

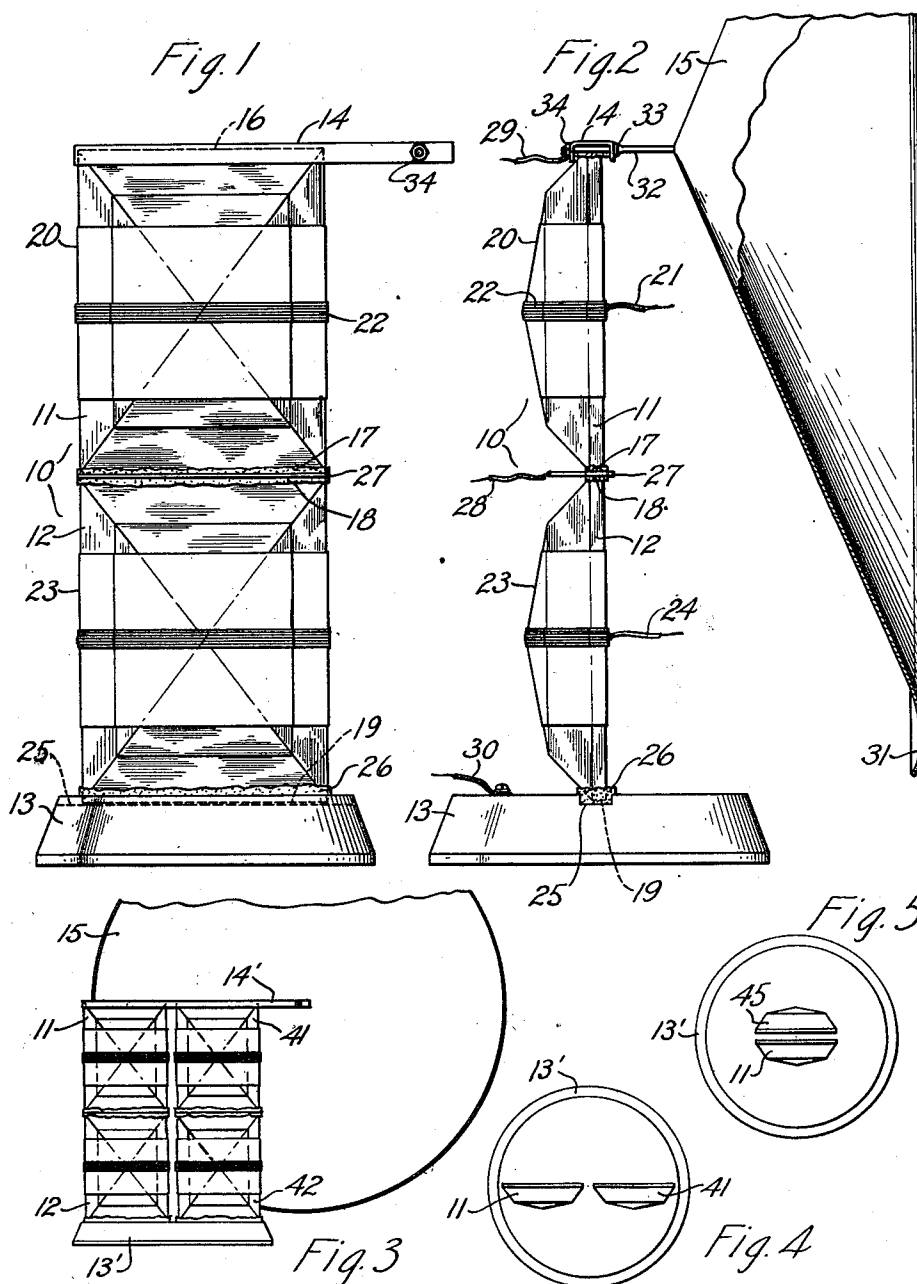
Jan. 10, 1928.

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A. Mc L. NICOLSON

PIEZO ELECTRIC DEVICE

Original Filed Feb. 28, 1923 2 Sheets-Sheet 1



Inventor:
Alexander M. Nicolson,
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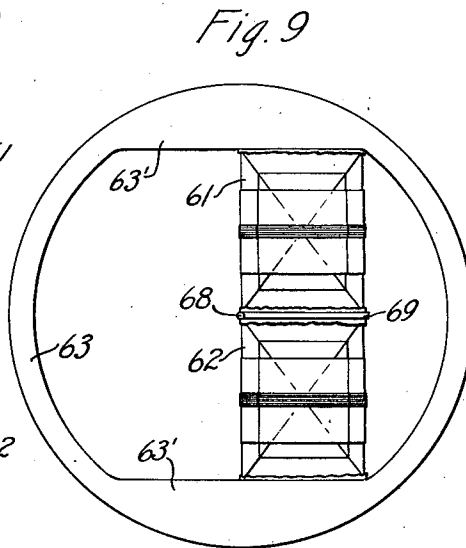
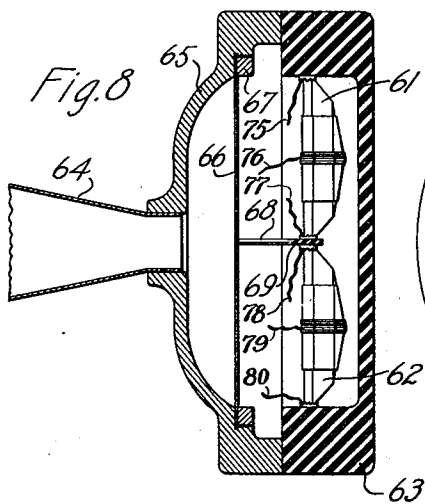
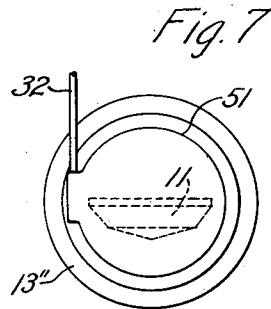
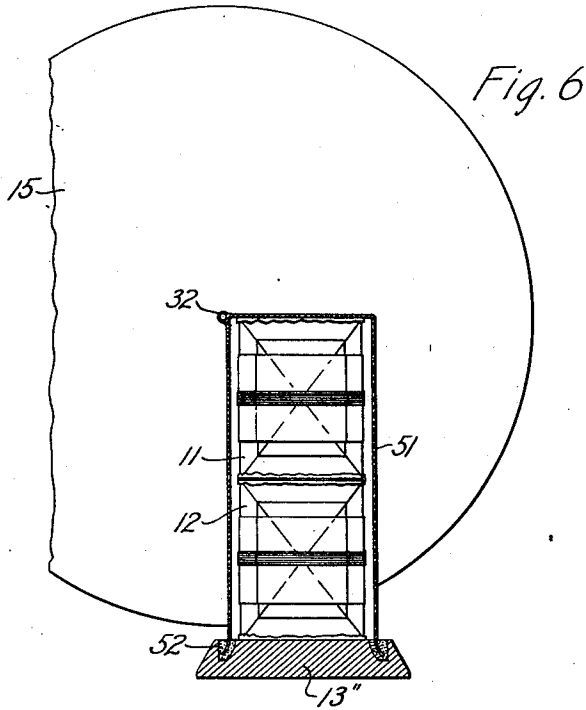
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PIEZO ELECTRIC DEVICE

Original Filed Feb. 28, 1923 2 Sheets-Sheet 2



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UNITED STATES PATENT OFFICE.

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PIEZO-ELECTRIC DEVICE.

Application filed February 28, 1923, Serial No. 621,704. Renewed March 19, 1927.

This invention relates to transforming one form of energy into another where one of the forms of energy is the energy of electric current waves, and especially where the other form of energy is the energy of sound waves.

An object of the invention is an efficient means for accomplishing such transformations, either of electrical energy to mechanical energy or vice versa, and especially an efficient piezo-electric loud speaking telephone receiver.

In accordance with the invention a piezo-electric structure and a diaphragm or the like are so associated that elastic strains of the structure will be accompanied by motion of the diaphragm. Elastic vibrations may be set up in the piezo-electric structure by the application thereto of electric forces, for example forces due to voice currents. The piezo-electric structure may be formed of crystals so arranged that the displacements in a plurality of the crystals are integrated for application to the diaphragm, or so arranged that the stress exerted on the diaphragm by a plurality of the crystals is the summation of the stresses exerted by the individual ones of these crystals, or so arranged that both the displacements and the stresses are thus integrated. The diaphragm may be so associated with the crystal structure as to be operated by twisting of the structure, which is preferably attached to a base having an inertia large in comparison to the resistance that the diaphragm offers to being vibrated, so that the vibrations of the crystal structure are efficiently transmitted to the diaphragm. The instrument is reversible as regards its functioning, so that if the diaphragm be vibrated by forces external to the instrument, for instance by forces due to sound waves in air, the crystal structure will generate electromotive force waves corresponding to the vibrations of the diaphragm.

Fig. 1 is a front view of a form of the invention employing but two crystals, with the diaphragm removed; Fig. 2 is a side elevation of this form of the invention, with the diaphragm partly broken away; Fig. 3 is a front view of a form of the invention employing two pairs of crystals; Fig. 4 is a diagrammatic plan view indicating the arrangement of the two pairs of crystals in the structure of Fig. 3; Fig. 5 is a similar dia-

grammatic plan view indicating a different arrangement of crystals; Fig. 6 is a front view of a modification of the structure of Fig. 1 employing a closed container for the crystals, the diaphragm being partly broken away; Fig. 7 is a plan view of the form of the invention shown in Fig. 6, with the diaphragm removed; Fig. 8 is a sectional elevation of a form of the invention employing a watch case form of mounting for the crystals; and Fig. 9 is a front view of Fig. 8, with the diaphragm and the horn removed.

Referring especially to Figs. 1 and 2, a piezo-electric structure 10 is formed of two crystals 11 and 12, one secured on top of the other, the structure being attached to a base 13. A channel bar 14 secured to the top of the crystal 11 carries a diaphragm 15. The crystals 11 and 12 are preferably sodium potassium tartrate crystals made in the form described in my article on the piezo-electric effect in the composite rochelle salt crystal, published in the Proceedings of the American Institute of Electrical Engineers, November, 1919, and by the process described in my Patent No. 1,438,965, December 19, 1922, piezo-electric devices and methods of producing the same.

As pointed out in the A. I. E. E. article just referred to, each crystal has two end poles or poles of like sign, the basal planes perpendicular to the principal axis, i. e., the C axis, of the crystal—and has an equatorial or girdle pole of the opposite sign orthogonal thereto comprising the remaining faces of the crystal. As the crystals are shown in Figs. 1 and 2, their C axes coincide and are vertical. Thus, 16 is the upper basal plane of crystal 11, 17 is the lower basal plane of crystal 11, 18 is the upper basal plane of crystal 12, and 19 is the lower basal plane of crystal 12. The vertical faces of the crystal 11 are electrically connected together by a girdle electrode 20 which may be a strip of tinfoil wrapped about a crystal to form a loop or band having as its axis the principal axis of the crystal. A lead 21 is brought from the girdle electrode 20, the drawing showing one end, 22, of lead 21 wrapped several times around the girdle electrode 20. Similarly, the vertical faces of crystal 12 are electrically connected together by a girdle electrode 23, from which is brought a lead 24.

The base 13 is shown as circular, and may

be, for instance, of cast iron, preferably grooved as shown at 25, to receive the lower end of crystal 12. The crystal is secured in the groove preferably by cement 26, made, if desired, by melting crystalline sodium potassium tartrate. The fused mass may be allowed to cool below the fusion temperature without immediate setting, but when thus supercooled will quickly set upon agitation, such for instance as that incident to its application to the surfaces which are to be joined. Similarly, the upper end of crystal 11 is cemented in the channel bar 14. The basal plane 17 is cemented to the upper side, and the basal plane 18 to the lower side, of an electrode 27 which may be in the form of a metal plate, or preferably in the form of a wire grid since the cement, filling the meshes of the grid, then holds very securely.

A lead 28 is brought off from electrode 27, and leads 29 and 30 are brought off from the channel bar 14 and the base 13 respectively, the channel bar, as well as the base, being of electrically conducting material, such for instance as a suitable metal. The diaphragm 15 is preferably conical and of fibrous material such, for example, as paper, with the periphery of the diaphragm free but turned back to form an annular groove as at 31. This turned back periphery assists the diaphragm to maintain its shape when the reaction of the air tends to strain it. The apex of the diaphragm is secured to the channel bar 14 by means of a short rod 32 having a shoulder 33 which abuts against one side of the bar 14, the rod carrying a nut 34 which screws against the other side of bar 14. The shorter the part of the rod 32 between the shoulder 33 and the apex of the diaphragm, the less will be its inertia and its maximum deformation, and therefore the better will be the operation of the device.

In the operation of the device as a loud-speaking receiver it is ordinarily preferable to connect leads 21 and 24 to one pole and leads 28 and 29 and 30 to the other pole of the source (not shown) of the electromotive force waves which are to be faithfully reproduced as sound waves. This source may be, for example, a vacuum tube amplifier fed from a telephone transmitter circuit. Upon the application of the electromotive force to the crystals, each crystal undergoes vibrations about its principal axis, and the angular displacement which the bar 14 undergoes is equal to the sum of the angular displacement of the upper basal plane of crystal 11 with respect to the lower basal plane of that crystal and the angular displacement of the upper basal plane of crystal 12 with respect to the lower basal plane of that crystal. The vibration of the bar 14 causes the apex of the diaphragm to vibrate in the direction of the axis of the cone

formed by the diaphragm, so that the diaphragm is set in vibration and causes in the surrounding medium, for example the air, elastic vibrations of the frequency of the electromotive force waves applied to the crystals. If one of the crystals be disconnected from the source, the volume of sound produced by the diaphragm will be decreased; providing the voltage applied to the other crystal remains the same; for the angular displacement of the bar 14 can not then exceed the angular displacement between the basal planes of the crystal to which voltage is applied. One crystal may be effectively disconnected from the source by disconnecting lead 21 or lead 24 from the source. Since the impedance of each crystal is high, the impedance of the source, such as a vacuum tube amplifier, will often be more nearly equal to the impedance of the two crystals in parallel than to the impedance of a single crystal, or than to the impedance of two crystals connected in series. Moreover, when the two crystals are connected in parallel the full voltage delivered by the source is, of course, applied to each crystal, and further, it is not necessary to insulate the basal planes of one crystal from those of the other, since they may all be at the same potential.

The mass of the base 13 should be sufficiently great to insure that when the crystal structure 10 undergoes elastic vibrations due to the application of varying currents thereto, the lower surface of the crystal 12 will remain firmly anchored and the displacement of any part of the crystal structure 10 will be proportional to the distance of that part from the lower end of the structure, the displacement of the top end of the structure being a maximum. For, even though the mass of the diaphragm be small, the reaction of the air or other surrounding medium, when the diaphragm vibrates, tends to anchor the diaphragm and the top of the crystal structure and cause the displacement of the crystal structure about its axis to be greater at the lower end of the axis than at the upper end, and if the mass of the base 13 be inadequate to overcome this tendency, the base rather than the diaphragm will vibrate, and the efficiency with which the elastic vibrations of the crystal are transmitted to the air will thus be reduced. The lighter the crystal structure the more important it is that the base be heavy, if the reaction of the diaphragm against the crystal structure, and other factors, remain the same.

The loud speaking receiver may be used as a transmitter by applying sound waves to the diaphragm and taking off corresponding currents from the positive and negative poles of the crystal structure.

Figs. 3 and 4 show a loud speaker similar in construction to that of Fig. 1, except that

in Figs. 3 and 4 the crystal structure comprises four crystals 11, 12, 41 and 42 instead of merely the crystals 11 and 12. The crystals 41 and 42 form a pair fastened together and to the base 13' and the channel bar 14' just as the crystals 11 and 12 are fastened together and to the base and the channel bar in Fig. 1 or in Fig. 3. Preferably the four crystals are all connected in parallel, that is, with the four girdle or equatorial poles of the crystals electrically connected to one pole of the source (not shown) and all of the basal planes of the crystals connected to the other pole of the source. The crystals 11 and 12 act, as in Figs. 1 and 2, to give to the bar carrying the diaphragm angular displacement larger than either crystal alone would give it. The crystals 41 and 42 act similarly to the crystals 11 and 12, each pair of crystals tending to turn the bar 14' in the same direction as the other pair. Inasmuch as the upper basal planes of crystals 11 and 41 are rigidly united by means of the bar 14' and since the equatorial poles of both these crystals are charged synchronously from the same source of electromotive force, the rotational displacement of bar 14' will correspond to the summation of the torsional forces exerted by the base of crystal sets 11, 12 and 41, 42. The force exerted on the bar 14' is therefore the resultant of the torsional forces exerted by the two pairs of crystals, and consequently is greater than the force that would be exerted by either pair alone. By omitting from circuit any desired crystal or crystals, the amplitude of vibration of the bar 14', and the volume of the sound produced by diaphragm 15, can be correspondingly reduced. The device of Figs. 3 and 4 has the frequency range of its maximum responsiveness lower than has the device of Figs. 1 and 2, since the radius of gyration of the crystal structure of Figs. 3 and 4 is larger than that of the crystal structure of Figs. 1 and 2. However, the frequency range of maximum responsiveness may be different for each of the four crystals in Fig. 3, so that the quality of the sound produced by the device may be altered by disconnecting any desired one or ones of the crystals from circuit. It is pointed out here that, in Figs. 3 and 4, even when only one crystal is connected in circuit the frequency of maximum response of the loud speaker is affected by the presence of the other three crystals, both because of the resistance which they offer to being strained and because of their inertia. Further, the effects, from the natural frequency of the loud speaker, of this resistance and this inertia will depend upon the relative position of the crystals.

Instead of mounting two pairs of crystals on the same diameter of the base, as in Figs. 3 and 4, one pair may be mounted to one side of a diameter and the other pair to the

other side, as in Fig. 5, in which 11 and 45 are intended to indicate either two single crystals mounted back to back, or two pairs or stacks of crystals with the pairs or stack mounted back to back. It is not necessary that the number of crystals in each stack be the same, but it is convenient to have the stacks equal in height so that the bar which carries the diaphragm 15 as shown in Fig. 3 may fit onto the tops of both of the stacks. Each stack will tend to give the bar an angular displacement dependent upon the height of the stack, and the force exerted upon the bar by the two stacks will be the summation of the forces exerted by the individual stacks, and consequently will be greater than the force that either stack alone would exert. Because of the shape of the crystals, where the stacks are placed back to back the channel bar which carries the diaphragm 15 as shown in Figs. 1 to 4 can be narrower than if the stacks were orientated in the same way or were placed face to face.

Figs. 6 and 7 show a modification of the loud speaker of Figs. 1 and 2, in that the crystal structure comprising crystal 11 and 12 is mounted in a container which comprises a cylinder 51 closed at the top and a base 13'' similar to base 13 but grooved as shown at 52 to receive the lower edge of the cylinder. The crystal structure is preferably cemented to the base and to the top of the cylinder with cement. In assembling the crystal structure in the container, the crystal structure is cemented to the top of the cylinder 51, the groove 52 is filled with cement, cement is placed on the base where the bottom of the crystal structure is to rest, and the cylinder and the crystal structure are then pressed downwardly onto the base, and the cement at the bottom and at the top of the crystal structure allowed to set. Of course, before the cylinder has been cemented to the base, leads 21 and 24 (see Fig. 2), for connecting the girdle poles of crystals 11 and 12 to the source of current for the loud-speaker, should be brought out from the container, and the lead 28 (see Fig. 2), for applying potential to the lower basal plane of crystal 11 and the upper basal plane of crystal 12, should be connected either to the cylinder 51, which is preferably of metal a few thousandths of an inch thick, or to the base. The electrical conductivity of the cement in groove 52 preferably should be sufficient for establishing electrical connection between the cylinder and the base. The leads 21 and 24 may unite before passing through the envelope of the container, so that only one lead need be brought through the envelope, and that lead should be insulated from the envelope, and should be sealed in the envelope so that the container will be air tight in order to better protect

the crystals from change in humidity or other conditions of the air outside of the container. The electrical connection between the basal planes of the crystals 11, 12 and a pole of the source which supplies the currents for operating the loud speaker may be made at any part of the cylinder 51 or the base 13".

The diaphragm 15 is attached to the top of the cylinder 51 with the axis of the diaphragm perpendicular to that radius of the cylinder top which passes through the point of attachment, so that twisting of the cylinder will cause the apex of the diaphragm to move in the direction of the axis of the diaphragm. The means for attaching the diaphragm to the cylinder top may be, for instance, like that used to fasten the diaphragm to the bar 14 in Figs. 1 and 2.

In the operation of the device of Figs. 6 and 7 as a loud speaker, when an alternating electromotive force is applied to the crystals the crystal structure undergoes elastic vibratory twisting, and the cylinder 51 is thus caused to undergo elastic vibratory twisting about its longitudinal axis. This twisting of the cylinder causes the apex of the diaphragm 15 to vibrate in the direction of the axis of the diaphragm, and consequently the diaphragm produces sound waves corresponding to the electromotive force waves applied to the crystals.

In order to improve the electrical connection between the pole faces of the crystals employed in the loud-speakers described herein and the conducting surfaces or electrodes in contact therewith, these pole faces are preferably coated with graphite.

Where the cement referred to above is made from sodium potassium tartrate in the manner indicated, the cement after it has set, is preferably moistened with any liquid containing graphite or other conducting material where this can conveniently be done, by impregnating or painting the cement joints, in order to improve the electrical conductivity of the cement. The liquid applied to the surface will be absorbed by the cement and will permeate it.

Figs. 8 and 9 show a form of loud speaker wherein the crystals 61 and 62 of the type referred to above are secured end to end, after the fashion in which crystals 11 and 12 are secured end to end in Figs. 1 and 2, but with their adjacent basal planes electrically insulated from each other by a strip of insulation 69 such for instance as bakelite. The electrodes on these basal planes are preferably of grid form, for example wire mesh, as described above, so that the basal planes may be cemented to the strip 69 with an electrode between each basal plane and the strip 69. This crystal structure comprising the crystals 61 and 62 is mounted in a watch-case form of container comprising the bowl

shaped member 63 and the cap or cover 65 attached thereto by any suitable means (not shown). The cap 65 carries a horn 64 and a disc shaped diaphragm 66 which is clamped at its edges between a clamping ring 67 and a shoulder on the cap. The member 63 consists of a disc shaped part and a ring or flange extending to one side of the periphery thereof and coaxial with the disc shaped part. This ring shaped part is thickened, in the manner indicated at 63', at opposite ends of a diameter, so that the interior surface of the ring at each of these thickened parts is a plane surface containing a chord of the ring, these two plane surfaces being parallel. One end of the crystal structure comprising crystals 61 and 62 is cemented to one of these plane surfaces and the other end of the crystal structure is cemented to the other plane surface, each end of the crystal structure being provided with an electrode of grid form as described above interposed between the crystal structure and the ring, which is of insulating material, such, for example, as bakelite. In cementing the crystal structure in the member 63, the structure is preferably located to one side of the center of the ring shaped part of member 63, so that one end of the insulating strip 69 will be at the center of this ring shaped part. This end of the insulating strip is connected to the center of the diaphragm 66 by means of a rod 68, so that elastic vibratory twisting of the crystals will cause the center of the diaphragm to vibrate in the direction of the axis of the diaphragm. The diaphragm, the horn, the cap 65 and the clamping ring 67 may be of any suitable materials, and although Figs. 8 and 9 show a disc diaphragm and a horn for transmitting elastic vibrations of the crystal structure to the air, it is clear that other means, for example a diaphragm of the form shown in the other figures of the drawing, may be used instead.

With the form of the invention shown in Figs. 8 and 9, the crystals, although connected in parallel, are preferably oppositely connected electrically, in circuit. That is, one pole of the source of currents for operating the loud speaker should be connected to the girdle pole of one crystal and to the basal planes of the other crystal; and the other pole of the source should be connected to the other girdle pole and the other basal planes. The wire connections to the crystals are indicated at 75, 76, 77, 78, 79 and 80.

In the operation of this form of the invention as a loud speaker the electromotive force waves from the source when applied to the crystals, cause each crystal to undergo elastic vibratory twisting with respect to the principal axis of the crystals, and since one end of each crystal is anchored to the member 63 the other ends of the crystals undergo angular displacements, both crystals

tending to turn the strip 69 in the same direction about the principal axis of the crystals. Therefore, the strip 69 vibrates about this axis, and causes the center of the diaphragm 66 to vibrate in the direction of the axis of the diaphragm. It should be noted that the torques, rather than the displacements, due to the vibrating crystals are integrated for vibrating the diaphragm.

The diaphragms shown in Figs. 1 to 7 are intended to represent any suitable means for transmitting the elastic vibrations of the crystals to the air or other surrounding medium, and although the conical diaphragm is the preferred means, it is clear that other forms, for example, the form shown in Figs. 8 and 9, may be used. Although the invention has been set forth with especial reference to its application to telephonic reception, it is applicable in various other fields, as for instance in the generation of electric currents in response to elastic deformation of piezo-electric bodies.

The invention is of course not limited to the materials specifically mentioned above, and, moreover, it will be obvious that the general principles herein disclosed may be embodied in many organizations widely different from those illustrated without departing from the spirit of the invention as defined in the appended claims.

Certain broad features disclosed herein are claimed in application Serial No. 227,802, filed April 10, 1918, (now Patent No. 1,495,439, May 27, 1924) entitled Piezophony, and in application Serial No. 295,967, filed May 9, 1919, (now Patent No. 1,525,823, Feb. 10, 1925) entitled Piezo-electric transmitter, and my application Serial No. 740,746, filed September 30, 1924, entitled Cement composition and method of preparation, claims a cement made from sodium potassium tartrate, and the process of making the cement.

The invention claimed is:

1. In combination, a piezo-electric structure, means comprising a diaphragm for transmitting elastic vibrations between said structure and a surrounding medium capable of propagating elastic vibrations, said means being so associated with said structure that said structure is capable of vibrating said diaphragm, and means associated with said structure for opposing the forces exerted by said diaphragm upon said structure when said diaphragm is undergoing vibrations.

2. A telephone instrument comprising two means, one a crystalline structure and the other a diaphragm so associated with said structure that vibrations of either of said two means will be transmitted to the other, and non-yielding means attached to said structure for reacting against elastic vibrations of said structure.

3. In combination, a diaphragm subject to

vibration in a ponderable medium capable of transmitting elastic vibrations, and means comprising an elastic piezo-electric structure connected to said diaphragm in such manner as to be capable of causing a portion of said diaphragm at which said means is connected to vibrate in response to vibration of said structure, said means having a mass sufficiently large to insure that the forces transmitted between said diaphragm and said means when said diaphragm is undergoing said vibrations in said medium will have no material effect in determining what part of said means vibrates with the greatest displacement.

4. A telephone receiver comprising a piezo-electric structure, means for setting up elastic vibrations in said structure, a diaphragm for producing sound waves arranged to be vibrated by said structure, and non-yielding reaction means attached to said structure for reflecting vibrations of said structure and said diaphragm and causing the elastic vibrations of said structure to be efficiently transmitted to said diaphragm.

5. In combination, a diaphragm subject to vibration in a ponderable medium capable of transmitting elastic vibrations and a piezo-electric crystalline structure attached to a heavy base, said diaphragm being so associated with said structure that said structure is capable of vibrating said diaphragm in response to vibration of said structure, the mass of said base being sufficient to insure that the forces transmitted between said diaphragm and said structure when said diaphragm is undergoing said vibrations in said medium will not cause said base to be moved as a whole.

6. In a loud speaking telephone receiver, a piezo-electric structure comprising a sodium potassium tartrate crystalline body, means responsive to electric currents for causing said structure to undergo elastic vibratory twisting, a conical diaphragm for transmitting said elastic vibrations of said structure to the surrounding air, a connection between said structure and the apex of said diaphragm for moving said apex in the direction of the axis of said diaphragm in response to said vibratory twisting of said structure, and a base to which said structure is rigidly connected, said base having sufficient inertia to insure that the elastic vibrations of said structure are efficiently transmitted to said diaphragm.

7. A piezo-electric crystalline body, an airtight container therefor, a conical diaphragm and means comprising said container connecting said body to the apex of said diaphragm in such manner that elastic vibratory twisting of said body is capable of producing vibrations of said apex in the direction of the axis of said diaphragm.

8. A piezo-electric structure, a fibrous dia-

phragm free at its periphery and subject to vibrations in a ponderable medium capable of transmitting elastic vibrations, said diaphragm and said structure being so connected that vibrations of one will be transmitted to the other, and a mass so attached to said structure and having such inertia as to render said structure capable of efficiently transmitting elastic vibrations of said structure to said diaphragm in said medium.

9. A piezo-electric structure comprising a plurality of crystalline bodies, and means for causing elastic strain of said structure, said crystalline bodies being so arranged that the accompanying strains of said bodies are physically integrated.

10. A piezo-electric structure comprising a plurality of crystalline bodies, and means for causing elastic strain of said structure, said crystalline bodies being so arranged that the accompanying strains of certain of said bodies are physically integrated and the accompanying stresses of certain of said bodies are physically integrated.

11. A piezo-electric structure comprising two crystalline sodium potassium tartrate bodies each having a principal axis and faces in which said axis terminates, and means for securing said crystals together with two of said faces in opposing relation.

12. A piezo-electric structure comprising a plurality of crystalline bodies and a diaphragm so associated with said structure that elastic vibratory twisting of said structure is capable of causing vibration of said diaphragm in the direction of the axis of said diaphragm, said crystalline bodies being so arranged that the twisting stress exerted upon said structure by said diaphragm when said diaphragm vibrates is transmitted to said bodies.

13. A piezo-electric structure comprising a plurality of sodium potassium tartrate crystalline bodies each having a principal axis and faces in which said axis terminates, and means for securing said crystals together in such manner that two of said faces are in opposing relation and two of said axes are in alignment.

14. A loud-speaking telephone receiver comprising two sodium potassium tartrate crystals placed end to end, and a diaphragm attached to the free end of one of said crystals.

15. A piezo-electric structure comprising a plurality of crystalline bodies, and means for causing elastic vibratory twisting of each of said bodies with respect to a crystal axis of said body, said bodies being so arranged that the accompanying twisting strains of said bodies are physically integrated.

16. A telephone instrument comprising two means, one of said means comprising a piezo-electric crystalline structure and the other of said means comprising a diaphragm

and being so associated with said structure that vibrations of either of said two means will be transmitted to the other, and a support to which said structure is rigidly attached, the mass of said support being sufficient to enable elastic vibrations of said structure to be efficiently transmitted to said other means, and the reaction opposed by said other means to being vibrated in response to elastic vibrations of said structure being of such magnitude that said elastic vibrations of said structure could not be efficiently transmitted to said other means in the absence of sufficient inertia in said support.

17. In combination, a piezo-electric crystalline structure, means comprising a diaphragm for transmitting elastic vibrations between said structure and a surrounding medium capable of transmitting elastic vibrations, said means being so associated with said structure that said structure is capable of vibrating said diaphragm in the direction of the axis of said diaphragm in response to vibratory twisting of said structure, and a base to which said structure is rigidly attached, said base reacting against elastic vibrations of said structure.

18. In combination, a piezo-electric structure, means capable of setting up elastic twisting vibrations in said structure in response to varying electric currents, means comprising a diaphragm for transmitting elastic vibrations between said structure and a surrounding medium capable of propagating elastic vibrations, said last mentioned means being so associated with said structure that said structure is capable of vibrating said diaphragm in the direction of the axis of said diaphragm in response to said elastic twisting vibrations of said structure, and means associated with said structure for opposing the twisting forces exerted by said diaphragm upon said structure when said diaphragm is undergoing vibration in the direction of the axis of the diaphragm.

19. In combination, a diaphragm subject to vibration in a ponderable medium capable of transmitting elastic vibrations, and means comprising an elastic piezo-electric structure connected to said diaphragm in such manner as to be capable of causing a portion of said diaphragm at which said means is connected to vibrate in the direction of the axis of said diaphragm in response to elastic vibratory twisting of said structure, said means having a mass sufficiently large to insure that the forces transmitted between said diaphragm and said means when said diaphragm is undergoing said vibrations in said medium will have no material effect in determining what part of said means vibrates with the greatest displacement.

20. In combination, a diaphragm subject to vibration in a ponderable medium capable

of transmitting elastic vibrations, and a piezo-electric crystalline structure attached to a heavy base, said diaphragm being so associated with said structure that said structure is capable of vibrating said diaphragm in the direction of the axis of said diaphragm in response to elastic vibratory twisting of said structure, the mass of said base being sufficient to insure that the forces transmitted between said diaphragm and said structure when said diaphragm is undergoing said vibrations in said medium will not cause said base to be moved as a whole.

21. A piezo-electric structure, a diaphragm comprising a conical member for transmitting vibrations corresponding to sound waves, and means connecting said diaphragm

to said structure for transmitting said vibrations between said diaphragm and said structure.

22. A telephone instrument comprising two means, one of said means comprising a piezo-electric crystalline structure and the other of said means comprising a diaphragm so associated with said structure that vibrations of either of said two means will be transmitted to the other, and a base to which said structure is rigidly attached, said base reacting against elastic vibrations of said structure.

In witness whereof, I hereunto subscribe my name this 27th day of February, A. D. 1923.

ALEXANDER McL. NICOLSON.