Aug. 18, 1959 M. M. PALO **2,900,536**

DESIGN OF ELECTRO-MECHANICAL TRANSDUCER ELEMENTS

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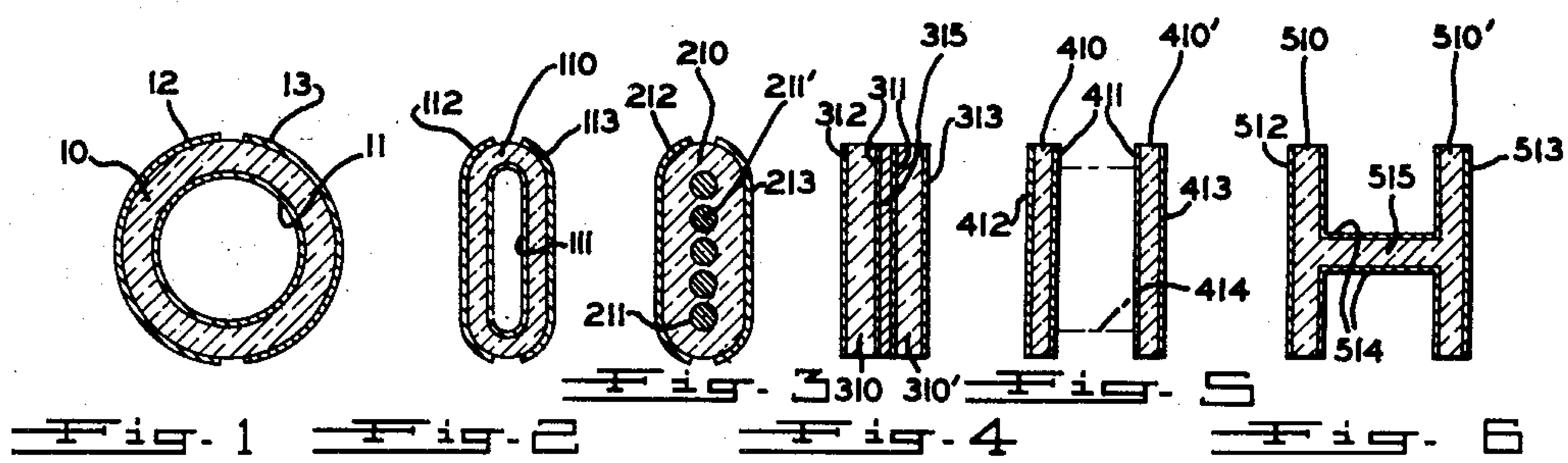

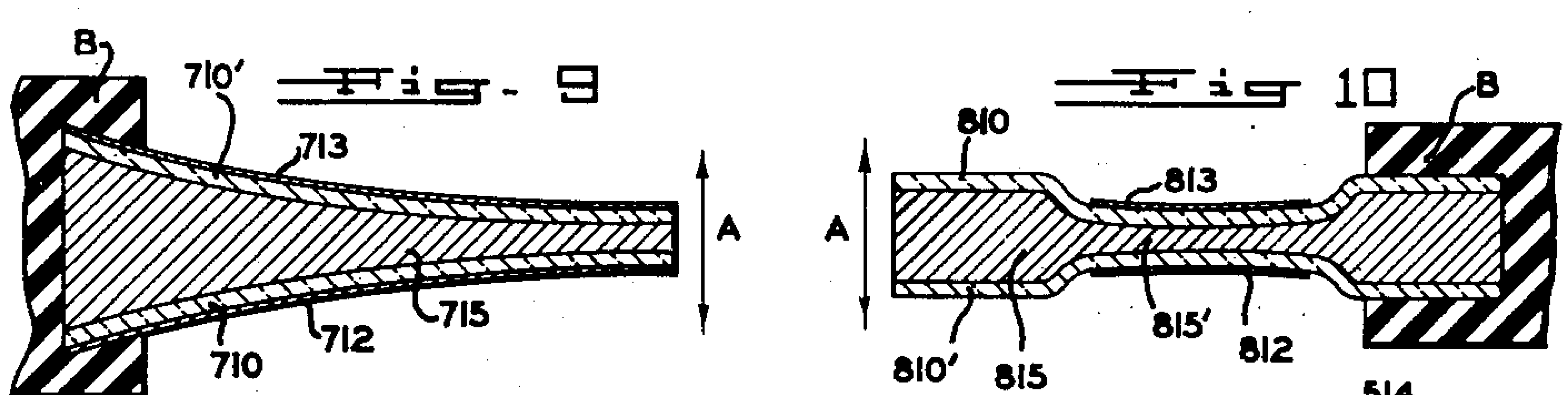

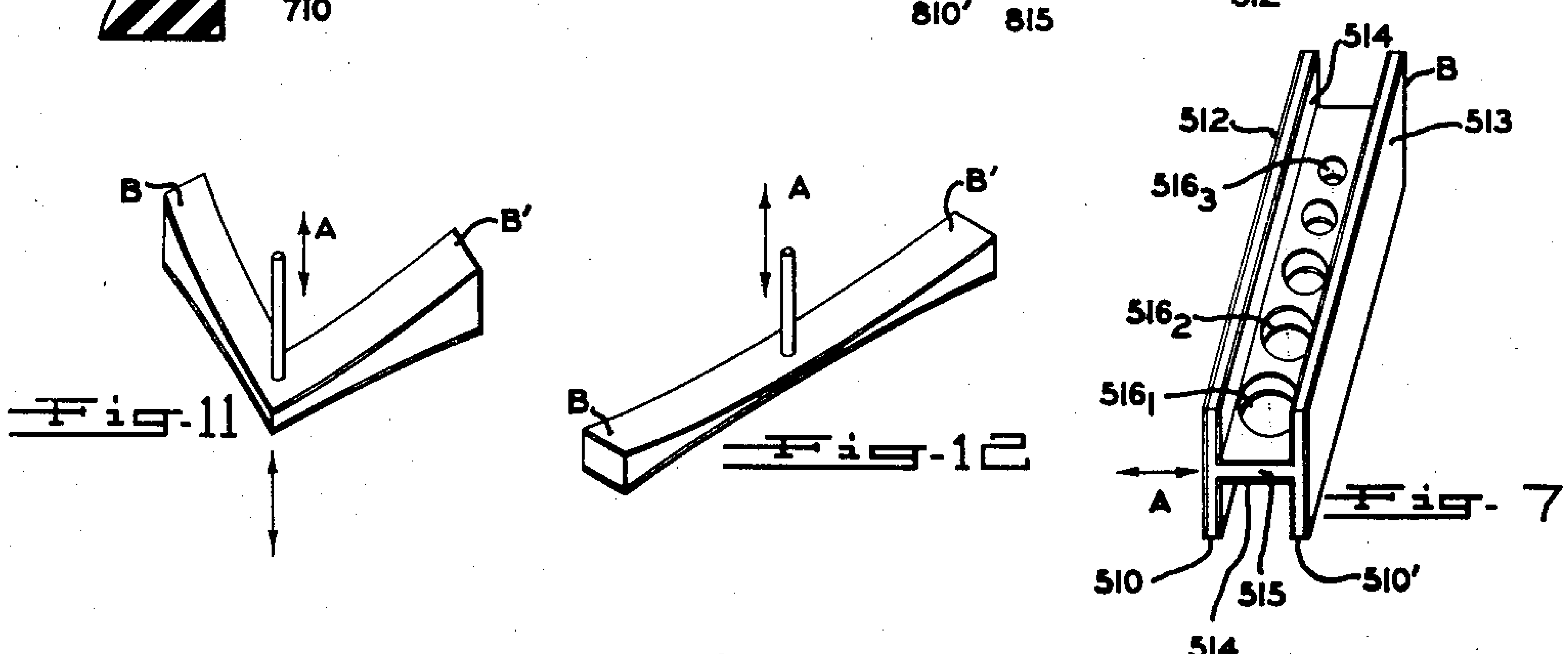

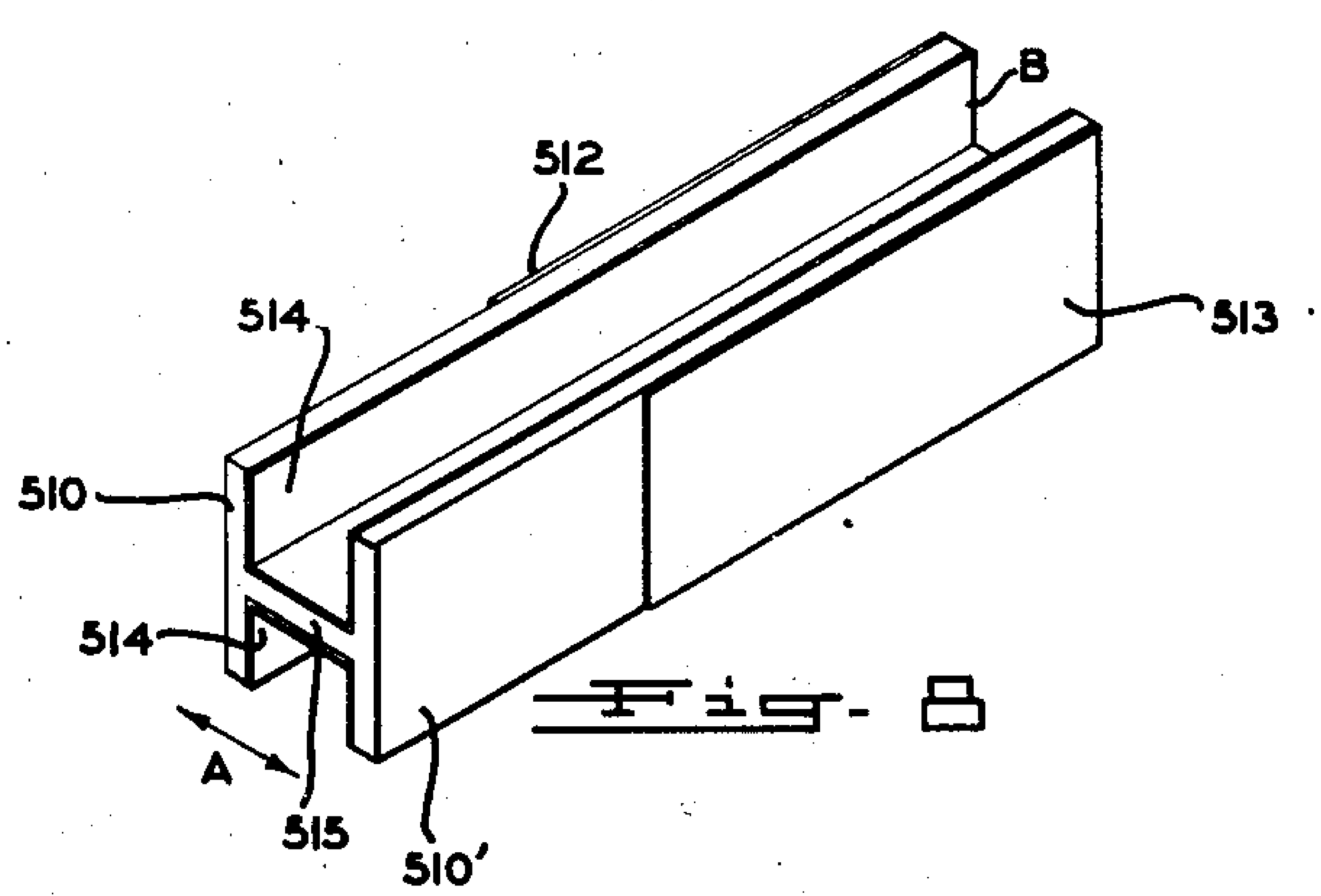

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DESIGN OF ELECTRO-MECHANICAL TRANSDUCER ELEMENTS

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The present invention relates generally to the art of converting mechanical vibrations and movements into electrical signals, and has particular reference to improvements in the design of piezo-electric transducer elements of the type commonly employed in phonograph apparatus, microphones, and the like.

As an overall object, the present invention seeks to provide piezo-electric transducer elements of novel and practical design, having improved physical and electrical characteristics rendering the elements more suitable for specific intended applications.

More specifically, it is an object of the present invention to provide an improved transducer element which substantially approximates certain desired ideal characteristics of a physical and/or electrical nature, while at the same time being capable of economical commercial manufacture. In this respect, the invention contemplates the provision of an improved transducer element which may be formed of extruded ceramic piezo-electric material, such as barium titanate, for example, and which is possessed of certain ideal characteristics heretofore impossible or difficult of obtainment.

Another specific object of the invention resides in the provision of a novel and improved piezo-electric transducer element adapted upon bending or flexing thereof to generate electrical charges or signals wherein the charges or signals produced therein are uniform, or substantially so, over the entire extent of the active portion of the transducer. It will be understood, of course, that electrical charges or signals generated by piezo-electrical elements are proportional to the severity of the flexing or bending thereof. It follows that where the bending or flexing of the element is of changing severity over the active extent of the element the charges produced in different areas or sections of the element will vary accordingly. Thus, it is one of the objects of this invention to provide transducer elements of such design that the stressing of the active piezo-electric portions thereof is uniform throughout, as is the electrical charge or signal produced thereby.

The above and other objects and advantages of the invention will become apparent upon full consideration of the following detailed specification and accompanying drawing wherein are disclosed certain preferred embodiments of the invention.

In the drawing:

Figures 1–4 are enlarged cross section views of certain piezo-electric elements of heretofore known design;

Figure 5 is an enlarged cross section view of a piezo-electric element of theoretical design, having certain ideal characteristics;

Figure 6 is an enlarged cross section view of a piezo-electric element embodying the teachings of my invention and closely approximating the theoretically ideal design of Figure 5;

Figure 7 is a perspective view of a modified element of the type shown in Figure 6;

Figure 8 is a perspective view of a further modification of the element shown in Figure 6;

Figures 9 and 10 are enlarged section views of transducer elements incorporating further teachings of my invention; and

Figures 11 and 12 are perspective views of further modifications of the transducer element of Figure 9.

Referring now to the drawing, and initially to Figures 1–4 thereof, the numeral **10** designates an extruded ceramic piezo-electric member of substantially circular tubular cross section. The member so represented is a common type of element, known in the art, and is provided with a continuous inner electrode surface **11** and separate outer electrode surface portions **12** and **13**. The complete element is in the form of a tube, which, upon side-to-side bending movements is placed under compression along one side and under tension along the opposite side, the arrangement being such that electrical charges of opposite polarity are built up along the opposite sides of the element, the charges being drawn off through the electrodes **12** and **13** for amplification in any wall known manner. It will be observed, of course, that in any side-to-side bending movements about a vertical axis the extreme side portions of the element will be most greatly flexed, while the upper and lower portions, being close to the axis of flexure, will be but slightly affected.

In the element of Figure 2 the tubular ceramic body member **110** is of a more or less oval cross section, having flattened side portions, so that during side-to-side bending movements about a vertical axis there is a more uniform stressing of the side wall portions over any cross sectional portion of the element. Moreover, the structural characteristics of the element of Figure 2 are more desirable for certain purposes since, as will be readily observed, there will be substantial compliance to bending in transverse directions, with little compliance to bending in vertical directions. As in the case of the element of Figure 1, a continuous inner electrode **111**, and separate outer electrodes **112** and **113** are provided, the inner electrode being employed in initially polarizing the element while the outer electrodes are employed to pick up the charges or signals developed during flexing of the element.

In Figure 3, there is an essentially oval extruded ceramic body member **210** having outer electrodes **212** and **213** and a plurality of core filaments **211'** in tubular openings **211** provided therefor. In this instance, the core filaments **211'** take the place of the inner electrode. Otherwise, in its essential characteristics, the element of Figure 3 is equivalent to that of Figure 2.

In Figure 4 there is shown a transducer element having preferred operating characteristics, but which is somewhat undesirable from the standpoint of cost of manufacture. In this element a pair of flat ceramic plates **310** and **310'** are provided with outer electrode coatings **312** and **313** and inner electrode coatings **311**. The plates **310** and **310'** are soldered or otherwise bonded to a center plate or vane **315** of brass or similar material. The vane **315** constitutes a neutral plane about which the ceramic plates are bent to generate the desired electrical signals.

In Figure 5 there is shown a theoretically ideal transducer assembly wherein two flat ceramic piezo-electric plates **410** and **410'**, having the proper electrode coatings **411**, **412** and **413**, are maintained in relatively widely spaced relation by means of a theoretical infinitely compliant material, indicated by broken lines **414**. In this theoretically ideal element lateral or side-to-side bending forces will efficiently place the spaced ceramic plates under tension or compression, depending upon the direction of the bending force; and, as will be readily understood, the tension and compression forces so produced will be substantially uniform throughout the whole of the cross section of the plates **410** and **410'**, as compared to the element of Figure 4, for example, where bending forces will cause negligible tension or compression forces adjacent the vane **315**, constituting the neutral bending plane.

In accordance with the teachings of the present invention, as represented in the embodiment of Figure 6, I may realize the various production and other advantages inherent in the designs of Figures 1–3, while realizing the various operating advantages of the designs of Figures 4 and 5. Thus, in the cross sectional view of Figure 6 there is shown a transducer element which has a body portion of H-shaped section, which is preferably formed by extrusion processes or suitable ceramic piezoelectric material. The vertically extending flanges **510** and **510'** of the H-shaped section constitute the active operating portions of the transducer element, and are equivalent to the spaced ceramic plates **410** and **410'** of the theoretically ideal transducer element of Figure 5. Suitable electrode coatings **512** and **513** are provided upon the outer surfaces of the flanges **510** and **510'** in the conventional manner.

Connecting the flanges **510** and **510'**, and maintaining the same in spaced relation, is a center web section **515** which is preferably of a minimum thickness consonant with the required physical strength of the element for the application intended. An inner electrode is of course required for initially polarizing the element, and for this purpose separate conductive coatings **514** are provided about the upper and lower inside surfaces of the H-shaped section, in the manner shown in Figure 6.

It will be observed that the transducer element of Figure 6 closely approximates the theoretically ideal section of Figure 5, being modified only by the provision of a thin connecting web **515**. The arrangement is such that an efficient push-pull stress relation is produced during side-to-side bending movements of the transducer element so that most effective use is made of the active portions of the element.

In Figure 7 there is shown a modification of the element of Figure 6 wherein further provisions have been made to insure even distribution of bending stresses throughout the whole of the element. In many applications of piezo-electric elements the same are fixedly mounted at one end while being drivingly connected at the other end to a movable member such as the record engaging stylus of a phonograph apparatus, for example. The element is thus supported in the manner of a cantilever beam, and when the free end is flexed bending stresses are set up within the beam or element which increase from the free to the fixed end of the element. And, of course, since the magnitude of the electrical signal generated varies in accordance with the severity of the stress imposed upon the ceramic material the signal will vary over the unsupported length of the element. In such cases the full capacity of the element is not realized, and in some instances the fidelity of reproduction may be less than could or should be realized from the element.

In the element of Figure 7 the upper end of the element, designated as "B," would be the fixed end in a complete transducer assembly, while the lower end, designated as "A," would be the free end, being connected by suitable means to a phonograph stylus or other detecting device, not shown. As will be observed, the web member **515** is provided with a series of holes or apertures 516_1–516_3 along its length, the size of the apertures decreasing from the free end A toward the fixed end B of the element. In this manner the physical strength of the element is progressively reduced toward the free end A; and when side-to-side vibratory forces are applied to the end A the element will be flexed substantially uniformly along its entire length. It is thus possible to realize a maximum effective operating efficiency from the transducer element.

In the embodiment of Figure 8 there is shown another embodiment of the element of Figure 6 wherein means are afforded for utilizing the areas of the transducer element which are most greatly stressed during operation thereof. Thus, in the embodiment of Figure 8 the element is of substantially uniform strength throughout its length, so that when assembled as a cantilever beam, with the fixed end at B and the free end at A, stresses caused by side-to-side forces applied at the free end A will cause the greatest stresses at and adjacent to the fixed end B. Accordingly, I propose to provide only the portion of the element adjacent the fixed end B with conductive electrode coatings **512** and **513**. As will be readily understood, this will render the element more sensitive or responsive to movements of the free end A, but will correspondingly reduce the electrical capacity of the overall unit. Therefore, the requirements of various particular applications will determine the most proper balance of the two factors.

Referring now to Figure 9, there is shown a preferred type of transducer element having special contours so that when bending forces are applied thereto a uniform stress is created in the active ceramic portions thereof in the manner desired. The element of Figure 9 is fixedly mounted at its left hand end B, in any suitable manner, and is connected at or near its free end A with a record engaging stylus or other device for detecting vibratory mechanical movements. The center portion of the element **715** may be of brass or other conductive material and is provided along each outer surface with a layer of ceramic piezoelectric material, as indicated at **710** and **710'**. At the outer surfaces of the ceramic layers **710** and **710'** are provided conductive electrode coatings **712** and **713**, the conductive vane or center member **715** constituting an inner electrode for polarization purposes in this case.

In accordance with the teachings of the invention the vane **715** and/or ceramic layers **710** and **710'** are so contoured with respect to the load applied thereto that upon application of the load the transducer element will bend uniformly throughout its length. In this manner the ceramic layers are uniformly stressed throughout and most efficient use is made of the element. It will be understood, of course, that actual longitudinal cross section of the element taken along the plane illustrated will vary according to the type and manner of application of application of the side-to-side force, as well as the longitudinal cross section taken along other planes. The basic principles of forming a beam having uniform strength in bending are well known in the structural arts, for example, and in general these same principles are applied in the present case in obtaining a beam-like transducer element having a primary characteristic of uniform strength in bending throughout its entire active length.

In Figures 11 and 12 are shown modifications of the element of Figure 9 wherein the element is anchored at opposite ends, B and B', with the vibratory activating force being applied intermediate such fixed ends. The general structure of the elements of Figures 11 and 12 is similar to the element of Figure 9, having reference again to the nature and application of forces thereto in order to arrive at a cross section which uniformly resists bending throughout its unsupported length.

In Figure 10 there is shown a further modification of the element of Figure 9 wherein the center portion or vane **815** is formed with a portion of reduced cross section adjacent its fixed end B. The arrangement is such that upon application of lateral forces at the outer or free end A of the element the bending stresses are highly concentrated at the portion of reduced cross section. Electrode coatings **812** and **813** are applied only at the area of reduced cross section, and accordingly the element is highly responsive or sensitive to any movements of the outer end A. In addition, the area or reduced cross section is so contoured, in accordance with the teachings set forth above, that the stresses produced therein are substantially constant throughout the entire length of the area.

It should thus be apparent that I have fulfilled the objects initially set forth. The invention consists basically in the provision of transducer elements having improved physical and electrical characteristics, and to this end I have provided a novel ceramic piezo-electric element of H-shaped cross section having operating characteristics closely approximating a theoretically ideal transducer element, and having the further important advantage of being capable of manufacture by economical extrusion processes. The element referred to is so arranged that a substantially uniform push-pull stressing of the active elements results at any cross sectional layer thereof during side-to-side bending movements of the element.

It should be particularly observed that since the piezo-electric elements of the present invention are of the ceramic type, preferably of barium titanate, the lattice structure of the material is polycrystalline and as such can be and is polarized in desired orientations throughout various desired sections of the physical body. Thus, in the body of Figure 6, for example, it is possible to orient the polerization in the two slab sections **510** and **510'** in such a manner that the generative effect across the thickness of these slabs upon bending of the element as herein discussed is in series and thus additive when the electrical output of the element is taken from the two outer electrodes **512** and **513**. Such polarization of piezo-electric elements comprising spaced slabs of polycrystalline material is in accordance with standard practice and is well known to those skilled in the art as is evidenced by the prior art patent to Howatt, No. 2,640,165.

In addition, the invention teaches a novel arrangement for proportioning a transducer element throughout its length so that the bending stresses therein are uniform under the load applied. In this manner the electrical charges produced are uniform throughout the length of the element, and a maximum operating capacity may be realized therefrom. In combination with this latter feature, or in some cases independently thereof, I may provide a conductive electrode coating over only a portion of a complete transducer element, that portion being at and adjacent the area at which the greatest stress occurs during bending of the element. By this arrangement the transducer is rendered accurately responsive to applied bending forces.

It will be understood, however, that the embodiments herein shown and specifically described are intended to be illustrative only, and reference should therefore be made to the following appended claims in determining the full scope of the invention.

I claim:

1. A piezo-electric transducer element comprising spaced layers of polarized polycrystalline piezo-electric material disposed in symmetrical relation to a principal longitudinal neutral plane, means interconnecting said spaced layers, said element being adapted to be fixedly mounted at one end portion and flexed at its other end portion, and electrode means covering only portions of said element which upon bending of the electrode are subtsantially uniformly stressed.

2. An element according to claim 1 wherein said electrode means cover only a portion of said element adjacent the fixed end thereof.

3. A piezo-electric transducer element comprising spaced parallel layers of polarized polycrystalline piezo-electric material disposed in symmetrical relation to a principal longitudinal neutral plane, a thin web-like member disposed transversely to said layers and interconnecting the same at their inner principal surfaces, each of said layers having electrode means on their outer principal surfaces, said element being adapted to be fixedly connected at one end portion and flexed at its other end portion, and said web-like member being structurally weakened progressively toward the free end of said element.

4. A piezo-electric transducer element comprising spaced parallel layers of polarized polycrystalline piezo-electric material disposed in symmetrical relation to a principal longitudinal neutral plane, a thin web-like member disposed transversely to said layers and interconnecting the same at their inner principal surfaces, each of said layers having electrode means on their outer principal surfaces, said element being adapted to be fixedly connected at one end portion and flexed at its other end portion, and said web-like member having a plurality of apertures therein of progressively decreasing size in a direction from the free end of said element to the point at which said element is mounted.

5. A piezo-electric transducer element comprising spaced parallel layers of polarized polycrystalline piezo-eletcric material disposed in symmetrical relation to a principal longitudinal neutral plane, a thin web-like member disposed transversely of said layers and interconnecting the same at their inner principal surfaces, each of said layers having electrode means of their outer principal surfaces, said element being adapted to be fixedly connected at one end portion and flexed at its other end portion, and said electrode means covering only a portion of said element adjacent the fixed end thereof.

6. A piezo-electric transducer element comprising spaced layers of polycrystalline piezo-electric material disposed in spaced relation to a principal longitudinal neutral plane, a thin web-like member disposed transversely to said layers and interconnecting the same at their inner principal surfaces, each of said layers having electrodes on its inner and outer principal surfaces whereby said spaced layers may be initially polarized so that upon bending of said element in a direction transversely of said layers and said neutral plane the generative effect across said electrodes on said outer principal surfaces of said layers is in series and additive.

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