United States Patent

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[54] PIEZOELECTRIC TRANSDUCER CONFIGURATION

10 Claims, 4 Drawing Figs.

[52] U.S. Cl. 340/10
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[50] Field of Search 340/10

[56] **References Cited**

UNITED STATES PATENTS

3,094,636	6/1963	Gauld	340/10
3,202,962	8/1965	Elston	340/10
3,249,912	5/1966	Straube	340/10
3,255,431	6/1966	Howatt	340/10

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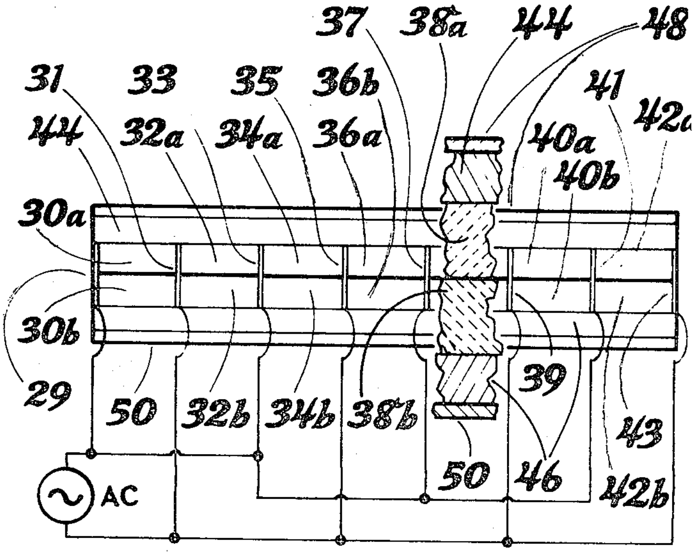
ABSTRACT: Piezoelectric transducer elements are polarized to vibrate in a number of different planes such as longitudinally, radially, or axially. Polarized flat disk or bar transducers have been severely limited in power-handling capacity because of the inherent weakness of the usual piezoelectric materials in tension. Applicant has found that flexural disk-type elements as well as "bender bar" types of transducers, all of which require that the piezoelectric elements be stressed in tension, gain very substantially in power-handling capacity when a thin layer of material, such as a metal plate, is bonded to the face exposed to tensile forces. Alternately, a laminate layer of glass epoxy was also found effective to improve the power handling capabilities of the transducers, and this has been found especially useful where an electrical insulating layer is required.



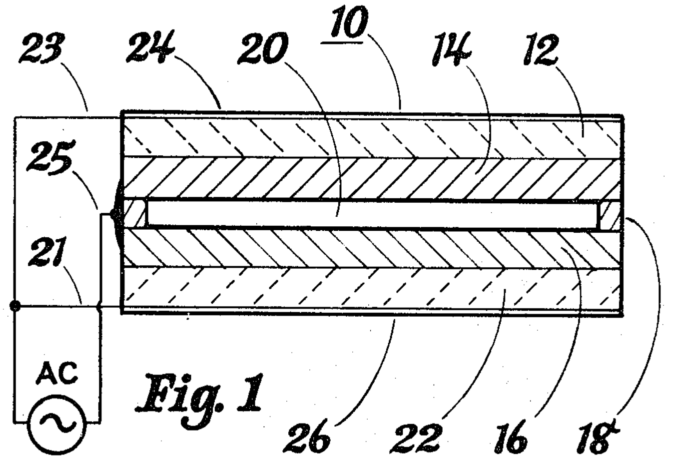


Fig. 1

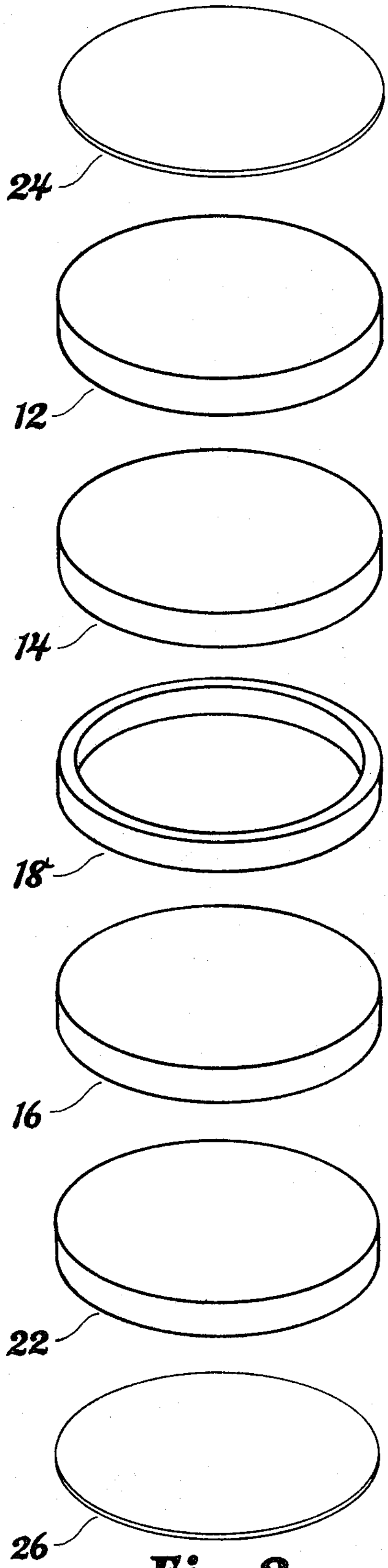
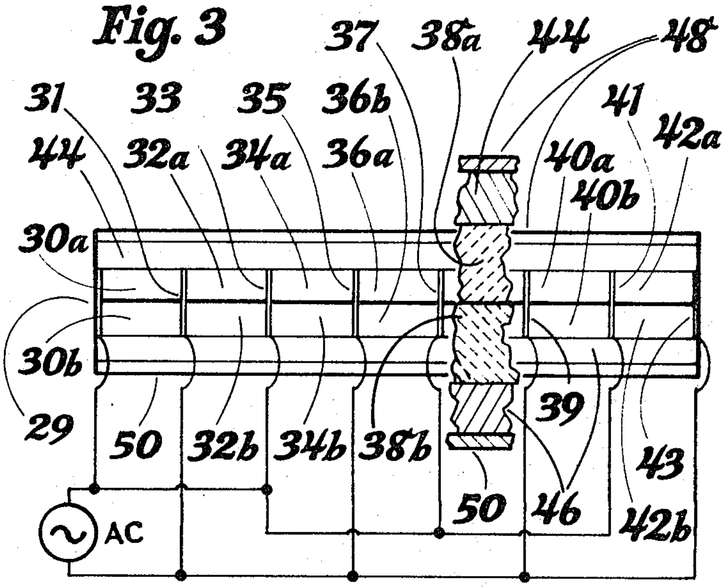


Fig. 2

Fig. 3



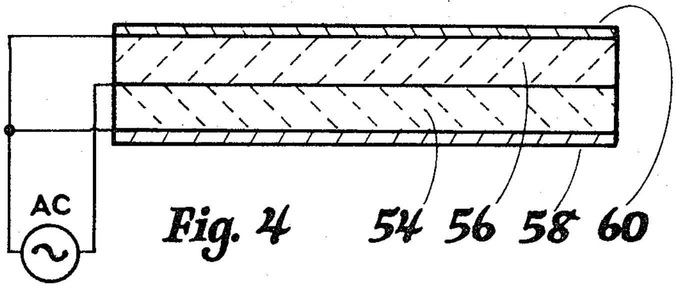


Fig. 4

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PIEZOELECTRIC TRANSDUCER CONFIGURATION

BACKGROUND OF THE INVENTION

Piezoelectric transducers have long been used to convert electrical energy to acoustic energy and vice versa. These transducer elements deform along a given axis in response to an electrical AC input signal, depending upon how the material is polarized. Piezoelectric materials such as barium titanate and lead zirconates have characteristics of ceramics in that they are strong in compression, but weak in tension. Most piezoelectric transducers have been manufactured (poled) to vibrate longitudinally or radially. Longitudinal vibrators formed of a series of axially poled rings have been prestressed by being compressed between top and bottom housing members by means of a through bolt. Other transducers have been formed in a bar with alternate oppositely poled segments to form a "bender bar" type of transducer. A single segment may also act as a flexure bar or be formed as a disk which deflects in "oil can" fashion. Disk-type transducer elements have had limited use because of stress limitations. Their power-handling capabilities are severely limited because they normally crack and break from physical stress long before they become electrically depolarized.

SUMMARY OF THE INVENTION

Disk-type piezoelectric transducers are normally thickness polarized (along an axis perpendicular to its faces), and in order to accomplish the polarization, a very thin plating of highly conductive material such as silver or copper is placed on each face, with output terminals attached to each plated surface. Numerous failures of these disk elements at moderate power output, apparently from tensile stress during vibration, prompted applicant to bond a prestressed metal disk to the surface of the disk. This gave rise to a very substantial improvement in power output. It was later determined that prestressing of the metal disk was not required and that much the same results could be obtained with an unstressed metal disk. The same technique was found effective with a flexural bar or with a bender bar of many separate segments. In this latter case the problem of short circuits across the segments made it desirable to use a nonconductive reinforcing laminate, and a glass epoxy layer was also found to be effective to permit substantially higher power output from a bar of a given size.

DESCRIPTION OF THE PREFERRED EMBODIMENTS

FIG. 1 shows, in section, a disk-type transducer **10** in which two disk elements are arranged back to back. One such element consists of a disk of ceramic piezoelectric material **12** having a thin layer of highly conductive material such as silver or copper plated to each face. Each face thus becomes an electrode and is connected to a source of alternating current. The face is bonded to a backing member of metal including two parallel plates **14** and **16** separated by a radially compliant spacer ring **18** leaving an air space **20**. Plates **14** and **16** are typically of about the same thickness as disk **12**. Plate **16** is bonded to a second ceramic disk **22** which is identical to disk **12**. Thin metal disk **24** and **26**—ordinarily from 0.001 to 0.020 inch thick, depending upon the diameter of the transducer and its desired frequency range—are bonded to the faces of the ceramic disks **12** and **22**. Electrical leads **21, 23, 25** are connected as shown so that an alternating current may be impressed across the opposite faces of the ceramic disks.

The members of FIG. 1 are shown in an exploded view in FIG. 2. Members **14, 16** and **18** are shown separated. These members are normally bonded together to form a flat cylindrical member with an airspace in the center. The transducer operates in the buckling or "oil can" deflection mode with each of the separate transducer elements moving outwardly and inwardly at the same time. Outward deflection places the outside surface in tension, and without the thin metal laminate layers **24** and **26** the transducers are limited in the power they can delivery because of the lack of tensile strength of the ceramic disks. By bonding the thin metal disks **24** and **26** to

the ceramic disks as shown, it has been found that the permissible deflection and hence the power-handling capacity may be increased by up to about four times. Both prestressed and unstressed members **24** and **26** have been used, and both are satisfactory. It appears that no advantage is conferred by prestressing these disks. The bonding may be accomplished through the use of a strong epoxy cement such as Epon VI manufactured by Shell Chemical Company. The cement should not be too thick or stiff since this could cause breakage of the bond during operation and will tend to stiffen the entire transducer thus raising its frequency and reducing its bandwidth.

The same technique is shown in FIG. 3 in connection with a bender bar type of transducer. In this type of transducer a series of bars of piezoelectric material **30*a*, 30*b*, 32*a*, 32*b*, 34*a*, 34*b*, 36*a*, 36*b*** are connected side by side in series and back to back such that electrode segments **29, 31, 33, 35, 37, 39, 41,** and **43** are poled alternately. Thus upper segments are oppositely poled with respect to those immediately below with the result that the upper segments tend to expand while the lower ones contract. Exactly the opposite happens in the next half-cycle so that the bar will tend to bend back and forth in synchronism with applied alternating current. As in the case of the disk transducer, the expansion causes tensile stress in the transducer, and ordinarily this would limit the power-handling capacity of the transducer on a structural basis. Because the bonding of a metal laminate directly to the transducer faces would result in shorting the electrodes positioned between the segments, a layer of insulating material **44, 46** such as glass epoxy resin is bonded to each of the top and bottom faces of the segments, and a metal laminate strip **48, 50** is then attached to each such layer such that this strip is insulated from the electrodes. It has been found that considerable advantage may be gained by using the glass epoxy resin alone, but for maximum strength the metal laminate should be used in combination with the insulating layer.

FIG. 4 is a sectional view of flexural bar transducer using two ceramic transducer elements **54** and **56** together. When this arrangement is used, each bar opposes the expansion of the other, thereby exciting flexural vibrations, and thus tends to perform some of the functions of the heavy metal plates **14** and **16** shown in FIG. 1. With current connected as shown, the bars **54** and **56** will tend to bow outwardly during one half-cycle and inwardly during the oppositely half-cycle. A layer of highly conductive material, such as silver, is plated to each side of bars **54** and **56**, and each layer is connected to an alternating-current source as shown. Thin metal laminate bars **58** and **60** are attached to each of transducers **54** and **56**, respectively, and these serve to extend the amount of deflection which can be tolerated by the transducer elements in the same manner as described above.

It is believed that the reason for the inherent limitation in power-handling capacity experienced with transducers having no bonded laminate layer is that the ceramic material always has minute surface cracks which initiate catastrophic failure as the element is caused to deflect beyond a given amount. By bonding a material having high tensile strength to the surface, the ceramic surface is given a greater integrity, the stress is distributed over a higher strength material, and growth of these cracks is inhibited to the point where structural failure becomes a less sever limitation on operation than does electrical depolarization of the transducer elements. This invention is not limited to the specific forms of piezoelectric transducers shown but may be used for other shapes where tensile forces tend to limit the power-handling capacity of the transducers. Both insulating and conductive materials may be used for this purpose, as described, or both may be used together. It will also be apparent that the teachings of the present invention apply both to transmitting and receiving transducers. Thus a receiving transducer made as described may be exposed to larger acoustic forces resulting in greater deflection and greater voltage output through the use of elements made according to the present invention.

I claim:

1. An underwater transducer for converting electrical energy into acoustic energy and operative in the bending mode for projecting said acoustic energy into the surrounding water comprising
   - at least one member of piezoelectric material having oppositely directed faces of significant area polarized such that when energized at least one of its faces is subject to tension forces,
   - a backing member of substantial stiffness positioned adjacent the opposite face of said member,
   - electrode means fastened to both of said opposite faces, and
   - a layer of material of higher tensile strength than said member bonded to said one face, said layer being sufficiently thin that it has negligible effect on the frequency characteristics of said transducer.

2. A transducer as set forth in claim **1** wherein said member and said backing member comprise disks, said backing member being of substantial thickness and being bonded to said member and said member being polarized and mounted such that said disks vibrate in flexure as a unit parallel to the axis of said transducer.

3. A transducer as set forth in claim **2** wherein two pairs of said disks are arranged back to back and are spaced from each other by means providing an airspace between said backing members, and said backing members are electrically connected to adjacent electrodes to form one side of an electrical circuit and the remaining electrodes are connected together to form the opposite side of said circuit.

4. A transducer as set forth in claim **1** wherein a plurality of individual flexural segments of piezoelectric material are alternately poled and mechanically positioned to form a bender bar, said segments are assembled in layers such that each layer acts as a backing member for the other, and one of said layers is bonded to each exposed face of said bar, said layers being formed of high-strength insulating material.

5. A transducer as set forth in claim **4** wherein each of said layers also includes a thin metal strip separated from said segments by said insulating material.

6. An underwater transducer for converting electrical energy to acoustic energy and operative in the bending mode for projecting said acoustic energy into the surrounding water comprising
   - first and second thickness polarized disks of piezoelectric material including electrode means,
   - first and second disk-shaped metal backing plates bonded to one face of said first and second piezoelectric disks respectively,
   - a radially compliant spacer member fastened to said first and second backing plates such that an airspace is confined between said backing plates, and
   - a layer of material of substantially higher tensile strength than said piezoelectric material bonded to each opposite face of said disks, said layer being sufficiently thin that it has negligible effect on the frequency characteristics of said transducer.

7. A transducer as set forth in claim **6** wherein each said layer of material comprises a thin metal disk.

8. A transducer as set forth in claim **6** wherein said metal backing plates are substantially the same thickness as said piezoelectric disks.

9. A method of making disk-type transducers for projecting acoustic energy into the surrounding water comprising the steps of
   - forming a first disk of piezoelectric material polarized such that when energized with an electrical alternating current signal it tends to vibrate perpendicular to its faces,
   - forming a backing member comprising a second disk of substantial stiffness and of essentially the same dimensions as said first disk,
   - bonding said first disk to said second disk,
   - forming a very thin disk of material having substantially greater strength in tension than said piezoelectric material,
   - and bonding said thin disk to the opposite side of said piezoelectric material from said second disk.

10. A method of making piezoelectric transducers of the type which, when energized, have at least one surface stressed in tension comprising
    - forming said transducer of piezoelectric material to the desired shape and connecting electrodes thereto,
    - bonding a backing member of substantial stiffness to another surface of said transducer, and
    - bonding a thin layer of material having substantial strength in tension to said one surface of said transducer.

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