Sept. 26, 1961 D. W. KUESTER 3,002,179

LOW FREQUENCY HYDROPHONE

Filed Sept. 3, 1952 2 Sheets-Sheet 1

FIG. 1.

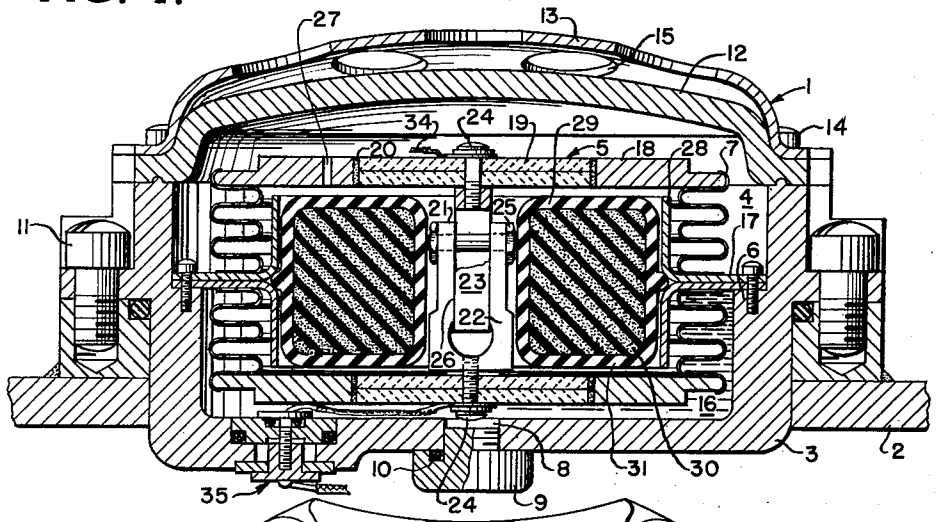
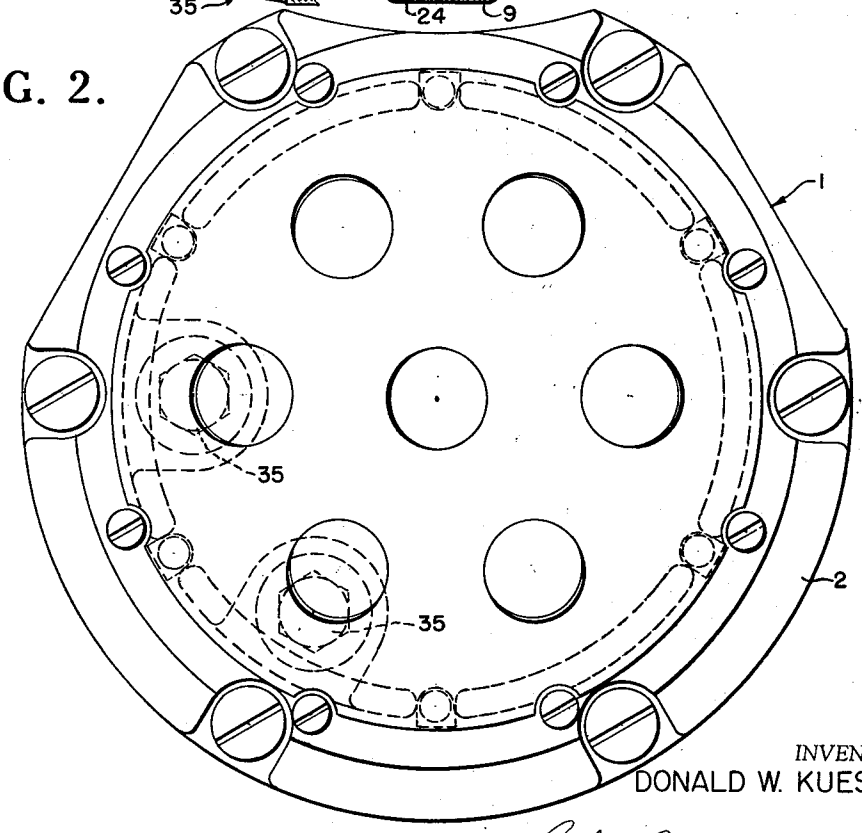


FIG. 2.



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Filed Sept. 3, 1952 2 Sheets-Sheet 2

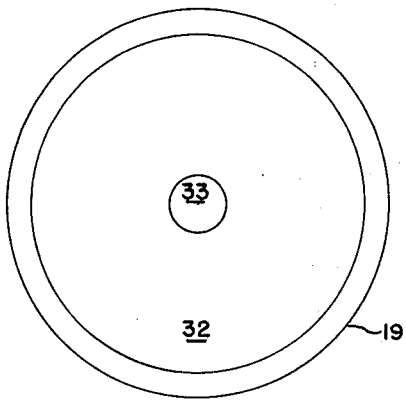


FIG. 3.

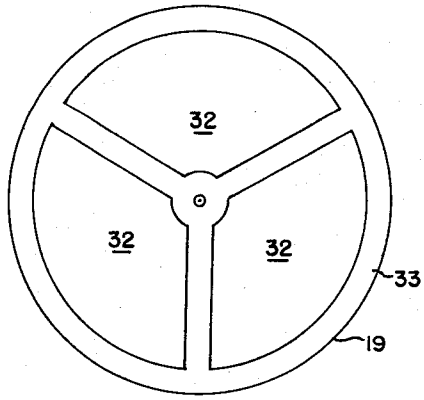


FIG. 4.

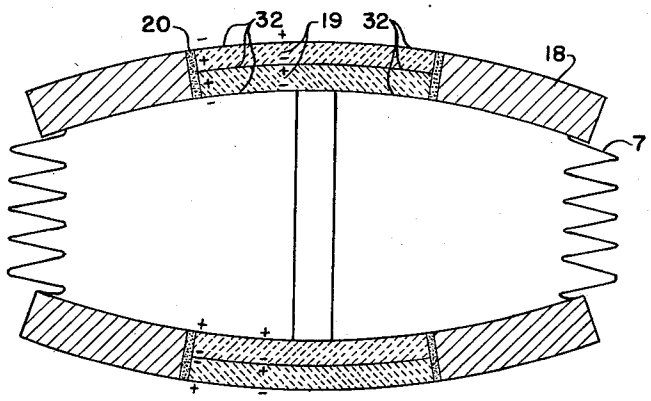


FIG. 5.

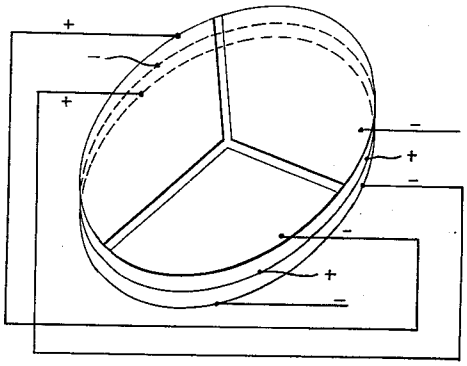


FIG.6.

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LOW FREQUENCY HYDROPHONE

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11 Claims. (Cl. 340—10)
(Granted under Title 35, U.S. Code (1952), sec. 266)

The invention described herein may be manufactured and used by or for the Government of the United States of America for governmental purposes without payment of any royalties thereon or therefor.

The invention relates to an underwater transducing device and more particularly to a structure embodying a crystal of the barium titanate piezoelectric ceramic variety, compressional wave influence stressing structure and a new and novel manner of mounting and loading the same.

The instant invention is particularly adapted for low frequency underwater signalling and detection at frequencies in the range of 5 to 400 cycles per second and provides increased sensitivity characteristics over prior art underwater crystal type transducers.

Both the improved crystal mounting arrangement of this application and that of the copending application, supra, incorporate an assembly of a pair of disc configured centrally loaded Bimorph ceramic crystals, and a Sylphon bellows mounted at the periphery of the crystal plane for the purpose of masking the interior surfaces of the oil immersed Bimorph discs from signal energy. The term Bimorph as employed herein may be defined as indicating that two crystal elements are cemented together.

Although the prior type structure incorporates a relatively large Bimorph disc while the improved type incorporates a smaller disc both versions are subjected to bending moment loading under signal energy conditions to drive the crystals to a voltage output relationship under compressional and tensional stressing as hereinafter described in greater detail.

In hydrophones incorporating the large diameter Bimorph crystal discs it has been observed that the voltage increments developed across the crystal structure at the outer periphery thereof are of less magnitude than that of the voltage increments produced at the central portion of the crystal. The reason is apparent if a diametric cross section of the crystal is considered as a double cantilever beam wherein the outer extremity of the beam or the peripheral areas when taken as a disc, are subjected to less bending moment stressing and as a consequence thereof, less tensional stressing in the upper crystal of the Bimorph and compression in the lower crystal under positive signal load conditions. This relationship will be apparent when consideration is given to the relationship wherein a radial section across half of the disc is taken for analysis and considered as a cantilever beam with the support thereof at the center and a uniformly distributed load applied thereto by the input signal energy. This reduced voltage output at the outer edge or zone of the crystals resulting from bending moment effects is particularly evident when this output voltage effect occurring with tensional stressing in the upper crystal of the Bimorph and compressional wave loading of the transducer segments in the lower crystal of the two under a uniformly distributed signal lead is compared with that taken at the central zone portion thereof. This stressing under consideration is that taken in the plane of the crystal rather than the compressional effects which appear across the thickness thereof.

In the prior type hydrophone it appeared desirable to

connect the several electroded pairs of crystal elements of the transducers in a manner effecting a series relationship to provide an additive voltage output therefrom. However, it has been observed that in so doing, the segment configured crystal element electroded areas which extend to the outer peripheral edges, when considered on an incremental area basis, are in effect a group of voltage averaged increments appearing electrically as a voltage generator and a series capacitance, and connected in shunt with a similar generator and series capacitance for each of the adjacent incremental transducers thereSurrounding. The unequally stressed parallel coupled transducer generators at the disc periphery are subjected to less force and consequently less tensional and compressional voltage producing effects than that of the transducer increment near the center and therefore produce considerably lower output voltage.

This effect is particularly evident when the transducer segments comprise, respectively, a first or inner circular electroded area and a series of annular configurations in concentric relationship. The use of concentric segments for test purposes provides a means of comparison of the actual voltage output at various radial distances from the center. It has been determined by these tests that the additional capacitance resulting from the electroded area at the periphery produces increased voltage averaging and less total voltage output than that of a smaller centrally loaded crystal if driven by an annular metallic stressing member of the character of the instant invention and in an arrangement as herein embodied. This smaller diameter Bimorph transducer as driven by signal responsive arrangements of the hydrophone produces an increased total output voltage when compared to that of a larger crystal with less voltage averaging effect. It also provides resultant economy in crystal material and greater ease of production.

This improved device in essence overcomes the disadvantages of output averaging effects of electroded segment areas at the peripheral stressing zones which are apparent when consideration is taken with respect to the relationship as hereinabove described and occurring across either a group of annular segments or a radial extensive segment. The coupling of incremental transducive elements in both instances is such as to produce a shunt capacitance resulting from parallel electroded dielectric material and connects the same in parallel with each of the incremental crystals generative outputs. This shunting or averaging effect is not to be confused with the series capacitance existing due to distributed capacitive effects when segmented units are series connected to provide a voltage additive output from the entire series of segmental elements.

The instant invention is directed to a ceramic crystal type voltage generator of relatively small diameter, and a driver therefor providing bending type loading for the barium titanate piezoelectric material of a disc type Bimorph in a manner to produce an equivalent satisfactory voltage output therefrom with reduced capacitive characteristics over that of prior type large crystal units. Moreover, the instant invention obviates manufacturing problems involved in producing a crystal of comparatively large diameter which requires special manufacturing, polarizing and handling techniques to prevent breakage thereof and to insure the desired piezoelectric characteristics. In the present invention the crystal produces greater output than that of larger crystal units, with a considerably reduced crystal size and additionally provides for crystal loading of the same order whereby the Bimorph element and driver therefor are adapted for use in the same or a similar mounting structure environment in a hydrophone transducer.

In accordance with the foregoing, one feature of the instant invention resides in the provision of a highly sensitive underwater transducer incorporating a Bimorph ceramic type crystal element of reduced diameter over prior devices, and the provision of a driver element therefor for improved crystal response wherein all the advantages of prior art crystal loading devices are obtained with a more economical utilization of ceramic material and further wherein many of the disadvantages of such devices heretofore or now in general use are obviated.

One object of the instant invention resides in the incorporation of a plurality of signal sensitive driver elements for a plurality of disc type Bimorph crystal elements wherein improved crystal driving action is provided in conjunction with advantageous central loading thereof.

Another object lies in the advantageous signal stressing of Bimorph disc type ceramic transducer crystals with reduced capacitive averaging effects appearing in the voltage output therefrom.

An additional object resides in the provision of improved utilization of barium titanate ceramic type Bimorph transducer crystals thereby providing higher sensitivity and output characteristics in low frequency applications.

It is also an object of this invention to provide a transducer which is highly sensitive to low frequency signal intelligence in which transient peak signals of high intensity are limited by an overload device thereof and which functions in conjunction with the driver for the crystal element thereof to prevent damage thereto.

Other objects and many of the attendant advantages of this invention will be readily appreciated as the same becomes better understood by reference to the following detailed description when considered in connection with the accompanying drawings wherein:

FIG. 1 is an elevational view in vertical section showing the general construction of the hydrophone transducer and details of the annular drivers for the ceramic crystal elements;

FIG. 2 is a plan view of the hydrophone of FIG. 1;

FIG. 3 is an illustration in plan showing a single electroded crystal element;

FIG. 4 is a plan view of a ceramic disc showing a plurality of segmentally electroded areas thereon;

FIG. 5 is a diagrammatic view illustrating the signal loaded conditions of the pair of Bimorph crystals in a transducer assembly and a comparison of the developed voltage polarities under loading with the polarities at assembly under static conditions, and;

FIG. 6 is a diagrammatic illustration showing the manner of polarization and connection of a segmented Bimorph crystal of FIG. 4.

Referring now more particularly to FIG. 1 of the drawings wherein the showing is of a crystal mounting and loading structure of a preferred embodiment of the mounting arrangement therefor, the hydrophone generally indicated by reference character 1 comprises a support or base 2 to which is mounted a housing member 3 which provides a chamber 4 therein for reception of the crystal assembly generally indicated at 5.

The hydrophone assembly 1 is described with respect to a multi-segment transducer arrangement of one embodiment thereof as shown in FIG. 4. It is to be understood, however, that the continuous electrode surfaced crystal of FIG. 3 discloses structure in accordance with a preferred embodiment of the invention.

The transducer crystal mounting arrangement for either type of electrode configuration comprises a set of mounting bosses 6 which are integral with the housing to provide support for the Sylphon bellows element 7. The bosses are preferably provided on the interior of the housing assembly in order that the crystal assembly may be mounted within the chamber with a fluid medium 16 there surrounding and in sealed relationship with respect to the exterior housing. The chamber 4 is provided with a filling hole 8 in the bottom for the introduction of fluid to the interior thereof. The cap 9 functions to close this hole after the filling of the chamber with suitable fluid 16 such for example, as silicone oil or other liquid having an acoustic impedance similar to that of sea water. The cap 9 is inserted after all free or entrapped air or other compressible gas, other than that sealed within the gas bag 29 has been eliminated. Suitable seal between the housing and the cap is provided by the gasket or O-ring member 10 which is carried thereby.

The housing member 3 is attached by any suitable means, such for example as bolts 11 to the base member 2, and is adapted at the upper extremity thereof for mating engagement with a formed rubber cover element 12. The cover element is protected by a guard member 13 which maintains an assembled relationship of the cover 12 and housing member 3 by screws 14 or other suitable attachment arrangements. The guard member 13 is provided with suitable apertures at 15 for fluid communication between the exterior thereof and the rubber cover. The interior of the housing as enclosed by the rubber cover is adapted for the reception of hydraulic fluid 16 which provides signal communication between the rubber cover element 12 and the exterior surfaces of the crystal assembly indicated generally at 5. The crystal assembly is maintained in a fixed position by a screw mounted spider assembly 17 which is attached to the boss elements 6 provided in the housing and to which the bellows assembly is centrally affixed in interposed relation between the pair of crystal driver elements 18. The barium titanate circular Bimorph crystals 19 are attached to the bore of the metallic driver elements 18 by low dielectric constant cement 20 at the outer peripheral edges thereof. These elements 18 are in turn attached as by a spinning over operation, to the upper and lower extremities of the bellows at their respective peripheral face portions. The bellows functions as a mask to prevent transfer of signal energy from the fluid in chamber 4 to the interior Bimorph surfaces. It prevents voltage cancellation effects since it is substantially rigid to signal influence applied thereto in a radial direction while being extremely compliant to driver element movement in an axial direction. The crystal units 19 are loaded by a suitable loading assembly 21 at the center thereof which effects a substantially rigid loading under signal pressure but which yields in sliding frictional relationships to a bottoming condition under high amplitude energy such as produced by countermining explosions. The crystals are thus arranged in a parallel spaced relationship with suitable loading being provided by the assembly 21 which comprises a frictionally yieldable clamp 22 and a block member 23 respectively attached to the spaced crystals 19 by screw type fasteners 24 or other attachment arrangements. A clamping screw 25 is interposed between slots of the block for controlling the slip of the frictional surfaces at 26 between the clamp 22 and the block 23 to provide a predetermined loading at the centers of the crystal element for signal sensitive loading operation and to permit slip under adverse loading to thereby prevent crystal damage.

The electrical connections to the crystal elements are made at terminals 34 attached to screws 24 and brought out of the casing 3 through a sealing type insulated thru-panel terminal at 35 with the location on the casing bottom as shown in FIG. 2. The interelectrode connections are as shown in FIG. 6. One of the crystals as illustrated in FIG. 1 is provided with an orifice 27 for communication between the hydraulic fluid exteriorly of the crystal and the interior of the bellows system, and functions to filter out very low frequency changes such for example as tide effects.

The interior arrangement of the bellows assembly in-

cludes a cylindrical element **28** formed by the extension of the inner portion of the spider element **17**. It is so formed as to provide a generally tubular anti-overload element which extends therefrom into spaced adjacent relation with the inner surfaces of the pair of annular driver elements **18** for the pairs of Bimorph elements **19** to prevent damage to the crystal structures under adverse transient effects as may be encountered when a nearby mine or countermining explosion occurs.

The bellows assembly additionally includes an annular gas bag unit **29** which by way of example is shown in FIG. 1 as comprising an inner rubber sponge **30** and a rubber skin **31** in encasing relation therewith. This unit may however comprise any suitable cellular mass preferably of synthetic rubber which is resistive to any destructive effects thereon by the hydraulic fluid utilized in the unit. It is this unit which is compressibly deformed by the fluid **16** within the bellows when the crystals are subjected to, and deformed by, signal energy. As the crystals are returned to the normal condition thereof or are under negative signal wave energy effects by action of the stress relaxation in the deformed elements with reduction in signal energy intensity, the gas bag then reforms for the next succeeding positive signal cycle.

Although the drawing figures are directed to a device utilizing a pair of Bimorph units which are separated by a common bellows, and which incorporates a common central pillar for crystal loading purposes, it is within the scope of this invention to utilize a single Bimorph only; in which case one of the Bimorph and driver units would be replaced by a metallic member attached to the central support member **22** by screws **24** at the center and to the bellows in the same manner as illustrated, and which constitutes a circular disc rather than the annular driver and crystal arrangement shown in FIG. 1. This structural modification is not shown since it is believed obvious to one skilled in the art. The voltage output derived from such a modification would be proportionately less than for the preferred embodiment herein described.

In the operation of the hydrophone as mounted on a mine casing in sealed relationship therewith, the guard and cover external thereto are arranged to present the rubber cover in contact with the surrounding water in a manner whereby the signals transmitted through the fluid are passed by the openings in the guard structure to the effective diaphragm or cover. This rubber cover which is in fluid communicative relationship with the hydraulic fluid in the chamber has an acoustic impedance substantially equivalent to that of sea water as does the hydraulic fluid with which the hydrophone is filled. The sound energy thus imposed through the water to the fluid therein is transmitted in substantially undiminished relationship to the opposed surfaces of the polarized circular Bimorph discs and masked from the interior surfaces by the bellows structure.

The electrical characteristics of the barium titanate crystal as hereinbefore set forth are such as to produce voltage across the electrodes thereof as the Bimorph disc plates are deformed by application of signal pressure energy thereto and provide a radially uniform characteristic therefrom. The voltages derived from the electroded area or segments **32** on the ceramic discs **33** of FIGS. 3 and 4, which are initially polarized and assembled as shown in FIG. 6, and in FIG. 5 at the left edge of the Bimorph units, are effectively connected in series relationship from crystal segment to the next adjacent electrode segment in a manner to provide an output voltage representing the summation of the voltage developed across the several elements thereof with application of signals thereto. The signal load functions to alter the polarities of the tensionally stressed element of the Bimorph in a manner as shown at the center of FIG. 5. Since the outputs of all voltage generative segments are series additive the assembled relationship as to initial polarity of the upper Bimorph with respect to that of the lower Bimorph is reversed.

The signal may thereby be applied simultaneously to both the upper and lower Bimorph.

The fluid contained by the casing is permitted to pass through the bleed-off orifice **27** with very low frequency pressure changes such as may be due to tide and wave action. It provides a filter function which is analogous to an electrical inductance with some resistance. The fluid within the bellows, as displaced by signal energy loading action and applied to the drivers and the crystal units, functions to compress the rubber sponge gas bag within the bellows. This gas bag displays characteristics comparable to an electrical capacitance. This bag thereafter reforms or discharges with the negative cycle of the signal or with return of the crystal to normal position.

It is thus apparent that a hydrophone has been disclosed which may be used for signal reception or transmission and which provides properties of greater sensitivity to underwater signal influence applied thereto at low frequencies with a resultant economy in crystal size. The new and novel driving arrangement for the crystal when combined with the central loading arrangement and the peripherally mounted bellows suspension by which the crystal is substantially freely suspended provides improved voltage output characteristics and provides a relationship wherein adjacent segmental electrode plates may have the same polarity without detrimental effects. Furthermore the distributed capacitance effects of series connected crystal segments is minimized by use of smaller electrode areas than that of prior types.

The capacitive effects between the driver elements and the high dielectric constant ceramic is minimized by utilization of a low dielectric cement bond **20** therebetween and by suitable spacing of the electrodes from the driver.

Obviously many modifications and variations of the present invention are possible in the light of the above teachings. It is therefore to be understood that within the scope of the appended claims the invention may be practiced otherwise than as specifically described.

What is claimed as new and desired to be secured by Letters Patent of the United States is:

1. A low frequency underwater transducer of the character described, comprising a pair of parallel spaced Bimorph ceramic crystal elements, axial loading means therefor centrally disposed between said pair of Bimorph crystal elements, a pair of plate type annular driving members respectively for each of said pair of crystal elements affixed to the peripheral edge of said Bimorph crystal elements and extend outwardly therefrom, and a bellows type resilient signal masking means disposed between said pair of driver means and arranged coaxially with respect to said axial loading means.

2. A crystal hydrophone comprising a pair of parallel supported barium titanate Bimorph ceramic crystal elements, a pair of annular driver plate members comprising one respectively for each of said elements and connected to the peripheral edges thereof and extending radially therefrom, a resilient signal masking means extending between the outer peripheral edges respectively of said pair of driver means in concentric relation with said pair of ceramic crystal elements, and a crystal loading means for said pair of crystals and connected thereto in coaxial relationship with said masking means.

3. The hydrophone of claim 2 further characterized by a casing means therefor, fluid in said casing, said casing comprising a yieldable cover therefor adapted for receptive and transmissive response to signal energy applied thereto and for passing said energy therethrough to and from a fluid energy coupling means in said casing which is in signal communication with the external surfaces of said drivers and said pair of crystals.

4. In a hydrophone of the character disclosed, a casing, a yieldable cover therefor, a Bimorph ceramic crystal microphone therein, suspension means for said micro-

phone whereby the same is suspended from said casing, fluid means for signal energy coupling between said cover and said microphone, said microphone comprising a pair of parallel supported Bimorph ceramic crystal elements, a pair of annular driver means for said crystals and arranged respectively in concentric radially extending relationship thereto, an expansible bellows means peripherally attached to said pair of driver elements at the respective ends of the bellows and supported by said supporting means in the casing, and an axial loading means for said pair of crystals which is yieldable under excess loading conditions.

5. The structure of claim 4, wherein each of the crystal elements comprises a Bimorph structure having electroded areas oppositely disposed and in concentric relation with the crystal Bimorph.

6. A claim according to claim 5 in which the electroded areas are electrically connected in a series additive voltage output relationship.

7. The structure of claim 6 wherein the last named means in said microphone comprises a sealed annular gas bag element which is disposed about said axial loading means and between said pair of crystals.

8. The structure of claim 4, wherein the crystal elements comprise a plurality of segmented pairs of electroded areas, electrically connected in a series additive voltage output relationship in a manner to provide for signal reception thereby.

9. The structure of claim 4 further characterized by the inclusion of said microphone of anti-overload means supported by and connected to said support and extending in transverse spaced adjacently to said driver elements and in concentric adjacency to the inner surfaces of said bellows, and means interiorly of said anti-overload means and concentric with loading means for yieldably maintaining said fluid means disposed about said crystals and thereby positioning said Bimorph normally out of contact with said overload means whereby the crystals are aided in repositioning after application of overload stresses thereto.

10. The structure of claim 9 further characterized by the inclusion within said hydrophone of a collapsible annular gas bag disposed about said loading means and between said crystals, and a hydraulic fluid contained by said casing for coupling signal energy passed by said casing to the pair of outer crystal surfaces.

11. A Bimorph ceramic crystal hydrophone comprising a casing, a pair of parallel disposed disc configured Bimorph ceramic crystals in said casing, a pair of annular driver elements respectively for each of said crystals and connected by low dielectric constant cement in coplanar relationship respectively to the outer peripheral edges of each of said crystals, a bellows type supporting means coaxially arranged with respect to said pair of drivers and at the outer periphery thereof, and a yieldable loading device disposed centrally between the crystals, said loading device comprising a receiver element, a plunger element frictionally received by said receiver element and control means for maintaining a substantially rigid relationship between the plunger and receiver elements under normal signal intensity conditions and for permitting yieldable movement therebetween under overload signal energy conditions.

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