July 22, 1958 L. BATCHELDER 2,844,809

COMPRESSIONAL WAVE TRANSDUCERS

Filed Jan. 5, 1955 2 Sheets-Sheet 1

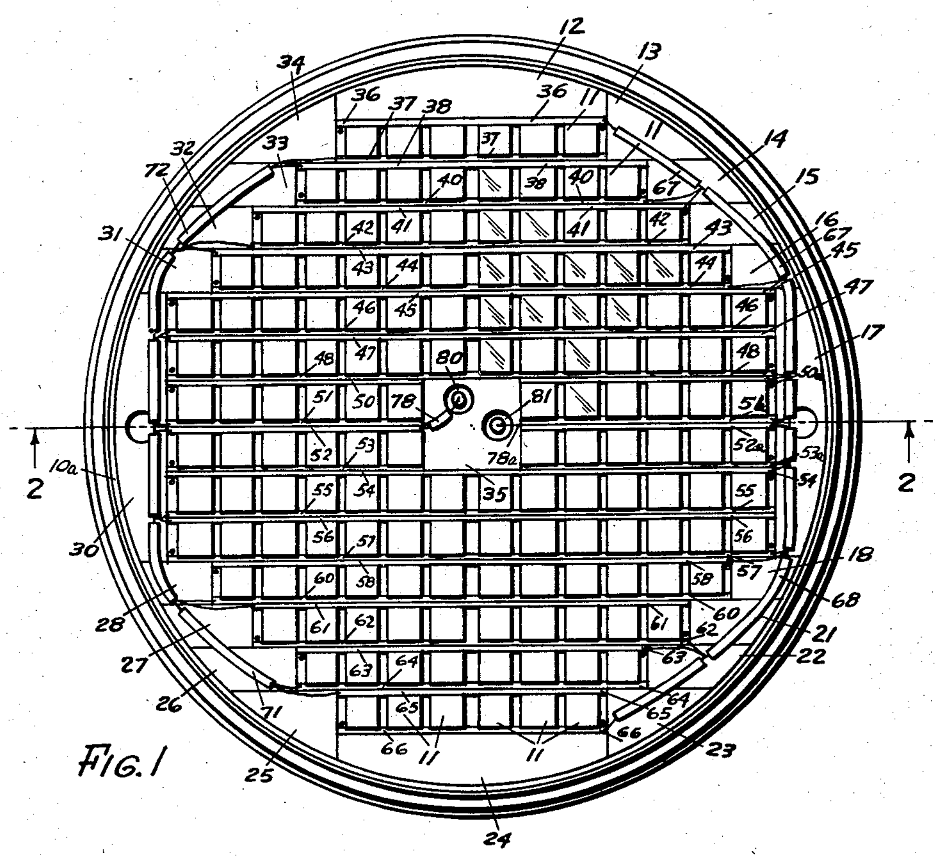

FIG. 1

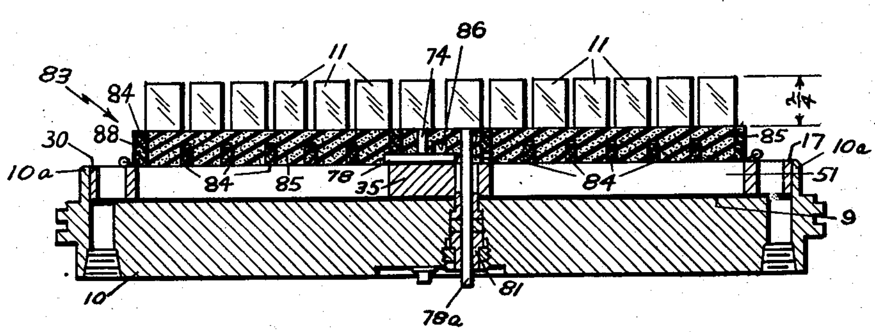

FIG. 2

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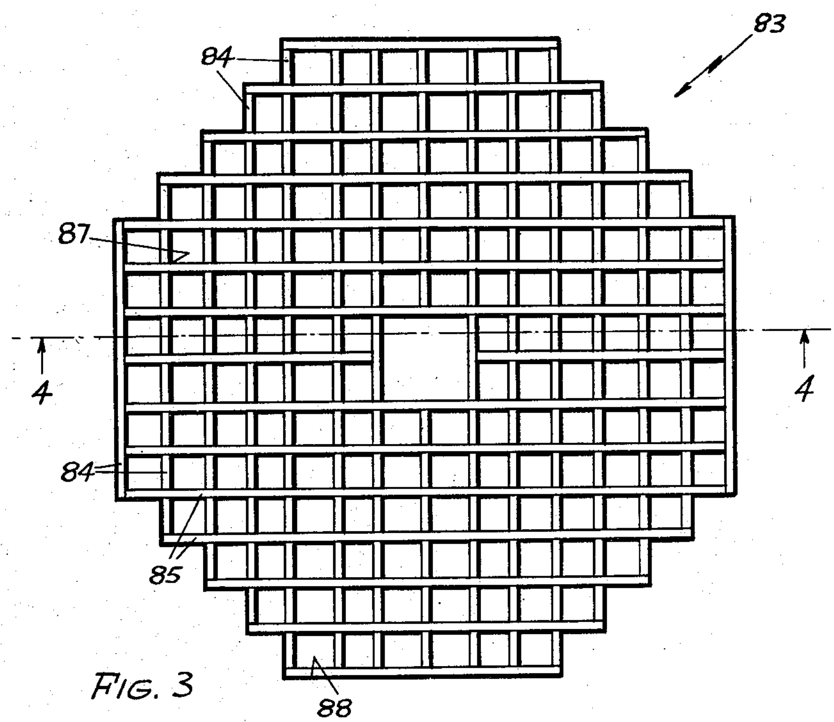
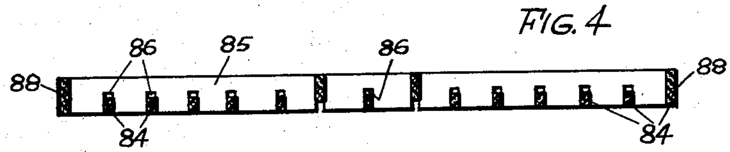


FIG. 3

FIG. 4



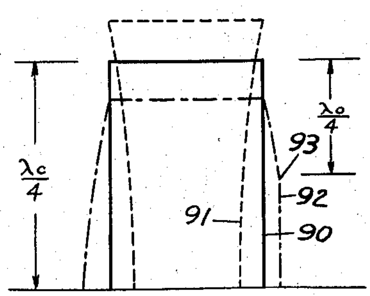


FIG. 5

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COMPRESSIONAL WAVE TRANSDUCERS

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Application January 5, 1955, Serial No. 479,907

9 Claims. (Cl. 340—10)

This invention relates to compressional wave transducers and more particularly to transducers of the general type disclosed in applicant's U. S. Patent No. 2,408,028, issued September 24, 1946.

In general, in such transducers, a plurality of piezoelectric crystal elements, or electrostrictive ceramic elements, are mounted on a metal plate from which they are separated by a sheet of insulating material. Hereinafter the word "crystal" is used for brevity, but, whenever used, it is understood to include also ceramic elements, such as barium titanate, which have a suitable electroacoustic transducing property. The crystals are arranged with their long axes facing outward from the plate. Electrodes are applied to opposing faces of the crystals to produce an electrical field in a direction at right angles to the long axes. The array of crystals is covered by such a material as rubber or other material that has the same transmission characteristics for compressional wave energy as sea water, and filled with a liquid, such as castor oil, that also has these characteristics, and the array is mounted in an opening in the hull of the vessel in which it is to be used. When an alternating E. M. F. is impressed on the electrodes, the crystals respond by alternately expanding and contacting along their longitudinal axis. This motion causes the primary radiation of compressional waves from the outer faces of the crystals which lie in a common plane. At the same time that the long dimension of the crystals is increasing or decreasing, the other dimensions of each crystal are decreasing or increasing, respectively, to a somewhat lesser degree in accordance with Poisson's ratio. This motion causes radiation of compressional waves into the narrow spaces between the crystal blocks. The oil which fills these spaces can respond only by flowing in and out of the narrow crevices, and a large viscous dissipation of energy accompanies such restricted flow. One object of this invention is to provide an electroacoustic transducer of increased efficiency by effecting a substantial reduction in the amount of energy lost by viscous dissipation in such crevices.

The primary radiation arises at the end faces of the individual crystal blocks, each of which vibrates forth and back like a piston. It is well known that a piston radiates sound most effectively when it is surrounded by a stiff baffle. The baffle serves to increase the resistive loading and decrease the reactive loading which the medium imposes on the piston. The increased resistive loading permits an improved match of the radiation impedance to the mechanical impedance of the crystal vibrators, with consequent increase in the projector efficiency. Ideally, the baffle should be infinitely stiff. For a loudspeaker designed to radiate into air, the ideal stiffness of the baffle is approximated by any solid material, such as wood. The acoustic impedance of sea water or other liquid is so much higher than that of air that no material, even metal, is sufficiently stiff to constitute an ideal baffle for an underwater sound projector. A second object of this invention is accomplished by providing each crystal block with a fictitious baffle which approaches the ideal of infinite stiffness. This fictitious baffle is produced by inserting a compliant reflector grid of foam rubber, or a mixture of cork and neoprene.

The electroacoustic transducer of this invention behaves in a reciprocal fashion and obeys substantially the electroacoustic reciprocity principle, which may be stated as follows: The quotient of the magnitude of the ratio of the open-circuit voltage at the output terminals (or short-circuit current) of the transducer, when used as a sound receiver, to the free-field sound pressure referred to an arbitrarily selected reference point on or near the transducer, divided by the magnitude of the ratio of the sound pressure apparent at a distance from the reference point to the current flowing at the input terminals (or the voltage applied at the input terminals), when used as a sound emitter, is a constant independent of the type or constructional details of the transducer.

In consequence of the reciprocity principle, any improvement in the transmitting response of the transducer when used as a projector inevitably produces a proportional improvement in the receiving response when the same transducer is used to convert acoustic signals to electrical signals. Therefore, it is to be understood that this invention, which is described above with respect to the transmission and reception of compressional waves, has the same advantages and objectives when the transducer is used for the reception of compressional waves.

Other and further advantages of the invention will be apparent as the description thereof progresses, reference being had to the accompanying drawings wherein:

Fig. 1 is a plan view of a transducer array without the pressure relieving structure;

Fig. 2 is a section along the line 2—2 of Fig. 1 with the pressure relieving baffle added;

Fig. 3 is a plan view of the pressure relieving baffle;

Fig. 4 is a section along the line 4—4 of Fig. 3; and

Fig. 5 is a diagram of the motion of a single crystal block greatly exaggerated.

In Figs. 1 and 2, the transducer comprises an insulating disc **9** backed by a plate **10**, and to which are attached piezoelectric crystals **11**, which are held in position within an annular flange **10*a*** formed on the plate **10** by spacers **12** through **18**, **21** through **28**, and **30** through **34** which are fastened to the plate **10**. Opposing faces of the crystals **11** are connected to electrodes **36** through **38**, **40** through **48**, **50** through **58**, **50*a*** through **53*a*** and **60** through **66**. Electrodes **36**, **40**, **41**, **44**, **45**, **48** and **50*a*** are connected to wire **67**; electrodes **53*a***, **54**, **57**, **58**, **62**, **63** and **66** to wire **68**; electrodes **37**, **38**, **42**, **43**, **46*a***, and **47** to wire **72**; electrodes **55**, **56**, **60**, **61**, **64** and **65** to wire **71**. Wire **72** is connected through electrode **51** to cable **78**. Wire **71** is connected through electrode **52** to cable **78**. Wire **67** is connected through electrode **51*a*** to cable **78*a***, wire **68** is connected through electrode **52*a*** to cable **78*a***. Cables **78**, and **78*a*** are passed to the electrical part of the echo ranging system through bushing **80**, and cable **78*a*** through bushing **81**. These connections are so made as to either excite the crystals in the proper phase or to gather their electrical outputs in the proper phase for use in the rest of the associated sonar apparatus, much as described in the applicant's cited patent.

In addition, a reflector assembly **83**, shown in Figs. 2, 3, and 4, is mounted about the crystals **11**. It comprises mutually perpendicular sets of strips, one set **84** shown vertically in Fig. 3, and the other set **85** shown horizontally in Fig. 3. These strips are made of a very compliant material, such as foam rubber or a mixture of neoprene and cork known as Corprene. These strips are formed with notches **86** and **87** and arranged in an interlocked grid of the shape shown in Fig. 3 and bound together by a tape **88** about its outer edges. The strips are dimensioned to fit loosely between the crystals **11**. The openings in the grid are large enough to receive a crystal **11** in each opening. The reflector grid **83** fits down into the spaces between the crystals **11** and over the wires **67**, **68**, **71**, **78** and **78***a*, and the electrodes **36** through **38**, **40** through **48**, **50** through **58**, **50***a* through **53***a*, and **60** through **66**, and extends up along the major axes of the crystals to within approximately a quarter wavelength at the operating frequency in the liquid of the radiating surfaces of the crystals. While this distance of a quarter wavelength has been found to give the desired result, slight variations from this dimension may even produce better results. In use, the transducer is fitted with a cover of rubber (not shown) and the space between the crystals and behind the rubber is filled with a liquid having transmission characteristics for compressional wave energy as close as possible to those of sea water. The assembled transducer is mounted in an opening in the hull of a ship with the crystals facing outward in much the same manner as is shown in Fig. 1 of applicant's cited patent.

Fig. 5 illustrates to an exaggerated degree the motion of a single crystal block. In its quiescent state it assumes the rectangular outline indicated by the heavy solid line **90**. When the crystal is elongated longitudinally, it contracts laterally, as shown in the exaggerated form indicated by the dotted line **91**. Similarly, when contracted longitudinally, it expands laterally as indicated by the dot-dash line **92**. The amplitude of lateral motion increases progressively from a negligible amount at the outer end, and attains a maximum at a quarter wavelength $\lambda c/4$, back along the crystal at the propagation velocity in the crystal medium. In the design illustrated in Fig. 5, the total length of the crystal is a quarter wavelength $\lambda c/4$ at the propagating velocity in the crystal. While this is one common type of design, the invention is not limited to this type.

It happens that the velocity of sound in most crystal and ceramic materials is considerably greater (in the order of twice as great) than the velocity in castor oil, or whatever liquid is used to fill the transducer. Accordingly, a quarter wavelength in the oil extends from the outer end of the crystal block to some point, such as **93**. It is obvious from Fig. 5 that the majority of the lateral displacement occurs at distances greater than a quarter wavelength in the liquid from the outer end of the block.

In accordance with one object of the invention, the inner segments of the crevices between crystal blocks are filled not with oil but with a pressure relieving material, as described above. Air cell rubber, or a mixture of neoprene and cork known as Corprene, has been found suitable for this purpose. This material extends from the base of the crystal blocks to a point approximately a quarter wavelength in oil from the outer end of the crystals. This pressure relieving material does not inhibit free lateral motion of the crystals, but it eliminates most of the oil which would otherwise be forced to flow in and out of the narrow crevices between the vibrating blocks. A major portion of the viscous losses is thereby eliminated.

The remaining portion of the crevices which is not filled with pressure release material has a dimension of one-quarter wavelength in the direction perpendicular to the common outer face of the crystal blocks. Acoustically, the crevices behave like a quarter-wavelength waveguide or transmission line for electromagnetic waves. This analogy is not exact because the side walls formed by the crystal blocks are not infinitely rigid, but it is sufficiently close for practical purposes. At one edge of the quarter-wavelength oil-filled crevices, the pressure release material provides a termination which is so compliant compared with the oil that it has substantially zero impedance. This is analogous to a short circuit at the end of the quasi-equivalent, quarter-wavelength electric transmission line. By the familiar theory, it follows that, at the other end of the quarter-wavelength line or at the other edge of the crevice, the impedance is substantially infinite. Thus the crevices provide a fictitious stiff baffle at the common outer plane of the crystal blocks. The radiation from the outer faces of the crystals is therefore substantially the same as would be obtained from an array of pistons vibrating in an ideal stiff baffle.

While the relieving structure of the invention has been described as used with a particular transducer, this is merely by way of example, and the principle of the invention could be used with any transducer using an array of crystals. The important point is that a highly compliant relieving baffle be mounted at a position where it will have the described effects of relieving pressures built up by lateral oscillations, and of providing an effectively high acoustic impedance at the outer ends of the crystals.

This invention is not limited to the particular details of construction, materials and processes described, as many equivalents will suggest themselves to those skilled in the art. It is accordingly desired that the appended claims be given a broad interpretation commensurate with the scope of the invention within the art.

What is claimed is:

1. A compressional wave transducer comprising a plurality of rows of oscillatory elements mounted with their principal oscillatory surfaces in a common plane and their major axes perpendicular to this plane, and compliant material occupying the space between the oscillatory elements extending from their bases up to a distance of approximately a quarter of a wavelength at the operating frequency from the principal oscillatory surfaces of said oscillatory elements such as to provide a minimum impedance at the inner portions of said oscillatory elements and provide a maximum impedance at the principal radiating surfaces.

2. A compressional wave transducer comprising a plurality of rows of oscillatory elements mounted with their principal oscillatory surfaces in a common plane and their major axes perpendicular to this plane, and compliant material occupying the space between the oscillatory elements extending from their bases up to a distance of approximately a quarter of a wavelength at the operating frequency from the principal oscillatory surfaces of said oscillatory elements such as to provide a minimum impedance at the inner portions of said oscillatory elements.

3. A compressional wave transducer comprising a plurality of rows of oscillatory elements mounted with their principal oscillatory surfaces in a common plane and their major axes perpendicular to this plane, and compliant material occupying the space between the oscillatory elements extending from their bases up to a distance of approximately a quarter of a wavelength at the operating frequency from the principal oscillatory surfaces of said oscillatory elements such as to provide a maximum impedance at the principal radiating surfaces.

4. A compressional wave transducer comprising a plurality of rows of oscillatory crystals mounted with their principal oscillatory surfaces in a common plane and their major axes perpendicular to this plane, and compliant material occupying the space between the crystals extending from their bases up to a distance of approximately a quarter of a wavelength at the operating frequency from the principal oscillatory surfaces of said crystals such as to provide a minimum impedance at the inner portions of said crystals and provide a maximum impedance at the principal radiating surfaces.

5. A compressional wave transducer comprising a plurality of rows of oscillatory elements mounted with their principal oscillatory surfaces in a common plane and their

major axes perpendicular to this plane, and compliant material comprising cork and neoprene occupying the space between the oscillatory elements extending from their bases up to a distance of approximately a quarter of a wavelength at the operating frequency from the principal oscillatory surfaces of said oscillatory elements such as to provide a minimum impedance at the inner portions of said oscillatory elements and provide a maximum impedance at the principal radiating surfaces.

6. A compressional wave transducer comprising a plurality of rows of oscillatory elements mounted with their principal oscillatory surfaces in a common plane and their major axes perpendicular to this plane, and compliant material comprising foam rubber occupying the space between the oscillating elements extending from their bases up to a distance of approximately a quarter of a wavelength at the operating frequency from the principal oscillating surfaces of said oscillatory elements such as to provide a minimum impedance at the inner portions of said oscillatory elements and provide a maximum impedance at the principal radiating surfaces.

7. A compressional wave transducer comprising a plurality of rows of oscillatory crystals mounted with their principal oscillatory surfaces in a common plane and their major axes perpendicular to this plane, and compliant material comprising cork and neoprene occupying the space between the crystals extending from their bases up to a distance of approximately a quarter of a wavelength at the operating frequency from the principal oscillatory surfaces of said crystals such as to provide a minimum impedance at the inner portions of said crystals and provide a maximum impedance at the principal radiating surfaces.

8. A compressional wave transducer comprising a plurality of rows of oscillatory crystals mounted with their principal oscillatory surfaces in a common plane and their major axes perpendicular to this plane, and compliant material comprising foam rubber occupying the space between the crystals extending from their bases up to a distance of approximately a quarter of a wavelength at the operating frequency from the principal oscillatory surfaces of said crystals such as to provide a minimum impedance at the inner portions of said crystals and provide a maximum impedance at the principal radiating surfaces.

9. A compressional wave transducer comprising a plurality of oscillatory elements mounted with their principal oscillatory surfaces in a common plane and their major axes perpendicular to this plane, and compliant material occupying the space between the oscillatory elements extending from their bases up to a distance of approximately a quarter wavelength at the operating frequency from the principal oscillatory surfaces of said oscillatory elements.

No references cited.

UNITED STATES PATENT OFFICE

CERTIFICATE OF CORRECTION

Patent No. 2,844,809 July 22, 1958

Laurence Batchelder

It is hereby certified that error appears in the printed specification of the above numbered patent requiring correction and that the said Letters Patent should read as corrected below.

Column 1, line 38, for "contacting" read -- contracting --; column 5, lines 15 and 18, for "oscillating", each occurrence, read -- oscillatory --.

Signed and sealed this 23rd day of September 1958.

(SEAL)
Attest:

KARL H. AXLINE

Attesting Officer

ROBERT C. WATSON
Commissioner of Patents

UNITED STATES PATENT OFFICE

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