Dec. 4, 1928. 1,693,806

W. G. CADY

ELECTROMECHANICAL SYSTEM

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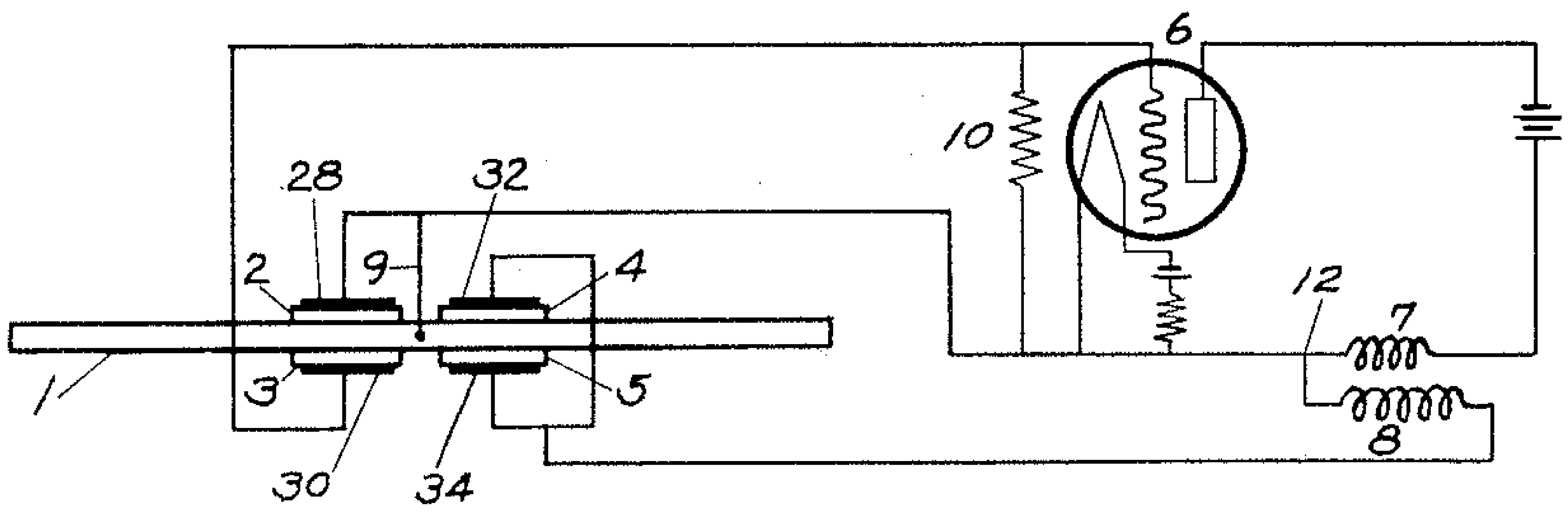

FIG. 1.

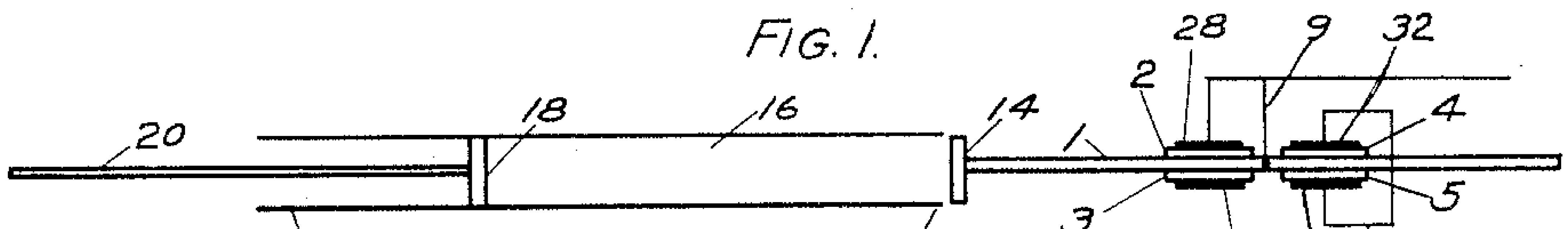

FIG. 2.

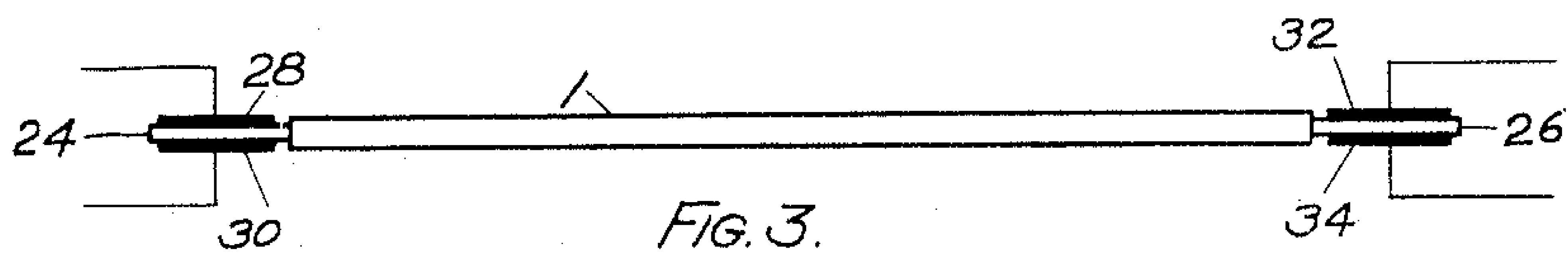

FIG. 3.

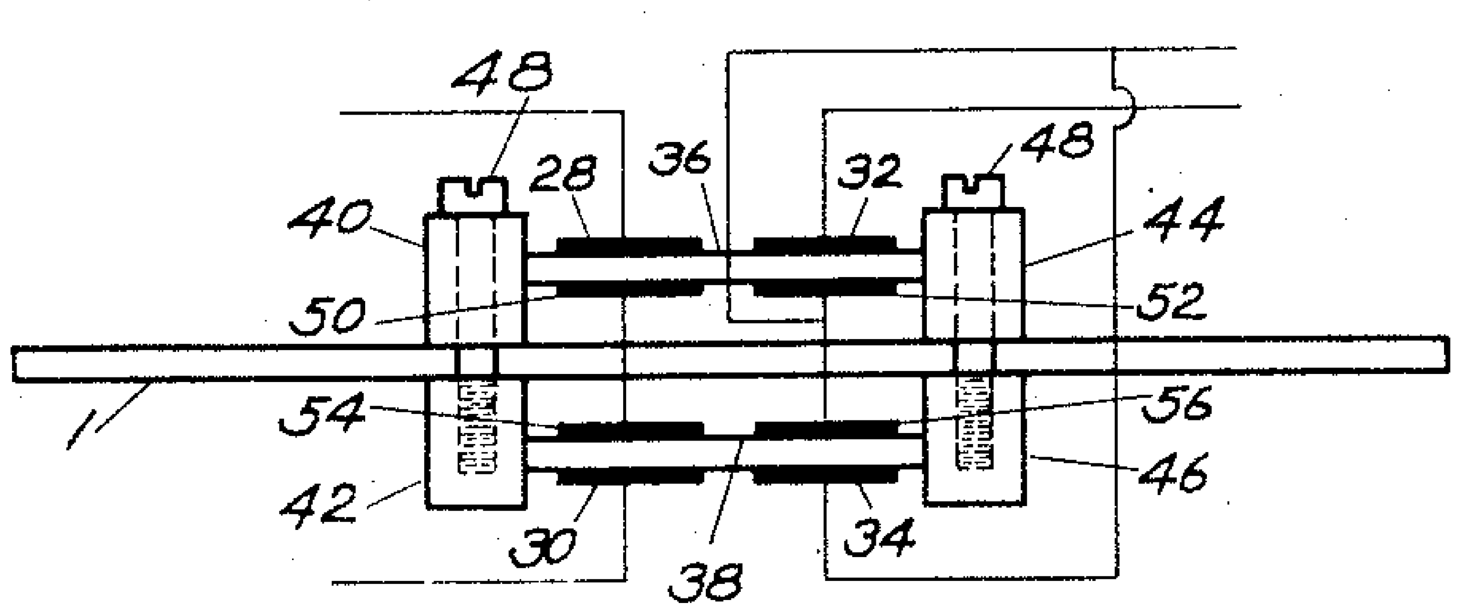

FIG. 4.

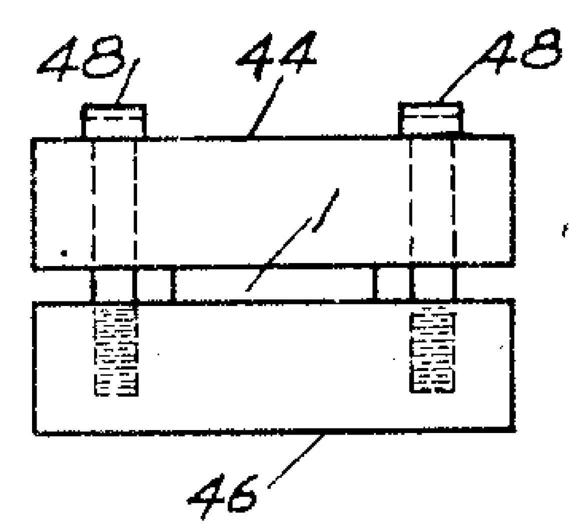

FIG. 5.

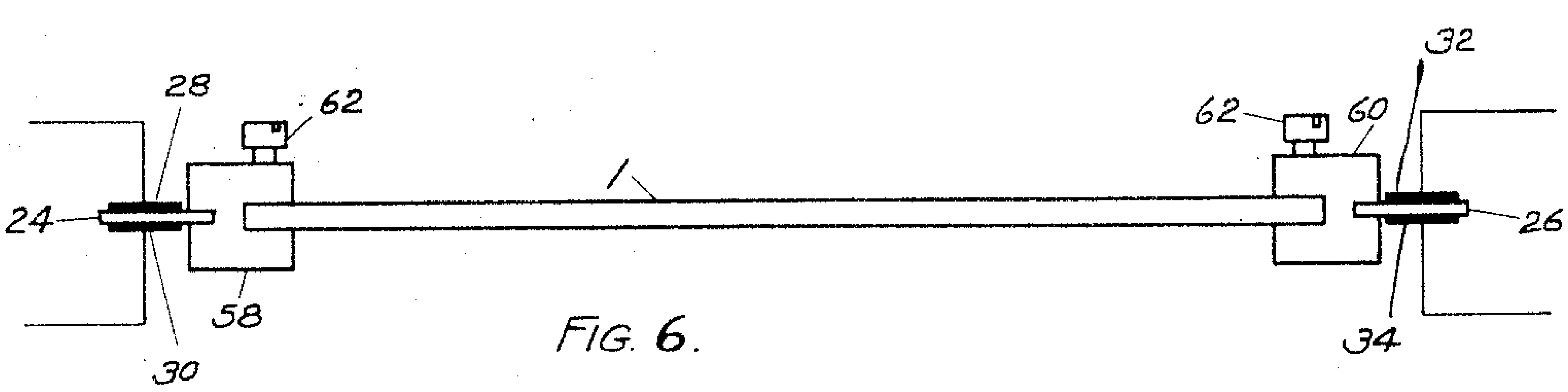

FIG. 6.

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ELECTROMECHANICAL SYSTEM

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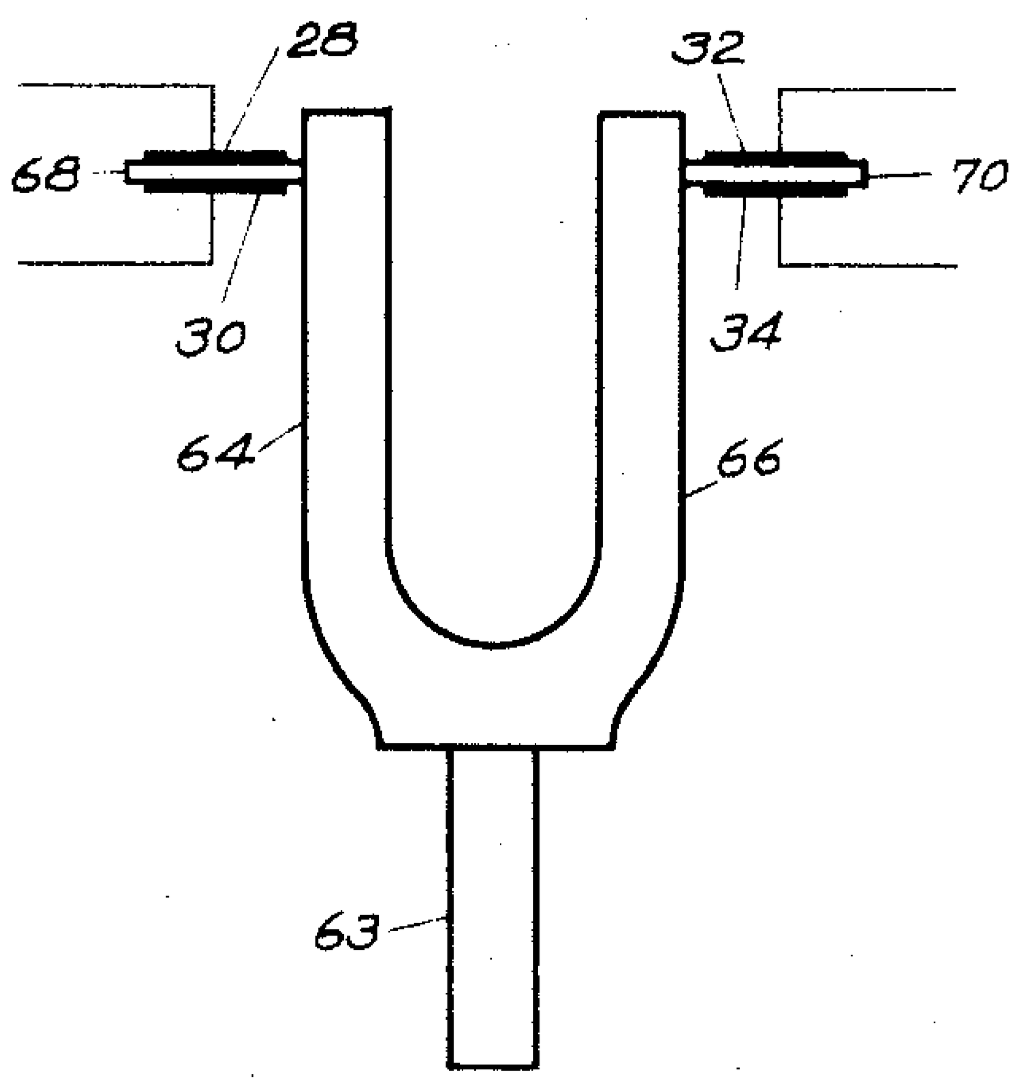

FIG. 7

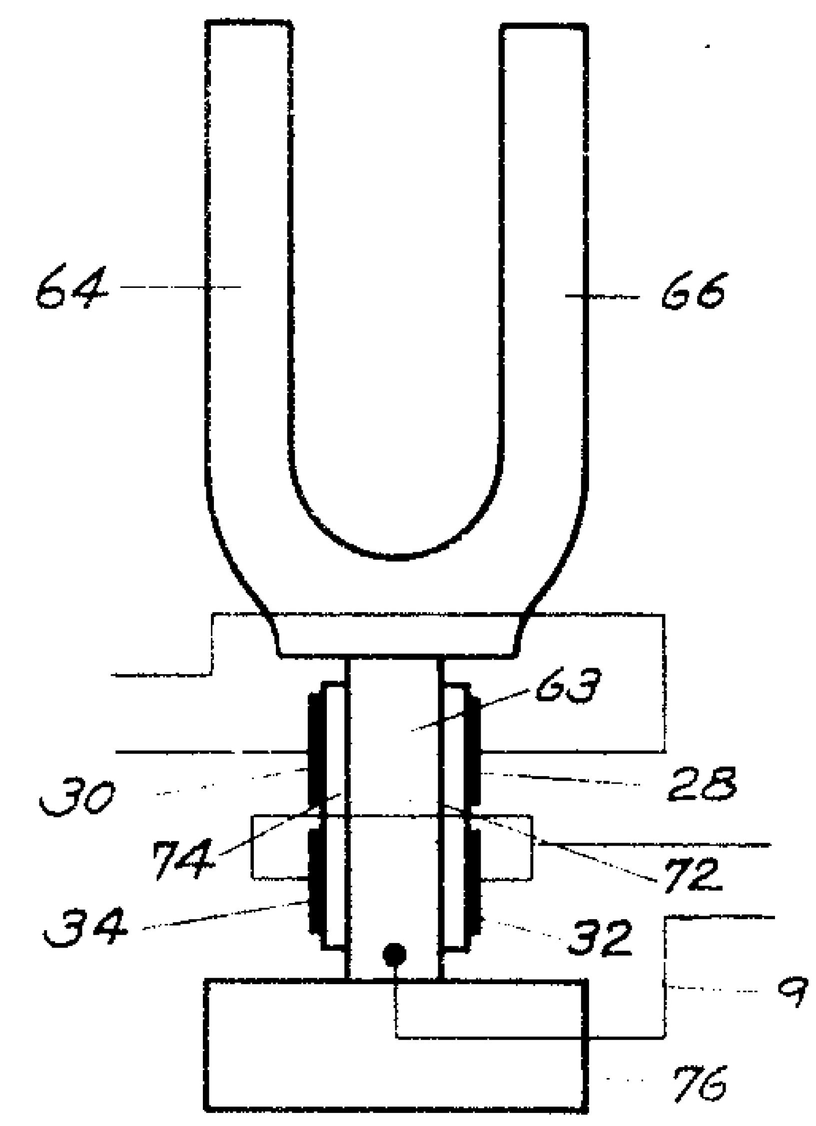

FIG. 8

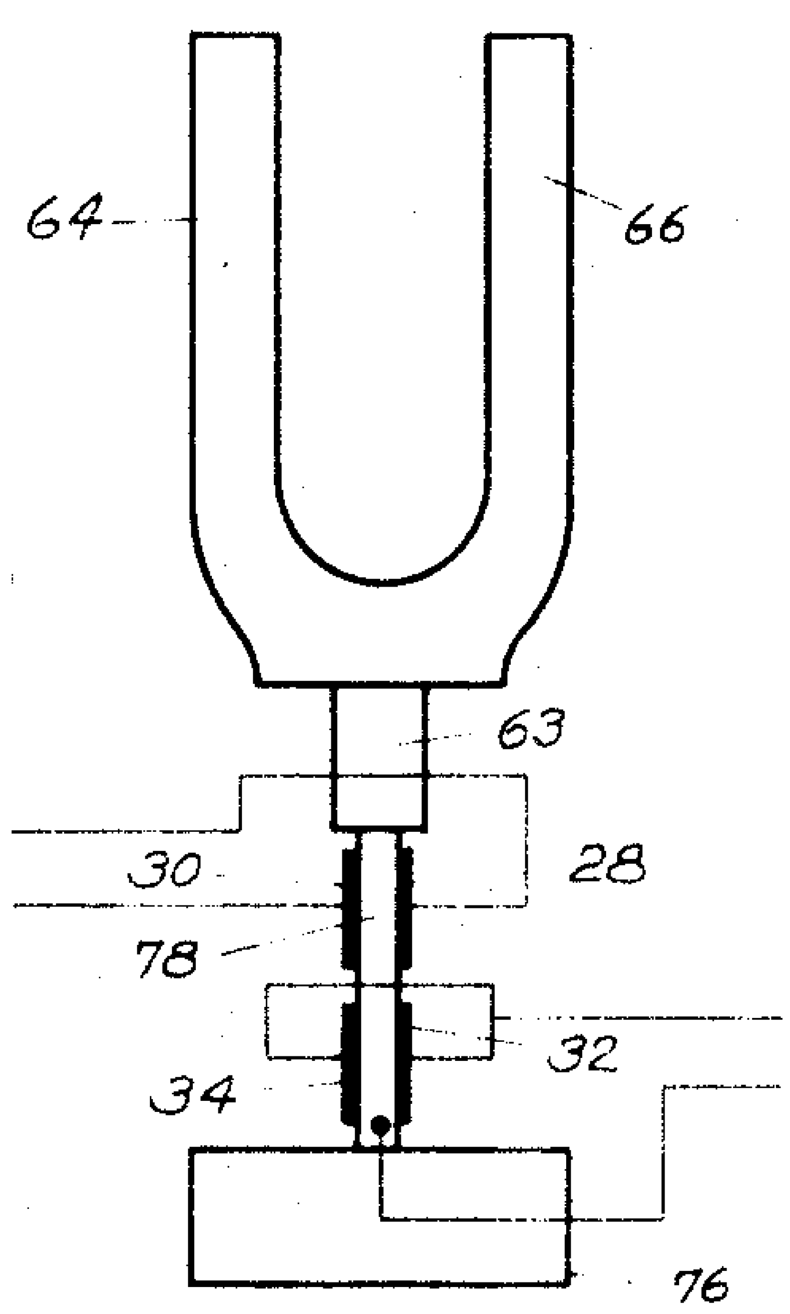

FIG. 9

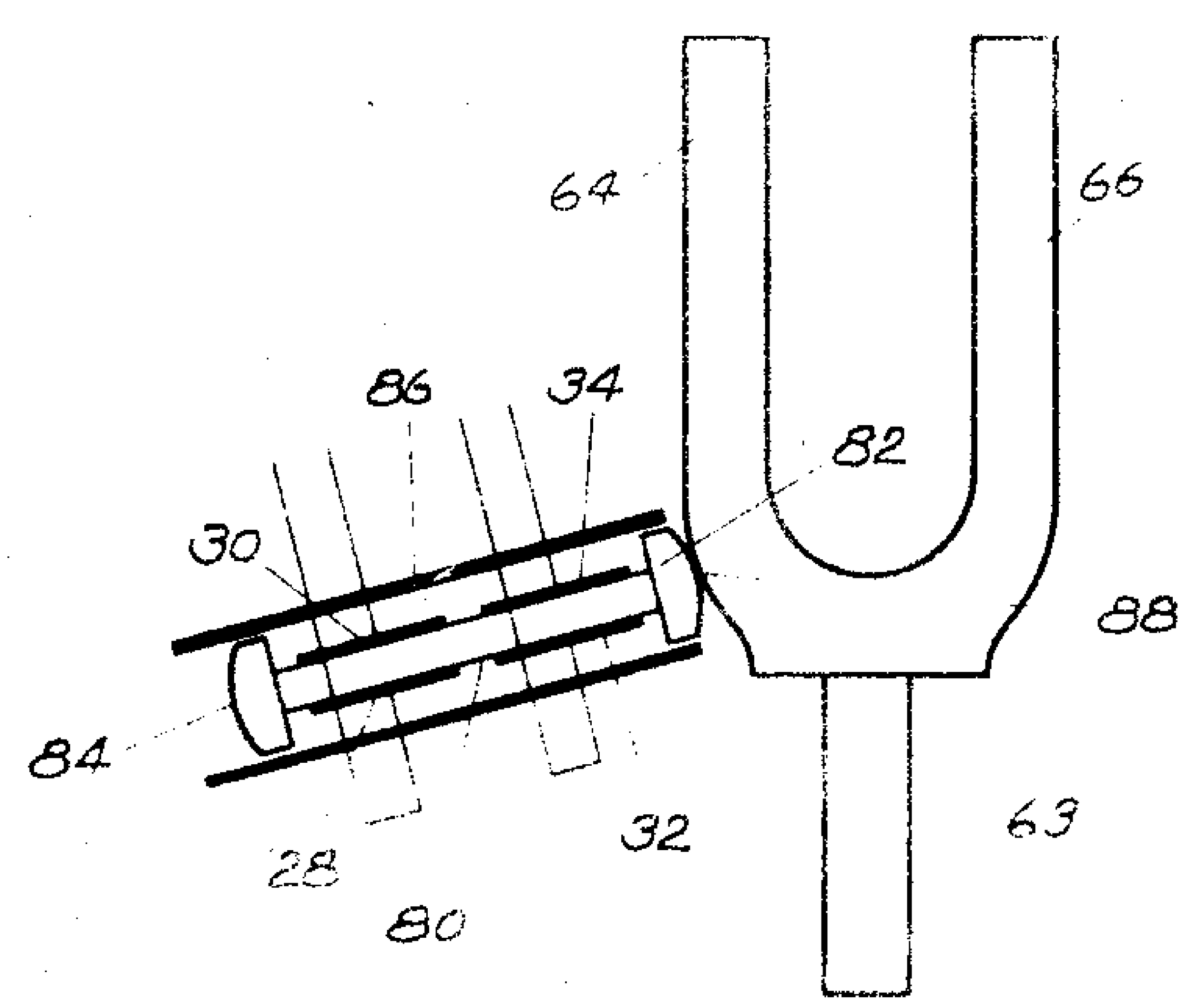

FIG. 10

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UNITED STATES PATENT OFFICE.

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ELECTROMECHANICAL SYSTEM.

Application filed February 28, 1925. Serial No. 12,463.

The present invention relates to electro-mechanical systems, and more particularly to methods of and apparatus for producing and sustaining the vibrations of mechanical and electro-mechanical vibrators. From a more limited aspect, the invention relates to methods of and apparatus for maintaining tuning forks, rods and other mechanical systems in constant vibration.

The object of the invention is to improve upon methods and apparatus of the above-described character.

The invention will be explained in connection with the accompanying drawings, in which Fig. 1 is a diagrammatic view of circuits and apparatus arranged according to a preferred embodiment of the present invention; Fig. 2 is a similar view illustrating an application of the invention to the production of resonant vibrations in a column of air or other gas contained within a tube; Figs. 3 and 4 are views of modifications; Fig. 5 is an end view corresponding to Fig. 4; and Figs. 6 to 10 are views of further modifications.

According to the preferred embodiment of the invention that is illustrated in Fig. 1, a long, flat, steel rod 1 is provided with four Rochelle-salt plates 2, 3, 4 and 5, symmetrically disposed in pairs on opposite sides of the rod at points equally spaced from, and close to, the center of the rod. Though steel is preferred, any other suitable, elastic solid may be employed; and though suitably cut plates of Rochelle-salt crystals have been found to be well suited, in practice, because of their large piezo-electric activity, it will be understood that other electro-mechanical vibrators may also be employed, and the more particularly if they are piezo-electric. The best manner of cutting the plates—if plates are used—from the crystals will be known to persons skilled in the art without further description. In the following description, for the sake of simplicity, the plates will be assumed to be so cut and mounted that the transverse piezo-electric effect shall be utilized. The deformation of the plate is then in a direction at right angles to the impressed electric field. The longitudinal effect, in which the deformation of the crystal is in the same direction as the impressed electric field, may equally well be utilized. The crystal plates are secured to the rod 1 in such fashion that they shall vibrate together as a unit. This may be effected by cementing with shellac, wax or other material along the contacting faces of the rod 1 and the plates, or the rod and the plates may be held together in any other desired manner. The use of cement has been found most effective, in practice. Each plate is provided with a coating, indicated at 28, 30, 32 and 34, respectively, preferably of tinfoil or other conducting material, cemented to a free face of the crystal plate. A vibrator is thus produced constituted of the mechanical vibrator 1 and the electro-mechanical vibrators 2, 3, 4 and 5. The natural period of vibration of this composite vibrator will be determined by the natural period of vibration of the rod 1, with a correction for the masses of the crystal plates 2, 3, 4 and 5. As the crystal plates are small compared to the rod 1, however, the correction is negligible, and the natural period of vibration of the vibrator will be very close to that of the rod 1.

In order that this vibrator may vibrate freely, it must not be damped. If it is permitted to rest upon a support, as upon soft pads, therefore, the ends of the rod 1 must be left sufficiently free. Preferably, the vibrator is suspended by a wire 9 from its central point.

The source of energy for vibrating the vibrator may comprise one or more vacuum tubes or space-current amplifiers 6. One tube 6 only is illustrated, in order to simplify the drawings, and this tube is shown of conventional form provided with an anode or plate, a grid, and a cathode or filament. The cathode or input circuit is provided with the customary leak 10 between the grid and the filament. The plate or output circuit is illustrated as comprising, in addition to the plate battery, the primary winding 7 of a step-up transformer. The secondary winding 8 of the transformer is connected with a point 12 of the output circuit, in series with the coatings 32 and 34 of the crystal plates 4 and 5, the latter being connected in parallel, as illustrated. It is not essential to connect the plates 4 and 5 in parallel, and it is not essential to utilize both plates 4 and 5; but the parallel connection introduces a capacity in series with the winding 8 that is twice the capacity of either plate 4 or 5 if used by itself, and this makes it possible to reduce the ratio of transformation of the transformer 7, 8. The transformer should obviously be so designed as to make the electric field in the plates 4 and 5 as strong as possible; and if the parallel connection of these plates is employed, the plates will naturally be so mounted upon the rod 1 that they shall both contract and elongate together when their coatings are charged with charges of the same sign.

The coatings 28 and 30 of the plates 2 and 3 are connected in series between the filament and the grid, in order that the grid may be subjected to a maximum potential. In this case, of course, the plates will be so mounted upon the rod 1 that when simultaneously elongated or contracted, their coatings will be charged oppositely. The suspension wire 9 may serve as a terminal, connected to the amplifying circuit, as illustrated.

In operation, energy from the output circuit of the tube 6 will be communicated, through the winding 8, to the plates 4 and 5. These plates will therefore be stimulated electrically to vibrate mechanically. If they are mounted as above described, they will elongate and contract together, causing corresponding waves of compression and rarefaction to travel along the rod 1, in both directions. These waves will be reflected at the free ends of the rod 1. The vibrator will thus be set into longitudinal vibration at a frequency very close to the natural, fundamental frequency of the rod 1, as before described.

The waves of compression and rarefaction in the rod 1 cause corresponding compressions and extensions in the plates 2 and 3. These mechanical vibrations of the plates 2 and 3, in accordance with the laws of piezo-electricity, cause these plates to respond electrically. If the plates are mounted upon the rod 1, as before described, a positive charge will appear upon the coating of the plate 2 or the plate 3 when a negative charge is found on the coating of the plate 3 or the plate 2, and these charges will alternate in synchronism with the vibrations of the plates. These charges are periodically transmitted from the coating of the plate 3 to the grid, and they will be transmitted in proper phase if the crystal plates are properly disposed upon the rod 1. If they have not been properly mounted, a trial will demonstrate the fact, but a trial is unnecessary, since the polarity of the plates may readily be determined before the plates are cemented in place. Owing to the amplifying action of the space-current device 6, an amplified current of the same frequency will flow in the output circuit and will be communicated, through the winding 7, to the winding 8. From the winding 8, currents of the same frequency will flow to the plates 4 and 5, thus reinforcing the original electrical stimulation of these plates. The electric reaction of the piezo-electric plates 2 and 3 upon the amplifier 6 thus causes energy of the right frequency and phase to flow from the output circuit of the amplifier to the piezo-electric plates 4 and 5, and the rod 1 is thus maintained in mechanical vibration at substantially its natural frequency. The rod 1 is thus maintained in longitudinal vibration at constant frequency, and a sustained musical note is thus produced.

The vibrator 1 may therefore be utilized in applications where a constant-frequency vibrator is needed. One such application is illustrated in Fig. 2 in connection with a determination of the velocity of sound in air or other gas. The vibrator before described in connection with Fig. 1 is illustrated at the right of Fig. 2, but its connections to the space-current device are omitted, for simplicity. It will be understood that the vibrator may be connected to the space-current device as in Fig. 1 or in any other suitable manner. The left-hand end of the rod 1 of the vibrator is provided with a flat disc 14. The disc 14 may be secured to the rod 1 in any well known way, as by the use of the cement. The vibrations of the rod will therefore be communicated to the disc 14 and the latter will vibrate at constant frequency. The disc 14 is positioned close to an open end 15 of a glass, resonance tube 16 within which is slidably mounted a piston 18. The position of the piston 18 within the tube 16 may be adjusted by manipulating a rod 20 to which it is secured. By adjusting the piston 18 within the tube 16, the various positions of the piston 18 may be determined corresponding to which the vibrations of the column of air in the tube are in resonance with the vibrations of the vibrator. The positions of the nodes in the tube, using lycopodium powder, for example, may be determined with great accuracy. The method of determining the velocity of sound from the data obtained by the experiment need not be explained, as it is well known. The described apparatus is more compact than apparatus heretofore employed, since rods less than a meter long may be used, and they have the further advantage that they furnish a sustained note.

If it is desired to determine the velocity of sound in some other medium than air, the medium may be confined in the tube 16 between membranes (not shown) fastened at the ends 15 and 22 of the tube 16. The gas or other medium to be tested is confined in the tube 16 between the ends 15 and 22. A stuffing box may be substituted for the membrane at the end 22, but the member at the end 15 should be a thin membrane or similar device with which the disc 14 contacts lightly. The piston 18 should, in this case, fit loosely in the tube 16, or it may be provided with one or more small openings to permit adjustment of the piston 18 within the tube 16.

The circuit connections may, of course, be varied, as will be understood by persons skilled in the art. The use of a transformer

7, 8, for example, though usually convenient, is not essential. If the amplification of the amplifier 6 is sufficient, for example, the plates 4, 5, may be connected directly to the terminals of the winding 7, and the winding 8 may be omitted. If the voltages across the piezo-electric plates 4, 5 connected with the output circuit are so great as to cause electric discharges from the metal coatings, and thus injure the plates, thin sheets of mica or other dielectric may be interposed between the coatings and the plates, as will readily occur to persons skilled in the art. And the arrangement and number of crystal plates, too, may be varied. It will readily be understood, for example, that the plates 2 and 3, like the plates 4 and 5, if suitably oriented, may be connected in parallel and that the plates 4 and 5, like the plates 2 and 3, may be connected in series. In fact, both pairs of plates may be connected in parallel, or both in series, and in the last case, the metal connection 9 with the rod 1 may be dispensed with. Though the use of four crystal plates is preferred, it will further be understood that this number may be increased or diminished. A single pair of plates may be used, for example, as is illustrated in Figs. 3 to 6. These plates may be respectively connected with the input and the output circuits. Each plate of such a single pair may, furthermore, be provided with two separate coatings, as is also illustrated in Figs. 3 to 6. In fact, a single plate will operate, provided with only one pair of coatings; and this is equally true of the tuning-fork combinations illustrated in Figs. 7 to 10. A single plate must, however, be differently mounted, as at the side of the rod 1. In general, any one of various parallel or series connections may be used for the coatings, the choice depending, among other things, on the material and the dimensions of the piezo-electric plates, and on the characteristics of the amplifier and of the output transformer 7, 8.

According to the construction illustrated in Fig. 3, two plates 24 and 26 only are used, cemented or otherwise secured to the ends of the rod 1, instead of near the center of the rod. The plates are each provided with two of the coatings 28, 30 and 32 and 34. The coatings 28 and 30 may be connected to the input circuit and the coatings 32 and 34 to the output circuit of the space-current device 6, in the same manner as before described in connection with Fig. 1. The operation is similar to that described in connection with Fig. 1, except that the rod is vibrated by periodic forces received from the end of one of the piezo-electric plates. The inertia of the plates 24 and 26 is sufficient to enable the necessary forces to be transmitted.

It has been stated above that the crystal plates may be secured to the mechanical vibrator 1 in other ways than by the use of cement. Fig. 4 illustrates one such way. The vibrator is shown provided with two crystal plates 36 and 38, held between two pairs of yokes 40, 42 and 44, 46. The yokes are clamped across the rod 1 by screws or bolts 48. The force for vibrating the rod 1 is, of course, transmitted from the crystal plates to the rod 1 through the yokes. The plates 36 and 38 are each shown provided with four coatings 28, 50, 32 and 52, and 30, 54, 34 and 56, respectively. The four-coating construction will not be described further herein, as a full description will be found in my prior Patents Nos. 1,450,246 and 1,472,583. Correspondingly numbered coatings are connected with the space-current device as in Fig. 1, the coating 50 being electrically connected with the coating 54 and the coating 52 with the coating 56. The illustrated construction has the advantage in that only two pairs of yokes are employed. Four separate crystal plates, each having a single coating, as in Fig. 1, may be used, but it would then be necessary to employ at least three yokes. Obviously, also, a single plate, between two yokes, could be used.

The construction of Fig. 4 makes it possible to secure the crystal plates detachably at various positions longitudinally disposed along the rod 1, thus enabling the rod 1 to be so vibrated as to excite overtones or the fundamental, at will. If the plates are attached to the rod 1 at a distance from one end equal to one-third the length of the rod 1, for example, the frequency of vibration of the vibrator will be approximately equal to three times the fundamental frequency of the rod 1. A further advantage of this detachable construction is that the crystal plates may readily be detached from one rod and mounted upon another.

In order to mount crystal plates detachably at the ends of the rod, as in Fig. 3, the construction illustrated in Fig. 6 may be employed. The crystal plates 24 and 26 are each cemented or otherwise secured to small metal blocks 58 and 60, respectively. The blocks 58 and 60 may be secured to the rod 1 by clamps, screws, or the like 62. As in the case of Fig. 4, therefore, the plates are adjustable along the rod and interchangeable from one rod to another. In both cases, on the other hand, the mass of the additional yokes or blocks introduces a larger correction to the natural frequency of vibration of the rod 1, so that the composite vibrator vibrates at a frequency that is farther removed from the natural frequency of the rod 1 than is the case when the crystal plates are cemented directly to the rod 1.

The present invention is obviously as applicable to driving tuning forks as vibrating rods or plates, and this feature of the invention is illustrated in Figs. 7 to 10. The tuning fork is shown provided with a stem 63 and two prongs 64 and 66. Each of these prongs is shown provided in Fig. 7 with a piezo-electric plate, indicated at 68 and 70. Each plate is connected endwise to its corresponding prong near the tip of the prong, in a direction at right angles to the longitudinal direction of the prong. It is obviously immaterial whether the plane of the plate is in the same plane as the prong or at right angles thereto. The plates are provided with coatings 28, 30, 32 and 34, connected as described in connection with Figs. 1 and 3. The operation is similar to that of Fig. 3, the frequency of vibration of the tuning fork being its natural, fundamental frequency, slightly modified by the masses of the plates. The inertia of the plates furnishes the necessary reaction.

The piezo-electric plates may be mounted upon the stem 63 of the tuning fork, instead of upon the prongs. Such a construction is illustrated in Fig. 8. The plates 72 and 74 are cemented on opposite sides of the stem 63, as in Fig. 1, and they are similarly provided with coatings 28, 30, 32 and 34, similarly connected, the first two with the input circuit and the second two with the output circuit. A connection 9 is also provided, similar to the connection 9 of Fig. 1. The operation is very much the same as that described in connection with Fig. 1, except that the frequency of compressional vibration of the stem 63, as is well known, is twice that of the prongs 64 and 66. The stem 63 is secured to a massive base 76 constituted of rigid material, like metal, in order that the stresses set up in the stem 63 by the changes in dimensions of the crystal plates may be transmitted most effectively to the prongs 64 and 66.

Instead of two crystal plates, four may be provided, one on each of the four longitudinal faces of the stem 63. A more symmetrical arrangement is thus obtained. Each of the four plates may be provided with a single coating, and the coatings may be connected as illustrated in Fig. 1.

In Fig. 9, a single, long, piezo-electric plate 78 is shown cemented lengthwise between the stem 63 and the massive base 76. The plate is provided with four coatings, two of which, 28 and 30, are connected with the input circuit, and the other two, 32 and 34, with the output circuit, as in Fig. 1. The stresses periodically set up in the crystal plate in response to the electrical stimulation of the plate are transmitted directly to the stem, and the stem reacts upon the crystal plate, the latter responding electrically to impress periodic potential changes on the grid. The operation is very much as in the construction of Fig. 3, the chief difference being that all four coatings are on the same plate. This method of mounting is very effective when the tuning fork is of high pitch, and the prongs are widely spaced, the tuning fork vibrating at a frequency close to its natural frequency.

It is not, of course, essential that the crystal plate be rigidly secured to the tuning fork. The tuning fork may be piezo-electrically vibrated in some other manner as, for example, by means of the piezo-electric cartridge illustrated in Fig. 10. This cartridge comprises a piezo-electric plate 80, illustrated as provided with two pairs of coatings, 28, 30 and 32, 34, the first pair connected with the input circuit and the second pair with the output circuit, as illustrated in Fig. 1. Metal or other solid shoes 82 and 84 are rigidly secured to the ends of the plate 80, chiefly to protect the ends of the plate against injury, and the whole is loosely fitted in a tube 86, preferably of insulating material. The wires for connecting the coatings with the space-current device may lead through suitably provided openings (not shown) in the sides or the ends of the tube. The plate will vibrate as before described, and the vibrations will be transmitted to the shoes 82 and 84. By holding the shoe 82 against the tuning fork, and pressing against the shoe 84, the vibration of the plate 80 will be transmitted to the tuning fork in a manner similar to that described in connection with Fig. 9. The shoe 82 may be held against any convenient spot of the tuning fork, preferably against a shoulder 88, or against the end of the stem 63.

The piezo-electric plate or plates may be replaced by a single plate having but one pair of coatings; or by two or more plates having their coatings all connected together in two groups. The wires leading from these coatings or groups of coatings may, furthermore, be connected between the grid and the filament or between the grid and the anode of the space-current device. Other modifications also will occur to persons skilled in the art, and all such are considered to fall within the spirit and the scope of the invention. In the appended claims, it is intended to cover all the novelty that the invention may possess.

What is claimed is:

1. The method of vibrating a mechanical vibrator which comprises, generating electrical oscillations, producing mechanical vibrations by means of said oscillations, producing electrical oscillations by means of said mechanical vibrations, and controlling the generation of said first mentioned oscillations by means of said last mentioned electrical oscillations.

2. The method of vibrating a mechanical vibrator, which comprises generating electrical oscillations, converting said electrical oscillations into mechanical vibrations, reconverting a portion of said mechanical vibrations into electrical oscillations, and utilizing said last mentioned electrical oscillations to control the generation of said first mentioned electrical oscillations.

3. The method of vibrating a mechanical vibrator which comprises, producing electri-

cal oscillations, converting such electrical oscillations into mechanical vibrations, re-converting said mechanical vibrations into electrical oscillations, and utilizing said last mentioned electrical oscillations in producing said first mentioned electrical oscillations.

4. The method of vibrating a mechanical vibrator which comprises, generating electrical oscillations, converting said electrical oscillations into mechanical vibrations, and reenforcing said electrical oscillations by converting said mechanical vibrations into additional electrical oscillations.

5. A vibrating system having, in combination, a mechanical vibrator and an electro-mechanical vibrator so constructed and arranged that the electro-mechanical vibrator shall vibrate only when the mechanical vibrator vibrates, the electro-mechanical vibrator being adapted to respond electrically when vibrated mechanically, means for vibrating the mechanical vibrator, and means controlled by the electro-mechanical vibrator for controlling the vibrating means.

6. A vibrating system having, in combination, a mechanical vibrator and two electro-mechanical vibrators so constructed and arranged that the mechanical vibrator shall vibrate when one of the electro-mechanical vibrators vibrates and so that the other electro-mechanical vibrator shall vibrate when the mechanical vibrator vibrates, the said one electro-mechanical vibrator being adapted to vibrate mechanically when stimulated electrically and the said other electro-mechanical vibrator being adapted to respond electrically when vibrated mechanically, means for electrically stimulating the said one electro-mechanical vibrator, and means controlled by the said other electro-mechanical vibrator for controlling the stimulating means.

7. A vibrating system having, in combination, two vibrators so constructed and arranged that one of the vibrators shall vibrate when the other vibrator vibrates, means comprising a space-current device for controlling the vibrations of the said other vibrator, and means controlled by the said one vibrator for controlling the space-current device.

8. A vibrating system having, in combination, three mechanical vibrators so constructed and arranged that one of the vibrators shall vibrate when a second of the vibrators vibrates and so that the third vibrator shall vibrate when the said one vibrator vibrates, means comprising a space-current device for controlling the vibrations of the second vibrator, and means controlled by the third vibrator for controlling the space-current device.

9. A vibrating system having, in combination, a mechanical vibrator and an electro-mechanical vibrator so constructed and arranged that the electro-mechanical vibrator shall vibrate when the mechanical vibrator vibrates, the electro-mechanical vibrator being adapted to respond electrically when vibrated mechanically, means comprising a space-current device for vibrating the mechanical vibrator, and means controlled by the electro-mechanical vibrator for controlling the space-current device.

10. A vibrating system having, in combination, a mechanical vibrator and two-electro-mechanical vibrators so constructed and arranged that the mechanical vibrator shall vibrate when one of the electro-mechanical vibrators vibrates and so that the other electro-mechanical vibrator shall vibrate when the mechanical vibrator vibrates, the said one electro-mechanical vibrator being adapted to vibrate mechanically when stimulated electricaly and the other electro-mechanical vibrator being adapted to respond electrically when vibrated mechanically, means comprising a space-current device for electrically stimulating the said one electro-mechanical vibrator, and means controlled by the other electro-mechanical vibrator for controlling the space-current device.

11. A vibrating system, having, in combination, a mechanical vibrator and two electro-mechanical vibrators so constructed and arranged that the mechanical vibrator shall vibrate when one of the electro-mechanical vibrators vibrates and so that the other electro-mechanical vibrator shall vibrate when the mechanical vibrator vibrates, the said one electro-mechanical vibrator being adapted to vibrate mechanically when stimulated electrically and the other electro-mechanical vibrator being adapted to respond electrically when vibrated mechanically, and a space-current device having an input circuit and an output circuit, the said other electro-mechanical vibrator being connected with the input circuit and the said one electro-mechanical vibrator being connected with the output circuit.

12. A vibrating system having, in combination, a mechanical vibrator and two electro-mechanical vibrators so constructed and arranged that the mechanical vibrator shall vibrate when one of the electro-mechanical vibrators vibrates and so that the other electro-mechanical vibrator shall vibrate when the mechanical vibrator vibrates, the said one electro-mechanical vibrator being adapted to vibrate mechanically when stimulated electrically and the other electro-mechanical vibrator being adapted to respond electrically when vibrated mechanically, a space-current device having an input circuit and an output circuit, the said other electro-mechanical vibrator being connected with the input circuit, a transformer having two windings one of which is connected in the output circuit, and means connecting the other winding and the said one electro-mechanical vibrator in series with a point of the output circuit.

13. A vibrating system having, in combination, a mechanical vibrator and electro-mechanical means so constructed and arranged as to vibrate as a unit, the electro-mechanical means being adapted to vibrate mechanically when stimulated electrically and to respond electrically when vibrated mechanically, a space-current device having an input circuit and an output circuit, means for transmitting energy from the output circuit to the electro-mechanical means to stimulate the electro-mechanical means electrically, and means for transmitting energy from the electro-mechanical means to the input circuit.

14. A vibrating system having, in combination, a mechanical vibrator and a piezo-electric body constructed and arranged to vibrate together as a unit, means for electrically stimulating the piezo-electric body, and means controlled by the mechanical vibrator for controlling the stimulating means.

15. A vibrating system having, in combination, a mechanical vibrator and two piezo-electric bodies constructed and arranged to vibrate together as a unit, means for electrically stimulating one of the piezo-electric bodies, and means controlled by the other piezo-electric body for controlling the electrical stimulating means.

16. A vibrating system having, in combination, a mechanical vibrator and two piezo-electric bodies constructed and arranged to vibrate together as a unit, means comprising a space-current device for electrically stimulating one of the piezo-electric bodies, and means connecting the other piezo-electric body for controlling the space-current device.

17. A vibrating system having, in combination, a mechanical vibrator and two piezo-electric bodies constructed and arranged to vibrate together as a unit, and a space-current device having an input circuit and an output circuit, one of the piezo-electric bodies being connected with the input circuit and the other piezo-electric body being connected with the output circuit.

18. A device of the class described comprising a mechanical vibrator and two electro-mechanical vibrators longitudinally disposed on the mechanical vibrator, the vibrators being constructed and arranged to vibrate together as a unit, one of the electro-mechanical vibrators being adapted to vibrate mechanically when stimulated electrically and the other electro-mechanical vibrator being adapted to respond electrically when vibrated mechanically.

19. A device of the class described comprising a mechanical vibrator and four electro-mechanical vibrators disposed in pairs longitudinally on the mechanical vibrator, the vibrators being constructed and arranged to vibrate together as a unit.

20. A device of the class described having, in combination, a mechanical vibrator and four piezo-electric bodies symmetrically disposed in pairs with respect to the center of the vibrator, the vibrator and the piezo-electric bodies being constructed and arranged to vibrate together as a unit.

21. A vibrating system having, in combination, a mechanical vibrator and three electro-mechanical vibrators constructed and arranged to vibrate together as a unit, two of the electro-mechanical vibrators being adapted to respond electrically when vibrated mechanically and the third electro-mechanical vibrator being adapted to vibrate mechanically when stimulated electrically, and a space-current device having an input circuit and an output circuit, the said two electro-mechanical vibrators being connected in series in the input circuit and the said third electro-mechanical vibrator being connected with the output circuit.

22. A vibrating system having, in combination, a mechanical vibrator and three electro-mechanical vibrators constructed and arranged to vibrate together as a unit, two of the electro-mechanical vibrators being adapted to vibrate mechanically when stimulated electrically and the third electro-mechanical vibrator being adapted to respond electrically when vibrated mechanically, a space-current device having an input circuit and an output circuit, the said third electro-mechanical vibrator being connected with the input circuit, a transformer having two windings one of which is connected in the output circuit, and means connecting the said two electro-mechanical vibrators in parallel and the other winding in series with a point of the output circuit.

23. A vibrating system having, in combination, a mechanical vibrator and four piezo-electric bodies symmetrically disposed in pairs with respect to the center of the vibrator, the vibrator and the piezo-electric bodies being constructed and arranged to vibrate together as a unit, a space-current device having an input circuit and an output circuit, the two piezo-electric bodies of one of the pairs being connected in series in the input circuit, a transformer having two windings one of which is connected in the output circuit, and means connecting the two piezo-electric bodies of the other pair in parallel and the other winding in series with a point of the output circuit.

24. A device of the class described comprising a mechanical vibrator, an electro-mechanical vibrator, a yoke for securing the electro-mechanical vibrator to the mechanical vibrator, and means for securing the yoke to the mechanical vibrator.

25. A device of the class described comprising a mechanical vibrator, a plurality of electro-mechanical vibrators, a plurality of yokes for securing the electro-mechanical

vibrators to the mechanical vibrator, and means for detachably securing the yokes to the mechanical vibrator.

26. A device of the class described comprising a mechanical vibrator, a plurality of electro-mechanical vibrators, a plurality of yokes mounted on the mechanical vibrator, and means for detachably securing the yokes to the mechanical vibrator to detachably secure the mechanical vibrator and the electro-mechanical vibrators together to cause them to vibrate together as a unit.

27. A device of the class described comprising a mechanical vibrator, an electro-mechanical vibrator, a holder to which the electro-mechanical vibrator is secured, and means for detachably securing the holder to the mechanical vibrator.

28. A vibrating system having, in combination, a tuning fork having a stem and two prongs, a comparatively massive base constituted of rigid material connected with the stem, and means for vibrating the stem.

29. A vibrating system having, in combination, a tuning fork having a stem and two prongs, and piëzo-electric means for vibrating the stem.

30. A vibrating stem having, in combination, a tuning fork having a stem and two prongs, and a piezo-electric body secured to the stem, the construction and arrangement being such that the tuning fork and the body shall vibrate together as a unit.

31. A device of the class described comprising a longitudinally disposed mechanical vibrator and a piezo-electric plate mounted endwise at an end of the mechanical vibrator at right angles to the longitudinal direction of the mechanical vibrator.

32. An electro-mechanical cartridge comprising an electro-mechanical vibrator adapted to be vibrated mechanically when stimulated electrically, a shoe secured to the vibrator, means for electrically stimulating the vibrator, and a covering for the vibrator and the shoe.

33. A piezo-electric cartridge comprising a piezo-electric body, a shoe secured to the body, means for electrically stimulating the body, and a covering for the body and the shoe.

34. A vibrating system having, in combination, a tuning fork and two electro-mechanical vibrators so constructed and arranged that the tuning fork shall vibrate when one of the electro-mechanical vibrators vibrates and so that the other electro-mechanical vibrator shall vibrate when the tuning fork vibrates, the said one electro-mechanical vibrator being adapted to vibrate mechanically when stimulated electrically and the said other electro-mechanical vibrator being adapted to respond electrically when vibrated mechanically, means for electrically stimulating the said one electro-mechanical vibrator, and means controlled by the said other electro-mechanical vibrator for controlling the stimulating means.

In testimony whereof, I have hereunto subscribed my name.

WALTER G. CADY.