Dec. 31, 1946. F. MASSA 2,413,462

TRANSDUCER

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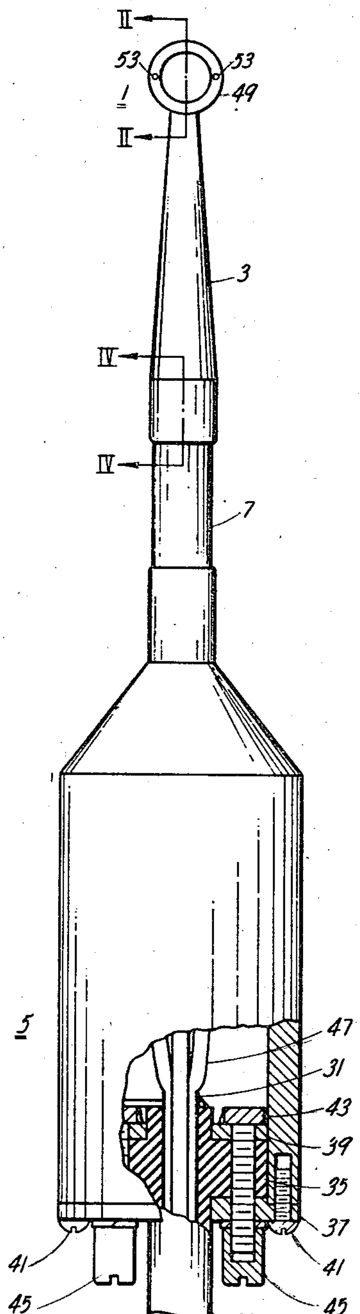

FIG. 1

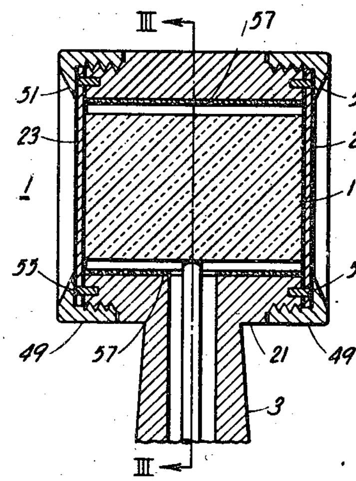

FIG. 2

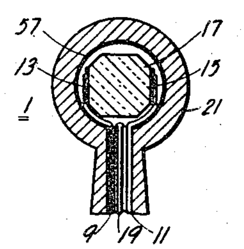

FIG. 3

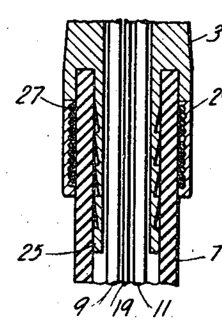

FIG. 4

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Application July 30, 1942, Serial No. 452,906

4 Claims. (Cl. 177—386)

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This invention relates to transducers and, more particularly, to pressure-wave receivers and transmitters of the type adapted for operation when immersed in a fluid medium such as water or the like.

As indicative of the type of underwater transducers in general use prior to this invention, attention may be directed to the U. S. patent granted to Willy Kunze, No. 2,138,036. The device disclosed in the patent comprises a water-tight casing provided with oppositely disposed massive piston-diaphragms between which a pressure-responsive Rochelle salt crystal section is clamped, the casing being adapted for threaded connection to a supporting cable by means of which it may be lowered to the desired depth. When utilized as a submarine microphone or for measuring wave-pressures, at frequencies in the audio range, such a device has given reasonable satisfaction. However, if non-directional reception at supersonic frequencies is required, as well as a flat response over a wide range of frequencies, a different type of construction should be used.

By way of example, if it is desired that an underwater microphone shall be substantially non-directional up to 50,000 cycles per second and that the response shall be substantially flat up to 100,000 cycles, the effective spacing between the outer surfaces of the piston-diaphragms should not be materially greater than one quarter of the wavelength in water at 50.000 cycles. Also, the greatest dimension of the active portion of each diaphragm and of the housing should be less than one-half of the wavelength and, preferably, of the order of one-quarter of said wavelength. By "active portion" is meant that area of the diaphragm on which the integrated instantaneous wave-pressure is effective to impose stress upon the crystal section.

The foregoing requirements may be met by a circular housing the inter-diaphragm, or front-to-back, dimension of which is approximately $\frac{5}{16}$'' and the diameter of which, in the plane of a diaphragm, is of the order of $\frac{7}{16}$''.

Because of these small dimensions, it is not feasible to utilize a plurality of screws for holding the two diaphragms in place. Accordingly, one object of the invention is to provide an improved underwater microphone, or transducer, wherein diaphragm-holding screws are not required.

Another disadvantage of prior art structures is the inherently low resonant frequency of the mechanical vibratory system comprising the piezoelectric crystal section and the relatively

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massive piston-diaphragms associated therewith. Such resonance, because of the changes in the mechano-acoustical impedance of the microphone occasioned thereby, produces severe variations in sensitivity in the supersonic frequency region, both near and above the fundamental resonance frequency of the composite mechanical vibratory system.

Another object, therefore, is to provide a device of the type described that shall be devoid of composite mechanical vibratory systems adapted to resonate at relatively low frequencies, and one wherein the sensitivity, therefore, is substantially constant over a wide range of frequencies extending into the supersonic.

Another object is to provide a piezoelectric transducer wherein the stiffness of the crystal element is substantially the sole frequency-sensitivity-controlling factor.

Another object is to provide a piezoelectric transducer, the mechanical impedance of which to pressure waves shall be very high at all frequencies within the range for which it is designed.

Another object is to provide a transducer of such type that a piezoelectric crystal element, comprised therein, may be coupled substantially directly to the fluid medium in which the transducer is immersed.

Obviously, as the dimensions of the crystal housing are reduced for the purpose of adapting the device to higher and higher supersonic frequencies, the dimensions of the enclosed crystal section must correspondingly be reduced and the inter-electrode capacity will reach so low a value that it is impracticable to interpose a suspension cable between the unit and a remote amplifier. Accordingly, in the prior art it has been proposed to mount a pre-amplifier tube closely adjacent to a piezoelectric transducer, within a single waterproof housing. The pre-amplifier housing, however, introduces diffraction errors and, furthermore, resonance vibrations thereof are transferred to the crystal unit to cause interference. In addition, vibrations and water-noises are picked up by the suspension cable and are passed on to the crystal with the result that the disclosed device has not given entire satisfaction.

Another object of the invention, therefore, is to so isolate a piezoelectric transducer from a pre-amplifier housing and a suspension cable that the effects of stray noise and of pressure-wave reflection and diffraction are minimized.

An underwater sending or receiving device constructed according to this invention preferably comprises an elongated, waterproof pre-amplifier housing to one end of which a suspension cable is attached and from the other end of which extends elongated means for supporting a separate microphone head constituted by a waterproof container or housing wherein a pressure-responsive piezoelectric crystal unit is mounted. The supporting means for the microphone head is sufficiently long to remove the crystal element from the influence of pressure waves diffracted by or reflected from the surface of the pre-amplifier housing. The distance between the microphone head and the pre-amplifier housing preferably should be several times the length of a pressure wave in water at the highest frequency at which observations are to be made.

In the preferred embodiment of the invention, the pre-amplifier housing is generally cylindrical in contour, but the exact shape is substantially immaterial.

The container for the piezoelectric crystal unit may be constituted by a drum-like housing or frame, formed from any suitable material, each end of which is hermetically closed by a thin diaphragm. In the preferred embodiment of the invention, designed for use at supersonic frequencies, the diaphragms are metallic and each is held in place by a threaded clamping ring.

The piezoelectric crystal unit may be a single 45° X-cut Rochelle salt crystal section, having a natural period above the highest frequency at which the device is to be operated. The end surfaces of the unit, normal to its compressional axis, are cemented, respectively, to the inner surfaces of the sealing diaphragms. The diaphragms have negligible mass, the thickness thereof being of the order of a few thousandths of an inch. Their stiffness is negligible in comparison with the stiffness of the crystal unit. No stress is applied to the crystal unit by the diaphragms; they serve merely as sealing elements.

For the purpose of preventing the crystal unit from responding to unwanted vibrations picked up by the supporting cable, or vibrations occasioned by mechanical and/or acoustical resonance of the pre-amplifier housing, the elongated supporting means for the crystal unit container includes a vibration-attenuating element, such as a section of rubber hose or the like, which effectively isolates the crystal container from the said housing and through which extend the conductors that connect the crystal-electrodes to the input circuit of the pre-amplifier tube.

In order to provide a watertight and slip-proof joint between the pre-amplifier housing and the supporting cable, the rubber sheath of the latter carries an integral resilient collar, or grommet, which fits into the end of the cylindrical pre-amplifier housing wherein it is anchored by adjustable pressure means which cause it to bulge radially against the inner wall of the housing.

To prevent moisture from condensing upon the crystal-electrodes and elsewhere within the apparatus, and thus causing electrical leakage, "silica gel" is employed. The manner in which that material may best be utilized will be explained in more detail hereinafter.

It is to be understood that the use herein of the term "microphone" is not intended as a limitation, inasmuch as the invention is broadly applicable to pressure-wave sending apparatus as well as to receiving apparatus.

Furthermore, the invention is not limited to the utilization of a piezoelectric crystal element, although such an element, preferably, is employed. For example, a pressure-responsive device such as a double button carbon microphone might be employed, or a microphone wherein a resistance element, such as "conductive" rubber or the like, is utilized in lieu of the crystal section, the electrical resistance of the element being inversely proportional to the pressure applied to the end closures.

The novel features considered to be characteristic of the invention are set forth with particularity in the appended claims. The invention itself, however, both as to its organization and its method of operation together with additional objects and advantages thereof, will be understood best from the following description of certain specific embodiments thereof, when read in connection with the accompanying drawing, in which:

Figure 1 is a front view in elevation of a submarine compressional wave sending or receiving device constructed according to this invention, a portion thereof being broken away in order to illustrate the preferred manner of anchoring a supporting cable thereto.

Figure 2 is a vertical sectional view of the microphone head per se, very greatly enlarged, taken along a line corresponding to the line II—II in Figure 1;

Figure 3 is a vertical sectional view of the microphone head, considerably enlarged, taken along a line corresponding to the line III—III in Figure 2, and

Figure 4 is a vertical sectional view, considerably enlarged, of a portion of the device taken along a line corresponding to the line IV—IV in Figure 1, showing the mechanical connection of the transducer to an isolating element.

Referring to Figures 1, 2 and 3 of the drawing, a submarine compressional wave sender or receiver, constructed according to this invention, includes a microphone head, indicated generally by the numeral 1, having a hollow stem 3, and a pre-amplifier tube housing designated in its entirety by the numeral 5. A hollow isolating element 7, such as a section of rubber hose or a tube of any other suitable material capable of damping mechanical vibrations, connects the stem to one end of the housing 5. A plurality of conductors 9 and 11 extend through the stem and the isolating element, between the electrodes 13 and 15, respectively, of a piezoelectric crystal element 17, disposed within the microphone head, and the input terminals of the pre-amplifier tube (not shown). A ground connection 19 may also be included.

As shown in Figure 2, the crystal unit housing or microphone head 1 is constituted by a drum-like circular container 21 provided with two oppositely disposed flexible end closures or diaphragms 23, the space between which is just sufficient to accommodate the pressure-responsive piezoelectric crystal unit 17.

In one commercial embodiment of the invention, the crystal element is a 45° X-cut Rochelle salt section, having parallel end faces $\frac{3}{8}''$ square, the length thereof, along the compressional axis to which the faces are normal, being $\frac{1}{8}''$. The element has a natural frequency well above 100,000 cycles per second.

The microphone head 1 may be made integral with the hollow stem 3, if desired. The stem terminates in a serrated nipple 25 which fits into one end of the isolating element 7 as shown in detail in Figure 4. For the purpose of making a water-tight connection between the nipple and the hose, the junction may be wrapped tightly with copper wire 27. The wire wrapping may be spot-soldered at a number of points, then rubbed thoroughly with graphite and copper-plated. The electrodeposited metal 29 firmly bonds the turns of the wire wrapping together and to the stem of the microphone head.

The microphone head 1, the stem 3 thereof and the pre-amplifier housing or shell 5 are made from a metal that resists corrosion, such as brass or the like.

One end of the pre-amplifier housing 5 may be provided with a serrated nipple which fits into the other end of the isolating hose and it may be held therein by an electro-plated wrapping of wire such as was described in connection with Figure 4. Inasmuch as the two nipples may be identical and may be held to the hose in identically the same manner, further illustration is not believed to be needed.

The described mode of connecting the isolating element 7 to the stem 3 and to the pre-amplifier housing 5 is disclosed in the copending application of Dean R. Christian, Serial No. 528,454, filed March 28, 1944. Other modes of connection, such as pressure-vulcanizing, may be resorted to if desired.

As shown by the sectionalized portion of Figure 1 a multi-conductor cable, provided with an inner metallic shield 31 and having an outer rubber sheath 33, is anchored into the end of the pre-amplifier housing 5 opposite to the end provided with the hose-connection. In order that the anchorage shall be water-tight and strain-proof, the anchored end of the cable is provided with an exterior collar 35, or grommet, integral with the rubber sheath thereof, which collar fits into the end of the housing 5 and is held under compression between a cover-plate 37 affixed to the said end and a movable pressure plate 39 within the housing. The cover-plate is provided with a central aperture through which the cable extends and it is held to the open end of the housing by a plurality of screws 41 or the like. The pressure plate 39, within the housing, also has a central aperture to accommodate the cable and it carries a plurality of bolts 43 that extend through the cable collar and cover-plate to the exterior of the housing. Each bolt is provided with an exterior castle nut 45 or the like whereby the pressure plate 39 may be urged toward the fixed cover-plate 37 to cause the collar 35 to bulge radially into water-tight engagement with the inner wall of the housing 5.

Because of the fact that the collar 35 is gripped firmly in position, the conductors 47 extending into the pre-amplifier housing from the cable are protected against strain and, consequently, there is little likelihood that the connections to the pre-amplifier tube will be broken while the device is in use.

Referring once more to Figure 2 of the drawing, it is to be understood, if the device is to be utilized under water at supersonic frequencies, that the wall of the microphone head must be relatively thin if the largest dimension of the housing is to be less than half a wavelength. For purposes of explanation, the wall in Figure 2 is shown as being disproportionately thick but in an actual commercial embodiment of the invention, that is non-directional up to 50,000 cycles, the thickness is of the order of $\frac{3}{16}''$ and the diameter of the housing, in a plane parallel to the diaphragms, is of the order of $\frac{7}{8}''$.

In accordance with this invention, each of the diaphragms or membranes 23 must have substantially negligible mass and stiffness and, accordingly, they are fabricated from phosphor-bronze and have a thickness of the order of five one thousandths of an inch. In order, therefore, that the diaphragms may be held across the open ends of the crystal housing, the inner faces thereof being in contact, respectively, with the opposite faces of the piezoelectric crystal element 17 without exerting pressure thereon and without being tensioned, the ends of the housing are screw threaded exteriorly, and interiorly threaded clamping rings 49 are provided. Each ring has an inwardly extending flange 51 which overlies the periphery of the diaphragm associated therewith and compresses it tightly against the rim of the housing 21. The outer surface of each ring may be provided with a plurality of wells 53, or slots, wherein the prongs of a spanner may be inserted for the purpose of tightening it.

In order to prevent the diaphragms from turning during the tightening operation, each rim of the housing is provided with one or more axially projecting pins 55 that extend part way into corresponding openings in the associated diaphragm.

A suitable material for the crystal housing 21 and the stem 3 is brass, although any other material that effectively resists corrosion may be utilized. The pins 55, preferably, are fabricated from a material such as steel piano wire that offers high resistance to shear.

During assembly of the head, the rim at one end of the housing and the threads surrounding it are coated with a water-proof cement, one of the diaphragms is placed on the pins and a clamping ring is drawn up to a snug fit. The interior surface of the diaphragm is then given a thin coating of cement and the crystal section, which has previously been supplied with electrodes and terminal leads is inserted within the housing and one face thereof is pressed into engagement with the inner surface of the cement-covered diaphragm. At this point in the assembly, despite the most careful machining of the housing and sizing of the crystal section, it is likely to be found that the free end of the crystal section and the rim of the housing do not lie in precisely the same plane. If such is the case, either the end of the crystal or the rim of the housing is carefully ground down, while the crystal is in place, until they are co-planar. The free end of the crystal section and the rim of the housing are then given a coating of water-proof cement and the second diaphragm is applied and clamped in place.

In the completed microphone head or crystal housing, the thin diaphragms are unstressed and, because of the care taken during assembly, they exert no pressure upon the piezoelectric crystal element. Such being the case, the stiffness of the crystal element per se is the sole factor that determines the sensitivity of the device, and the response is flat below the natural resonance frequency thereof. The crystal element, furthermore, is coupled at each face substantially directly to the water or other medium in which the device is immersed and the crystal offers very high mechanical impedance to pressure waves in the liquid.

If desired, thin strips of cork 57 or of analogous damping material may be interposed between the crystal element and the walls of the housing as indicated in Figure 2.

In order that moisture shall not be precipitated upon the crystal or upon the terminals of the pre-amplifier tube, when the device is changed from one medium to a cooler medium, it has been found expedient to place a certain amount of partially dehydrated "silica gel" within the stem 3 and a small bag (not shown) containing "silica gel" within the pre-amplifier housing. The use of "silica gel" is disclosed and claimed in the copending application of Frank Massa, Serial No. 431,429, filed February 18, 1942.

An underwater receiver or transmitter constructed according to this invention has a number of other important advantages. Inasmuch as the microphone head is spaced away from the pre-amplifier housing, pressure waves refracted by or reflected from the said housing do not interfere with the reception of wanted signals nor do they interfere with the measurement of sound-pressures. Furthermore, the provision of the isolating element prevents the transfer of noise vibrations from the supporting cable to the crystal and also the transfer thereto of vibrations caused by resonance of the preamplifier housing itself.

The anchorage of the supporting cable to the pre-amplifier housing is water-tight and strain-proof, while at the same time easy access to the pre-amplifier tube (not shown) is afforded for the purpose of replacement if necessary.

Although but a single embodiment of the invention has been chosen for purposes of explanation, other embodiments will at once be apparent to those skilled in the art, as well as other advantages thereof. The invention, therefore, is not to be restricted except insofar as is necessitated by the prior art and by the spirit of the appended claims.

What is claimed is:

1. A compressional wave submarine sender or receiver comprising a housing, a piezoelectric crystal unit within and substantially filling the housing, the crystal unit having diametrically opposite end-faces that are substantially normal to its compressional axis, each end of the housing being hermetically sealed by a substantially unstressed flexible sealing means individual thereto, and the said end-faces of the crystal unit, throughout their extent, being cemented directly in contact, respectively, with the said sealing means for mounting said crystal unit within said housing and away from contact with the walls of said housing, the mass and stiffness of each sealing means being negligibly low in comparison with the mass and stiffness of the crystal unit per se and each of said sealing means being substantially stiff to motion in directions perpendicular to the compressional axis of said crystal unit.

2. The invention set forth in claim 1, characterized in this: that the area of a crystal end-face coupled substantially directly to the medium, is a large proportion of the projected area presented to the medium by a sealed end of the housing.

3. The invention set forth in claim 1, characterized in this: that the largest diameter of the housing is of the order of one-half inch and that the resonant frequency of the piezoelectric crystal unit exceeds 100,000 cycles per second.

4. In a compressional wave sender or receiver, an open-ended drum-like housing having screw threads on its outside end portions, a pair of oppositely disposed vibration transmitting diaphragms, pin means pinning said diaphragms to said housing, one to each open end thereof, without exerting stress thereon, interiorly threaded clamping rings, one at each end of said housing, in threaded engagement with the screw threads on said housing, each of said clamping rings overlying said pin means and overlying a peripheral portion of one of said diaphragms and compressing said diaphragm tightly against the rim of the said housing with substantially uniform pressure, piezoelectric crystal element means having a pair of substantially parallel faces perpendicular to a compressional axis of the crystalline material, the said faces, respectively, being cemented in intimate contact with the inside surfaces of said diaphragms for centrally mounting said piezoelectric crystal element within said housing and out of contact with said housing, and lead means connected to said piezoelectric crystal element and extending through said housing for connection into an outside electrical circuit.

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