Jan. 30, 1945. E. BURKHARDT 2,368,609

ELECTRO-ACOUSTIC TRANSDUCER

Filed June 7, 1941 2 Sheets-Sheet 1

Fig. 1.

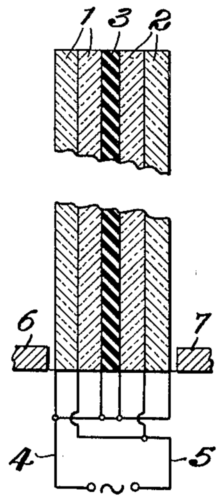

Fig. 2.

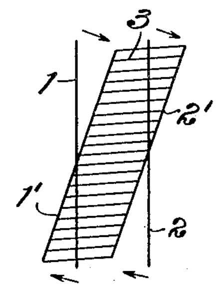

Fig. 3.

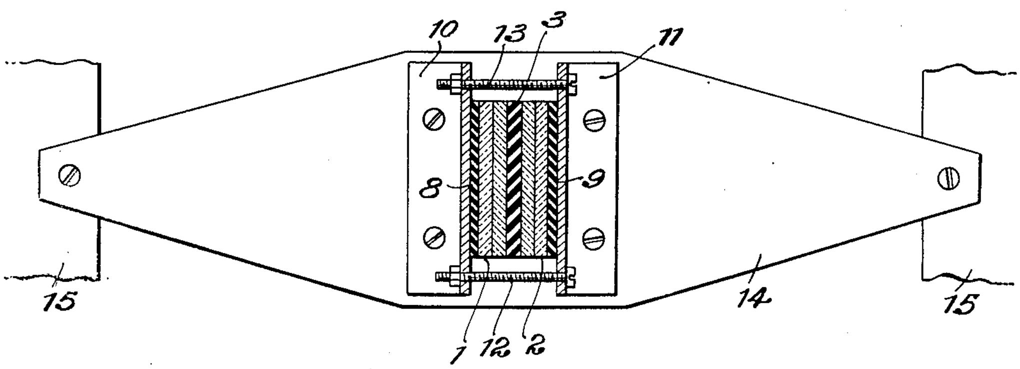

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Fig. 4.

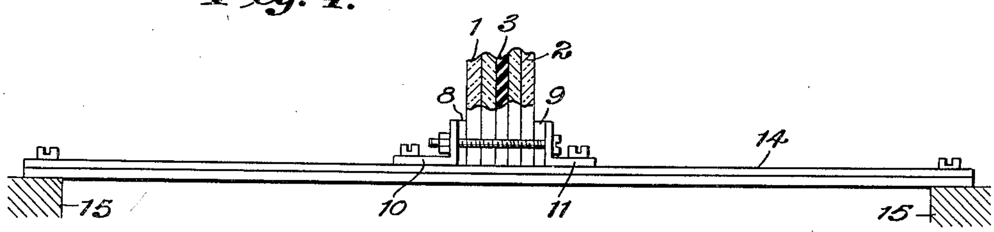


Fig. 5.

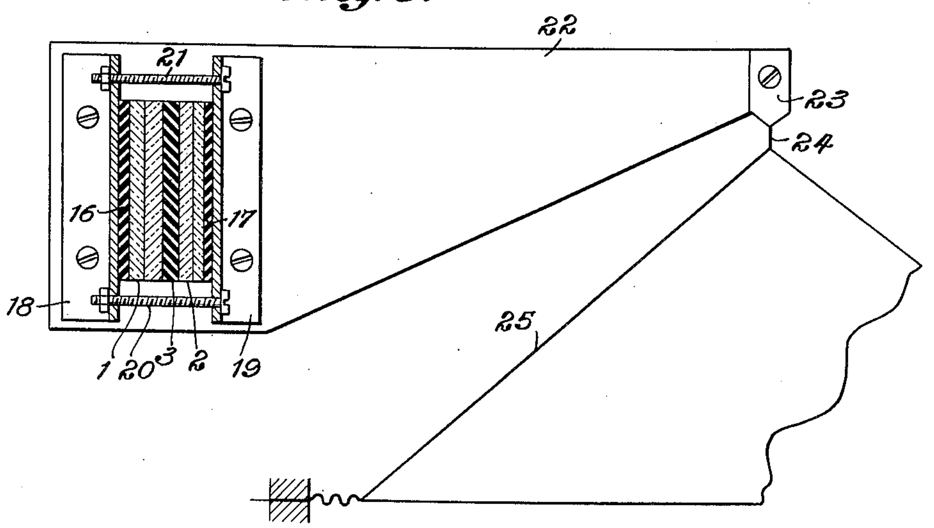
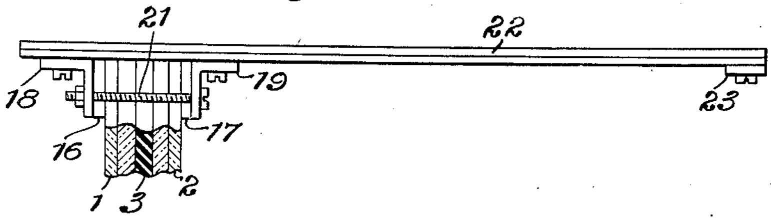


Fig. 6.



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UNITED STATES PATENT OFFICE

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ELECTROACOUSTIC TRANSDUCER

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Application June 7, 1941, Serial No. 397,034
In Germany April 20, 1940

8 Claims. (Cl. 171—327)

This invention relates to a device adapted to the conversion of electrical energy into kinetic or motional energy, or vice versa, and more particularly with the conversion of electrical energy into acoustic energy, said devices being known as acoustic transducers. It is known in the prior art to use for converter or transducer devices of the said sort so-called twin or double plates, say, of Rochelle salt crystals. Thus, if an electric potential is impressed upon the electrodes of such plates or crystals, deformation is produced which, where the latter are of square form, assumes the shape of a saddle surface, while a helically twisted surface results in the case of rectangular strips. Deformations of this kind have been utilized, for instance, for loudspeakers by supporting and holding a twin plate or crystal at three corners, while the apex of the cone-shaped diaphragm of the loud-speaker has been attached to the freely vibrating fourth corner.

It has been ascertained that crystal assemblies of this sort possess a comparatively high natural frequency of vibration. The result is that loudspeakers equipped with such crystal drive mechanisms are practically useful only for high response or treble range loudspeakers because the resonance point lies roughly midway of the tonal frequency range or band to be handled so that for vibrations below the resonance point there occurs a drop of oscillation amplitude. Now, it is not readily feasible to lower the natural frequency of vibration of such crystal systems, say, by enlarging the geometric dimensions of the crystal, for this would conduce to intolerably large dimensions. Another fact is that crystals of such a size would be highly sensitive, not to mention their comparatively high cost.

Now, the invention has the object to create an electro-mechanical, more particularly an electro-acoustic, transducer consisting of piezo-electric twin plates or crystals having a low natural period of vibration, preferably falling inside the range of 50—150 cycles per second, without the dimensions of the crystal system becoming inadmissibly large and without the efficiency and the operating safety and reliability of the arrangement being incidentally impaired.

According to the chief object of the invention, the above problem is solved by uniting two or more twin plates or crystals by intermediate layers consisting of an elastic material capable of deformation when small force is applied thereto, such as rubber or Mipolam (polyvenyl chloride) this resulting in a superposed pile so operating that the torsional forces set up by the twin crystals or plates become added to one another. The invention will be clearly understood by referring to the accompanying drawings, in which Fig. 1 is a sectional view of two twin crystals with an intermediate elastic layer.

Fig. 2 is a schematic showing of the mechanical stresses set up in this device.

Fig. 3 is a plan view of the clamping and support members of the crystal assembly.

Fig. 4 is a side view partly in section of Fig. 3.

Fig. 5 is a plan view showing the lever system of a loudspeaker.

Fig. 6 is a side view of Fig. 5.

Referring now in detail to the drawings, Fig. 1 illustrates the case in which two twin crystals are united according to the invention by means of an intermediate elastic layer, this figure also showing the electrode connections and their polarity. 1 and 2 denote each a twin strip or crystal (piezo-electric in nature) constructed in a way known in the prior art, these crystals being preferably of oblong form. The two twin strips are electrically connected in parallel to each other and are mounted to be united by means of an intermediate layer of elastic material indicated at 3. This intermediate layer has the property that it is capable of being deformed quite easily and that at the same time it is elastic such that it yields to such deformative forces will arise in the operation of the crystal assembly, without, however, the mechanical cohesion or union of the two twin strips being incidentally lost. The way the intermediate layer is stressed mechanically is illustrated schematically in Fig. 2. This figure seen from above shows the deformation arising at the upper, narrow end of the twin crystal pair if the crystal assembly shown in Fig. 1 is held or locked in position at the lower narrow end as indicated by the supporting means 6 and 7. Upon an electric potential being applied across the terminals 4 and 5 of the twin strip or crystal pair 1, 2, the upper end experiences a motion in the direction of the arrows and assumes the position marked 1′, 2′. In other words, the intermediary layer is subject to shearing forces. Now, the interposed layer is of a nature such that it offers only a low resistance to these deformational forces and that it will resume its original form upon cessation of these forces. Among other substances, Mipolam (polyvenyl chloride) has proven advantageous for the said intermediary layer. However, also other rubber-like materials could be used therefor.

For a given material, the thickness of the intermediary layer is conveniently so chosen that disturbing natural vibrations, such as flexural vibrations, will be attenuated and reduced to a sufficient degree. Where twin crystals or strips of 15 centimeters' length, 4 centimeters' breadth, and 4 millimeters' thickness are concerned, a layer of Mipolam half the thickness of a twin crystal strip has proved of advantage.

There will be no particular need for gluing or cementing the intermediary layer together with the crystal plates if the pair of twin crystals is pressed together at both ends by tensioning or clamping means as is true of most practical applications.

The piezo-electric twin crystals arranged according to this invention may be made of substantially greater crystal thickness and thus respond to a lower natural period of vibration than that of a simple or a single twin crystal strip for the same permissible maximum load. For example, using a strip or crystal having a rectangular cross-sectional form, the maximum angle of torsion to which the crystal strip may be deformed is much greater for a smaller thickness of the crystal plates. Now, in the crystal arrangement of this invention, the maximum angle of torsion is governed practically only by the thickness of one twin crystal strip rather than by the thickness of the entire system or assembly. A system composed of two twin crystal strips, for a given maximum permissible torsion angle, therefore, may be made of a crystal thickness over twice that of a simple twin crystal strip. As a result, however, the ensuing natural period of vibration is substantially less than for a single or simple twin strip, that is, for the same load carrying capacity. Another advantage of the twin strip crystal pair with an intermediary layer as here disclosed is that the moment of resistance of the pair of twin strips is appreciably raised so far as undesired or stray flexures are concerned, more particularly flexures at right angles to the longitudinal axis and normal to the plane of the plate, while the torsion resistance moment in the longitudinal axis which is decisive for the movement that is to be utilized is practically unchanged because of the fact that union and cohesion is insured by the aid of the intermediary layer.

It is not necessary in this connection to make the intermediary layer of solid material, in other words, spaces and cavities may be interposed. The intermediary layer may consist of elementary strips which are spaced apart from one another, but it could also be perforated.

If, within the scope and spirit of this invention, a plurality of twin strips or crystals are united by elastic intermediate layers as hereinbefore described rather than only two, then the thickness of the aggregate system can be still further increased without endangering the working safety and reliability, with a resultant further reduction of the natural period of vibration of the system. For also in this instance, the maximum admissible torsion angle is practically governed by the maximum angle of torsion of the various twin strips.

Where a greater number of twin strips is so united, also the resistance moment in respect to disturbing flexural vibrations is raised still further.

In order that the electro-mechanical energy conversion insured by a piezo-electric twin crystal plate system as here disclosed may be utilized as favorably and efficiently as feasible, it has been found to be expedient according to another object of the present invention to use an intermediate layer of a sort of material as here disclosed for the plates or crystals also for the supporting means. The result is that practically no energy losses are occasioned, while at the same time the arising of mechanical tensions in the crystal upon deformation of the crystal system under operating conditions is precluded, for such tensions are liable to lead to electric saturation phenomena and thereby to non-linear distortions, and they would arise if the supporting or holding means were of a completely rigid nature. One condition which is insured by the elastic holding or clamping of the twin strip pair is that there is no loss of the useful length the crystal strip which governs the natural period, with the result that the desired low resonance point of the crystal system is preserved. As regards the thickness of the intermediate layers used for the clamping or holder means, the same considerations hold good as for the intermediary layer used in uniting and joining the crystal strips. The thickness of the intermediary layer employed for the supports is most expediently chosen so that sufficiently great damping will be secured to the end of suppressing disturbing or stray resonances.

Figs. 3 and 4 show in plan and side elevation the holding means of a twin crystal pair with interposition of an elastic, deformable layer consisting, for instance, of Mipolam. These figures at the same time show further objects and features of the invention as regards the holder and supporter means.

The supporter means as shown are suited especially for a loudspeaker drive mechanism. However, it will be found useful also for other practical applications of the crystal system, say, for microphones, sound-pickups, acceleration meters or relays. Moreover, it is not confined to the holding and supporting of twin crystal pairs, but it will be found serviceable also in cases where single twin strips are involved.

In the embodiments shown in Figs. 3 and 4 the electrical connector means or terminals with the electrodes provided on the inner and outer surfaces of the crystal elements consisting, as known in the earlier art, of conducting coats, have been omitted for the sake of greater clearness and simplification of illustration.

As will be noted the twin strips 1 and 2 which are joined together by means of an elastic intermediary layer 3 are clamped at their lower reduced end, with interposition of elastic intermediate layers 8 and 9 consisting, for instance, of Mipolam, between jaws of angular form 10 and 11 by the agency of screws 12 and 13. These angle pieces 10 and 11 are secured upon the middle of a base plate 14 which is tapered in both (opposite) directions. The ends of the base plate 14 are fixedly connected with a rigid support 15.

The base plate according to this invention is so shaped that it will offer high resistance to torsional motions experienced by the crystal assembly mounted thereon whereas in any other direction offering a low resistance moment. At the same time it is made so flexible and thin that for pendulous or reciprocating motions about its longitudinal axis it has a low period of vibration; in other words, the elasticity of the plates is so tuned to the mass of the crystal system, including holding or clamping means, that the frequency of the pendulous movement lies substantially below the network frequency range fed to the crystal system, that is, for example, 5 cycles per second whenever vibrations of the tonal frequency band are fed in. In order that the said conditions may be fulfilled the above plate could, for instance, be made of stratified material of reduced thickness. As extremely suitable have been found thin molded or compressed "cell" plates with interposed layers of Mipolam or rubber material. The base plate, in the presence of a weight of the crystal system including securing or clamping means around 200 grams may, for instance, be made of the following dimensions:

Overall length____cm__	20
Length of middle part____cm__	4
Width of middle part____cm__	6
Thickness ____mm__	3 x .5

In order to insure transmission of the torsional movements experienced by the free end of the crystal system under favorable circumstances, say, to a loudspeaker diaphragm, arrangements could be similar to those chosen in connection with the clamping and the securing of the lower end of the crystal system, as hereinbefore outlined. Fig. 5 shows by way of example an embodiment of a piezo-electric loudspeaker drive mechanism, only the top end being shown looking from below. In the case of Fig. 6 the loudspeaker diaphragm has been omitted. The supporting of the lower end of the crystal assembly is the same preferably as shown in Figs. 3 and 4.

The mode of clamping and holding the crystal system as represented in Figs. 5 and 6, as well as the lever scheme adapted to utilize the torsional movements experienced by the crystal system, is not restricted to loudspeaker drive or moving systems; neither is it confined to the use of twin strip pairs, for it will be found useful also in connection with simple twin strips.

According to Figs. 5 and 6, the twin strips **1** and **2** joined by the elastic intermediary layer **3** are clamped by the aid of screws **20** and **21** between angular jaws **18** and **19**, with interposition of an elastic intermediary layer **16** and **17**, respectively, said layer consisting, say, of Mipolam, this arrangement resembling that previously described in connection with the holding and clamping of the narrowed bottom end of the crystal system. Angular jaws **18** and **19** are secured upon the plate **22** which tapers towards one end. Provided on the tapered end is a transmitting link **23** with a connector strip **24** designed to transfer the movements of the plate **22** to the apex of the cone diaphragm **25** of the loudspeaker. So far as the construction of the plate **22** is concerned there apply here the same considerations as made in connection with the base plate in reference to Figs. 3 and 4. If plate **22** is to be used for the drive or impulsing of a loudspeaker diaphragm then it will be sufficient, as illustrated in Figs. 5 and 6, to utilize only one tapered end of the plate for the transmission of motional impulses. For some practical purposes, it may be found to be expedient to design plate **22** in such a manner that also the other end of the plate is reduced, thus resulting in a form as indicated for the base plate in Fig. 3. In this case, the motional impulses could be transferred from both ends of the plate **24**.

The invention may be used not only in connection with piezo-electric loudspeakers, but will also be found useful with piezo-electric microphones, sound pickups, acceleration meters, or similar piezo-electric crystal apparatus and devices wherever the special desideratum is a low resonance or tuning point.

What is claimed is:

1. An electro-mechanical conversion device comprising a plurality of piezo electric crystals arranged in pairs, an elastic layer interposed between said pairs of crystals, means for binding said crystals and said elastic layer together; whereby the torsional forces set up by said pairs of crystals will become added to one another, and means for making electrical connections to said crystals.

2. An electro-mechanical conversion device comprising a plurality of piezo electric crystals arranged in pairs, an elastic layer of like area as the crystals and interposed between said pairs of crystals, means for binding said crystals and said elastic layer together, said elastic layer having the properties of being easily deformed in its normal operation with said crystals and without losing the mechanical cohesion therewith; whereby the torsional forces set up by said pairs of crystals will become added to one another, and means for making electrical connections to said crystals.

3. An electro-mechanical conversion device comprising a plurality of piezo electric crystals arranged in pairs, an elastic layer of polyvenyl chloride interposed between said pairs of crystals, means for binding said crystals and said elastic layer together; whereby the torsional forces set up by said pairs of crystals will become added to one another, and means for making electrical connections to said crystals.

4. An electro-mechanical conversion device comprising a plurality of piezo electric crystal plate members arranged in pairs, an elastic plate member interposed between said pairs of crystal plate members, means for binding said crystal plate members and said elastic plate member together; whereby the torsional forces set up by said pairs of crystal plate members will become added to one another, and means for making electrical connections to said crystal plate members.

5. An electro-mechanical conversion device comprising a plurality of piezo electric crystal plate members arranged in pairs, an elastic plate member interposed between said pairs of crystal plate members, metallic binding members located at one end of said crystal plate members for binding said crystal plate members and said elastic plate member together; whereby the torsional forces set up by said pairs of crystal plate members will become added to one another, and means for making electrical connections to said crystal plate members.

6. An electro-mechanical conversion device comprising a plurality of piezo electric crystal plate members arranged in pairs, a plurality of elastic plate members, one of said plate members interposed between said pairs of crystal plate members, the other of said elastic plate members located at one end of said pairs of crystal plate members, and means for binding said crystal plate members and said elastic plate members together; whereby the torsional forces set up by said pairs of crystal plate members will become added to one another, and means for making electrical connections to said crystal plate members.

7. An electro-mechanical conversion device comprising a plurality of piezo electric crystal plate members arranged in pairs, a plurality of elastic plate members, one of said plate members

interposed between said pairs of crystal plate members, the other of said elastic plate members located at one end of said pairs of crystal plate members, and means for binding said crystal plate members and said elastic plate members together; whereby the torsional forces set up by said pairs of crystal plate members will become added to one another, a base plate for supporting said crystal, which is tapered at both ends thereof.

8. An electro-mechanical conversion device comprising a plurality of pairs of piezo electric crystals, an elastic layer which is equal to approximately half the thickness of said crystals, said elastic layer being interposed between said crystals, means for binding said crystals and elastic layer together at one end thereof; whereby the torsional forces set up by said pairs of crystals will become added to one another, and means for making electrical connections to said crystals.

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