May 9, 1933. W. A. MARRISON 1,907,427

PIEZO ELECTRIC CRYSTAL

Original Filed Dec. 19, 1928

FIG. 1

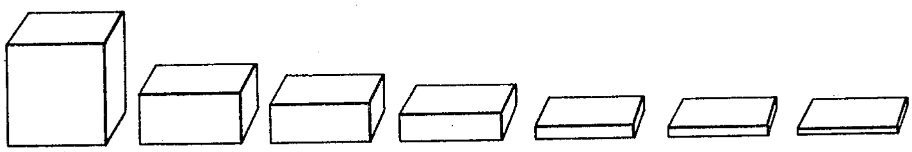


FIG. 2

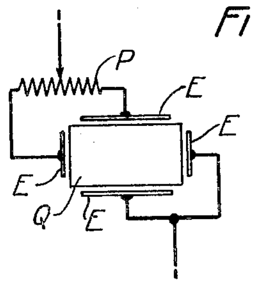


FIG. 3

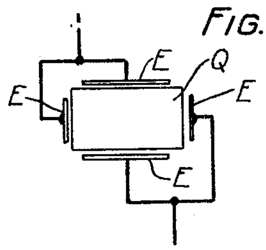


FIG. 4

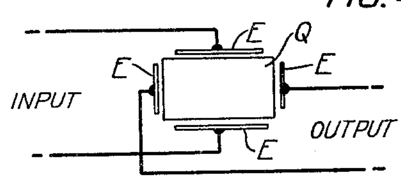


FIG. 5

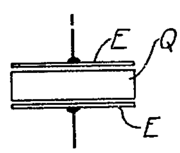
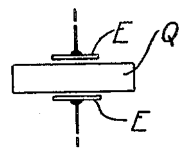


FIG. 6



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Patented May 9, 1933

1,907,427

UNITED STATES PATENT OFFICE

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PIEZO-ELECTRIC CRYSTAL

Original application filed December 19, 1928, Serial No. 327,017. Divided and this application filed November 24, 1930. Serial No. 497,783.

This application is a division of my copending application Serial No. 327,017 filed December 19, 1928.

This invention relates to piezo-electric crystals and particularly to crystals having a small temperature coefficient of frequency, and methods of cutting such crystals and mounting them for connection in an electric circuit.

The advantages of utilizing the piezo-electric effect of substances possessing such properties have been known for some time. The uses for a constant frequency control and especially the need of such control within more rigid limits are constantly increasing. Such uses include the control of broadcasting stations on their assigned wave lengths, whether locally or by transmission of a wave from a central control point, and control of the frequency of local oscillations in a heterodyne receiver. Frequency control means are also useful in connection with sending and receiving sets in picture transmission and television, in order to avoid the necessity of a synchronization channel, and similarly in systems of carrier wave telephony and telegraphy and are also important elements of laboratory reference standards.

An object of this invention is to provide a piezo-electric resonator whose resonant frequency of vibration does not change with variations in temperature.

A feature of this invention is a piezo-electric resonator of rectangular cross-section having a temperature coefficient of frequency approximately equal to zero.

Another feature of this invention is the provision of means for mounting such a resonator in connection with an electrical circuit so that minor adjustments in its temperature coefficient may be made.

In the drawing,

Fig. 1 shows a plurality of piezo-electric resonators cut from a crystal, the successive resonators from left to right each being formed by cutting down the thickness of the resonator at the left, so that they are of uniform cross-sectional area;

Fig. 2 is a diagrammatic view of a resonator adapted for predetermination of the temperature coefficient of frequency by relative adjustment of the energies of vibration in different directions with two pairs of electrodes, one pair being electrically connected through a resistance having a variable tap, the other pair directly, and the electrodes of each pair being perpendicular to one another;

Fig. 3 is a diagrammatic view of a resonator adapted for predetermination of the temperature coefficient of frequency by variation of the spacings of certain electrodes, or a certain electrode from the resonator;

Fig. 4 is a diagrammatic view of a resonator with two pairs of electrodes, the electrodes of each pair being parallel to one another, one pair constituting an input coupling, and the other an output coupling, to the resonator;

Fig. 5 is a diagrammatic view of a resonator with two electrodes; and

Fig. 6 is a diagrammatic view of a piezo-electric resonator with two electrodes of smaller area than those of Fig. 5.

The stiffness, and the temperature coefficient of stiffness, of quartz crystals, are different along different axes. The effective stiffness along any given axis is the sum of at least two effects, one being the usual mechanical stiffness, such as exists in ordinary isotropic substances, and another being due to the reaction of the electric field set up within and around a piece of mechanically strained piezo-electrically active material.

When an elastic body is deformed in a given direction by a force applied in that direction, there is a corresponding, but smaller, deformation in the perpendicular direction, as well as a change in volume. When a quartz resonator is set in resonant vibration, there is a large periodic change of length in one direction, called the direction of vibration, and a vibration of the same frequency in a transverse direction. The transverse vibration is due partly to the mechanical tendency of the material to maintain constant volume, partly to the mechanical coupling between the two modes of vibration, and parly to the electrical coupling between the electrodes and the resonator perpendicular to the principal direction of vibration. Thus the effective stiffness which determines the resonant frequency of a resonator in a given mode is a complex quantity dependent on the relative dimensions along different resonator axes, the orientation with respect to the original crystal axes, the size, number, spacing, and arrangement of electrodes about the resonator, the voltage impressed upon the resonator in various directions in relation to the dimensions and orientation of the resonator, and the impedance of the electrical circuit to which the resonator is coupled.

Because of the various factors above mentioned which determine the stiffness characteristics for given modes of vibration, there results a similar complexity as to the temperature coefficient of stiffness for the corresponding modes of vibration, hence it tends to result that the temperature coefficient of stiffness, and therefore the frequency, of a resonator, in a given mode, may be varied over a considerable range by suitably proportioning the resonator.

The inherent temperature coefficient of frequency is different along an electrical axis of a crystal from that in a perpendicular direction along a crystallographic axis.

Thin plates of relatively large area cut so that their long dimensions are parallel to the optical and electrical axes, have a positive temperature coefficient of frequency for vibration along the short dimension, while thin plates of relatively large area cut so that their long dimensions are parallel to the optical and crystallographic axes have a negative coefficient. If a plate is cut from a quartz crystal in the plane of the optical and electrical axes as above, but having a sufficient thickness in proportion to its cross-sectional area, such as that shown on the left in Fig. 1, it will be found to have a small negative temperature coefficent of frequency. If a portion of its surface is removed, the cross-sectional area remaining constant while the thickness diminishes, the temperature coefficient becomes less negative, or more nearly positive. If successive tests are made with progressively decreasing thicknesses of resonators having the same cross-sectional area, such as those shown from left to right in Fig. 1, it will be found that as the proportion of the thickness of the resonators to the cross-sectional area decreases, the temperature coefficient of frequency of the resonator for vibrations along the short dimensions will rise from negative through zero to positive values. This is apparently due to the mutual dependence of different vibrations and to the opposite temperature coefficients in perpendicular directions.

If it is desired to cut a quartz resonator of rectangular cross-section designed to vibrate at a desired frequency and having a zero temperature coefficient of frequency, the first step is to cut such a plate from a crystal parallel to the optical and electrical axes of the crystal, of slightly greater thickness than required for this frequency. The plate is then ground to the proper thickness to vibrate at a slightly lower frequency than the frequency desired. The sides of the crystal are then cut down to decrease the cross-sectional area, tests being made at suitable intervals until the point is reached where the plate has a slightly negative temperature coefficient of frequency. A final adjustment of temperature coefficient of frequency is then made by grinding to the proper thickness. The tests mentioned are of course all at the same temperature so that the crystal will vibrate at a desired frequency at a desired temperature.

It is necessary to make the adjustments in three steps instead of two because the first adjustment of frequency has an effect on the temperature coefficient, and the adjustment of the temperature coefficient has a very slight effect on the frequency. If the exact dimensions are known for a desired frequency with a zero temperature coefficient at a given orientation of the resonator with respect to its crystal axes, it may be cut directly to these dimensions in two steps.

In Figs. 2 to 6 inclusive there are shown various methods of associating a resonator with electrodes and of connecting the electrodes to an electrical circuit.

It has been previously noted herein that a piezo-electric resonator tends to have temperature coefficients of frequency of opposite signs in the cases of a resonator cut in the plane of the optical and electrical axes and a resonator cut in the plane of the optical and crystallographic axes. The resultant temperature coefficient of the resonator depends upon the extent of its vibration and the corresponding temperature coefficients in both directions. Analogously to the above, the opposite sign rule is applicable to the case of vibrations parallel to both the electrical and crystallographic axes in a given resonator. It is therefore possible to adjust the coefficient of a resonator by exciting it to greater vibration in one direction than in the other. This may be done to a certain extent by means of a differential adjustment of the voltage applied to the perpendicular surfaces as shown in Fig. 2, for example, where a resonator Q has four electrodes E, as shown, and two adjacent electrodes are connected through a potentiometer P to which the exciting voltage is applied. By moving the contact point along the potentiometer in a desired direction, the temperature coefficient of frequency may be adjusted accordingly.

The relative amount of vibration in any direction, and hence the temperature coefficient of frequency of the resonator, may also be controlled to a slight extent by connecting the electrodes directly instead of through the potentiometer, and adjusting the relative potentials applied by changing the spacing between the electrodes and the resonator or by changing the area of the crystal exposed to the electrodes. The coupling to the crystal may be varied and its temperature coefficient of frequency adjusted to a slight extent by changing the spacing of the electrodes or by the other means suggested above by means of the coupling arrangements shown in Figs. 3 and 4.

The size of the electrodes has also been mentioned as affecting the temperature coefficient of frequency of a piezo-electric resonator. It is possible to change the coefficient of the resonator, or, if it has a low coefficient, it is possible to adjust it to zero, by changing the size of the electrodes. This is shown in the organizations illustrated by Figs. 5 and 6 in which the resonators will have different coefficients due to the difference in size of the respective pairs of electrodes.

Advantages of resonators which have a zero temperature coefficient of frequency are that the necessity for temperature controlling means is avoided, and furthermore as the resonator heats up due to load applied to it, the frequency does not change due to either the initial heating or to variations in load.

The various methods of adjustment of the temperature coefficient mentioned herein in connection with Figs. 2 to 6, are particularly useful in the final adjustment of a resonator. It may be that in preparing a resonator to have a zero temperature coefficient in the manner described in connection with Fig. 1, a point is reached where the temperature coefficient has been reduced to a very small value. It may then be easier to make a final adjustment by one or more of these other methods than by further shaping.

What is claimed is:

1. The method of reducing the temperature coefficient of frequency of a piezo-electric resonator having two pairs of electrodes associated therewith for exciting different modes of vibration of said resonator which comprises controlling the relative vibration in the diffirent modes of said resonator by varying the relative potentials applied to said pairs of electrodes.

2. A piezo-electric resonator plate of rectangular cross-section cut from a quartz crystal, the plane of said plate being parallel to the optical and electrical axes of the crystal and its dimensions so related that the resonator has substantially a zero temperature coefficient of frequency.

3. A quartz crystal piezo-electric resonator plate of rectangular cross-section, the dimensions of which are so related that it has a very small temperature coefficient of frequency, two pairs of electrodes for exciting said resonator, said pairs of electrodes being located with respect to the crystal so as to control the degrees of the vibrations of the crystal in the different directions in such a manner that the temperature coefficient of frequency of the vibrations is zero.

4. A piezo-electric resonator plate of rectangular cross-section, the plane of which is parallel to the optical and electrical axes of the quartz crystal from which it was cut, the dimensions of this resonator being so related that it has very small temperature coefficient of frequency, two pairs of electrodes to excite and control the vibration of the resonator in two different directions, means for applying electric potentials to these electrodes in such a manner that the temperature coefficient of frequency of the vibrations of the resonator is substantially zero at a specified temperature.

5. A quartz crystal piezo-electric resonator plate of rectangular cross-section the principal plane of which is parallel to the optical and one of the electrical axes of the quartz crystal, the areea of said resonator plate being so related to its thickness that the resonator has a substantially zero temperature coefficient of frequency.

6. A rectangular shaped piezo-electric resonator plate cut from a quartz crystal in the plane of the optical and one of the electrical axes of the crystal, the length, width, and thickness of said resonator plate being so related to each other that the temperature coefficient of frequency is substantially zero.

7. A quartz crystal piezo-electric resonator plate of rectangular cross-section the principal plane of which is parallel to the optical and one of the electrical axes of the quartz crystal and having its dimensions so related that it has a small temperature coefficient, two pairs of electrodes therefor for exciting different modes of vibration of said resonator and a potentiometer connected to said two pair of electrodes for controlling the relative potentials applied to the two pairs of electrodes.

In witnesss whereof, I heretunto subscribe my name this 20th day of November, 1930.

WARREN A. MARRISON.