May 24, 1949. J. J. CRESS 2,471,143

PIEZOELECTRIC APPARATUS

Filed Feb. 8, 1945

Fig. 1.

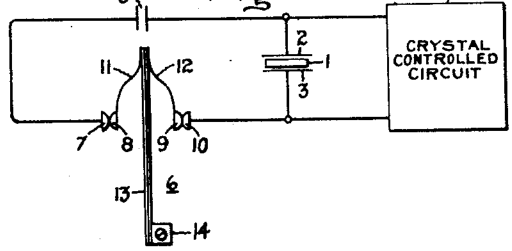


Fig. 2.

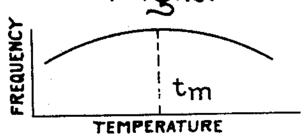


Fig. 3.

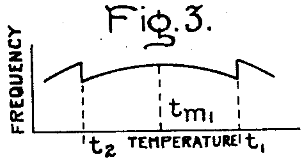


Fig. 4.

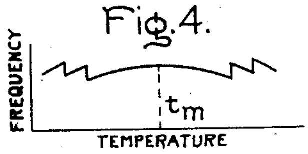


Fig. 5.

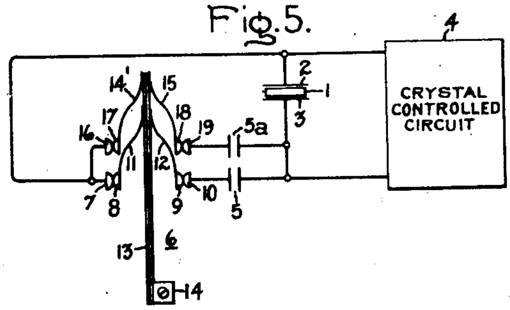
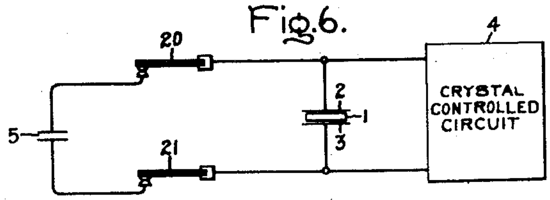


Fig. 6.



Inventor:
Jay J. Cress,
by Harry E. Dunham
His Attorney.

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UNITED STATES PATENT OFFICE

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PIEZOELECTRIC APPARATUS

Jay J. Cress, Schenectady, N. Y., assignor to General Electric Company, a corporation of New York

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7 Claims. (Cl. 171—327)

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My invention relates to piezoelectric apparatus and more particularly to means for compensating for the effect of temperature variation upon piezoelectric crystal elements and the like.

It is well known that, in general, the natural frequency of vibration of a piezoelectric crystal element or the like is subject to variation with temperature. The temperature curve of frequency of a crystal cut at the correct crystallographic orientation evidences a maximum value at a mean or center temperature, the frequency decreasing with variations in temperature either above or below the mean value. Heretofore the effect of temperature upon crystal frequency has been minimized by means of heat control and by orientation of the crystal about its crystallographic axes in such a way as to reduce its temperature coefficient to as small a value as possible. However, in some applications, such as in mobile installations and the like, it has been found impossible to meet the requirements for constancy of crystal frequency without temperature control, while power for temperature control is not always available.

Accordingly, it is a general object of my invention to provide new and improved means for compensating for the effect of temperature upon crystal frequency.

It is a further object of my invention to provide a new and improved thermal responsive tuning means for piezoelectric crystal elements or the like.

It is a more specific object of my invention to provide thermal responsive switching means for controlling the tuning of a piezoelectric crystal element or the like to compensate for the effect of temperature variation of the natural frequency of the crystal.

It is known that the natural frequency of vibration or the tuning of a piezoelectric crystal element or the like may be controlled by connecting reactive impedance elements in series or parallel circuit relation therewith. I have found that, by thermally controlling the effective value of the reactive impedance connected in circuit with the crystal element, the frequency of the crystal may be controlled in such a manner as to approximately compensate for the effect of temperature variation upon the natural frequency of the crystal element itself. In a specific embodiment of my invention, a trimming capacitor normally connected in parallel circuit relation with the crystal element is disconnected by a thermal responsive switching member upon either an increase or a decrease of temperature from a mean or center value.

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My invention will be more fully understood and its objects and advantages further appreciated by referring now to the following detailed specification taken in conjunction with the accompanying drawings, in which Fig. 1 is a schematic circuit diagram of a piezoelectric apparatus embodying my invention; Figs. 2, 3 and 4 are graphical representations of certain of the temperature characteristics of piezoelectric crystal elements illustrating the effect of my invention; and Figs. 5 and 6 are schematic circuit diagrams of piezoelectric apparatus illustrating other embodiments of my invention.

Referring now to the drawings, and particularly to Fig. 1, I have shown a piezoelectric crystal element 1 having electrodes 2 and 3 and connected to a crystal controlled circuit 4 illustrated in block form. It will be understood by those skilled in the art that the circuit 4 may be an electric discharge oscillator circuit, a wave filter circuit, or the like. A frequency determining trimming capacitor 5 is normally connected in parallel circuit relation with the crystal element 1 through a thermal responsive switch member 6. The switch 6 comprises two pairs of separable switch contacts 7, 8 and 9, 10, the contacts 8 and 9 being movable and the contacts 7 and 10 being stationary. The movable contacts 8 and 9 are attached to the free ends of light cantilever leaf springs 11 and 12, respectively, which are mounted upon opposite sides of one end of a thermal responsive bimetallic strip 13. The opposite end of the bimetallic strip 13 is secured to a fixed support 14.

The operation of the crystal apparatus shown at Fig. 1 may best be illustrated by referring in connection therewith to Figs. 2 and 3. At Fig. 2 is shown a typical curve of natural crystal frequency variation with temperature. Fig. 3 is a similar characteristic curve for a crystal apparatus embodying my invention. It will be observed from Fig. 2 that the natural frequency of vibration of a crystal exhibits a maximum value at some predetermined mean or center temperature

t_m, and decreases with temperature variations either above or below the mean temperature.

Referring now to Fig. 1, the thermal responsive switch **6** is arranged to assume the mid-position shown with both pairs of contacts **7**, **8** and **9**, **10** closed when the crystal temperature is within a predetermined range on either side of the center frequency. If the crystal temperature increases beyond this range, as for example to a temperature t_1 at Fig. 3, the bimetallic strip **13** bends sufficiently in one direction to separate one of the pairs of contacts **7**, **8** or **9**, **10**. By way of example, let it be assumed that upon increase in temperature the contacts **9**, **10** are separated. As soon as these contacts are separated, the crystal shunt including the condenser **5** is broken, so that the shunt capacitance is decreased. Decrease in the shunt capacitance has the effect of raising the crystal frequency, as illustrated at Fig. 3. Similarly, upon decrease of the crystal temperature by a predetermined amount below the mean temperature, as for example to a temperature t_2 shown at Fig. 3, the bimetallic strip **13** bends sufficiently in the opposite direction to separate the contacts **7** and **8**, thereby to disconnect the shunt capacitor **5** and again increase the crystal frequency.

At Fig. 5, I have shown another embodiment of my invention in which the crystal frequency is more closely controlled by mounting upon the bimetallic strip **13** an additional pair of oppositely disposed contact springs **14** and **15** arranged to control additional pairs of separable switch contacts **16**, **17** and **18**, **19**, respectively. Other parts of the circuit of Fig. 5 are similar to Fig. 1 and have been assigned the same reference numerals. In the normal position of the bimetallic strip **13** of Fig. 5, the contacts **16**, **17** and **18**, **19** connect an additional trimming capacitor **5a** in parallel circuit relation with the trimming capacitor **5**. The contact springs **11**, **12** and **14**, **15** are so biased that, upon movement of the bimetallic strip in one direction, for example, to the left upon increase in temperature, the contacts **9**, **10** separate at a lower temperature than do the contacts **18**, **19**, while upon movement of the bimetallic strip to the right upon decrease in temperature, the contacts **7**, **8** separate prior to the separation of the contacts **16**, **17**. The effect of the multiple capacitor control shown at Fig. 5 upon the frequency characteristic of the crystal apparatus is illustrated by the frequency-temperature curve at Fig. 4.

It will of course be understood by those skilled in the art that it is not necessary that the trimming capacitor circuit be controlled, upon both increase and decrease in temperature, by the movement of a single bimetallic strip in opposite directions. If desired separate thermal responsive switching means may be arranged to open the shunt circuit upon temperature increase and temperature decrease, respectively. By way of illustration, I have shown at Fig. 6 a piezoelectric crystal apparatus generally similar to that shown at Fig. 1, but in which the trimming capacitor **5** is normally connected in parallel circuit relation with the crystal **1** through a pair of thermal responsive bimetallic switches **20** and **21**. In operation, the bimetallic switches **20** and **21** are arranged to maintain the shunt capacitor circuit normally closed within a predetermined range of temperature upon either side of the mean temperature. One of the switches, for example the switch **20**, is arranged to open its contacts upon increase in temperature beyond the range, as at

a temperature t_1 in Fig. 3, while the other switch, for example the switch **21**, is arranged to open its contacts upon decrease of temperature beyond the range, as at a temperature t_2 in Fig. 3.

While I have shown and described only certain preferred embodiments of my invention by way of illustration, many modifications will occur to those skilled in the art. For example, while I have shown only shunt capacitor circuits for compensating for natural frequency variation of the crystal, it will be understood that series capacitor or shunt or series inductance circuits may be similarly utilized. Accordingly, therefore, I wish to have it understood that I intend in the appended claims to cover all such modifications as fall within the true spirit and scope of my invention.

What I claim as new and desired to secure by Letters Patent of the United States is:

1. In combination, a piezoelectric element having a natural frequency of vibration subject to variation with temperature, a trimming capacitance connected in frequency determining circuit relation with said element, and thermal responsive means for disabling said trimming capacitance upon variation of temperature beyond a normal range.

2. In combination, a piezoelectric element having a natural frequency of vibration subject to variation with temperature, a trimming capacitance connected in parallel circuit relation with said element to determine said frequency, and thermal responsive means for disconnecting said capacitance upon a predetermined temperature variation from a desired temperature.

3. In combination, a piezoelectric element having a natural frequency of vibration subject to variation with temperature, reactive impedance means, and switching means responsive to the temperature of said element for controlling the connection of said impedance means in frequency determining circuit relation with said element to compensate for temperature variation from a normal value.

4. In combination, a piezoelectric element having a natural frequency of vibration subject to variation with temperature, said frequency having a maximum value at a predetermined mean temperature, impedance means associated in frequency determining relation with said element, and thermal responsive means arranged to vary the effectiveness of said impedance means in a predetermined direction upon predetermined variation of temperature in either direction from said mean value.

5. In combination, a piezoelectric crystal element having a natural frequency of vibration subject to variation with temperature, said frequency having a maximum value at a predetermined mean temperature, a reactive impedance element associated with said crystal element in frequency determining circuit relation, and thermal responsive switching means for controlling the connection of said impedance element to said crystal element in like manner upon a predetermined variation in temperature in either direction from said mean temperature.

6. In combination, a piezoelectric crystal element having a natural frequency of vibration subject to variation with temperature, said frequency having a maximum value at a predetermined mean temperature, a trimming capacitor connected in frequency determining circuit relation with said crystal element, and thermal responsive switching means for disabling said

trimming capacitor upon a predetermined variation in temperature in either direction from said mean temperature.

7. In combination, a piezoelectric crystal element having a natural frequency of vibration subject to variation with temperature, a trimming capacitor, and thermal responsive switching means normally connecting said capacitor in parallel circuit relation with said crystal element, said switching means comprising two pairs of separable switch contacts connected in series circuit relation and a thermally deformable member movable in one direction to separate one of said pairs of contacts and in the other direction to separate the other of said pairs of contacts.

JAY J. CRESS.

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The following references are of record in the file of this patent:

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