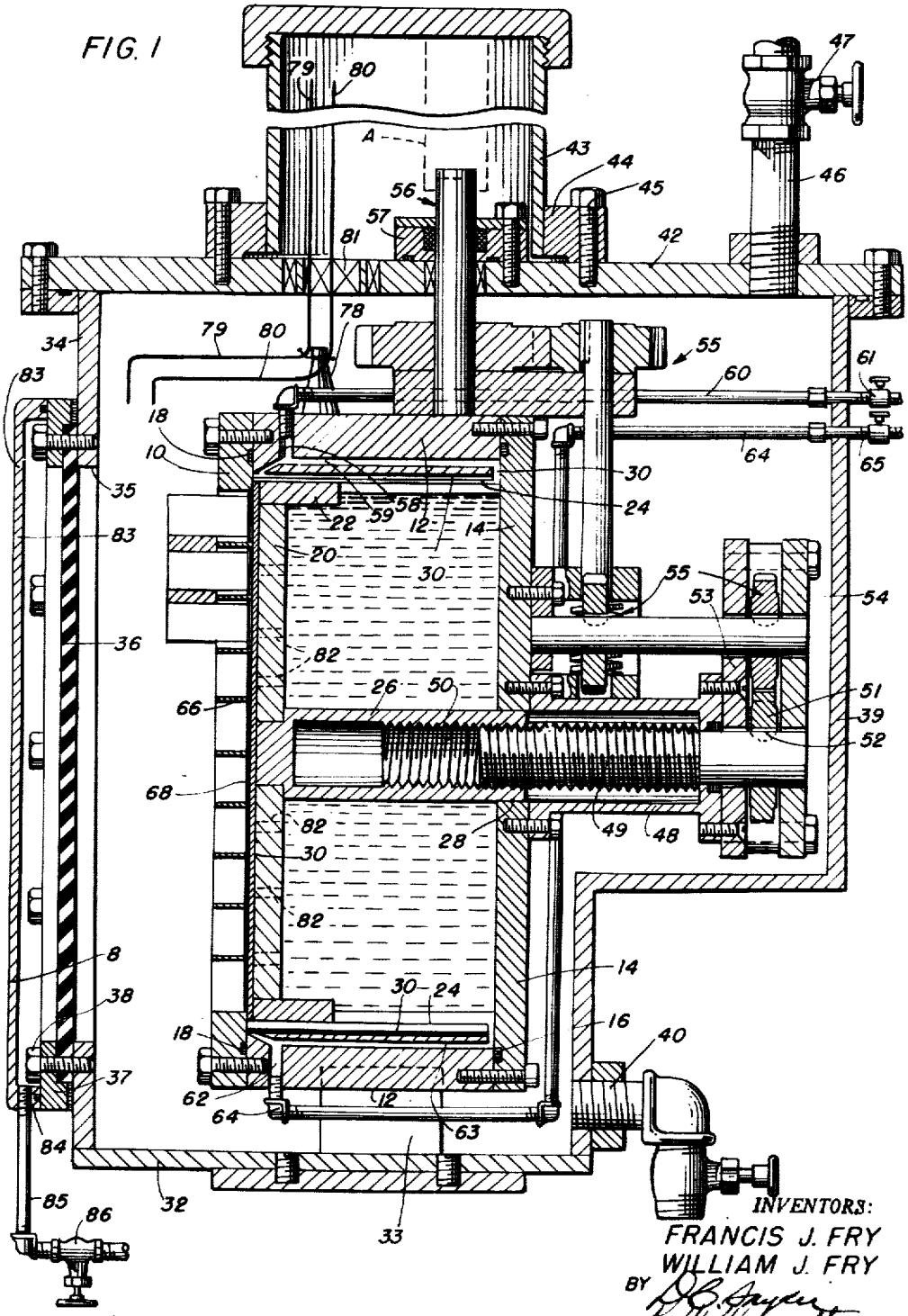
Aug. 6, 1957 F. J. FRY ET AL 2,802,196

VARIABLE FREQUENCY TRANSDUCER

Filed Aug. 24, 1954 3 Sheets-Sheet 1

FIG. 1



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VARIABLE FREQUENCY TRANSDUCER

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FIG. 2

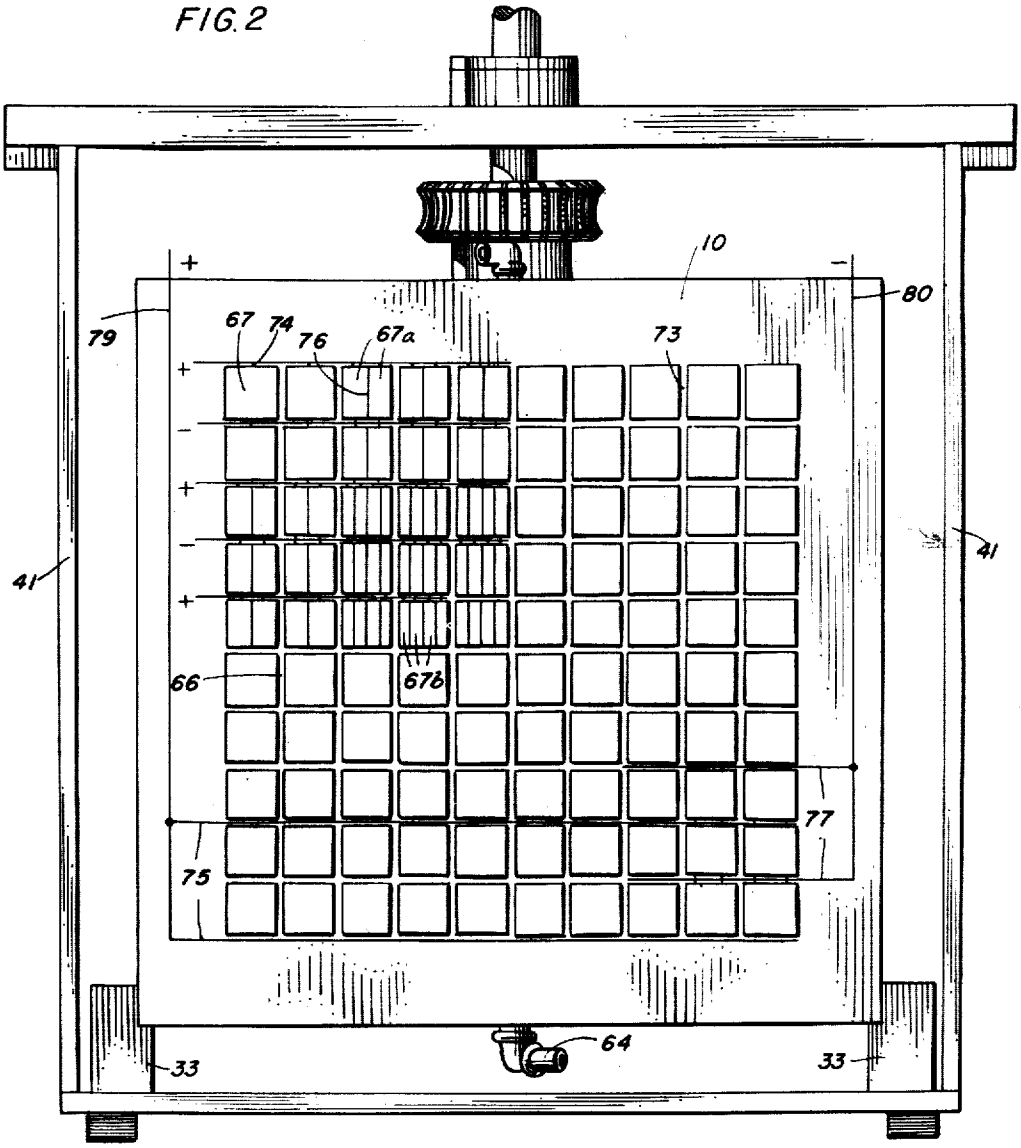
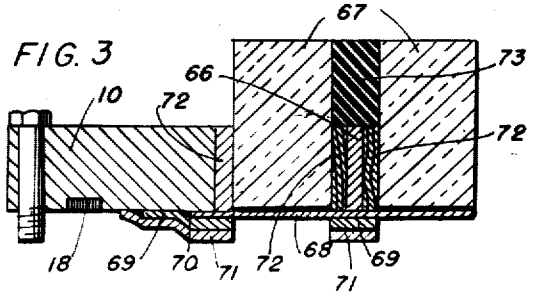


FIG. 3



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VARIABLE FREQUENCY TRANSDUCER

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FIG. 4

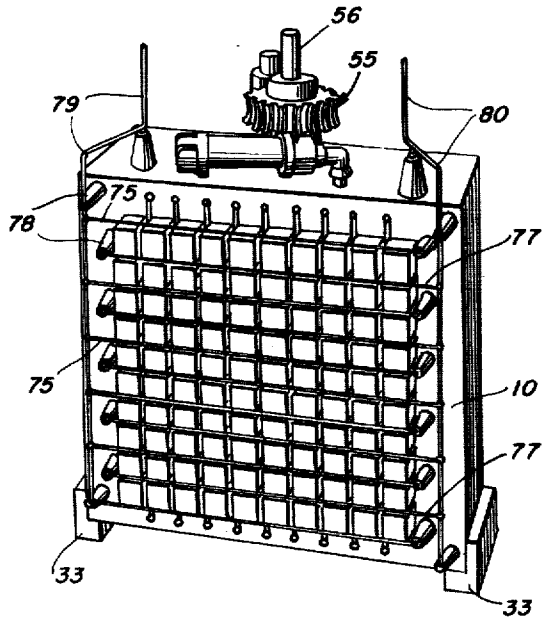


FIG. 5

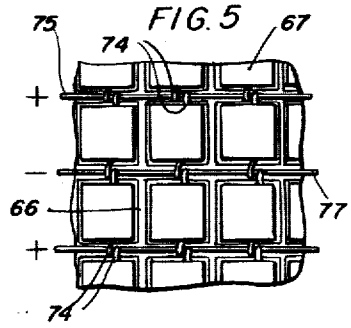
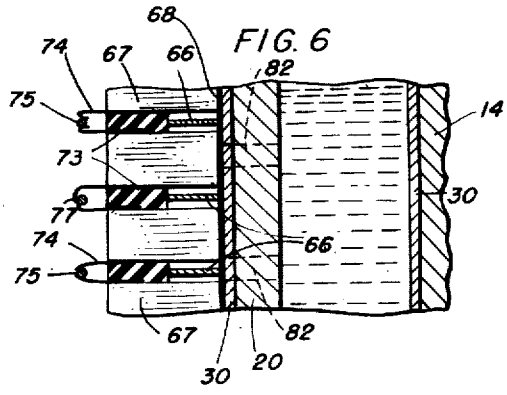


FIG. 6



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United States Patent Office 2,802,196 Patented Aug. 6, 1957

2,802,196

VARIABLE FREQUENCY TRANSDUCER

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Application August 24, 1954, Serial No. 451,992

12 Claims. (Cl. 340—10)

This invention relates generally to a transducer in which a mercury column of variable length is intimately coupled to a piezoelectric, electrically driven element so that a unit-vibrating element is formed, the frequency of which may be made resonant and is capable of being varied as desired within its prescribed limits. The invention is more particularly described as a sound-radiating area composed of a matrix in which a relatively large number of vibrating elements is employed.

More particularly, this invention relates to the novel construction and operation of a transducer of relatively large size having a plurality of piezoelectric units, electrically connected together so that a continuously variable resonant frequency characteristic is possible in the operation thereof. In the present invention, the variable frequency characteristic has been realized without greatly increasing the size over that of a fixed frequency transducer of the same radiating area.

An important object of the invention is to provide a transducer construction for large size transducers in which a continuously variable resonant frequency characteristic is possible.

A further object of the invention is to produce a transducer in which the variable feature resulting in a dimensional increase occurs mainly in a direction at right angles to the radiating area of the transducer which has this radiating area in one plane.

More particularly, the invention comprises a matrix arrangement of a plurality of piezoelectric elements in a relatively large square radiating face which is attached to a shell holding a mercury column whose dimension is varied by means of a mechanically driven piston.

A further object of the invention is to provide a transducer arrangement in which the piezoelectric elements comprise a pattern of single elements or a division thereof into two, three, or more pieces which occupy the same space as a single element but together are arranged in a symmetrical planar pattern, usually with the elements with the greatest number of pieces for each unit at the center of a rectangular pattern. This arrangement is to produce a desirable beam pattern of sound.

Still a further object of the invention is to provide a variable resonant frequency transducer system having a housing for supporting a mercury column continuously variable in one direction with a drive mechanism for varying the mercury column length and an overall housing enabling the system to radiate into the liquid medium.

Still a further object of the invention is to provide an improved mounting for the piezoelectric units and means for connecting them intimately and positively to a variable mercury column.

Other objects of the invention will appear in the specification and will be apparent from the accompanying drawings, in which:

Fig. 1 is a sectional view of a transducer construction in accordance with this invention;

Fig. 2 is a face view of a transducer element as shown in Fig. 1, also illustrating somewhat diagrammatically,

portions of one pattern of an arrangement of the piezoelectric elements dividing some of the unit spaces into one or more pieces per unit, but providing for a symmetrical arrangement of the elements in an entire rectangular plane unit;

Fig. 3 is an enlarged fragmentary view showing the construction and assembly of piezoelectric crystals in the supporting frame and the electrical contact space for engaging the mercury;

Fig. 4 is a perspective view of the transducer piezoelectric assembly with common electrical connections for the different units thereof;

Fig. 5 is a face view of a fragmentary portion of the piezoelectric unit showing connections of the divided piezoelectric units; and

Fig. 6 is a fragmentary sectional view showing the electrical connection of the parts shown in Fig. 5.

In this relatively large size sound transducer, which may be used for underwater sound, the matrix arrangement presents a square radiating face which is attached to a shell holding a mercury column having one dimension which is varied by means of a mechanically driven piston. The whole arrangement is enclosed in a steel tank with a sound rubber window so that it can be used as an underwater sound radiating transducer.

Although the piezoelectric element used in this construction is synthetically grown ammonium dihydrogen phosphate (ADP) crystal, it is equally possible to apply the same technique to a system using any electrochemical vibrating element. This includes the magnetostrictive vibrating elements as well as the newer ceramic elements such as barium titanate.

Referring now more particularly to the drawings, a relatively large underwater sound transducer is herein described which has a square crystal array mounted in a face plate **10** located at the front of a mercury housing which is also square, and the sides of which are four pieces **12** of solid metal, such as steel, carefully finished and surface ground on all of the exposed surfaces. These steel sides are painted with a suitable adhesive (Hysol 6020, Houghton Laboratories) in the area where they will come in contact when they are bolted and attached together. These sides are bolted together and the adhesive left to set so that liquid tightness in the corners is assured. With this construction, it is possible to make a housing with dimensional variations of less than $\frac{1}{1000}$ of an inch. At the back of the housing is a metal plate **14** secured to the plates **12** and having gasket grooves **16** to set the gaskets therein which engage the edges of the plates **12** to make a fluid-tight joint. The face plate **10** is also provided with gasket grooves **18** about the edges of the inner side which is secured to the mercury housing to also make a fluid-tight joint.

Within the housing is a square piston **20** preferably formed with marginal flanges **22** on each of its four sides and the corners of the piston supported in the housing by guide rails **24** in each of the four corners of the housing. At the center of the piston and tightly secured therethrough is a hollow piston shaft **26** which extends through a central opening **28** in the back plate **14** as a guide. The front piston face is surface ground so that an accurately planed and movable face is presented in the back of the entire crystal array which is mounted in the plate **10** bolted to the front face of the square housing.

To provide the necessary acoustical decoupling of the mercury column in the housing from the supporting chamber, a pressure-release material **30** is applied to the walls of the housing and to the face of the piston which preferably comprises a layer of balsa wood, approximately ¼ inch thick, which is held accurately planar by glu-

ing the wood to the steel with a surface-ground plate resting upon the wood during the setting process.

The mercury housing is mounted in a solid casing, preferably made of metal plates and comprising a bottom **32** with supporting side rails **33** upon which the mercury housing is rigidly supported at the sides thereof. At the front of the casing directly in front of the face plate **10** is a front plate **34** having a window aperture **35** therein about the same size as the face plate. Extending over the outside of the window aperture and overlapping the outer edges thereof is a sound-transmitting window **36** of rubber or other suitable material which is tightly secured about all of the edges of the window aperture by a marginal clamp **37** suitably secured in place by fastening bolts **38**.

At the rear of the casing is a back plate **39** with a discharge opening **40** having a valved pipe extending therefrom at the bottom thereof and at the sides are side plates **41** which extend upwardly to a common level with the front plate **34** where they are covered by a top plate **42**. A tubular extension **43** is suitably secured to the top of the casing surrounding the openings therethrough by a flange **44** and fastening bolts **45**. The top of this tubular extension **43** may be sealed by a threaded cap or in any well-known manner, and fluid seals may extend through the top plate **42** into the extension to be accessible therethrough when the cap is removed. Extending through the top plate **42** is a fill pipe **46** having a control valve **47**.

To reciprocate the piston **20** in the mercury chamber, a hollow sleeve **48** is attached to the rear plate **14** extending rearwardly therefrom and surrounding the central opening **28**. One end of a threaded shaft **49** extends within the hollow piston shaft **26** engaging internal threads **50** thereof, and the outer end of the threaded shaft **49** is connected to a gear **51** by a key **52** disposed between supporting plates **53** and **54** which are secured to the outer end of the sleeve **48** allowing free movement of the gear **51** and the shaft **49** in the rotary direction but confining the longitudinal movement of the shaft. A gear train **55** is connected to the gear **51** and is suitably supported by the mercury housing with a terminal drive shaft **56** extending through the top plate **42** and sealed in its passage therethrough by a packing gland **57** so that the outer end of the shaft projects into the extension **43** where it may be engaged by a tool A, similar to a socket ring or any other suitable means for turning the shaft and the gear train. The rotation of the shaft **56** in one direction or the other correspondingly moves the piston **20** at the back of the front plate **10** thereby varying the mercury column at the back of the front plate. By maintaining a fluid-tight connection through the top of the casing, the pressure in the casing may be varied as desired. This may be controlled through the inlet pipe **46**, and the fluid usually deposited in the casing is degassed which completely fills the casing surrounding the mercury housing.

In order to maintain a supply of mercury in the chamber in the mercury housing, an inlet opening **58** is provided in the top plate **12** with a passage **59** extending to the front and back of the chamber, and connected to this opening is a pipe **60** which extends through the casing, preferably through the rear wall **39** thereof, with a suitable controlling valve **61** at the outside of the casing. A similar connection may be provided in the bottom plate **12** comprising an outlet opening **62** having a passage **63** extending to the front and rear of the mercury chamber. To this opening a pipe **64** is connected, which also extends through the rear wall **39** and is provided with a controlling valve **65**. By this or any other suitable means, mercury may be supplied to the mercury housing and withdrawn therefrom if desired. In pipes **60** and **64**, couplings are provided so that the mercury housing can be removed conveniently from the outer chamber.

The front plate **10**, which is attached to the mercury housing, comprises a steel matrix having a plurality of partitions **66** forming rectangular or square cells in which piezoelectric crystals **67** are mounted. These crystals are adhesively connected at the rear side of the plate to a sheet **68** of silver palladium alloy (comprising 60 percent Ag and 40 percent Pd), which is supported by the matrix plate and its partitions. This alloy sheet **68** is of the order of .010 of an inch thick and is spot welded to the plate **10** and its partitions in a plurality of places to produce an extremely well-knit structure. The alloy sheet **68** provides the necessary intimate electric coupling between the crystals and the mercury column. The coupling is obtained by amalgamating the alloy with the mercury on the side opposite the glued crystals.

After completing the above assembly of the plate **10** with partitions **66** and alloy sheet **68**, the back surface of the alloy sheet is thoroughly cleaned with a scouring powder in preparation for electroplating of certain areas. The electroplated area covers the alloy sheet **68** and overlaps the marginal edge thereof onto the back of the front plate **10** except in the 100 regions immediately behind where the crystals are glued. A thin layer of nickel **69** of the order of .0005 of an inch is deposited leaving the regions immediately behind the crystals for contact and amalgamation with the mercury. The regions with the nickel coating will not amalgamate, neither does the mercury show a creeping tendency under the nickel. An adhesive fillet **70** is provided between the edges of the alloy and of the front plate **10** as clearly shown in Fig. 3. This fillet assures liquidtightness of the alloy sheet.

A paper mask **71** is applied by glue or another adhesive over the regions in which the nickel coating has been electroplated. This paper acts as an acoustical decoupling material, and about .0015 of an inch in thickness is taken up by the nickel glue and paper layers. The adhesive Hysol 6020 previously mentioned is satisfactorily used for these gluing operations with a room temperature set.

The piezoelectric crystals of various numbers of plies are glued into the matrix plate **10** between the partitions with a suitable adhesive (Hysol 6020) as shown more clearly in Figs. 2 and 3. During the adhesive-setting period, the crystals **67** are held in position spaced from the plate **10** and the partitions **66** thereof by balsa wood strips **72**. After the crystals are set, these strips are removed and a decoupling material **73** (Hycar ebonite) is installed. While positioning the crystals, the adhesive layer which connects them to the alloy sheet **68** is closely observed and worked so that no visible bubbles remain between the crystals and the alloy sheet. The crystals are provided with gold electrodes and tabs **74** to which silver conductor wires **75** are soldered and connected. In the slots between the crystals and the steel matrix and its partitions, the balsa wood strips may be replaced by the acoustical decoupling material **73**, and in the region between the crystals above the steel plate, the same material is installed. This material serves to acoustically decouple the crystals from steel matrix and from each other.

When the electrical connections between the crystals and the conductor wires **75** are completed, the exposed alloy surface of the sheet **68** is amalgamated with mercury. The amalgamation with mercury is accelerated by the use of a very small quantity of nitric acid which is wiped on the alloy plate and then wiped off by a slight scraping action of a knife blade over the various surfaces. A good amalgamation is one on which lint-free material can be used to wipe off the surface mercury, and then upon application of a small drop of clean mercury, there is immediate covering of the entire amalgamated region with a bright and shiny mercury film. In a complete set-up of the crystal assembly, the materials which come in contact with the mercury are steel, cast iron, balsa wood, Hysol adhesive, nickel, the paper mask, the silver palladium alloy, and the gasket material, such as neoprene on the front and back plates and in the piston drive

mechanism, the tubings **60** and **64** which may be plastic material, and the outside valves which enable the mercury to be placed into the mercury housing after the completed transducer assembly. Materials such as zinc and aluminum must be avoided because of their contaminating influence on the mercury.

The crystals in the cells of the matrix may be in the form of single unitary crystals **67**, or the crystals for each cell may be divided into two portions **67***a* with suitable separating insulation **76**, or they may be divided into four insulated parts **67***b*, each connected by suitable electrodes, usually arranged in a pattern as suggested in the upper left quadrant but extending over the entire matrix in Fig. 2 in which four of the solid units **67** are at each corner, then two line crystals **67***a* extend in the two outer rows between each corner, and the four section crystals **67***b* are in the thirty-six central cells. In this entire crystal system, the individual crystals or the divided parts thereof filling each cell are connected by the gold electrodes **74** either to a conductor wire **75** or to an opposite conductor wire **77**. These wires are supported in a raised position above the crystals by supporting posts **78** as shown in Fig. 4 and connected to common conductors **79** and **80**. These conductors **79** and **80** extend through a fluid-tight connection **81** in the top plate **42** of the conductor casing and into the space in the tubular extension **43**. This arrangement is for crystals in which the voltage is applied at right angles to the utilized direction of motion. There are many ways of connecting the various crystal elements and the visible portions thereof for obtaining different beam patterns.

In the piston **20**, a plurality of openings **82** may be provided, and the marginal flanges **22** are spaced from the sides of the mercury housing to provide for a quick passage and transfer of mercury in the mercury chamber from one side of the piston to the other in varying the frequency of the transducer.

For this type of transducer, a relatively slow speed drive is provided having a total stroke of approximately 4 inches. The mercury housing is completely filled with mercury, and the casing enclosing the housing is completely filled with degassed castor oil. Sound is transmitted from the crystal assembly to the sound window **36**. Pressure may be placed upon the castor oil through the fill openings and also upon the mercury, if desired. In order to fill the transducer casing with castor oil under the most favorable conditions, the casing is made air tight so that it may be completely evacuated of air whereby the oil is pumped in or admitted under vacuum. To accomplish this result, a solid metal window which may be in the form of a plate **83** with a peripheral flange **84** may be applied to the outside of the marginal clamp **37**, and an air-exhausting pipe **85** may be inserted from the outside and connected through a valve **86** with a suitable vacuum line. At the same time, vacuum connections are made with the top of the transducer casing and with the mercury housing through its pipe **60** since it is also emptied during the oil filling. With this technique, the hydrostatic pressures on both sides of the sound rubber window **36** are approximately equal. The degassed castor oil is evacuated to the same pressure as the transducer, and the oil flows by gravity or by pumping it into the transducer housing. After filling, the entire system is brought simultaneously to atmospheric pressure, and the valves leading to the castor oil region are closed. The mercury is then introduced into the mercury chamber through the valve **65** and the pipe **64**. The valve **61**, which is the air-exhaust valve for the mercury housing when it is being filled with mercury, may be closed when the mercury chamber is filled. After the hydrostatic pressure is equalized, the window plate **83** is removed and the sound window **36** is free for sound vibrations.

To support the transducer beneath the surface of the water for test purposes, the tubular extension **43** may be of a length desired for the depth in the water. This pipe provides passage for the tool A used as a turning rod for changing the piston location in the mercury chamber and for access to the terminals for the electrical supply conductors **79** and **80**. If the transducer casing is located sufficiently below the surface of the water to make a material change in the pressure applied to the sound window **36**, a balancing pressure may also be applied to the transducer casing through the fill pipe **46**.

This transducer design is thus able to meet the requirements of sonar (underwater sound) apparatus for use on naval and other vessels. For this purpose, a remote drive mechanism for varying the mercury column length is used, together with means for controlling the pressure in the transducer casing in the mercury housing as above described. The holes **82** through the piston and the spaces at the edges of the piston are provided for rapidly displacing mercury around the piston for adjusting the movement thereof.

With this construction and the adopted arrangement of crystals, a voltage is applied at right angles to the utilized direction of motion, the column of mercury may be varied and has an intimate acoustical coupling with a plurality of piezoelectric, electrically driven elements capable of vibrating the variable resonant frequencies. The vibrations thus produced will pass through the flexible sound window and may be thus projected for remote pickup. This action also may be reversed and varied to receive sound through the transducer window which activates the piezoelectric units to produce an electric signal, the resonant frequency of the units being varied by changing the mercury column.

While a preferred embodiment has been described in some detail, it should be regarded as an example or embodiment of the invention and not as a restriction or limitation therein as many changes may be made in the construction and arrangement of the parts without departing from the spirit and scope of the invention.

We claim:

1. A variable resonant frequency transducer comprising means for supporting a mercury column variably in one dimension, an array of piezoelectric elements intimately coupled at their inner faces to this mercury column and exposed at the outer faces, means for varying said one dimension of the mercury column, an overall fluid-tight casing for enveloping said supporting and varying means with an opening therethrough having a flexible partition in the outer wall spaced from the said outer faces but in position for the array of elements to radiate therefrom, a liquid medium in the casing between the elements and the partition, and electrical conductor means for supplying current connected to the elements and extending therefrom out of the casing.

2. In a transducer in accordance with claim 1, the array of piezoelectric elements comprising a metallic grid separated into adjacent closely related cells and a plurality of piezoelectric units mounted in the cells with their corresponding ends in a common plane and means for confining the mercury column in contact with said ends in a common plane.

3. In a transducer in accordance with claim 2, a housing for confining the mercury column, a piston having a hollow shaft extending horizontally from the housing and internally threaded, an externally threaded shaft fitting within the hollow shaft, and a train of gearing connected to the externally threaded shaft at the outside of the housing in said liquid and extending therefrom out of the top of the casing for varying the said one dimension of the mercury column.

4. In a transducer in accordance with claim 3, the piston having openings therethrough through which mercury may move, the housing having supporting rails for the piston providing marginal spaces between the piston and the housing through which mercury may pass from one side of the piston to the other when the piston is relatively moved in the housing.

5. A transducer in accordance with claim 4 in which the mercury housing has top and bottom openings with passage extensions therefrom with the front and rear of the housing and tubular supply connections to the openings and leading therefrom through the overall casing with valve means at the outside of the casing for controlling the supply of mercury and the pressure thereon in the housing.

6. In a transducer in accordance with claim 2, the piezoelectric units being both solid and having portions thereof which make up a unit and being mounted in individual cells of the plate spaced electrically from the partitions forming the plate and extending substantially flush with the plate at one end but projecting from the plate at the other end, a common alloy sheet of conducting metal attached to the ends of the units flush with the plate and over the adjacent edges of the partitions and the plate surrounding the cells, the piezoelectric units and the portions thereof being spaced from the partitions and from the marginal edges of the plate, an insulating means disposed between and secured to the outwardly projectends of the elements and portions thereof on top of the outer ends of the partitions.

7. In a transducer in accordance with claim 6, the outer exposed face of the common metal sheet and adjacent edge of the supporting plate being covered with a thin electroplated layer of nickel except for the regions immediately between the crystal units and parts thereof, and a thin mask of acoustical decoupling material, such as paper, applied over the regions in which the nickel coating has been electroplated.

8. In a transducer in accordance with claim 7, the face of the piston opposite the inner ends of the piezoelectric units being provided with an acoustical decoupling layer of material and the sides of the housing also having a thin acoustical decoupling material applied thereto thereby acoustically decoupling the mercury column into the housing from the supporting chamber.

9. In a variable frequency transducer, a housing for supporting a mercury column, an array of piezoelectric elements extending in a plane at the front of the housing and the rear of the elements electrically coupled to the mercury column, a piston movably mounted in the housing for varying the effective mercury column at the back of the elements, an overall casing for enclosing the housing having an opening therethrough in the path of radiation from said piezoelectric elements, a flexible sound-transmitting window fitting tightly in the opening, a shaft

extending from the piston through the housing, a train of gearing connected to the piston shaft and extending from the housing therefrom through the top of the casing, electrical connections from the piezoelectric elements also extending from the top of the casing, means for sealing the gearing and electrical connections at the top of the casing, a sound-transmitting liquid in the casing surrounding the housing, and sealed means extending through the casing for supplying mercury under pressure to the housing.

10. In a transducer in accordance with claim 9, the casing and the housing being liquid tight for keeping separate the liquids which they contain, the casing having an extension secured to the top through which the gearing and the electrical connections extend in fluid-tight arrangement, and the casing having valved tubular means for controlling pressure and vacuum therein.

11. In a transducer in accordance with claim 10, a removable plate or cover to fit over the outside of the opening in the casing and at the front of the flexible sound-transmitting window and means for varying the pressure in the space at the outside of the window covered by said plate and for equalizing the pressure at both sides of the window, the plate being removed when the transducer is in use.

12. In a transducer in accordance with claim 6, the top sealing means forming an extension of the casing of sufficient length so that the transducer may be located below the surface of the liquid in which it is immersed, the train of gearing and conductors being accessible through the extension from above the top of the liquid, and supply and pressure pipes from the housing and casing also extending above the surface of the liquid in which the transducer is immersed so that pressure may be applied thereto for equalizing the pressure within the casing to correspond with the external pressure of the liquid in which the transducer is immersed.

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