 11 are connected in parallel.

Figure 6 illustrates a multiplate flexing element made of two plates of piezoelectric crystal. The two plates 100 and 101 are cemented or otherwise

held together and electrodes 102 and 103 are applied to their thin edges. Leads 104 and 105 are provided for connecting the crystal element into a circuit. Upon a voltage of alternating potential being applied to the electrodes 102 and 103 with the lead end anchored, the multiplate crystal will bend according to the arrow. For a detailed description of a somewhat similar multiplate flexing action, reference may be had to the Patent Re. 20,213 issued to Charles B. Sawyer.

The action of my multiplate flexing element differs from the Sawyer element in that it has a simple bending action whereas the Sawyer element has a compound bending action. The Sawyer element, in exaggerated terms, may be said to assume a saddle shape whereas my element bends substantially in only one direction. Accordingly, less internal restraint to operation is evidenced by my crystal unit. As in the Sawyer unit, my construction to a large extent reduces variations in the specific piezoelectric effect incident to variations in temperature and incident to variations in the level of applied energy. Throughout parts of this description the term "multiplate flexing" has been used to characterize the composite unit. This term includes constructions wherein two or more plates are connected together, and also includes utilizing a non-piezoelectric plate with one or more piezoelectric plates.

Figures 13 to 15 illustrate the cutting of plates from a crystal of class V_d in accordance with my invention, and Figures 16 and 17 illustrate multiplate flexing elements made in accordance with my invention.

The crystal 160 illustrated in Figure 13 may be called a P-type crystal, and the term "P-type" crystal is to be understood as including primary ammonium phosphate ($NH_4H_2PO_4$), primary potassium phosphate, primary rubidium phosphate, the primary arsenates of ammonium, potassium, and rubidium, isomorphous mixtures of any of these named compounds, and all other piezoelectrically active crystalline materials isomorphous therewith. In Wyckoff's The Structure of Crystals (2nd ed., N. Y. 1931) this crystal type is called the KH_2PO_4-type; and in the Strukturbericht (Supplement to Zeitschrift fuer Kristallography) this crystal is called the H–2–2 type.

Reference character 161 in Figure 13 indicates the seed portion of the mother crystal, and the reference character 162 indicates the pyramidal end portions which are characteristic of this crystal class. Between the seed portion 161 and each pyramidal end portion lies a prismatic bar portion 163 which may be cut out of the mother crystal 160.

To provide an X-cut plate the prismatic bar 163 first is cut at an angle of 45 degrees to the X and Y axes to remove the edges of the bar to establish the edge faces 164 and 165 perpendicular to the X' and Y' axes respectively; the X' and Y' axes being rotated 45 degrees about the Z-axis with respect to the X and Y axes. This is illustrated in Figure 14 where the prismatic bar 163 is shown by dotted lines and the expander bar which is obtained by so cutting the prismatic bar 163 is shown in solid lines and is indicated by the reference character 166. The second step is shown by Figure 15 where the bar 166 (enlarged in its cross-sectional dimensions to better show the small expander plates 167, 168, and 169 which may be cut therefrom) is cut parallel to its edge faces to provide small crystal plates 167, 168, and 169. The arrows at the right-hand end of the bar 166 indicate the directions of change of dimension in the bar 166 and in the plates 167, 168, and 169 due to an electrical field of a given polarity being applied along the Z-axis of the crystalline material, or, in other words, applied between the end faces of the bar 160. For an electrical field of the opposite polarity the directions of the arrows would reverse.

Plates 167, 168, 169, have in common the characteristics that they are thin in one of the directions of piezoelectric expansion and contraction and they have one of their larger dimensions in a direction parallel to the Z or electrical axis of the crystalline material. This dimension of the plate which is parallel to the Z-axis of the crystalline material does not change due to the direct piezoelectric action.

The plates 167, 168, and 169 when connected together to form a multiplate flexing unit must be so oriented that for a given field between the electrodes, such as electrodes 170, 171 in Figure 16, one plate tends to expand in a direction parallel to the plane of the connecting faces while the other plate tends to contract in a direction parallel to the plane of the connecting faces. The unit will then bend about only one axis of curvature; the other direction of expansion and contraction in the plates being normal to the plane of the connecting faces. Thus, for a parallel connected element, if we consider the right-hand edges of the plates 167, 168, 169 as positive (+) for a given exciting electrical field and the left-hand edges negative (—), then any two of the plates should be put together with a negative edge above a positive edge, as shown by the (—) and (+) signs associated with the plates in Figure 16. Leads 172, 173 may be provided connected to the electrodes 170, 171 for connecting the unit in an electric circuit.

Figure 17 is a cross-sectional view on an enlarged scale, of any two of the plates 167, 168, 169 put together in a manner to form a series connected multiplate flexing element. In this construction the two plates, for example 167 and 168, should be put together with a positive edge of one plate adjacent the positive edge of the other plate. Between the two plates there is an insulator 175, and an electrode 176 common to both plates 167, 168 is provided at one edge face of the unit. The insulator 175 should be as stiff to lateral shear forces as possible and each of the piezoelectric plates should be firmly connected to the insulator. An electrode 177 is connected to the other edge face of the plate 167 and an electrode 178 is connected to the other edge face of the plate 168. These electrodes 177, 178 are separated from each other by an insulator. I prefer to extend the insulator 175 so that it lies between the electrodes 177, 178. Leads 172, 173 may be connected to the electrodes 177, 178 for connecting the unit in an electric circuit.

The electrical axis of the crystalline material in a piezoelectric plate is parallel to the direction along which the electrical field is impressed to produce changes in dimensions of the plate in two mutually perpendicular directions which are both perpendicular to the electrical axis. This is true whether the plate is an X, Y, or Z-cut plate.

Throughout the specification and claims I have said that there is no change in dimension of the crystal plate in a direction along the electrical axis due to the piezoelectric effect. There may, however, be mechanical stresses occurring in such single and multiplate piezoelectric units which cause a certain amount of motion parallel to the electrical field direction. This motion is a secondary effect due to the elastic coupling of

different stress and strain components of the crystal. For example, in a 45 degree X-cut Rochelle salt plate which is long in its X-axis dimension in accordance with my invention and which is long in its length dimension, the plate might be operated in the region of the lengthwise extensional resonant frequency. Such a plate will show cross contraction stresses not only in the thickness direction but also along the X-axis direction. In the case of a multiplate unit a change in dimension parallel to the X-axis direction will occur to some extent for frequencies well below the resonant range. This is due to the cross-contraction effect of an external stress set up by extensional and compressional stresses parallel to the length dimension which the two plates comprising the multiplate unit exert on each other. These cross-contraction effects are secondary effects, being caused by mechanical coupling to a direct piezoelectric effect, and therefore are not considered to be directly due to the piezoelectric action.

A convenient method of electroding the edge faces of thin crystal plates is to stack a number of them with their major faces together and then to gold plate the opposite edge faces which are in a plane perpendicular to the Z-axis thereof. Thus, each plate acts as a mask for the adjacent plate or plates to prevent gold from being deposited on the major faces. Other substances than gold obviously may be used, and the standard tin or silver foils may be used. Gold foil is also satisfactory.

Although I have described my invention with a certain degree of particularity, it is to be understood that the present disclosure has been made only by way of example and that numerous changes in the details of construction and the combination and arrangement of parts may be resorted to without departing from the spirit and the scope of the invention as hereinafter claimed.

I claim as my invention:

1. A transducer comprising a base plate having a raised edge portion and a raised center portion, a plurality of expander piezoelectric crystal elements positioned against said base plate between said raised edge portion and said raised center portion, diaphragm means positioned against said crystal elements and connected to the said raised edge and center portions of said base plate, and means for impressing an alternating electric field on said crystal elements to cause said crystal elements to expand and contract thereby driving said diaphragm with respect to said base plate.

2. A transducer comprising a base plate having a raised edge portion and a raised center portion, a plurality of expander piezoelectric crystal elements positioned against said base plate between said raised edge portion and said raised center portion, diaphragm means positioned against said crystal elements and connected to said raised edge and center portions of said base plate, a pair of lead means for impressing an alternating electric field on said crystal elements to cause said crystal elements to expand and contract thereby driving said diaphragm with respect to said base plate, one of said lead means being connected to said base plate and the other being electrically connected to said plurality of crystals to establish a parallel electrical connection.

3. A transducer comprising, in combination, a base having a raised edge portion and a raised center portion, a plurality of expander crystal elements each having two electrodes and radially positioned against said base between said raised edge portion and said raised center portion and forming a first and a second ring of crystals, said first ring of crystals being positioned to cause one of the said electrodes of some of the plurality of crystals to be adjacent said raised center portion and said second ring of crystals being positioned to cause one of the said electrodes of some of the plurality of crystals to be adjacent said raised edge portion, lead means in engagement with the electrode means which are adjacent the raised edge and center portions, spring lead means in engagement with the other electrode means, said spring lead means biasing the first ring of crystals toward the raised center portion and biasing the second ring of crystals toward the raised edge portion to keep all of said electrodes in engagement with either said lead means or said spring lead means, diaphragm means connected to said base and in engagement with said crystal means, and circuit means connected to said lead means.

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