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W. G. CADY

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ELECTROMECHANICAL SYSTEM

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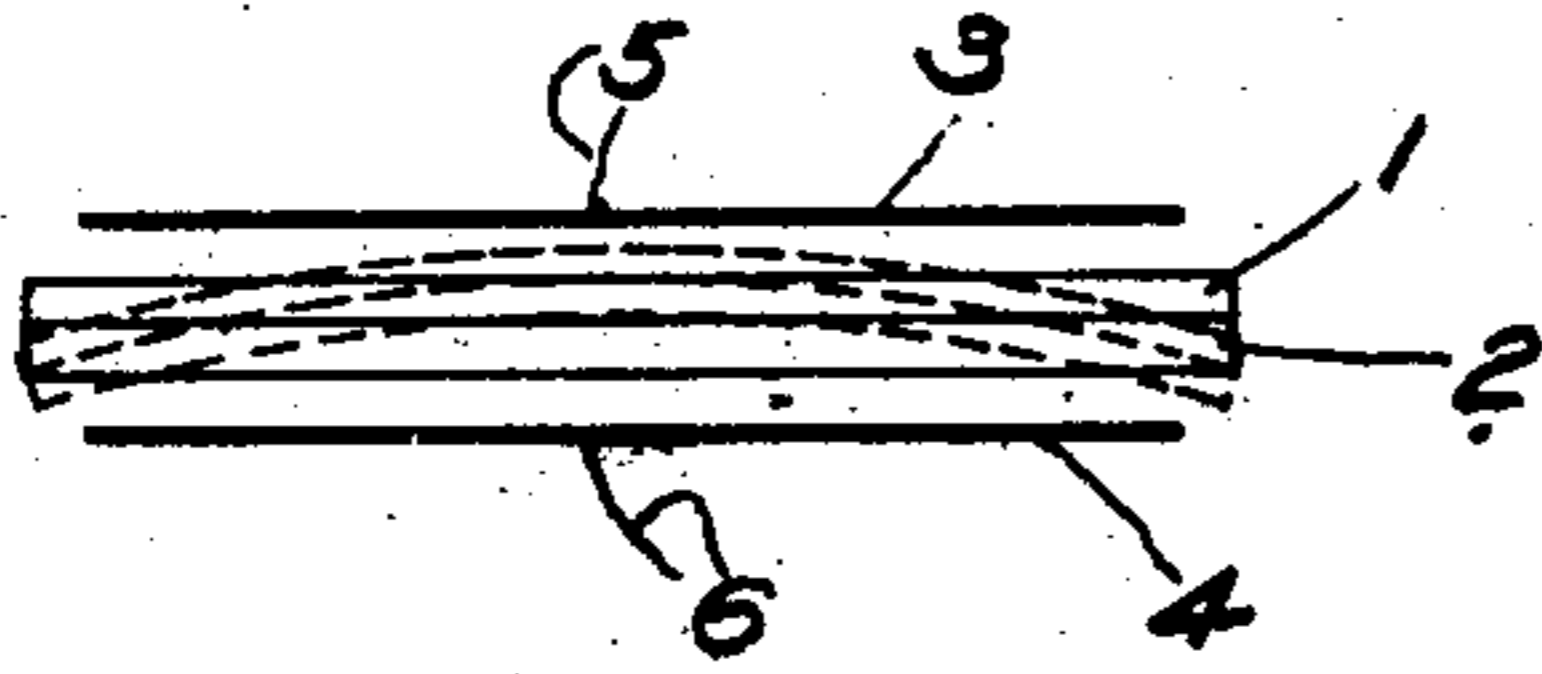


FIG. 1.

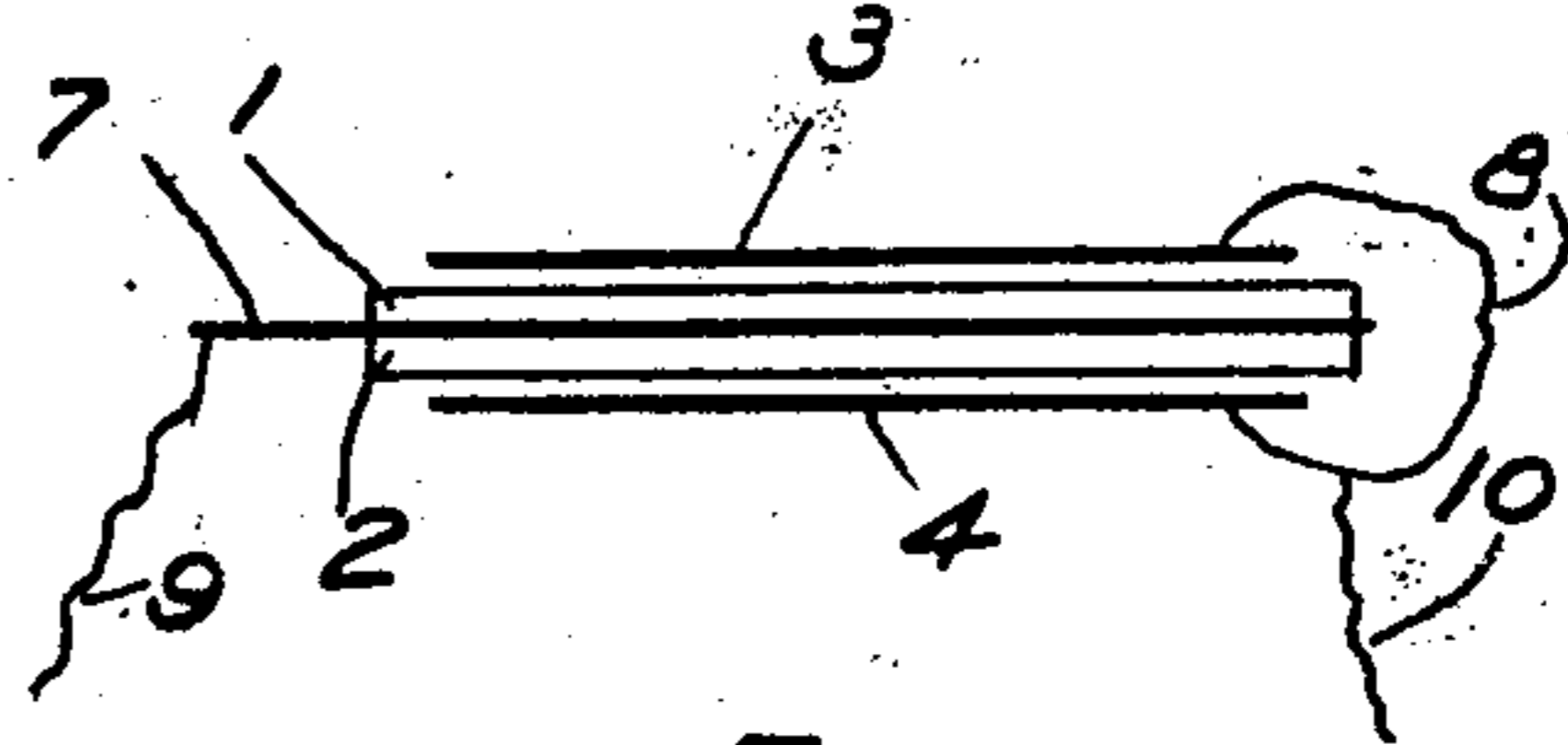


FIG. 2.

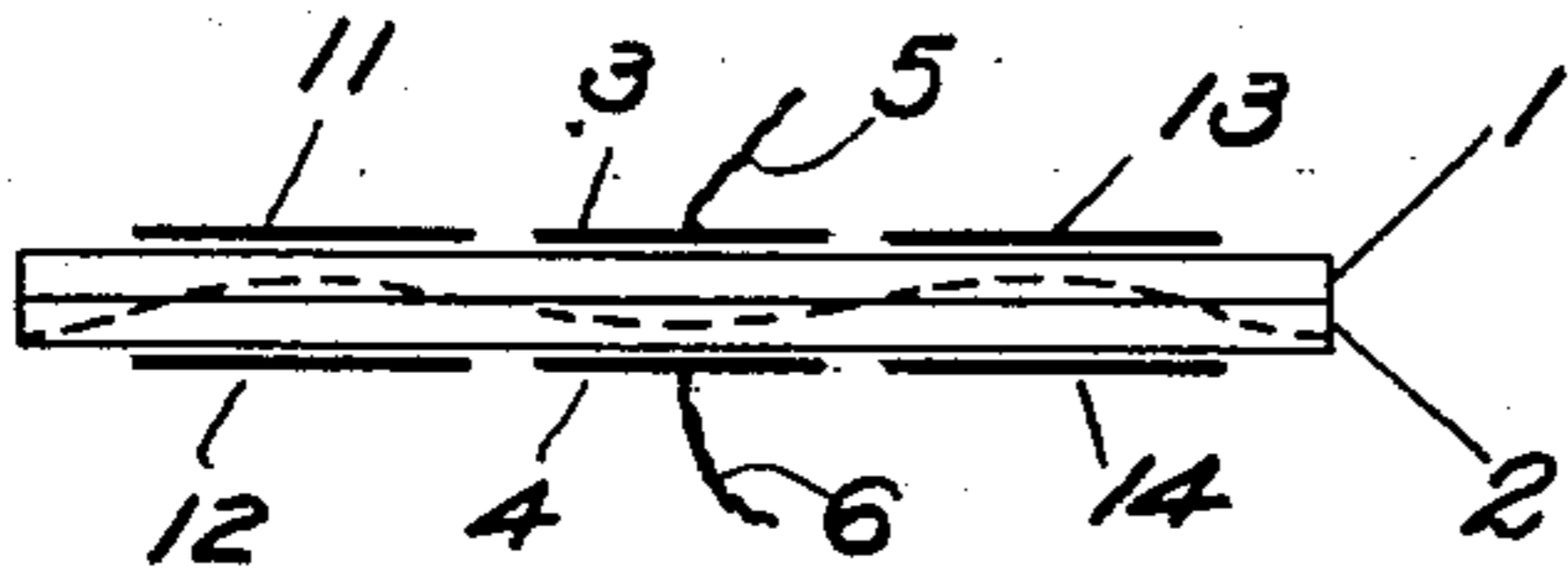


FIG. 3.

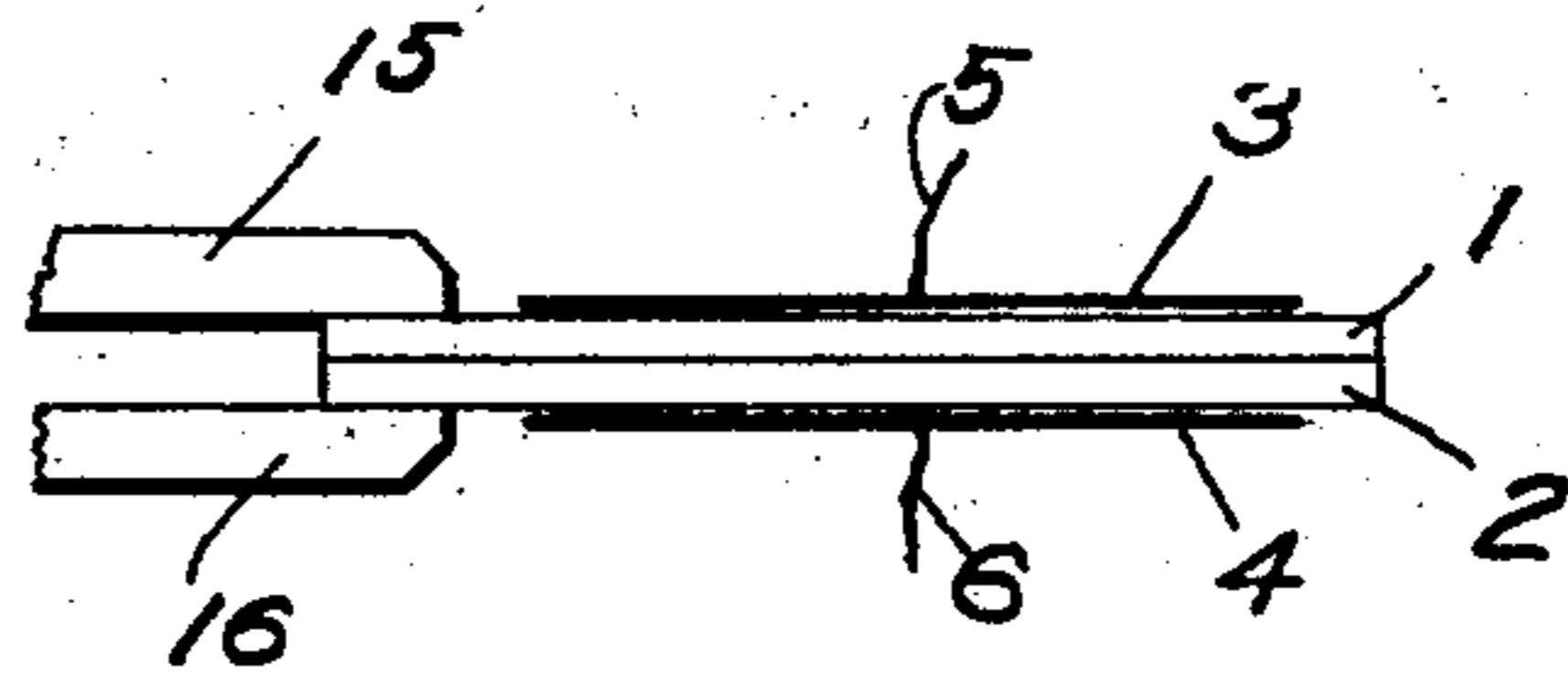


FIG. 4.

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## ELECTROMECHANICAL SYSTEM

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The present invention relates to electro-mechanical systems, and more particularly to alternating-current systems comprising piezo-electric bodies.

5 In Letters Patent No. 1,450,246, granted April 3, 1923, there is disclosed an alternating-current system the frequency of which is substantially the same as the natural frequency of mechanical vibration of the piezo-electric body. The piezo-electric body, at  
10 such frequencies, is set into vibration, and by virtue of its vibrations, it reacts upon the alternating current, thus constituting a piezo-electric resonator. Ordinary piezo-electric  
15 plates or rods, suitably cut from the native crystal, however, have comparatively high natural periods of vibration.

It is therefore an object of the present invention to provide an improved method and  
20 system of the above-described character that shall operate at comparatively low frequencies.

Other and further objects will be explained hereinafter and will be particularly  
25 pointed out in the appended claims.

In the accompanying drawings, Fig. 1 is a diagrammatic view of apparatus constructed according to a preferred embodiment of the present invention; and Figs. 2, 3 and 4  
30 are similar views of modifications.

The preferred form of the flexural piezo-electric resonator of the present invention comprises two narrow, flat piezo-electric plates 1 and 2, preferably cut parallel from the same crystal in the manner described in the aforesaid Letters Patent, one of the plates then being turned side for side and firmly secured to the other plate in such turned position, in face-to-face relation, as by the use  
40 of hard wax or cement, like solid brown shellac. The piezo-electric plates should preferably be capable of vibrating by the "transverse" effect; that is, they should tend to become elongated or shortened in a direction  
45 perpendicular to the electric field and parallel to their length. Secured together and oriented in the manner above-described, one of the plates, under the action of an electric field, will lengthen while the other will  
50 shorten; when the field is reversed, the one

plate shortens, the other lengthens. The plates are thus caused to curve slightly, as shown exaggerated, in dotted lines, in Fig. 1. In an alternating electric field, therefore, the plates will curve first in one direction and then in the other, producing flexural vibrations, whose amplitude will be a maximum when in resonance. The frequency of mechanical vibration will be the same as the frequency of the applied alternating voltage. The vibrator is thus a flexural piezo-electric resonator. The same effect, though less pronounced, will be obtained if one only of the plates is piezo-electric. The other plate may be of a piezo-electrically inactive substance, like steel.

For most practical applications, it is naturally of importance that the crystal be not too difficult to procure, free from flaws and twinning, mechanically strong and durable, of small damping, and that it shall be fairly strongly piezo-electric. These qualities are well combined in quartz, but other piezo-electric crystals may be used, or indeed any electro-mechanical system that is capable of being excited into flexural vibrations when stimulated electrically and which shows the converse effect, particularly if elastic.

In the following description of the device, wherever the word "plate" is used, it should be understood that other geometric forms may be employed, so long as the finished structure is capable of becoming bent or flexed in an electric field, and of vibrating flexurally when in an alternating electric field. The word "flexed" will, for brevity, be understood to mean "bent in such a manner as to convert a plane surface into a cylindrical surface."

Conductive coatings 3, 4 are fixed close to the outer surfaces of the resonator, as illustrated more particularly in Fig. 1, separated therefrom by a small air gap. This is preferable to cementing or plating thin conductive coatings directly on to the said outer surfaces, because producing less damping, but cemented or plated coatings may be employed. The plates 3, 4 are connected with a source of alternating current by conductors



5, 6, thus causing the coatings to become charged oppositely.

If the frequency of the source is tuned close to that of the natural frequency of flexural vibration of the resonator, the latter will be flexed back and forth between the dotted-line position shown in Fig. 1, and its opposite. The plates will thus be placed under a periodic mechanical strain, causing an alternating electric field to be produced, the direction of which at any instant is the same as that which it would be necessary to apply from without in order to flex the plates in the given direction. The electric field thus produced reacts upon the current in the manner described in the aforesaid Letters Patent.

The flexural vibrations are of considerable amplitude and their frequency is much lower than that of the longitudinal vibration of a corresponding single crystal plate 1 or 2. The frequency of the single plate may, for example, be in the neighborhood of 70,000; and that of the composite vibrator only one-tenth as high. The frequency may be varied with the length and thickness of the plates, their breadth being without effect, if not too large, except that the electric response is greater, the greater this breadth. A wide range of frequencies may be obtained by proper choice of the length and thickness of the plates. If frequencies other than the resonant frequency are used, vibrations of smaller amplitude will, of course, be produced.

In the modification of Fig. 2, the piezo-electric plates 1, 2 are cemented firmly on opposite sides of a thin leaf of conducting material 7, for example, a strip of metal foil. The conducting coatings 3, 4 are placed close to the outer surfaces of the plates and electrically connected together, for instance by the short wire 8. Leads 9 and 10 are attached to the coating 7 and the wire 8 in order to connect the resonator to the electric circuit. The crystal plates 1, 2 must be so cut and oriented that when an electric field is established between the conducting leaf 7 and the coatings 3, 4, in parallel, one of the plates tends to lengthen while the other tends to become shorter. Then, when an alternating field is applied of a frequency approximating the natural frequency of flexural vibration, the combination 1, 2, 7 will be set into resonant vibration.

While the devices pictured in Figs. 1 and 2 are suitable for an excitation of the fundamental mode of flexural vibration of the plates, it is possible by using coatings of proper size and located in the right position, to excite various other modes of flexural vibration whose frequencies, according to the theory of narrow vibrating plates, will be approximately equal to  $(5/3)^2$ ,  $(7/3)^2$ ,  $(9/3)^2$  etc. times the fundamental frequency.

In this connection see Winkelmann, Handbuch der Physik, 1908, vol. 1, part 1, page 735, Barton's "Textbook on Sound", London 1919, page 281, page 286, Rayleigh's Theory of Sound, 2nd edition, 1894, vol. 1, figure 28, page 282, figure 29, page 284, figure 30, page 284. In Fig. 3, for example, a flexural resonator is shown mounted between three pairs of coatings, 11, 12, 3, 4 and 13, 14, each pair occupying somewhat less than one-third the length of the crystal. Only the coatings 3, 4 are represented in the figure as connected to the source of alternating current, though vibrations could be excited by the use of either of the other two pairs or by all three pairs connected in parallel or series. If all are in parallel, coatings 11, 4, 13 should be connected together, and likewise 12, 3, 14, in order to bend the plate as indicated by the dotted line. This mode of vibration is the one whose frequency is  $(7/3)^2$  or 5.4 times that of the fundamental. In order to cause the crystal to vibrate at a mode having a frequency equal to  $(5/3)^2$  times the fundamental it is merely necessary to properly position a series of plates adjacent to the crystal in accordance with the principles of the arrangement shown in Fig. 3. Thus, for a frequency of  $(5/3)^2$  times the fundamental, two pairs of coatings are used, and for a frequency of  $(9/3)^2$  times the fundamental, four pairs are used. By using one pair of end coatings alone, it would be possible to excite either the fundamental vibration or a vibration of frequencies either approximately  $(5/3)^2$  or  $(7/3)^2$  times the fundamental frequency by applying an alternating electric field of the right frequency.

In the above description, both ends of the resonator have been assumed to be free.

In order to make the flexural resonator respond at a frequency lower than the fundamental frequency with both ends free, one end may be rigidly clamped, or otherwise rigidly held, as between massive jaws 15, 16, Fig. 4. In this case, only one end of the resonator is free and the fundamental frequency of flexural vibration is, according to the well known theory of narrow plates, less than one-sixth of the fundamental frequency of the same resonator when vibrating flexurally with both ends free. By using sufficiently long and thin plates, a musical tone of sufficiently low pitch for the ear to detect, and of very constant frequency, may be thus piezo-electrically generated.

The flexural resonator described above may be used in the same manner and for the same purposes as the piezo-electric resonators described in the said Letters Patent and in Letters Patent No. 1,472,583, granted October 30, 1923, including those applications in which more than two coatings are employed. An advantage of the flexural form, as stated, lies in its inherently low frequency in com-



parison with the frequency of the resonators in which compressional waves are employed.

Other modifications will occur to persons skilled in the art, and all such are considered  
5 to fall within the spirit and scope of the invention, as defined in the appended claims.

What is claimed is:

1. A piezo-electric resonator comprising two piezo-crystal plates attached on opposite  
10 sides of a layer of electrically conductive material, the outer faces of the plates being provided with conductive coatings electrical-ly connected together, the whole structure being adapted to vibrate flexurally with both  
15 ends free.

2. A piezo-electric resonator comprising two piezo-crystal plates attached on opposite sides of a layer of electrically conductive material, the whole structure being placed be-  
20 tween two or more conductive members and being adapted to vibrate flexurally with both ends free.

3. A piezo-electric resonator comprising a body made up of two piezo-electric crystal  
25 sections attached together in face to face relation, both ends of said body being free to vibrate, a pair of electrodes connected to two opposite faces of said body whereby to impress an alternating electric field upon said  
30 body, and an alternating current circuit connected to said electrodes.

4. A piezo-electric resonator comprising a piezo-electric element composed of a pair of piezo-electric crystal slabs joined together  
35 in face to face relation, both ends of said element being free to vibrate, and means to impress an alternating current field upon said element whereby to cause the same to vibrate flexurally.

40 In testimony whereof, I have hereunto subscribed my name.

WALTER G. CADY.

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