

April 2, 1940.

W. P. MASON

2,195,417

VIBRATING PIEZOELECTRIC RELAY

Filed Nov. 10, 1937

2 Sheets-Sheet 1

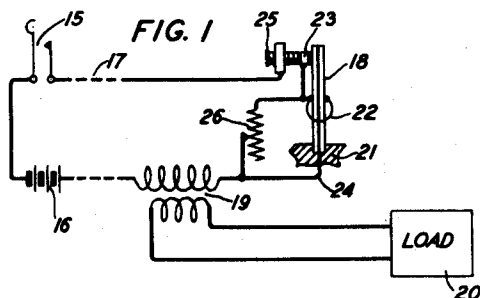
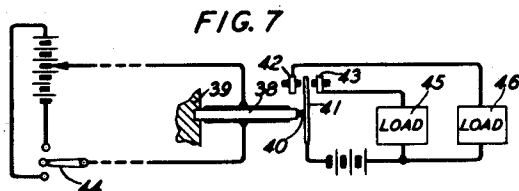
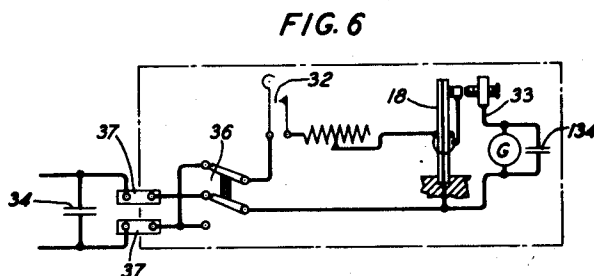
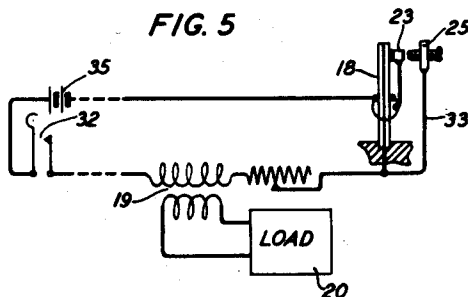
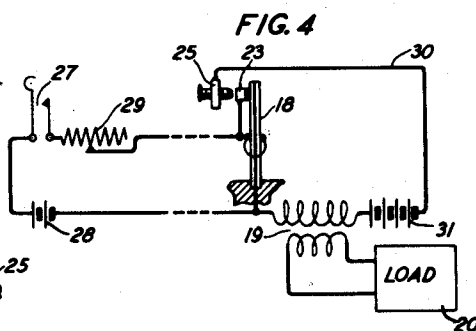


FIG. 2



FIG. 3



INVENTOR
W. P. MASON
BY
E. V. Briggs
ATTORNEY

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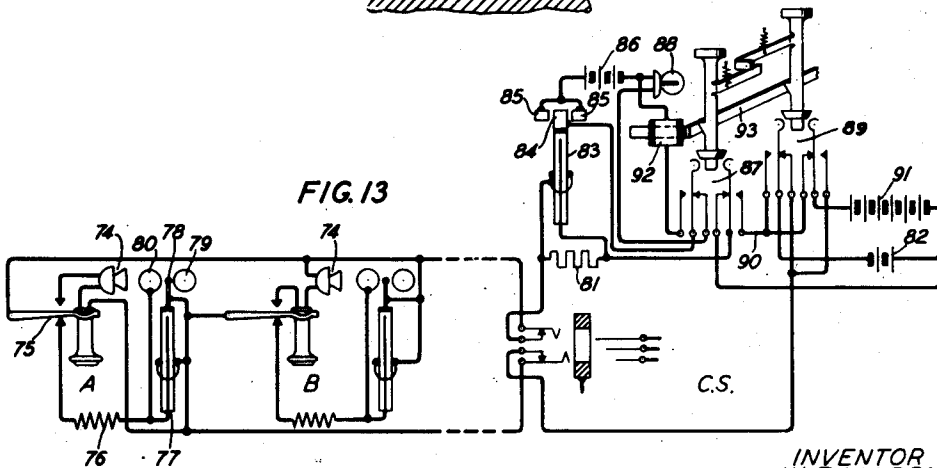
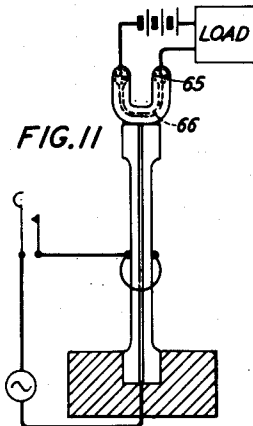
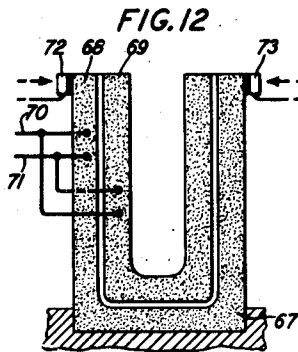
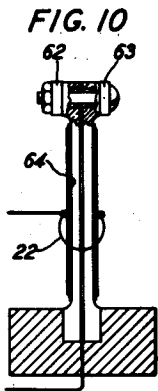
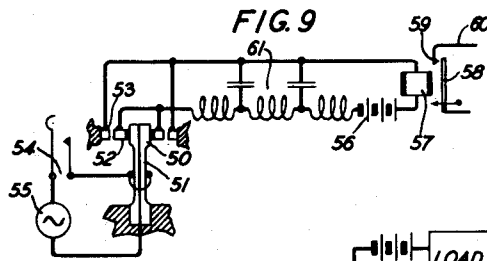
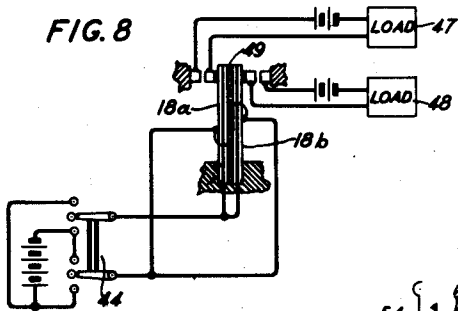
W. P. MASON

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VIBRATING PIEZOELECTRIC RELAY

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2 Sheets-Sheet 2



INVENTOR
W. P. MASON
BY
E. V. Griggs

ATTORNEY

UNITED STATES PATENT OFFICE

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VIBRATING PIEZOELECTRIC RELAY

Warren P. Mason, West Orange, N. J., assignor to
Bell Telephone Laboratories, Incorporated,
New York, N. Y., a corporation of New York

Application November 10, 1937, Serial No. 173,770

7 Claims. (Cl. 179—86)

This invention relates to vibrating piezoelectric relays and more particularly to ringing circuits employing such relays.

An object of the invention is to provide a vibrating device that may be operated over a relatively high resistance circuit such as a long telegraph conductor or submarine cable system.

Another object of the invention is to provide a device which will vibrate in response to a unidirectional electromotive force of a given polarity but not in response to one of opposite polarity whereby the polarity of the terminals of condensers and other apparatus may be ascertained.

An additional object is to provide an electromechanical vibrator, the rate of vibration of which may be readily varied.

Another object of the invention is to provide a vibrating piezoelectric circuit breaker in which the separation of the circuit-breaking contacts may be made as large as is desirable.

A further object of the invention is to produce an alternating current relay which is highly selective to currents of a given frequency.

A still further object of the invention is to decrease chattering of the contacts of piezoelectric relays.

Piezoelectric relays of various types, together with circuits for controlling their speed of operation, are described and claimed in the copending application of W. P. Mason (Case 37), Serial No. 131,160, filed March 16, 1937. The present invention has to do with additional improvements in the piezoelectric relay itself as well as with various applications of such relays and particularly with the use of piezoelectric relays as vibrating elements either to serve as generators of interrupted or alternating current impulses or as tuned alternating current relays.

The novel features characteristic of the invention are pointed out with particularity in the appended claims. The invention, itself, however, both as to the details of its organization and its mode of operation will be best understood by reference to the following description taken in connection with the accompanying drawings, in which

Fig. 1 illustrates a circuit employing a remotely-controlled mechanical biased piezoelectric vibrator to serve as a source of alternating current;

Figs. 2 and 3 illustrate two different modifications of the shape which the vibrating piezoelectric element itself may take;

Fig. 4 shows a modification of the circuit of

Fig. 1 in which an electrically biased piezoelectric element is employed;

Fig. 5 shows another modification of the circuit of Fig. 1 in which a mechanically biased piezoelectric element is provided with contacts normally opened instead of normally closed, as in Fig. 1;

Fig. 6 illustrates a circuit arrangement for employing vibrating apparatus similar to that of Fig. 5 to indicate the polarity of the terminals of a condenser or other electrical element which is charged or which is traversed by electric current;

Fig. 7 discloses a system utilizing a quartz piezoelectric relay operating by virtue of extensional or longitudinal displacement to serve as a polarized relay;

Fig. 8 discloses a multi-element polarized relay having pairs of piezoelectric elements in frictional engagement with each other to provide damping;

Fig. 9 shows a frequency selective piezoelectric relay actuated by alternating current;

Fig. 10 discloses a modification of the apparatus of Fig. 9;

Fig. 11 discloses a piezoelectric relay having a piezoelectric circuit closer of the mercury column type;

Fig. 12 illustrates a piezoelectric vibrator of U-shape provided with electrodes to operate it effectively as a pair of integrally connected tuning forks, and

Fig. 13 illustrates a two-party telephone circuit with a central ringing or calling station.

Referring to Fig. 1, there is shown key 15, together with its contact and electric source 16 and a relatively long circuit 17 connecting the key and source to a remote piezoelectric vibrator 18 in series with the primary winding of alternating current transformer 19 to the secondary winding of which load 20 is connected. The vibrator element preferably comprises two thin flat blades of piezoelectric material as, for example, Rochelle salt, clamped and held in juxtaposition as indicated by a base member 21. The clamping base member may be of the type disclosed in application Serial No. 131,160, to which reference has been made. The blades of Rochelle salt are preferably coated on their two flat faces with conducting material such as a thin film of metal or of aquadag, a colloidal fine suspension of carbon. The two outer conducting faces are connected by a conductor 22 which is also electrically connected to a contact member 23 insulated from but carried by one of the piezoelectric elements. The contiguous faces of the piezoelectric blades are likewise coated with conducting material and

are then preferably shellacked to protect the Rochelle salt against atmospheric moisture and to cause the juxtaposed surfaces of the two blades to adhere throughout their length. The coatings or electrodes on the contiguous faces are electrically connected by thin foil or in any other suitable manner to a conductor 24. An adjustable contact member 25 is mounted adjacent the contact member 23 and may be adjusted to such a position that the base 21 serves to mechanically bias the piezoelectric device 18 in such manner as to hold the contact 23 in close engagement with the contact 25. It will be apparent, therefore, that when key 15 at the remote position is closed, current will flow from the source 16 over the line and by way of conductors 22 and 24 to the outer and inner coatings respectively, of the two blades of Rochelle salt constituting the piezoelectric element 18. If the blades are cut in well-known manner so that upon application of an electromotive force to their opposite faces they tend to change their longitudinal dimension, and if the source 16 be so poled as to cause the right-hand blade to contract, it will simultaneously tend to cause the left-hand blade to which an oppositely poled electromotive force is applied to elongate. Under these circumstances, the piezoelectric element 18 as a whole is caused to warp to the right in the manner of the well-known bimetallic thermostat, thus withdrawing contact 23 from engagement with the adjustable contact 25. There is connected in shunt to the piezoelectric element 18 and between conductors 22 and 24, a path including a variable resistor 26. It will be appreciated that upon separation of the contacts 23 and 25 the individual blades of the element 18, together with their conductive coatings, behave as condensers which have been charged by current flowing over the line from the source 16. As long as the charge upon these condensers persists, the piezoelectric force produced will hold the contact 23 out of engagement with the contact 25. However, the path through resistance 26 enables the charge to be discharged at a rate depending upon the magnitude of that resistance. As explained in copending application, Serial No. 131,160, to which reference has been previously made, the duration of the period in which the element 18 is maintained in the operated position with the contacts 23 and 25 disengaged, may be determined by adjustment of the magnitude of resistance 26. It is possible in a practical case to vary that period from a minute portion of a second up to a duration of several seconds. When finally the charge has been dissipated to an extent sufficient to permit the element 18 to return to a position at which contact 23 re-engages contact 25, the capacity elements comprising the capacitances of the blades of element 18 will again receive a charge and the operation just described will be repeated. In this manner pulses of charging current pass through the primary winding of transformer 19 upon each engagement of the contacts. An alternating electromotive force is, therefore, induced in the secondary winding of the transformer 19 and impressed upon the load 20.

The blades of element 18 may be of the rectangular type disclosed in application, Serial No. 131,160, with the planes of their principal faces parallel to the B and C axes of the virgin Rochelle salt crystal and perpendicular to the A axis. They are preferably so cut that the central longitudinal axis of the blade is in a direction inclined 45° to the B and C axes of the virgin crystal.

In some instances, however, it may be desirable to increase the natural resonance frequency of the crystal. This may be done by decreasing the mass of material near the free or vibrating end, without substantially decreasing the strength or ruggedness of the blade as a whole by tapering the blade toward the free end, as indicated in Fig. 2 or Fig. 3. In one instance a vibrating element of rectangular form was found to have a resonance frequency of 130 cycles per second. When tapered off, as shown in Fig. 2, the same element exhibited a natural resonance frequency of 180 cycles, which represents an increase of almost 40%. With a further tapering to the form shown in Fig. 3, the resonance frequency was increased to 205 cycles.

Fig. 4 shows a device similar to that of Fig. 1, in which the vibrating element 18 is normally in a neutral position such that its contact 23 is disengaged from the adjustable stationary contact 25. A key 27 in series with an electrical biasing source 28 and a variable resistance 29 serves to control the relay. Upon closure of the key 27, an electromotive force is applied to the blades of element 18, causing it to bend in such direction as to bring the contacts into engagement. The rate of operation of the relay is determined by the time in which the capacities of the blades are charged through the variable resistance 29. Upon engagement of the contacts a path is established by way of conductor 30, source 31 and the primary winding of transformer 19. The charge impressed by the biasing source 28 is quickly neutralized by a counter-charge impressed by the oppositely poled source 31. Upon reversal of its charge the element 18 bends in such direction as to break the engagement with the contacts, whereupon the remanent charge is gradually overcome and reversed by the source 28 until finally the element 18 is caused to bend again in the direction to engage contact 23 with the stationary contact 25. The successive charging impulses from the source 31 serve to build up in the secondary winding of transformer 19 an alternating electromotive force which is impressed upon the load 20.

Fig. 5 shows an alternative apparatus in which the element 18 is normally mechanically biased to an open position. Upon closure of the key 32 the capacitances associated with the blades are so charged as to initiate an action tending to bring the contact 23 into engagement with the contact 25. The time required for the relay to close its contacts after the circuit has been closed by the key 32 may be regulated by adjusting the magnitude of the variable series resistance and the position of the adjustable contact 25. Upon engagement of the contacts a short-circuiting action immediately takes place over the path afforded by conductor 33, thus permitting the mechanically biased element 18 to return to its initial position. Thereupon the charging process begins again. The device, therefore, functions in the same manner as those of Figs. 1 and 4 to supply alternating current to impress an alternating electromotive force upon the load 20.

Fig. 6 illustrates an apparatus included within the broken line rectangle for ascertaining the polarity of the terminals of an electrical device which is charged or traversed by unidirectional current. In the particular example illustrated in Fig. 6, there is shown a condenser 34 possessing an electrical charge, the polarity of which is to be ascertained. Piezoelectric relay element 18 may be identical with that of Fig. 5. The charg-

ing circuit differs from that of Fig. 5 only in that the transformer 19 is omitted and that in lieu of the charging source 35, the charge of unknown polarity on the condenser 34 is employed. The charging circuit is provided with a key 32 and a reversing switch 36. Connections are established between the terminals of condenser 34 and of the reversing switch 36, in any simple manner as, for example, by means of conducting clips 37. It will be apparent, therefore, that if the polarity of the charge on the condenser 34 is correct and its magnitude sufficient, that upon closure of the key 32 the element 18 will be actuated in the same manner as in the apparatus of Fig. 5. A visual indication will, therefore, be had from the operation of the vibrating element 18. If for any reason it may be inconvenient to depend upon such a visual indication, there may be included in the path of the short-circuiting conductor 33 a galvanometer G shunted by a smoothing condenser 34, as illustrated. If, upon closure of the key 32, the element 18 does not vibrate, the reversing switch 36 may be thrown into its alternate position whereupon the relay 18 will be actuated to vibrate if the electromotive force across the terminals of the device 34 is sufficiently high. Since the element 18 vibrates only under the condition that an electromotive force of a particular polarity is applied to its terminals, the polarity of charge on the condenser 34 is definitely indicated. It is obvious that the apparatus is not limited to indication of polarity of the charge on a condenser but may equally well be applied to determine the polarity of the difference of potential existing between any two points in an electric circuit.

Fig. 7 illustrates a piezoelectric relay comprising a quartz element cut from a plane perpendicular to the natural face of a virgin crystal and parallel to the optical axis. It has been found that the maximum value of the piezoelectric constant d_{12} which relates the longitudinal extension along the Y' axis to the electric field, applied in a direction along an X axis perpendicular to the principal or electrode faces, occurs for a right-handed quartz crystal—defined as one which rotates the plane of polarization of plane polarized light traveling along the optic or Z axis in the manner of a right-handed screw or in a clockwise direction when viewed along the optic axis from the same side of the crystal as that on which the source of light is placed—when the rectangular strip or element has its length or principal longitudinal dimension Y' in a direction at an angle of $7\frac{1}{2}^\circ$ with respect to the Y axis and counter-clockwise with respect to the electrical axis X when viewed from the positive (by compression) terminal of that axis. For a left-handed crystal, the rotation about the X axis is $7\frac{1}{2}^\circ$ clockwise with the positive (by compression) end of the X axis pointed toward the observer. The quartz element is indicated at 38 with one end fixed to the base 39 in any desired manner and the other end connected by a link 40, preferably of insulating material, to armature 41 with which are associated inner and outer contacts 42 and 43, which may preferably be of the adjustable type, such as indicated at 25 in Fig. 1. If switch 44 be operated in one direction to impress an electromotive force upon the element 38, armature 41 will be moved to engagement with one contact whereas an opposite motion of switch 44 will cause the relay to move its armature into engagement with the other contact. It follows that the remotely controlled devices 45 and 46 may be selectively energized by so operating switch 44 as

to apply an electromotive force of the proper polarity to the polarized piezoelectric relay.

Fig. 8 discloses a system corresponding in its function to that of Fig. 7 in that it enables selective energization of devices 47 and 48 by actuation of a switch 44 in accordance with the polarity of the electromotive force applied to the polarized piezoelectric relay. The relay itself consists of two units 18a and 18b, each like the element 18 of Figs. 1, 4 and 5. The units are each provided with their individual electrodes and are connected electrically in parallel to the charging source. The units are pressed firmly together at the base. They are held in contact along the full length of their contiguous inner surfaces. The effect of the impressed electromotive force is to cause both units to bend in the same direction with a consequent tendency to slippage between their engaging surfaces. This frictional contact is utilized to introduce damping for the purpose of reducing chattering. In order to prevent a considerable wearing which might take place between the surfaces in frictional engagement, it is desirable to coat these surfaces with some wear-resisting material. For this purpose thin coatings or surfaces of metal, or even of some abrasive material, may be employed, as indicated at 49. In operation, the double unit 18a—18b bends either to the right or to the left, depending upon the polarity of the impressed electromotive force as determined by the position of switch 44 and, consequently, closing the circuit of the remote controlled apparatus 48 or 47, as the case may be. It will, of course, be understood that in this instance as in that of the previous disclosures, the moving electric contact member carried by the piezoelectric element is insulated from the coating on the blade. The double unit piezoelectric element of Fig. 8 also has the advantage that it develops an effective piezoelectric force in four different blades, thus giving rise to a greater energy translation than is readily obtainable with a structure of fewer blades. Moreover, the device having a greater electrical capacity, has a greatly reduced input impedance, which may advantageously be used in connection with certain control circuits.

Fig. 9 discloses a piezoelectric relay designed to respond selectively to relatively low frequency alternating currents. The vibrating element is preferably of the general type disclosed in Figs. 1 to 6 inclusive, but the free or contact carrying ends of the piezoelectric blades are enlarged as indicated at 50, to give them an increased mass. Thus, the natural frequency of the element is reduced in a manner converse to that in which the natural frequencies of the elements of Figs. 2 and 3 are increased. In order to produce a device which will be resonant at a definite predetermined frequency, the ends 50 may be made slightly more massive than is necessary and then ground at their outer tips until they attain the exact resonance frequency which is desired. It has been found readily possible to produce such piezoelectric relays of Rochelle salt to resonate at a frequency of 20 cycles. The vibrating element 51 consisting of two piezoelectric blades, as illustrated, is provided with electrical contact elements 52 carried by and insulated from the electrode coatings of the blades and adapted to engage with stationary contacts 53. When the key 54 is closed an alternating electromotive force from source 55 is applied to the piezoelectric element to tend to bend it first to the right and then to the left in an alternating motion which follows the frequency of the applied elec-

tromotive force. If the impressed electromotive force is of the natural frequency of the element 51, the motion of the element will build up to such an extent that it closes its contacts first to the right and then to the left in alternation. Upon each closure of a pair of contacts the circuit of source 56 is closed to transmit an impulse to slow-acting relay 57 which actuates an armature 58 associated with stationary contact 59 and circuit 60. A smoothing filter 61, consisting of shunt capacity elements and series inductance elements, as shown, enables the momentary impulses to function effectively as a continuous unidirectional current. In some cases it may be possible to dispense with the smoothing filter 61 and to rely entirely upon the slow-acting relay. Alternatively it is frequently possible to dispense with the slow-acting relay and to operate a relay of the ordinary type in conjunction with the smoothing filter 61.

It has been found possible to tune such relays to respond and to operate effectively at a definite frequency of, for example, 20 cycles, with as small an input power as 5 milliwatts and not to respond to currents of frequencies differing by as little as a single cycle from the desired response frequency.

Fig. 10 discloses a two-blade piezoelectric element of the general type disclosed in Fig. 9. In order to still further increase the mass of the outer extremities of the blades, iron or metallic members 62 and 63 are bolted in place, as illustrated. The electrical contactor system may, however, be identical with that disclosed in Fig. 9. It is found that the resonance frequency and the effective response of the piezoelectric vibrator, particularly in the case of Rochelle salt, are somewhat subject to temperature change. In order to compensate for this effect mica dielectric strips 64 may be cemented to the outer faces of the piezoelectric blades and the outer conductive coatings to which the conductor 22 is connected may be applied to the exterior surface of the mica. This effectively introduces in series with each piezoelectric blade the capacity of the condensers of which the mica sheet forms the dielectric. The series capacitances tend to stabilize the response frequency of the device with varying temperature. This is for the reason that Rochelle salt has a maximum capacitance and piezoelectric response at about 24.5° C., hence at that temperature most of the driving force is expended across the series condenser and the response of the piezoelectric device is reduced. As the temperature changes from 24.5° C., the effective capacity across the piezoelectric blade itself falls away rapidly and soon it becomes less than that of the series condenser so that the relative portion of the driving voltage effective on the piezoelectric element is increased in such manner as to tend to compensate for its reduced piezoelectric sensitivity. The broad idea of compensating for the effects of temperature changes upon the response of piezoelectric devices is disclosed and claimed in the copending application, Serial No. 131,160. It will, of course, be understood that the temperature compensating feature of the device of Fig. 10 is applicable to each of the Rochelle salt vibrators disclosed in the preceding figures and the drawings of these figures are to be deemed as including that feature in all instances in which temperature compensation is an important factor.

Fig. 11 discloses a structure similar to that of

Fig. 9 but differing in that the contact system of Fig. 9 is replaced by a U-shaped tube 65 filled with mercury and having a central portion 66 of capillary dimensions such that when the tube is vibrated from side to side during the operation of the relay, the capillary thread of mercury is broken and the circuit interrupted at that point. Modifications of this normally closed circuit to adapt it to the same uses as the normally open circuit of the preceding figures will be obvious to those skilled in the art. It will be understood, of course, that for applied electromotive forces of frequencies to which the vibrating device does not vigorously respond the mechanical excitation of the tube 65 is insufficient to interrupt the capillary column of mercury.

Fig. 12 illustrates a modified form of vibrator which may be used in any of the circuits of the preceding figures. The device consists of a single U-shaped vibrator element 67, preferably cut from a Rochelle salt crystal with the principal faces of the element 67 parallel to the B and C axes of the virgin crystal and perpendicular to the A axis. The central longitudinal axis of the element 67 is preferably in a direction inclined 45° to the B or C axes of the virgin crystal. The principal faces of the vibrating element each have two separate or divided conducting coatings 68, 69 of U-shaped form. The input conductors 70 and 71 are connected respectively to the back and front of the pair of outer coatings 68 and conversely to the front and back of the pair of inner coatings 69. It will be apparent that the device comprises effectively a Rochelle salt tuning fork between coatings 69 nested within and integral with an outer Rochelle salt tuning fork lying between the coatings 68. It will also be apparent that with the connections as indicated, the impressed electromotive force will tend to elongate the prongs of the inner tuning fork at the same time that it tends to contract the prongs of the other tuning fork, thus causing the prongs of the device as a whole to flex toward and away from each other. In this manner the normally open contacts 72 and 73 may be simultaneously closed and opened either in series in a single circuit or separately in individual circuits as may be desired. In an example of an apparatus in which such a device was used, the applied frequency was 1520 cycles and an amplitude of motion of the movable contacts of about 6 mils with an applied electromotive force of 30 volts was obtained. The device was operative to close the controlled circuit over a frequency range of about 40 cycles and failed to operate with impressed electromotive forces different more than 20 cycles from its major resonance frequency.

Fig. 13 illustrates an application of vibrating piezoelectric relays to a two-party telephone line. In this circuit subscriber's stations A and B are shown connected to a common pair of conductors leading to central station CS. All circuits are shown in the normal idle condition. At each subscriber's station there is the usual telephone subscriber's set 74 with its normally open switchhook contact 75. In an alternate path normally closed by the switchhook is a ringer comprising in series a resistance 76 and a piezoelectric vibrating element 77, which carries an insulated clapper 78 in position to strike two gongs 79 and 80, the latter of which is connected electrically at a point between resistance 76 and the vibrating element 77. It will be observed that the vibrator circuit comprising the ringing path just described, the line, resistance 81 and battery 82

at the central station corresponds quite closely to the vibrating system illustrated in Fig. 5. However, the electromotive force of the battery 82 normally connected to the line at the central station is insufficient to operate the piezoelectric ringer element 77. Accordingly, no current will flow over the line. A piezoelectric relay 83 at the central station is connected in shunt to the resistance 81 and is provided with contacts 84 and 85 to close the circuit of a local source 86, which normally passes by way of the upper contact of key 87 to signal lamp 88. When, in initiating a call, a subscriber at station A or station B removes his telephone receiver from its switchhook he establishes a unidirectional current path through resistance 81 and the potential difference between the terminals of the resistance is sufficient to actuate the piezoelectric relay 83 to close its local circuit and cause signal lamp 88 to give an indication to the operator at the central station. The switching mechanism and circuits at the central station by which the line of the calling subscriber may be connected to another line also terminating at the central station form no part of the present invention and are, therefore, not illustrated. It will be understood, however, that any suitable switching circuits and apparatus may be employed at the central station for that purpose.

The central station operator is provided with keys 87 and 89 for the purpose of calling the stations A and B respectively. Each of these keys is, for simplicity, illustrated as a two-pole, two-position switch but is preferably of any of the well-known forms of keys used in telephone practice. These keys are spring biased to the normal idle positions in which they are shown. Upon depression of key 87 to call station A, the line circuit through resistance 81 is transferred to the righthand contact of key 87 and passes by way of the connector 90 and a normally closed contact of key 89 to positive terminal of source 91 which is connected in series-aiding fashion with source 82 to the line circuit. The electromotive force impressed upon the line by the two sources in series is sufficiently large and is of the proper polarity to actuate the piezoelectric vibrator 77, the gong 80 of which corresponds electrically to the short-circuiting contact 25 of the vibrator of Fig. 5. Consequently, as long as the series electromotive force of sources 82 and 91 is applied to the line, the bell at the called station continues to ring. When the subscriber at the called station answers, the central station operator may connect the line circuit of that station to the calling line circuit by suitable local cord or connecting circuits provided for that purpose but which are not shown.

When the operator at the central station depresses key 87 to call station A she initiates vibration of the piezoelectric vibrator relay 77 at the called station as has been explained. This produces an impulse current over the line which operates the relay 83 to close its contacts thus energizing holding solenoid 92. As shown in the drawing the solenoid 92 is connected in a locking circuit associated with the armature or switch member of key 87 to lock the key 87 in depressed position. This is effected by a latch 93 carried by the moving element of the solenoid, when energized, into such position as to hold either or both of keys 87 and 89 that happen at the time to be depressed. When the called subscriber in answering actuates his switchhook he momentarily opens the line circuit interrupting the opera-

tion of his own bell and permitting solenoid 92 to deenergize and release keys 87 and 89, which thereupon return to their normal positions.

If the central station operator desires to call the subscriber at station B she may depress key 89 which carries along with it the key 87. In this instance the sources 82 and 91 are connected in series-aiding with the line circuit just as in the case in which station A was called but with their polarity reversed with respect to the line circuit as a result of the operation of the reversing switch associated with key 89. Consequently, vibrator 77 of station A will not respond and only the oppositely poled piezoelectric vibrator of station B operates. As before, the relay 83 responds to energize solenoid 92, which locks keys 87 and 89 in the ringing position. As soon as the called party at station B responds and lifts his receiver from its hook, the line circuit is temporarily opened to deenergize the locking circuit of solenoid 92 and release the keys 87 and 89 to their normal positions.

What is claimed is:

1. A vibrating device comprising a piezoelectric element, means to apply an electromotive force to said element to cause a deformation thereof and means responsive to said deformation to temporarily remove the applied electromotive force to permit the piezoelectric element to relieve the distortion.

2. A vibrating device comprising a piezoelectric element, means to apply an electromotive force to said element to cause a deformation thereof, and means responsive to the deformation of the element to effectively withdraw from it the applied electromotive force whereby the element returns to its position prior to deformation.

3. An electrostatic vibrator comprising a piezoelectric plate, a movable contact carried thereby, a fixed contact with which the movable contact is adapted to engage, a current source having its two terminals connected to said contacts through a series resistance element, and a pair of electrodes associated with the piezoelectric plate and connected respectively to the terminals of the resistance element.

4. An apparatus for ascertaining the polarity of the difference of potential existing between two points in an electric circuit comprising a pair of exploring terminals adapted to be electrically connected with the points whose potential difference is to be studied, a path connecting the exploring terminals including a piezoelectric vibrator responsive to electromotive forces of one polarity, and means for reversing the connections between the vibrator and the exploring terminals.

5. A telephone ringing circuit comprising a piezoelectric vibrator, an armature carried thereby, a signal-producing element with which the armature is adapted to contact during vibration of the vibrator, and means controlled by the contact of the armature and element to sustain vibrations of the vibrator.

6. A vibrating device comprising a piezoelectric element, means to subject the device to an electric field to cause a deformation thereof and means responsive to the deformation to apply a counter electric field to overcome the first applied field and to induce an opposite deformation to restore the device to its original state whereby through the successive actions of the counter fields the device is maintained in vibration.

7. A telephone system comprising a central

station having a source of electromotive force, a two-party line terminating at the station, two subscribers' stations connected to the line at points electrically remote from the central station, each of said subscribers' stations comprising a piezoelectric vibrator which responds to an electromotive force of one polarity only to pro-

duce a call signal whereby the operator at the central station may call one subscriber by applying an electromotive force of one polarity to the line and the other by applying an electromotive force of opposite polarity.

WARREN P. MASON.