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ROD-MOUNTED PLURAL CRYSTAL ASSEMBLY
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The present invention relates to the rod-mounting of oscillating or transducing structures. The term "transducer" will hereinafter be used generically to indicate any device capable of producing physical vibrations or converting applied physical vibrations into some other form of energy.

There are many instances where transducers must be located remote from the point where the oscillations are to be rendered active or sensed. Means must be provided for accurately transmitting the vibrations between the transducer and that point. Such means may comprise a rod, wire, or other elongated structural member (hereinafter generically designated by the term "rod"). It is a prime object of the present invention to mount a transducing element in such a way as to facilitate the transfer of vibratory energy between itself and the vibration-transmitting rod. It is a further prime object of the present invention to simplify the construction and arrangement of transducing assemblies.

To these ends, the transducing elements are in the form of plates or sheets adapted, when suitably actuated, to vibrate or oscillate in a direction substantially perpendicular to their normal shape. The plates are mounted directly on the rod which is to transmit vibrations between the transducing elements and some remote point. The rod physically supports the transducing elements, and constitutes substantially the entire support therefor. The areas of these elements remote from the points where the elements are physically mounted on the rod are therefore free to vibrate, the inertia of the transducing elements themselves conveying these vibrations to the rod.

An assembly of this type is particularly well adapted for the mounting of an array of transducing elements on a rod, the elements being appropriately spaced along the rod so as to not to interfere with one another. By means of such an array, appreciable amounts of power may be handled by the assembly, while at the same time relatively inexpensive and easily assembled units may be produced.

While the structure of the present invention is of quite broad applicability to any system where vibrations are to be transmitted between remote points by means of a rod or the like, the fact that the transducing elements are carried only by the rod, and that a plurality of relatively small transducing elements may be combined in an array, makes the present invention particularly applicable for use in self-contained and readily manually manipulatable oscillatory devices, such as probes or supersonic drills.

In accordance with the present invention, multilaminar plates are employed as the transducing elements, those plates being formed of materials of such types and so arranged as to alter their physical dimensions in different ways as electrical signals are applied thereto, the conjoint effect of these dimensional changes being such as to cause the plates to flex. Since the plates are supported on the rod or other structural elements substantially only at a single point, that point preferably being at their center of mass, the vibration of these plates as the electrical signal applied thereto varies will, because of the inertia of the plates themselves, be transmitted to the rod on which they are mounted, thereby causing that rod to vibrate in a corresponding manner. In one em-

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bodiment here illustrated, the plates are formed of piezoelectric material, two layers of which are so polarized and so electrically connected that, upon the application of a given electrical signal to the opposite electrodes of each layer, one layer tends to expand radially while the other layer tends to contract radially. This causes the plate to tend to "dish," the maximum amplitude of the dishing movement occurring at the center of the plate, where it is mounted on the rod. In a second illustrated embodiment in which the same type of movement is realized, each transducing element is formed of a plurality of layers of thermo-electric material, some of those layers tending to expand and others tending to contract when a current is passed therethrough, expansion or contraction depending upon the direction in which that current flows.

Through appropriate mechanical design, the assembly may be made to resonate at a predetermined frequency, and it will most efficiently transduce oscillations at that frequency. The resonant frequency of a given assembly may be varied within limits by the application thereto of simple loading elements which may readily be attached or detached.

To the accomplishment of the above, and to such other objects as may hereinafter appear, the present invention relates to a transducer structure, as defined in the appended claims, and as described in this specification, taken together with the accompanying drawings in which:

FIGURE 1 is a cross-sectional view of one embodiment of the present invention, the electrical connections thereto being schematically shown;

FIGURE 2 is a schematic view of the electrical connections to and the electrical polarization of a single transducing element of the assembly of FIGURE 1;

FIGURE 3 is a cross-sectional view on an enlarged scale of an alternate embodiment of the present invention;

FIGURE 4 is a fragmentary cross-sectional view illustrating one way in which the resonant frequency of the transducing elements of the embodiments of FIGURES 1 or 3 may be modified; and

FIGURES 5 and 6 are front elevational views of two different ways in which an array of transducing elements may be arranged and electrically connected.

In the embodiment of FIGURES 1 and 2, the individual transducing elements, generally designated 2, are each composed of a pair of layers 4 and 6 of piezoelectric ceramic material such as barium titanate or lead zirconate. These layers are in the form of similarly shaped plates or sheets, preferably circular in periphery, provided with registering apertures 8 passing therethrough, the apertures 8 preferably being at the centers of the sheets 4 and 6. Electrodes 10 and 12, formed of some suitable conductive material, are provided on the end faces of the sheets 4 and 6, and the material of which the sheets 4 and 6 are formed is electrically polarized as indicated in FIGURE 2. The electrodes 10 and 12 are ring-shaped, and extend only part-way toward the center of the sheets 4 and 6, as may be seen from FIGURE 1. The sheets 4 and 6, comprising the two layers of which the transducing element 2 is formed, are securely bonded together as shown, and appropriate electrical connections are made to the electrodes 10 and 12. Thus, one terminal 14 of an external circuit may be connected by lead 16 to the abutting electrodes 10 and 12 between the two sheets 4 and 6, while other terminal 18 of an external circuit may be connected via leads 20 to the electrodes 10 and 12 exposed on the end faces of the bi-laminar element 2.

One or more of the elements 2 are adapted to be mounted on a rod 22 or other structural mounting member.

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The end 24 of the rod 22 is externally threaded and is adapted to pass substantially snugly through the apertures 8 in the transducing elements 2. A back-up nut 26 is positioned on the threaded rod end 24, transducing element 2 is abutted thereagainst, a spacer 28 is positioned on the left hand end of the transducing elements 2, another transducing element is moved into position, and so on to desired length, the entire array of transducing elements 2 being firmly clamped in place on the rod end 24 by means of lock nut 30. Since piezo-electric ceramic transducer elements generally present high electrical impedance at low frequencies, polarization of the bi-laminar elements 2 to produce vibrations when electrically connected in parallel is preferable, and this is the arrangement shown.

In the embodiment of FIGURES 1 and 2, application of a voltage between the common center electrodes 10, 12 and the outer electrodes 10 and 12 respectively will, when the layers 4 and 6 are polarized as shown in FIGURE 2, cause one of the layers 4 or 6 tend to expand radially while the other layer 5 or 4 will tend to contract radially. Whether a given layer tends to expand or contract depends upon the direction in which the voltage is applied across that layer. These oppositely acting dimensional changes will cause the elements 2 to "dish" or buckle. As the voltage applied varies (alternates), the degree (and direction) of this buckling will change, and the element will vibrate. If the applied voltage varies (alternates) at the mechanical resonant frequency of the elements 2, highly efficient energy transducing will result.

Since the elements 2 are unsupported except insofar as they are rigidly mounted upon the rod 22, they will cause that rod to vibrate in a direction of its axial length, as indicated by the arrow 32 of FIGURE 1. The rod 22 will therefore serve to mechanically transmit the vibrations generated in the elements 2 to some appropriate remote point.

When more than one transducing element 2 is secured to the rod 22, as here specifically disclosed, the elements 2 are spaced along the rod 22 so as not to physically interfere with one another as they vibrate. With such an array of elements 2, the resonant frequency of the array will be different from the resonant frequency of each individual element 2 considered alone, since there will be some acoustical interaction of the individual elements 2 of the array with one another and with the rod end 24, but the resonant characteristics of the elements 2 themselves will constitute the major factor determining the overall resonant frequency of the array.

FIGURE 3 discloses an alternate embodiment, in which the transducing elements 2' are formed of thermo-electrical material. Each element 2' comprises a center layer 4' of P-type material such as lead antimonide, while the outer layers 6' bonded thereto may be formed of N-type material such as bismuth antimonide, or vice versa. The terminals 14 and 18 of the external electrical circuit may be connected by leads 16' and 20' respectively to the outer surfaces of the outer layers 6'. Since layers 4' and 6' are themselves conductive, they should be insulated from the rod end 24. Hence, the apertures 8' formed on the center of the elements 2' are somewhat larger than the rod end 24 which passes therethrough, and insulating spacers 34 are located between the rod end 24 and the inner surfaces of the apertures 8'. The elements 2' are separated from one another by insulating spacers 28' and they are separated from the back-up nut 26 and lock nut 30 by insulating spacers 36 and 38 respectively. Since thermo-electrical transducer elements generally present a relatively low electrical impedance, they may be electrically connected in series, the facing layers 6' of adjacent elements 2' being electrically connected by leads 40.

With thermo-electrical transducing material of the type here described, the passage of electrical current axially through each composite plate 2' will cause heating at

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one boundary between adjacent layers 4' and 6' and cooling at the other boundary. The resulting thermal expansion will cause the element 2' to "dish" or buckle in a manner similar to that previously described in connection with the embodiment of FIGURES 1 and 2. The application of alternating current will cause the element 2' to vibrate. The heat generated or removed from a boundary is not dissipated appreciably by conduction from the nearby material, so that high transducing efficiency is attained.

The resonant frequency of any given transducing element 2 or 2', or the resonant frequency of an array formed of plurality of such elements, may be varied within limits by loading the elements, as by increasing their mass. This may readily be accomplished by pressing or otherwise securing one or more metal loading rings 42 to the periphery of an element 2 or 2', as shown in FIGURE 4. For purposes of illustration, a piezo-electric element 2 is there specifically illustrated, but it will be understood that a thermo-electric element 2' could be employed.

As has been previously mentioned, a plurality of transducing elements 2 may be mounted on the rod 22 in an array in order to increase the power-handling capabilities of the assembly. Under normal circumstances, if the length of the array, measured along the rod 22, exceeds one-quarter of the wave length in the array of the resonant frequency vibrations, computing the wave length on the basis of the velocity of sound axially in the array (that velocity being less than the velocity of sound in the free portion of the rod 22), then some of the elements 2 will oppose or cancel out the vibratory effect of others of the elements 2. This may be avoided by the use of either of the arrangements illustrated in FIGURES 5 and 6.

In FIGURE 5, all of the transducing elements 2 are similarly electrically connected, the elements and connections being the same as shown in FIGURES 1 and 2. The elements 2 are arranged in two groups, each shown as consisting of seven elements 2, each of those groups having a length along the axis of the rod end 24 which is one-quarter of the wave length of the resonant frequency vibrations, computed in accordance with the velocity of sound in the overall array. These two groups are separated by a space also equal to one-quarter of that wave length. With this spacing, the vibratory action of each group of elements will reinforce the vibratory action of the other group of elements.

In FIGURE 6, the array is formed of the same two groups of elements 2, which groups are not spaced from one another along the rod end 24. Instead, the electrical connections to the first group are reversed relative to the electrical connections to the second group.

Hence, the vibrations of the elements 2 of one group will be 180° out of phase with the vibrations of the other group, so that their resultant will be additive.

The arrangement of the present invention permits the transmission of vibratory signals or power over a rod or wire 22 between a transducing station and a station remote therefrom. It also can be utilized in the construction of a readily manually manipulatable drilling or lapping tool. Appreciable amounts of energy may be handled with apparatus of minimum size and through the use of components which may be readily manufactured and assembled at low cost. The design factors are such that appreciable variations in resonant frequency may be attained with the use of standard components. In most instances, the transducing action will be reversible. Thus, although the description above set forth is primarily in terms of the application of electrical signals to the transducing elements 2 in order to generate vibrations therein, which vibrations are then imparted to the rod 22 on which the elements 2 are mounted, it will be understood that the mechanical application of vibrations to the rod 22 can be transformed by the elements 2 into correspondingly fluctuating electrical signals.

While but a limited number of embodiments of the pres-

ent invention have been here specifically disclosed, it will be apparent that many variations may be made therein, all within the scope of the invention as defined in the following claims.

I claim:

1. A transducer comprising a rod and a plurality of transducing plates mounted on said rod with their bodies spaced from one another axially of said rod so that each of said plates may vibrate independently of the other, said rod mounting constituting substantially the only mounting of said plates, said plates thereby being free to vibrate and to transmit their vibrations to said rod, and electrical connections to said transducing plates, in which said plates are multi-laminar in a direction substantially perpendicular to said rod, the nature of the laminations being such, in conjunction with the electrical connections thereto, as to cause the laminations to react differently upon the application of a given potential to said electrical connections, said plates thereby changing their shape.

2. The transducer of claim 1, in which said laminations comprise piezo-electric material polarized from one side surface thereof to the other.

3. The transducer of claim 1, in which said laminations comprise piezo-electric material polarized from one side surface thereof to the other, said laminations being electrically connected in parallel.

4. The transducer of claim 1, in which said laminations comprise piezo-electric material polarized from one side surface thereof to the other, said laminations being electrically connected in parallel, said plates being electrically connected in parallel with one another.

5. The transducer of claim 1, in which said plates comprise a plurality of laminations of thermoelectric material of different characteristics.

6. The transducer of claim 1, in which said plates comprise a plurality of laminations of thermo-electric material of different characteristics, said plates being electrically connected in series with one another.

7. A transducer comprising a rod and a plurality of transducing plates mounted on said rod substantially at their centers with their bodies spaced from one another axially of said rod so that each of said plates may vibrate independently of the other, said rod mounting constituting substantially the only mounting of said plates, said plates thereby being free to vibrate and to transmit their vibrations to said rod, and electrical connections to said transducing plates, in which said plates are multi-laminar in a direction substantially perpendicular to said rod, the nature of the laminations being such, in conjunction with the electrical connections thereto, as to cause the laminations to react differently upon the application of a given potential to said electrical connections, said plates thereby changing their shape.

8. The transducer of claim 7, in which said laminations comprise piezo-electric material polarized from one side surface thereof to the other.

9. The transducer of claim 7, in which said laminations comprise piezo-electric material polarized from one side surface thereof to the other, said laminations being electrically connected in parallel.

10. A transducer comprising a rod and a plurality of transducing plates mounted on said rod substantially at their centers with their bodies spaced from one another axially of said rod so that each of said plates may vibrate

independently of the other, said rod mounting constituting substantially the only mounting of said plates, said plates thereby being free to vibrate and to transmit their vibrations to said rod, and electrical connections to said transducing plates, in which said plates comprise a plurality of laminations of thermo-electric material of different characteristics.

11. A transducer comprising a rod and a plurality of transducing plates mounted on said rod with their bodies spaced from one another axially of said rod so that each of said plates may vibrate independently of the other, said rod mounting constituting substantially the only mounting of said plates, said plates thereby being free to vibrate and to transmit their vibrations to said rod, and electrical connections to said transducing plates, in which said plates are mounted on said rod in a plurality of sets of plates, at least one of said sets having an axial length along said rod equal to one-quarter of the wave length of the vibrations produced by the combination of said set of plates and said rod, said sets of plates being relatively positioned along said rod and electrically connected to one another so as to reinforce their respective vibratory actions.

12. The transducer of claim 11, in which the plates of each set are oppositely electrically connected and said sets are axially adjacent one another along said rod.

13. The transducer of claim 11, in which the plates of each set are similarly electrically connected and said sets are spaced from one another along said rod by a distance equal to one-quarter of the wave length of the vibrations produced by the combination of said one of said sets of plates and said rod.

14. A transducer comprising a rod and a plurality of transducing plates mounted on said rod substantially at their centers with their bodies spaced from one another axially of said rod so that each of said plates may vibrate independently of the other, said rod mounting constituting substantially the only mounting of said plates, said plates thereby being free to vibrate and to transmit their vibrations to said rod, and electrical connections to said transducing plates, in which said plates are mounted on said rod in a plurality of sets of plates, at least one of said sets having an axial length along said rod equal to one-quarter of the wave length of the vibrations produced by the combination of said set of plates and said rod, said sets of plates being relatively positioned along said rod and electrically connected to one another so as to reinforce their respective vibratory actions.

15. The transducer of claim 14, in which the plates of each set are oppositely electrically connected and said sets are axially adjacent one another along said rod.

16. The transducer of claim 14, in which the plates of each set are similarly electrically connected and said sets are spaced from one another along said rod by a distance equal to one-quarter of the wave length of the vibrations produced by the combination of said one of said sets of plates and said rod.

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