Oct. 16, 1945. J. P. ARNDT, JR., ET AL 2,387,108

PIEZOELECTRIC APPARATUS

Filed March 18, 1942

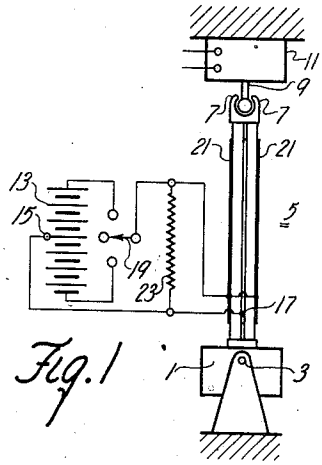

Fig. 1

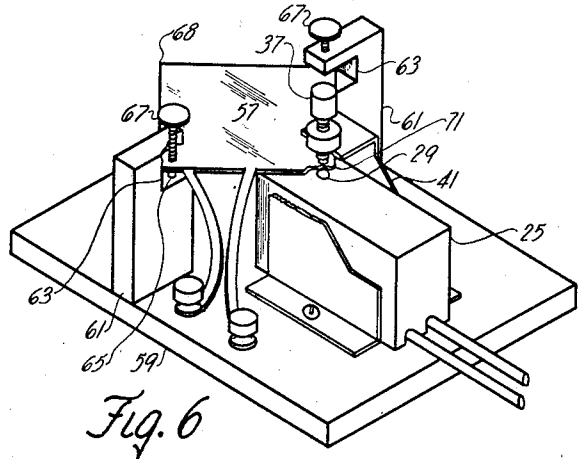

Fig. 6

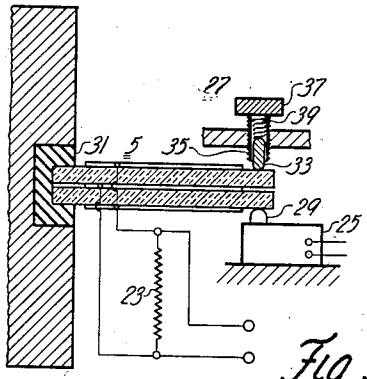

Fig 3

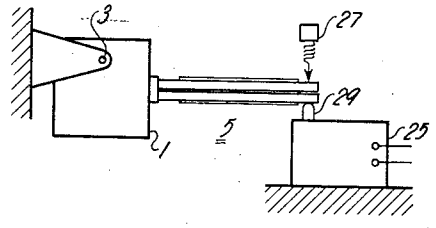

Fig. 2

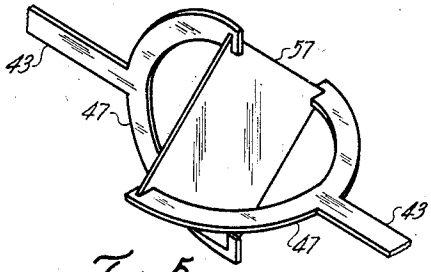

Fig. 5

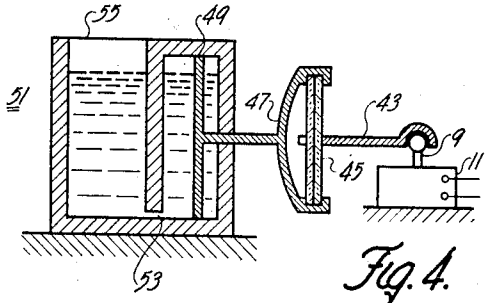

Fig. 4.

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PIEZOELECTRIC APPARATUS

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Application March 18, 1942, Serial No. 435,194

20 Claims. (Cl. 171—327)

This invention relates to piezoelectric apparatus and more particularly to relays or the like wherein the actuating member is similar to the piezoelectric motor element disclosed in the Sawyer Reissue Patent 20,213.

Piezoelectric crystal elements of the sodium-potassium tartrate type have many advantages for relay actuation. They tend, however, to contract or expand with changes in temperature and to "set" or sag while in use, with the result that the contact spacing, which must be exact, is often disturbed.

An object of the invention, therefore, is to provide a relay of the piezoelectric element type that shall be immune to the effects of "set" or sag.

Another object of the invention is to provide a relay, actuated by a piezoelectric element, that shall not depend upon critical contact spacing and one that is substantially unaffected by temperature changes.

Another object of the invention is to provide a relay, actuated by a piezoelectric element, that shall be rapid in action, inexpensive to manufacture, yet extremely rugged.

Another object of the invention is to provide a relay or the like, actuated by a piezoelectric element, wherein alteration of the shape of the element, from natural causes, or at very low velocity, does not interfere with reliability.

A still further object of the invention is to provide a relay or the like, actuated by a multiplate flexing piezoelectric element, wherein "set" or sag thereof shall be compensated automatically.

In accordance with the invention, a piezoelectric element, preferably a multiplate flexing element of the type disclosed in the Sawyer patent, is so supported in operative relation to an instrumentality having a movable part such, for example, as a "snap-action" switch, that slow changes in the shape of the element, at low velocity or from natural causes, are continuously compensated, whereas movements thereof at high velocity are transmitted to the said instrumentality. To obtain such action, a piezoelectric element of either the "bender" or the "twister" type may be utilized, one portion of which is operatively engaged with the switch at all times while another portion is permitted to move slowly, as the element "sets," without disturbing the engagement with the switch. Such elements are disclosed in the Sawyer Reissue Patent 20,213, and they are now well known to those skilled in the art. For example, a "bender" element may be mounted upright upon a horizontally pivoted weight, to flex in a plane at right angles to the pivot, the free upper end being operatively connected with the switch. The system is in stable equilibrium and, if the resistance offered by the switch to movement by the free end of the element is properly adjusted, slow bending of the element is compensated by rotary movement of the weight about its pivot, the free end of the element being effectively "decoupled" from the switch. When, however, potential is applied to the electrodes of the element such as to cause it to bend with high velocity, the inertia of the weight is such that it serves the purpose of a fixed mounting, causing operation of the switch. Another way of explaining the action is by analogy to a high pass filter, the movable part of the switch corresponding to the output terminals thereof, and the weight corresponding to a shunting inductor.

The novel features of the invention are set forth with particularity in the appended claims. The invention itself, however, both as to its organization and its method of operation, together with further objects and advantages thereof, will best be understood from a consideration of the following description of certain specific embodiments taken in connection with the accompanying drawing in which:

Fig. 1 is a diagrammatic elevational view of one embodiment of the invention, also showing an operating circuit therefor.

Fig. 2 is a conventionalized side elevational view of a modification of the device shown in Fig. 1.

Fig. 3 is a conventionalized sectional view of an alternative embodiment of the invention.

Fig. 4 is a conventional view, partly in vertical section and partly in elevation, of another embodiment of the invention.

Fig. 5 is a fragmentary view in perspective showing an alternative embodiment of the invention exemplified by Fig. 4.

Fig. 6 is a view in perspective of an actual relay constructed according to the invention, part of the apparatus being broken away in order to disclose more clearly the details thereof.

In all figures of the drawing, identical elements are similarly designated.

Referring now to Fig. 1 of the drawing, an embodiment of the invention may comprise a weight 1 rotatably supported upon a horizontal pivot 3 on the upper surface of which is vertically mounted a piezoelectric crystal element 5 of the multiplate bender type, the crystal sections constituting the element being disposed in planes parallel to the plane of the weight-supporting pivot 3. The upper end of the piezoelectric element is pro-

vided with means such as a plurality of fingers 7—7, or the like, which engage the movable part 9 of a snap-action switch 11, or the like, of the type that requires only a short "throw" for actuation.

As is well known to those skilled in the art, snap-action switches usually require a certain definite amount of force to throw them from one position past dead center to the other position. This action may be secured by a small spring so mounted with respect to the movable part of the switch or similar device that it is placed under tension as the said movable part moves through dead center, the tension being relaxed at either of the "rest" positions. There is also another well known short throw switch on the market known as a "micro switch," manufactured under United States Patent 1,960,020 by the Micro Switch Corporation of Freeport, Illinois. The latter switch requires a short throw for operation to the closed position, after which it tends, because of its construction, to return to the open position. A slight modification of this invention is necessary for the operation of a "micro switch" or switches of that general type, as hereinafter will be explained in connection with other figures of the drawing.

For the purpose of causing the multiplate flexing element 5 to bend to either one side or the other, a source of potential is provided for application to the inner and outer electrodes thereof. The source may, if desired, be unidirectional and a reversing switch (not shown) may be utilized or it may be constituted, as shown in Fig. 1, by a battery 13, a central tap 15 which is connected to the interior electrode 17 of the multiplate flexing element, a three-point switch 19 being so connected to the outer electrodes 21—21 of the multiplate flexing element that either the positive or negative terminal of the battery 13 may be connected thereto. A bleeding resistor 23 having a resistance usually of the order of $\frac{1}{10}$ to 10 megohms is connected across the electrodes of the multiplate flexing element for the purpose of dissipating the charge thereon after actuation thereof and after opening of the switch.

The weight 1 is so chosen and the position of the pivot 3 is so fixed that the system constituted by the piezoelectric element 5 and the weight is in a state of stable equilibrium. Furthermore, the inertia of the weight is so related to the force required to throw the snap-action switch past dead center that when the crystal element 5 tends to slowly sag or "set" or to change its shape because of temperature changes, the switch 11 is not actuated but the weight 1 is so moved in a small arc around the pivot 3 as to compensate for changes in crystal element configuration. However, if potential is applied to the electrodes, the crystal element flexes at high velocity and, because of the inertia of the weight and the crystal element itself, the lower end of the element does not move appreciably but the upper end thereof moves with great force to snap the switch past the dead center position.

The device, therefore, is immune to temperature effects, and to the effects of set or sag, responding, to actuate the switch, only to potentials such that the crystal is caused to flex suddenly.

Obviously, the apparatus will be immune to very low frequency alternating potentials if the frequency thereof is below the natural flexing period of the crystal and weight assembly, and the apparatus, accordingly, may be utilized to discriminate between high and low alternating frequency currents. Should the impressed potential correspond in frequency to flexing period of the system, the switch will be repeatedly actuated. It may be, of course, forced to operate, even at a different frequency, if the potential is sufficiently high.

There are a number of modified embodiments of the invention analogous to the device shown in Fig. 1. For example, referring to Fig. 2 of the drawing, the piezoelectric element 5 may be supported horizontally upon the weight 1 as shown in full lines in Fig. 2, or vertically below the pivot 3. In such event, the vertically suspended element would function in exactly the same manner as hereinbefore described in connection with Fig. 1. A "micro switch" 25 may be associated with the horizontally positioned piezoelectric element provided a resilient adjustment device 27 is supplied for maintaining a definite pressure upon the free end of the element to balance the tendency of the movable portion 29 of the "micro switch" to return to its open position. The action of the adjusting device 27 will be explained in more detail in connection with Figs. 3 and 6 of the drawing.

Inasmuch as the spirit of the invention resides in the provision of means whereby slow movements of the crystal element are permitted without disturbing its operative relation to a snap-action switch, or the like, substantially the same result may be obtained by providing a deformable mounting therefor in lieu of the pivotally supported weight 1, the inertia of the crystal element itself being relied upon to secure snap-action. Such alternative embodiment of the invention is exemplified by Fig. 3 of the drawing wherein one end of the crystal element is embedded in a mass 31 of deformable material such as "Viscoloid." The free end of the crystal element, still referring to Fig. 3, rests upon the movable portion 29 of a snap-action switch 25, such as the "micro switch" previously referred to, and is held against it by an adjusting device 27 shown partly in section and partly in elevation. The adjusting device 27 is constituted by a small plunger 33 that telescopes within a hollow screw 35 having a knurled head 37 and is resiliently urged against the upper face of the multiplate flexing element by a small spring 39 interposed between the inner end of the hollow screw and the top of the plunger. The pressure exerted by the spring upon the plunger and ultimately upon the crystal element is determined by adjustment of the hollow screw in a yoke 41 such as is shown more clearly in Fig. 6. The pressure is made just slightly to overbalance the tendency of the switch knob 29 to return to the open position but it is insufficient to cause any appreciable movement of the crystal element such as would actuate the switch 25.

If, in use, the crystal element 5 shown in Fig. 3 tends to sag or "set" or otherwise to change its configuration, such change is permitted at a slow rate by the semi-resilient mounting 31, the unmounted end of the element always being maintained, by the device 27, in operative relation with the movable portion 29 of the switch. On the other hand, when potentials are applied to the electrodes of the element, the sudden flexing thereof is resisted by the mounting and by the inertia of the mounted end, with the result that the end in contact with the switch mechanism either moves to cause the switch to close or to permit it to open. Essentially, the operation of the device is the same as that of the first de-

scribed alternative embodiment of the invention.

A still further embodiment of the invention is exemplified by Fig. 4 of the drawing, wherein a snap-action switch 11 is operatively connected by a rod 43, or the like, to the mid-portion of a piezo-electric crystal element 45 of the multiplate bender type, the ends of which are fixed in a yoke 47, which is in turn supported from the piston 49 of a dash-pot 51. No attempt has been made in the drawing to show the details of an actual dash-pot, the essential feature of which is the provision of a very small passageway 53 between the cylinder in which the piston carrying the yoke moves, and a storage reservoir 55.

Should the bender type element shown in Fig. 4 tend slowly to deform, only relatively slight resistance is offered to the flow of fluid through the interconnecting passageway 53, and the piston moves to compensate the changes in shape of the crystal while permitting the switch arm 9 to remain in position. When, however, potential is applied to the bender element, it tends to flex at high velocity and in such event the passageway 53 offers extremely high resistance to movement of the fluid against which the piston presses with the result that the yoke 47 carrying the piezo-electric element does not move, thus permitting the crystal to exert sufficient force upon the switch arm 9 to actuate it.

In some respects, the embodiment of the invention shown in Fig. 4 is advantageous because the opposition to movement of the crystal mounting is "resistive" rather than what might be termed "inductive" such as is the case with the embodiments exemplified by Figs. 1 and 2. Its action is quite closely analogous to the action of the mounting means 31 shown in Fig. 3 in that after the crystal has slowly deformed by reason of natural causes, no restoring force is applied to it other than the difference in level between the fluid in the cylinder of the dash-pot and in the storage chamber.

Referring to Fig. 5, if a "twister" element 57 is utilized in the embodiment exemplified by Fig. 4, a plurality of yokes 47 are utilized and they are connected, respectively, to pairs of opposite corners of the element.

Perhaps the simplest embodiment of the invention is one wherein resilient mountings, weights, and the like, are dispensed with and the inertia of the crystal element itself is relied upon to cause a switch to be thrown when the said element is energized. Such a device is shown in Fig. 6 of the drawing. It preferably comprises a base 59 having two uprights 61, the said uprights, respectively, serving to hold the opposite corners of a piezoelectric element 57 of the torque or "twister" type. For clamping purposes, each upright may be provided with a slot or niche 63 having a vertically extending abutment 65 on which a corner of the crystal rests and against which the corner is held by a clamping screw 67. One corner 68 of the crystal is left perfectly free while the diagonally opposite corner 71 rests upon the upwardly extending movable operating arm 29 of a switch 25 such as a "micro switch." The last-mentioned corner of the crystal is resiliently held against the operating arm of the "micro switch" by an adjusting device of the type shown in section in Fig. 3 that is mounted in a yoke 41 which extends over the said corner. By turning the knurled head 37 of the adjusting device, the pressure upon the switch arm 29 may be maintained just sufficient to hold it in the closed position after actuation by the piezoelectric element.

As will be apparent from an inspection of the drawing, the pairs of corner-clamping devices 65—67 are such as to permit a limited rocking movement of the piezo-electric element while restraining any movement of the corners in vertical planes. Accordingly, as the element sets or sags or changes its shape because of temperature changes, no force is applied to the switch arm, the free end of the element being permitted to move slowly to compensate such changes. However, when potential is applied to the electrodes as described in connection with Fig. 1, the free corner 68 and the corner 71 in contact with the switch arm tend to move with high velocity. Because of the construction of a twister type piezo-electric element, the free corner and the corner in contact with the switch tend to move downwardly while the clamped corners tend to move upwardly or vice versa, depending upon the polarity of the applied potential. If it is assumed that the momentarily applied potential is such as to cause the free corner to move downwardly at a high velocity while the corner in contact with the switch arm also tends to move downward, the tendency to movement of the said free corner introduces a reaction into the system that is the same in kind as the reaction that would be introduced were the said free corner to be provided with a weight. This effect, together with the actual inertia of the free corner, causes the crystal to flex around an axis interconnecting the clamped corners with the result that the switch is moved to the closed position where it is held by the resilient adjusting device until such time as a potential of opposite polarity is applied.

It will, accordingly, be apparent from a consideration of the foregoing description of several modifications of the invention, that it offers advantages heretofore unobtainable. The invention is mainly advantageous in that it obviates all need for exact and meticulous contact spacing and in that a device constructed in accordance therewith is free from the troublesome disturbance of contact spacing introduced by "set" or sag or by changes in crystal element configuration resulting from temperature changes or from other natural causes. Operative engagement between the crystal element and the switch arm is maintained throughout the useful life of the device and it has proven to be very rugged and reliable in operation.

Further advantages of the invention as well as further embodiments thereof will be apparent to those skilled in the art to which it pertains. For example, any other device, capable of being actuated by a relatively small movement of an element thereof, may be substituted for the switches shown. The invention, therefore, is not to be limited except insofar as is necessitated by the prior art and by the spirit of the following claims.

What is claimed is:

1. In combination, a piezoelectric element adapted to flex rapidly in response to an electrical potential applied thereto, a switch having a movable part biased into operative engagement with said element and yieldable mounting means for said element permitting it to move slowly while maintaining engagement with said movable part.

2. The invention set forth in claim 1, further characterized in that the switch is of the "snap-action" type.

3. In combination, a piezoelectric element adapted to flex at high velocity in response to

an electrical potential applied thereto, a switch having a movable part biased into operative engagement with said element, and yieldable mounting means for said element, the mounting means permitting the element to move slowly while maintaining a substantially fixed relation to said movable part.

4. The invention set forth in claim 3, further characterized in that the switch is of the "snap-action" type.

5. In combination, a piezoelectric element, a switch having a movable part operatively associated with said element for actuation thereby at high velocity and a yieldable support for the element against which it reacts during actuation of the movable part, said support permitting the element to move slowly while maintaining operative association with the movable part.

6. The invention set forth in claim 5, further characterized in that the switch is of the "snap-action" type.

7. In combination, a piezoelectric element, an instrumentality of the "snap-action" type having a movable part in operative engagement with a portion of the element, and a support for the element against which it reacts during operation of the instrumentality, the support offering a large opposing force to movements of the crystal at high velocity and relatively small opposing force to movements thereof at low velocity, whereby only movement at high velocity is imparted to the said movable part.

8. In combination, a piezoelectric element, a carrier therefor including a weight, means supporting the weight for rotary movement around an axis adjacent to its center of gravity, the entire movable system being so constructed and arranged that it is in stable equilibrium.

9. In combination a piezoelectric element, an instrumentality of the "snap-action" type having a movable member, means for establishing and maintaining operative engagement between said movable member and one portion of the piezoelectric element, and mounting means for holding another portion of said element in semi-fixed position, the said mounting means substantially impeding rapid motions of the portion of the element supported thereby while permitting slow movements thereof.

10. The invention set forth in claim 9, further characterized in that the said mounting means includes a material having high internal viscosity.

11. The invention set forth in claim 9, further characterized in that the piezoelectric element is of the multiplate flexing type.

12. In combination, a piezoelectric element and a carrier therefor constituted at least in part by a dash-pot.

13. In combination, a piezoelectric element and a carrier therefor comprising a dash-pot and means connecting the element to the dash-pot.

14. In combination, a piezoelectric element, means of the snap-action type having a movable part in operative engagement with a movable portion of the element, said movable part exerting a first force against the movement of the element which upon said force being overcome actuates said snap-action means, means associated with said element for exerting a second force against movement of said element, said force exerted by said associated means due to set or sag of said piezoelectric element being insufficient to overcome said first force and cause actuation of said snap-action means, and said force exerted by said associated means due to operation of said piezoelectric element being sufficient to overcome said first force and cause actuation of said snap-action means.

15. The invention as set forth in claim 1, further characterized by means for adjusting the force of the bias.

16. In combination, a piezoelectric element adapted to flex rapidly in response to an electrical potential applied thereto, a switch having a movable part biased into operative engagement with said piezoelectric element, and movable mounting means for said piezoelectric element permitting said element to move slowly while maintaining engagement with the said movable part of said switch without actuating said switch, the resistance of said mounting means to movement when said element flexes rapidly causing said switch to be actuated.

17. The invention as set forth in claim 16, further characterized in this: that said movable mounting means comprises a mass of deformable material within which a portion of said piezoelectric element is embedded.

18. The invention as set forth in claim 16, further characterized in this: that said movable mounting means comprises pivotably mounted inertia means to which a portion of said piezoelectric element is connected.

19. The invention as set forth in claim 5, further characterized in this: that said yieldable support comprises deformable material within which a portion of said piezoelectric element is embedded.

20. The invention as set forth in claim 5, further characterized in this: that said yieldable support comprises pivotably mounted inertia means to which a portion of said piezoelectric element is connected.

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