

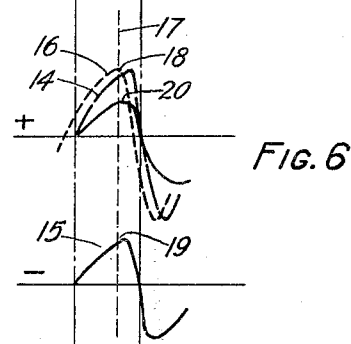
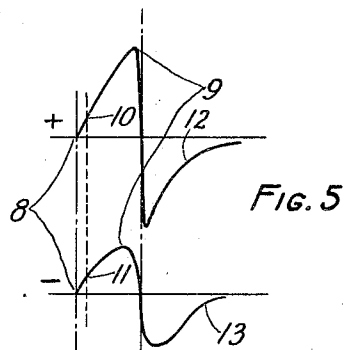
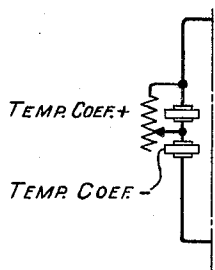
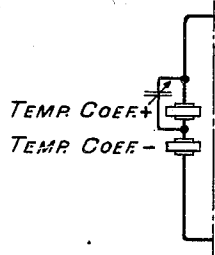
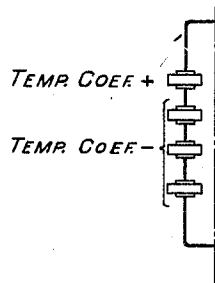
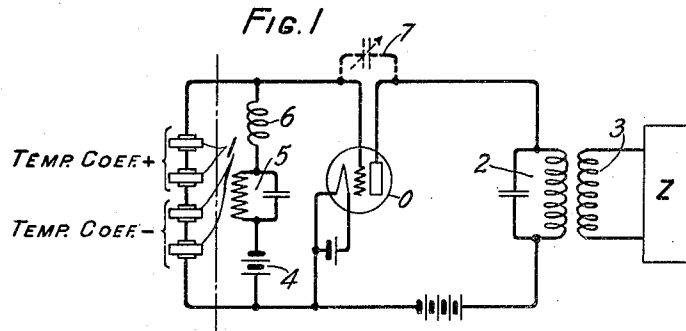
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PIEZO ELECTRIC OSCILLATOR

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PIEZO ELECTRIC OSCILLATOR

Application filed May 1, 1929. Serial No. 359,571.

This invention relates to control of operation of electric circuits and especially to frequency control of oscillators by piezo-electric crystals, the application being a continuation in part of my application, Serial No. 208,225, filed July 25, 1927.

An object of the invention is to increase the amount of power that can be conveniently controlled by a piezo-electric body.

When a piezo-electric crystal is used to control a circuit the control may be dependent upon temperature, since variations in the temperature of the crystal body cause it to change its natural frequency of vibration. Another object of the invention is to reduce undesired variations due to temperature changes as, for example, to reduce variations in the frequency of a crystal controlled electric space discharge oscillator due to temperature variations of the crystal device.

In one embodiment the invention comprises the use of a plurality of crystal bodies connected in series to control an electric space discharge tube oscillator so that the voltage across each crystal body is but a portion of the total voltage. As a result, the plate voltage of the oscillator tube and consequently the power output of the oscillator may be greatly increased without danger to any of the crystals.

By employing a plurality of piezo-electric crystal bodies for controlling a circuit and cutting part of them so that they have temperature coefficients of frequency opposite in sign to those of the remainder, variations due to changes in the temperature of the crystal control device, for instance oscillator frequency variations in the case of the oscillator just mentioned, can be reduced. The expression "temperature coefficient of frequency" as applied to a crystal body refers to the rate of change of the natural frequency of vibration of the body with its change of temperature. The rate and therefore the coefficient is positive or negative according to whether the frequency increases or decreases with increase of temperature.

If a piezo-electric crystal body or element is cut from a natural crystal so that its electrode faces are in planes parallel to the opti-

cal axis and an electrical axis of the crystal, it will ordinarily have a positive temperature coefficient of frequency. If it is cut so that its electrode faces are in planes parallel to the optical axis and perpendicular to an electrical axis of the crystal, it will have a negative temperature coefficient of frequency. However, the positive temperature coefficient in the first case will ordinarily be several times as large as the negative temperature coefficient in the second case. It is therefore necessary in order to provide crystal control with zero temperature coefficient that the arrangement of positive and negative coefficient crystal elements be such that the negative ones have several times the effective reactance of the positive ones at the operating frequency.

A feature of this invention is the provision of a sufficient number of negative coefficient crystal elements in proportion to the number of positive coefficient crystal elements in the control of an oscillator to have the necessary amount of reactance to provide zero temperature coefficient control.

Another feature of the invention is an alternative arrangement in which only two crystal elements are used and these have opposite temperature coefficients, and the positive coefficient crystal element has connected across it a condenser, which may be varied so that the reactance change of the negative coefficient crystal element with changes in temperature is sufficiently large in proportion to the reactance change of the positive coefficient crystal element with changes in temperature, at the operating frequency to provide zero coefficient control.

Another feature of this invention is a second alternative arrangement similar to that just mentioned in which a resistance is connected in shunt to the positive coefficient crystal element instead of a condenser, to accomplish the same result.

In order to control the oscillations of the system at the desired frequency a condenser may be connected between the grid and plate of the space discharge tube to provide additional capacity at this point in the circuit. It will then also serve to increase the feed back to the crystals.

In the drawings:

Fig. 1 is a diagram of an oscillator having separate series connected control crystal elements in accordance with the invention;

Fig. 2 is an alternative arrangement for a plurality of crystal elements connected in the circuit to the left of the broken line in Fig. 1;

Fig. 3 is a second alternative arrangement for that portion of the circuit to the left of the broken line in Fig. 1 in which only two piezo-electric crystal elements are used;

Fig. 4 is a third alternative arrangement in which again only two crystal elements are used;

Fig. 5 is a graph showing the reactance curves of a positive and a negative temperature coefficient crystal element, cut to vibrate at the same frequency; and

Fig. 6 shows the changes in the curves of a positive coefficient crystal element effected by connecting a condenser, and by connecting a resistance, in shunt thereto.

The vacuum tube oscillator in Fig. 1 comprises a three-electrode space discharge tube O with an input circuit including four piezo-electric crystal elements 1 (hereinafter to be referred to as "crystals") connected in series, and with a tuned plate circuit 2. It is not necessary that this plate circuit be tuned to a particular frequency and in fact a suitable coil alone might replace the condenser and coil comprised in the tuned circuit. Preferably, the crystals have the same fundamental natural frequency of vibration or very nearly the same frequency, although this is not necessary. For example, that of one may be a sub-multiple, such as $\frac{1}{3}$ or $\frac{1}{5}$ etc., of that of the others. The operating frequency is not a natural, that is, a resonant frequency, but is near it, and the combined reactance of all of the crystals is an inductance say L_1 .

A source of negative grid potential 4, a condenser and grid leak resistance 5, and a choke coil 6 are shown connected across the grid and filament for supplying biasing potential to the grid. Any of these grid biasing elements, or combinations of them, may be used to bias the grid properly. When the choke coil is not used, the by-pass condenser across the resistance also is not used.

The plate circuit 2, coupled by coil 3 to a load circuit Z of any desired type, operates at such a frequency as to have an inductive reactance, say L_2 . L_1 and L_2 together with the grid-plate capacity form a tuned circuit. Thus the oscillator is of the well-known Hartley type. When the tube is delivering its maximum power there will be a certain alternating plate voltage E_p between the plate and filament. This voltage will occur when delivering this amount of power regardless of the magnitudes of L_1 and L_2 . With the given L_2 and grid-plate capacity, the grid inductance L_1 will also be determined. A supplemental condenser 7 may be connected across

the plate and grid of the tube to provide additional capacity, if desired. Under maximum power conditions there is usually obtained a fixed E_g or alternating grid-filament voltage. If instead of the series connected crystals 1 a single crystal were employed as usual, this voltage E_g occurring across the crystal would give trouble when it reached certain values, ordinarily in the neighborhood of a few hundred volts. Connecting the four crystals 1 in series is a method of reducing the voltage across each crystal used. If these crystals are identical only a quarter of the voltage E_g occurs across each, and the value to which it is possible to raise the plate voltage on the oscillator tube before a dangerous voltage across each crystal is reached, is approximately four times as high as if a single crystal were used. Consequently, much more power can be secured from the controlled oscillator.

To reduce undesired variations in the frequency of the controlled oscillator due to temperature changes, part of the crystals may have temperature coefficients of frequency opposite in sign to those of the remainder of the crystals. For example, two of the crystals in Fig. 1 may be quartz crystals cut with their electrode faces, or if they are thin, with their principal face, perpendicular to a natural face of the whole crystal, and the remaining two may be cut with corresponding faces parallel to a natural face, since crystals cut perpendicular to a natural face usually have temperature coefficients opposite in sign to those of crystals cut parallel to a natural face, although crystals cut similarly sometimes have opposite temperature coefficients. The combinations of crystals to be used depend only on the signs of their temperature coefficients, whether obtained by the above method of cutting or otherwise, and their relative magnitudes. The algebraic sum of all the coefficients should approach zero.

As a general rule the temperature coefficient of a crystal having a positive temperature coefficient of frequency is approximately three times as great as the temperature coefficient of a crystal having a negative temperature coefficient of frequency. Thus in Fig. 2 the crystals shown in Fig. 1 have been replaced by three crystals having negative temperature coefficients and one crystal having a positive temperature coefficient, connected in series as in Fig. 1. As a rule, this will provide a more precise frequency control than the arrangement shown in Fig. 1.

This may be explained by reference to Fig. 5. When a piezo-electric crystal is operating as an oscillator, the frequency of its vibration is such that it will operate on a portion of its reactance curve between the points 8—9. Thus, for example, the oscillations generated may be of such frequency that the effective inductance of the two crystals whose react-

ance curves are shown, will be as indicated by the ordinates of the points 10 and 11 which are equal and at which points also the slopes of the curves may be equal. Therefore, if a positive temperature coefficient crystal having a reactance curve, such as the curve 12 in Fig. 5, and three negative temperature coefficient crystals having reactance curves such as the lower curve 13 in Fig. 5, are used, and the temperature coefficients of the negative crystals are one-third as great as the temperature coefficient of the positive crystal, the result will be crystal control of oscillations with zero temperature coefficient.

The arrangements shown in Figs. 3 and 4 may be explained by the graphs in Fig. 6. Since the slope of the positive coefficient crystal curve is usually greater than that for the negative coefficient crystal, a given change in operating frequency causes the positive temperature crystal to produce a greater percentage change in inductance than the negative coefficient crystal. Since the positive and negative coefficient crystals change their resonant frequencies in about a three to one magnitude ratio with a given temperature change, the inductance contributed by the positive coefficient crystal should be about one-third that contributed by the negative coefficient crystal as regards this factor alone. Combining with the difference in their slopes, the positive coefficient crystal must contribute less than one-third that contributed by the negative coefficient crystal. The use of the condenser in parallel with the positive coefficient crystal permits adjustment until this condition is reached. Curve 14 represents the reactance curve of the positive coefficient crystal used and curve 15 represents the reactance curve of the negative coefficient crystal used. A condenser connected in shunt to the positive coefficient crystal, as shown in Fig. 3, will affect the reactance of the crystal as indicated by the dotted line 16 in Fig. 6. This will change the position of its reactance curve with respect to the frequency of oscillations indicated by the dotted line 17 so as to secure the desired slope relation.

In Fig. 4 a single positive, and a single negative, coefficient crystal have been used, and these crystals are cut to respond at the same frequency. The reactance curve of the positive coefficient crystal is, however, distorted by the provision of a resistance in shunt thereto in the circuit, so that it has the shape of curve 20 of Fig. 6. This produces a result similar to that produced by the arrangement illustrated in Fig. 3, and curve 16 of Fig. 6. That is, at the frequency at which the oscillator operates the slope of the reactance curve of the negative coefficient crystal as at point 19 is such that its reactance change for a given change in temperature is equal to the reactance change of the positive temperature coefficient crystal as at

point 20, for the same change in temperature, and zero temperature coefficient control is effected.

The desired relation between the slopes of the reactance curves of two crystals might also be obtained by cutting the positive coefficient crystal to vibrate at slightly lower frequency, say 3 or 4 cycles lower, than the negative coefficient crystal, and operating at a point very near the maximum point of the positive crystal, but on a steeper part of the slope of the negative crystal.

It will be understood, of course, that it is not necessary to use a crystal of any particular shape, as it might be square, oblong, etc., and the arrangement of plates on the crystal may be other than that shown. This crystal combination can be placed in any circuit suitable for generating oscillations, and it may be used in any position in any well known circuit in which crystals are customarily employed.

What is claimed is:

1. A device comprising an oscillator having input and output circuits, a plurality of crystal bodies connected in series in one of said circuits, a part of said bodies being adapted to undergo changes of one sign in response to temperature variations and the remainder of said bodies being adapted to undergo changes similar in character but opposite in sign to the first mentioned changes, in response to temperature variations, whereby temperature effects are compensated.
2. A device comprising an oscillator, a plurality of piezo-electric crystal plates connected in series in the circuit of said oscillator, each of certain of said plates having its thickness in a given direction with respect to a natural crystal axis in the plate and each of certain of said plates having its thickness in another direction with respect to a corresponding natural crystal axis of the plate, whereby temperature effects are compensated.
3. An electrical circuit comprising a plurality of piezo-electric crystal bodies connected in series, certain of said bodies having temperature coefficients of frequency of one sign, and the remainder of said bodies having temperature coefficients of frequency of opposite sign, whereby temperature effects are compensated.
4. A circuit in accordance with claim 3, said crystal bodies having substantially the same natural frequency of vibration.
5. An oscillator comprising an electrical space discharge device, means for causing said device to generate self-sustained oscillations of a given frequency, and a plurality of piezo-electric crystal bodies connected in series included in said means, said crystal bodies having temperature coefficients of frequency opposite in sign, whereby temperature effects are compensated.

6. An oscillator comprising an electric space discharge device having cathode and discharge control elements, means for causing said device to generate self-sustained oscillations of a given frequency, and a piezo-electric crystal device included in said means, said crystal device comprising crystal bodies connected in series between said cathode and discharge control elements, certain of said bodies having temperature coefficients of frequency of one sign and other of said bodies having temperature coefficients of frequency of the opposite sign. 70
7. An oscillating system comprising an oscillator having input and output circuits, and a plurality of piezo-electric crystals of opposite temperature coefficients connected in series in said input circuit for compensating the effect of temperature variations. 75
8. An oscillating system comprising an oscillator and a plurality of piezo-electric crystals connected in series, at least one of which has a temperature coefficient of frequency of opposite sign from the others, whereby temperature effects are compensated. 80
9. Means for compensating temperature variations in a crystal controlled oscillator comprising two crystals arranged in series in the input circuit of said oscillator, one of said crystals having a positive temperature coefficient of frequency and the other of said crystals having a negative temperature coefficient of frequency. 85
10. Means for producing a constant frequency, comprising a space discharge oscillator having two crystals connected in its input circuit, one of said crystals being cut to vibrate in resonance at a predetermined frequency slightly different from that of the other, whereby temperature effects are compensated. 90
11. An oscillating system comprising an oscillator and a plurality of piezo-electric crystals connected in the input circuit thereof, one of said crystals being cut to vibrate at a predetermined frequency slightly different from the predetermined frequency at which the balance of said crystals are cut to respond. 95
12. An oscillating system comprising an oscillator, a pair of piezo-electric crystals of opposite temperature coefficients connected in the input circuit thereof, and a condenser connected in shunt to one of said piezo-electric crystals, whereby temperature effects are compensated. 100
13. An oscillating system comprising an oscillator, a piezo-electric crystal having a positive temperature coefficient of frequency, a piezo-electric crystal having a negative temperature coefficient of frequency and a condenser connected in shunt to said positive temperature coefficient crystal. 105
14. An oscillating system comprising an oscillator, a piezo-electric crystal having a positive temperature coefficient of frequency, and a piezo-electric crystal having a negative temperature coefficient of frequency, said negative temperature coefficient crystal being cut to respond at a frequency a few cycles higher than the frequency at which said positive temperature coefficient crystal responds. 110
15. An oscillating system comprising an oscillator, a plurality of piezo-electric crystals of opposite temperature coefficient connected in the input circuit thereof, and a resistance connected in shunt to one of said crystals, whereby temperature effects are compensated. 115
16. An oscillating system comprising an oscillator, a piezo-electric crystal having a positive temperature coefficient of frequency, a piezo-electric crystal having a negative temperature coefficient of frequency, and a resistance connected in shunt to said positive temperature coefficient crystal. 120
- In witness whereof, I hereunto subscribe my name this 30th day of April, 1929. 125
- RAYMOND A. HEISING. 130