Feb. 16, 1960 C. FRANX 2,925,502

PIEZO-ELECTRIC QUARTZ CRYSTAL OF ELONGATED SHAPE

Filed Dec. 18, 1957 2 Sheets-Sheet 1

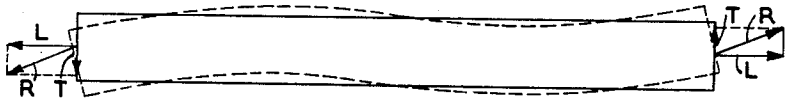


FIG.1

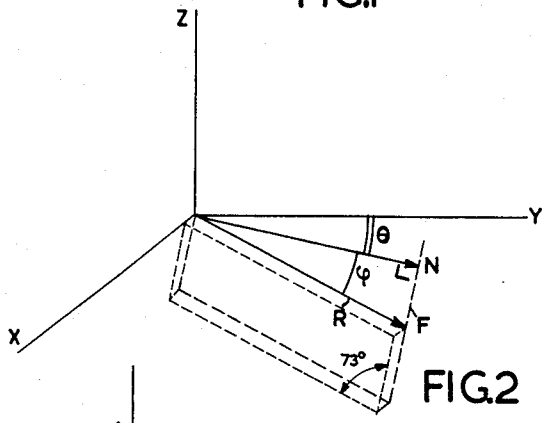


FIG.2

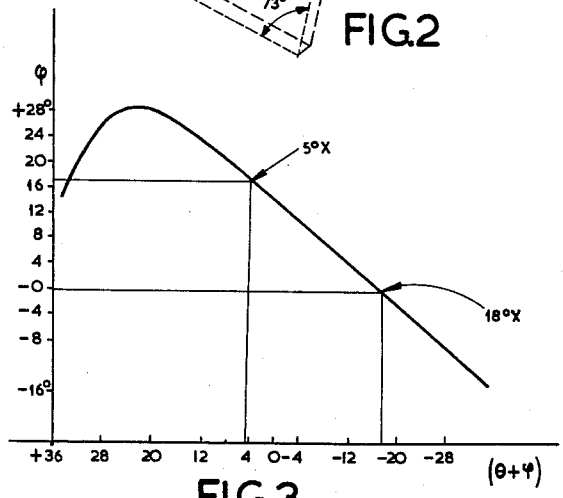


FIG.3

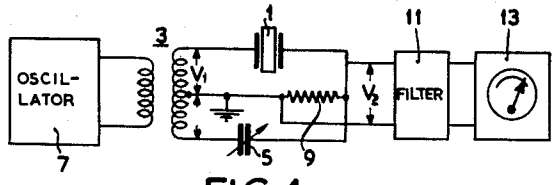


FIG.4

INVENTOR
CORNELIS FRANX
BY
Frank P. Lefevre
AGENT

Feb. 16, 1960 C. FRANX 2,925,502

PIEZO-ELECTRIC QUARTZ CRYSTAL OF ELONGATED SHAPE

Filed Dec. 18, 1957 2 Sheets-Sheet 2

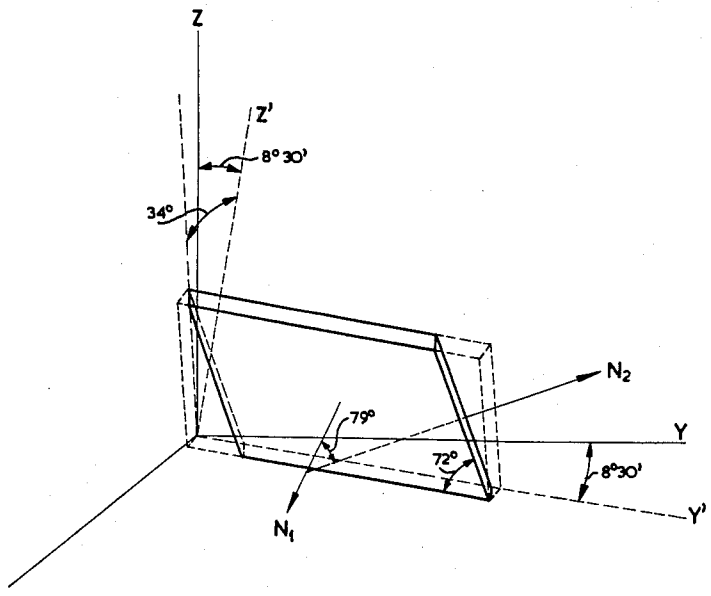


FIG. 5

INVENTOR
CORNELIS FRANX
BY
Frank R. Trifari
AGENT

United States Patent Office 2,925,502 Patented Feb. 16, 1960

2,925,502

PIEZO-ELECTRIC QUARTZ CRYSTAL OF ELONGATED SHAPE

Cornelis Franx, Eindhoven, Netherlands, assignor to North American Philips Company Inc., New York, N.Y., a corporation of Delaware

Application December 18, 1957, Serial No. 703,655

Claims priority, application Netherlands December 21, 1956

3 Claims. (Cl. 310—95)

This invention relates to piezo-electric quartz crystals of elongated shape which are capable of performing longitudinal oscillations, more particularly quartz crystals of X-cut.

Such crystals may be used as frequency stabilisers or filters in the frequency range of from 50–200 kc./s. Especially in the last-mentioned application, there is frequently interference from spurious resonance in this range, which results from the fact that the crystal can also perform flexural oscillations. With quartz crystals of X-cut, the spurious resonance may be suppressed by a determined choice of the angle made by the long side of the crystal and the Y-axis, since spurious resonance does not occur if this angle is about —18.5°. However, the temperature coefficient of the crystal is unduly high for this value. The limitation to the value of —18.5° is also disadvantageous in other respects, since some freedom in the choice of said angle is desirable to permit the further parameters of the crystal, such as for example the inductance, to be chosen according to requirements.

An obect of the invention is to provide steps by which the spurious resonance is suppressed at all orientations of the long side of the crystal including, for the X-cut, values of said angle which differ from —18.5°. According to the invention, this is achieved due to the largest surface of the crystal having the shape of a parallelogram having angles differing from 90° to an extent such that the crystal is substantially free of the spurious resonance at which the crystal performs flexural vibrations of an even order.

In order that the invention may be more readily carried into effect, it will now be described more fully, by way of example, with reference to the accompanying drawing, in which:

Fig. 1 illustrates the difficulties which occur with crystals of known type;

Figs. 2 and 3 serve to explain these difficulties and the principle underlying the invention, Fig. 2 showing an example of a crystal according to the invention;

Fig. 4 shows a measuring circuit of known type and Fig. 5 represents a second example of a crystal according to the invention.

It is known (see Cady, Piezo-Electricity 1946, pages 104–106) that a longitudinally oscillating piezo-crystal, for example a quartz crystal of X-cut, that is a crystal having its largest surface at right angles to the X-axis, does not usually perform purely longitudinal oscillations and that the oscillations (see Fig. 1) have a transverse component T in addition to the longitudinal component L, so that the resulting deviation R of the oscillating crystal parts makes a certain angle with the direction of length of the crystal. The transverse component T has the effect, that the flexural oscillation of the crystal may be excited in accordance with the pattern shown in dotted line (second order flexural oscillation), the resonance frequency of which is adjacent that of the main oscillation and may be very troublesome. It may be shown both empirically and by calculation that the transverse component is nil only with an orientation of the long side of the X-crystal of —18.5° with respect to the Y-axis. (In the annotation used by Cady this angle was indicated as +18.5°.)

In general, it may be assumed that in an oscillating anisotropic medium the direction of propagation of the oscillations, which direction is at right angles to the wave front F and hence coincident with the perpendicular N to this wave-front, makes a certain angle φ with the deviation (amplitude) R. For a quartz crystal of X-cut (see Fig. 2) this angle φ is dependent upon the angle θ between the perpendicular N and the Y-axis (see Fig. 2) and is plotted in Fig. 3 as a function of the angle $(\theta+\varphi)$ between the deviation R and the Y-axis. This graph shows that $\varphi=0°$ at $\theta+\varphi=$approximately $-18°$. For a rectangular crystal, the direction of length of which has this orientation, the oscillation is purely longitudinal and R and N are both parallel to the direction of length of the crystal.

If the direction of length of the crystal has a different orientation, for example the value +5°, which is advantageous in view of the temperature coefficient, the deviation R for a rectangular crystal, since the perpendicular N and the deviation R are not coincident, is no longer parallel to the direction of length (the long side) of the crystal but makes a certain angle with the long side, so that a transverse oscillation component occurs.

According to the invention, this may be avoided by choosing the angle between the two sides of the crystal face to be different from 90°, the crystal thus having the form of a parallelogram with angles differing from 90°. If the -previously chosen-orientation of the long side of the crystal is +5°, the desired value of the angle $\theta+\varphi$ also=5°, because evidently at this same value the deviation R actually lies in the direction of length of the crystal. This obtained if the (smallest) angle between the sides of the parallelogram-like crystal (shown in dotted line) is $90°-\varphi$, amounting, in the case under consideration, to 90°—17°=about 73° (see Fig. 3). As a matter of fact, the short side must be at right angles to N.

The angle $90°-\varphi$ may best be determined empirically, it being possible for quartz crystals of X-cut to derive, if desired, a first approximation for said angle from the curve shown in Fig. 3. For the sake of simplicity, the most important portion of the curve between $\theta+\varphi=-2°$ and $\theta+\varphi=+14°$ may be considered as straight. The curve may then be approximately represented by the equation.

$$\varphi=14.4+0.74\ (\theta+\varphi) \text{ degrees}$$

Naturally, the angle is preferably so chosen that the spurious oscillation is suppressed as far as possible. By the step according to the invention, it is possible for the activity of the spurious oscillation to be reduced by factor 100 or upwards. However, such considerable suppression may require a very accurate and expensive manufacture, so that for reasons of cost it may be preferable to be satisfied with a much less thorough suppression, for example by a factor from 2 to 3. The angle φ may in this case considerably differ (for example $\pm 10°$) from the value found from the equation. The extent to which the spurious oscillation is suppressed may be determined by measuring the series resistance R_k of the crystal.

The impedance of a piezo-electric crystal in the circuits of the main resonance and of the additional (spurious) resonance respectively may be represented with good approximation by the series-combination of inductance L_k and L'_k series-resistors R_k and R'_k, and capacitors C_k and C'_k respectively, the assembly shunted by parallel capacitors C_p and C'_p respectively. For determining the

loss resistance R'_k at the additional resonance, use may be made of the measuring circuit shown in Fig. 4.

In this circuit, the crystal 1 to be measured constitutes one branch of a measuring bridge, the other branches being constituted by the two halves of the secondary winding of a symmetric transformer 3 and by a variable capacitor 5. The transformer 3 is fed, at its primary side, by an oscillator 7 and the secondary voltage ($2V_1$) occurs across one diagonal of the bridge. The other diagonal is constituted by a reference resistor 9. The voltage (V_2) which occurs across the resistor is supplied through a filter 11, which interrupts the harmonics present in the output voltage of oscillator 7, to a sensitive voltmeter 13.

The oscillator 7 is adjusted to a frequency slightly differing from the additional resonance, the bridge being brought into equilibrium (V_2 minimum) by means of capacitor 5. Subsequently, the oscillator frequency is readjusted till V_2 is maximum. During this adjustment V_1 is also measured.

If the value R of resistance 9 is so chosen that

$$R'_k \gg R \text{ and } R \ll \frac{1}{\omega c}$$

(ω=angular frequency, c=value of capacitor 5), then applies

$$R'_k = \frac{V_1}{V_2} R$$

R_k may be measured in a so-called Heegner oscillator by the method of the substitution by a known resistor (see, for example, the article by Gerber, A Review of Methods for Measuring the Constants of Piezo-Electric Vibrators, Proc. IRE, 1953, page 1106).

The relation

$$\frac{R'_k}{R_k}$$

is a measure of the suppression of the additional resonance. The table following hereinafter shows the results of measurements on two rectangular crystals and two parallelogram-like crystals (f=main frequency; f'=additional frequency; l=length of longest side in mm.; b=width; d=thickness of the crystal).

RECTANGULAR CRYSTALS

f	f'	R_k	R'_k	$\frac{R'_k}{R_k}$	l	b	d	$\theta+\varphi$	$+90°-\varphi$
Kc.	*Kc.*	*Ohms*	*Ohms*					*Degrees*	*Degrees*
114	84.8	220	60K	$2.7.10^3$	24.74	3.7	0.8	5	90
114	84.8	185	63K	$2.2.10^3$	24.74	3.7	0.8	5	90
PARALLELOGRAM-LIKE CRYSTALS									
107.74	75	260	1.9M	$7.3.10^3$	26.1	3.71	0.8	5	abt. 71
107.76	74.9	150	12M	8.10^4	26.1	3.71	0.8	5	abt. 71

The table shows that the relation

$$\frac{R'_k}{R_k}$$

for crystals according to the invention may be a factor several hundreds larger than for crystals of known type. This applies, of course also for orientation angles different from 5°. For example, in an 80 kc. crystal (f'=56 kc.) with an orientation of about 2° an

$$\frac{R'_k}{R_k}$$

relation of about $2.6.10^4$ was measured.

The crystal may be housed in a hermetic envelope which is partly exhausted. The gas contained in the envelope has a damping effect upon the additional oscillation and, to a lesser extent, upon the main oscillation.

It is known to utilize this fact for slightly suppressing the additional oscillation, the disadvantage of a likewise attenuated main oscillation also being taken into consideration. With the crystal according to the invention, since the additional oscillation is already materially suppressed, this disadvantage may be avoided by the use of a comparatively high vacuum. The vacuum may advantageously be more than 50% (less than 380 mms. of mercury pressure), for example 90%.

The invention is also applicable to longitudinally oscillating crystals of a cut in which, in contradistinction to the X-cut the perpendicular to the largest surface of the crystal is not parallel to the X-axis, such as crystals of MT-cut. These crystals may be imagined to be obtained from an X-cut crystal by tilting it with respect to the reference axes about one of the long sides of the crystal plate. In order to satisfy the conditions for the occurrence of a purely longitudinal oscillation, it is desirable for these kinds of crystals not only that the angles of the largest surface of the crystal differ from 90°, but also that the end surfaces of the crystal make angles with the largest surface which differ from 90°. Fig. 5 shows an example of such an MT-crystal. It is derived from a rectangular MT-crystal (shown in dotted lines) which has an orientation (Y', Z') of 8° 30' with respect to the Y-(and Z-)axis and a tilting angle of 34° with respect to the Y—Z plane. The (acute) angle between adjacent sides of the large face of the crystal according to the invention is about 72° and the acute angle between the largest and the smallest face of the crystal (which is equal to the angle between the perpendiculars N_1 and N_2 to these faces) is 79°.

What is claimed is:

1. A piezo-electric crystal having a length-wise dimension exceeding dimensions in directions perpendicular thereto and being adapted to vibrate along said length-wise dimension, said crystal having at least one surface whose dimensions exceed those of another surface and which extends in the direction of said length-wise dimension, and the edges of which define a parallelogram, adjoining edges of said parallelogram defining angles which differ from 90° by an amount at which the crystal is substantially free of the spurious resonance at which the crystal performs flexural oscillations of an even order.

2. A piezo-electric crystal having a length-wise dimension exceeding dimensions in directions perpendicular thereto and being adapted to vibrate along said length-wise dimension, said crystal having at least one surface whose normal thereto forms an angle other than 90° with the X-axis and whose dimensions exceed those of another surface and which extends in the direction of said length-wise dimension, and the edges of which define a parallelogram, adjoining edges of said parallelogram defining angles which differ from 90° by an amount at which the crystal is substantially free of the spurious resonance at which the crystal performs flexural oscillations of an even order, said surface forming with adjoining surfaces of the crystal angles which differ from 90°.

3. A piezo-electric crystal having a length-wise dimension exceeding dimensions in directions perpendicular thereto and being adapted to vibrate along said length-

wise dimension, said crystal having at least one surface whose normal is parallel to the X-axis of the crystals and whose dimensions exceed those of another surface and which extends in the direction of said lengthwise dimension, and the edges of which define a parallelogram, adjoining edges of said parallelogram defining angles which differ from 90° by an amount at which the crystal is substantially free of the spurious resonance at which the crystal performs flexural oscillations of an even order.

References Cited in the file of this patent

UNITED STATES PATENTS

2,458,615 Mason ---------- Jan. 11, 1949

OTHER REFERENCES

Cady: "Piezoelectricity," McGraw-Hill Book Co. Inc., New York, New York, copyright 1956, pages 456–457.