

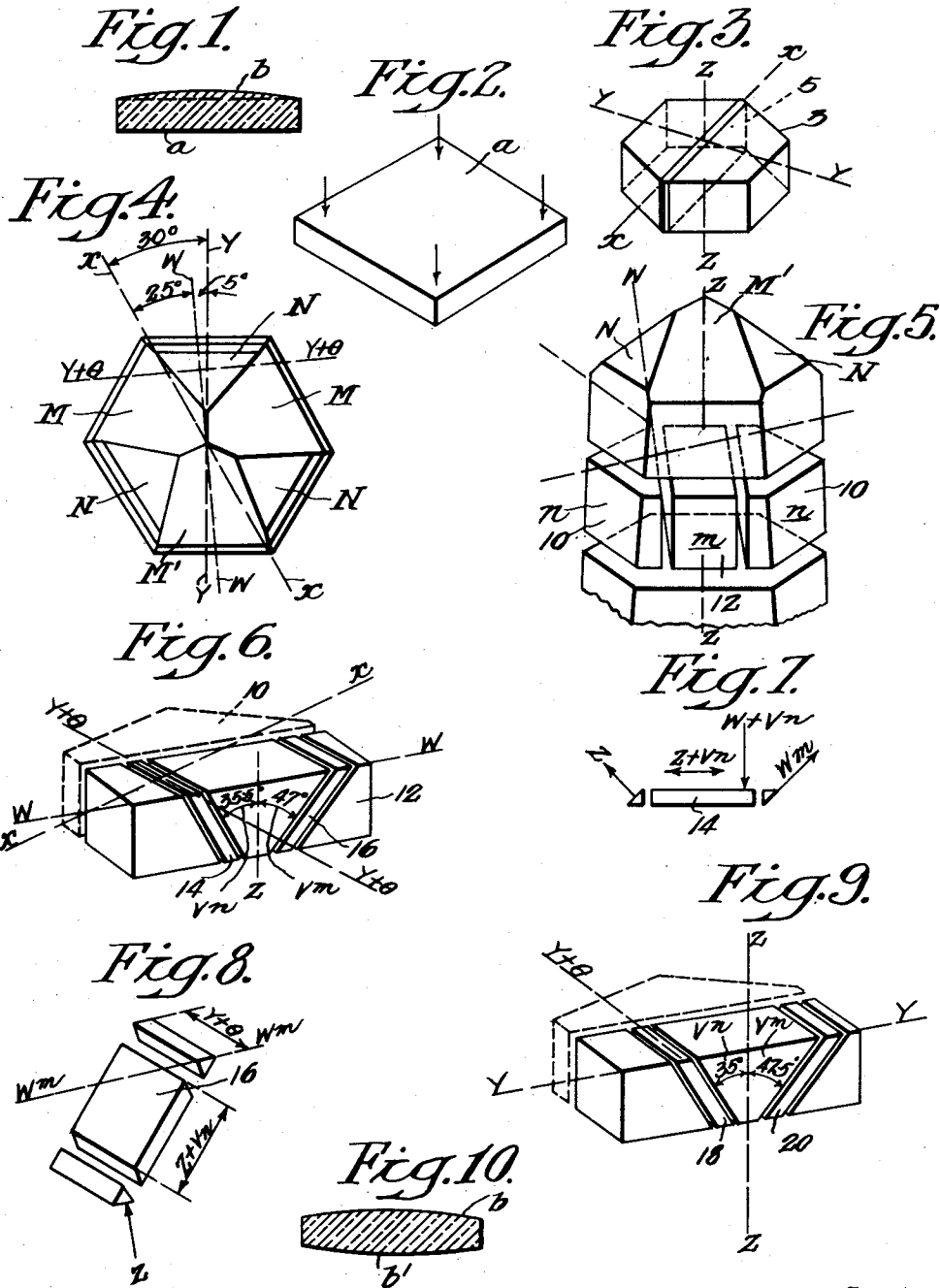
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QUARTZ PIEZOELECTRIC ELEMENT

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QUARTZ PIEZOELECTRIC ELEMENT

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This invention relates to the piezo-electric art, particularly to the cutting of quartz piezo-electric elements and has special reference to the manufacture of piezo-electric quartz elements of the type possessing a natural mode of vibration which is a function of thickness.

The prior art is replete with disclosures of different methods of cutting so-called "thickness-mode" piezo-electric oscillators from natural or "mother quartz". Such crystals have thickness-mode frequency constants peculiar to each type of cut. These constants are known to those skilled in the art and enable the technician to calculate in advance the precise thickness required to achieve a desired thickness-mode frequency, in agreement with the following formula:

$$t = \frac{K}{f} \quad (1)$$

where "t" is the thickness dimension, measured in thousandths of an inch, required to achieve a desired frequency, "K" is a constant which is different in different types of crystal cuts, and "f" is the desired frequency expressed in megacycles.

A crystal element cut in accordance with the prior art and in agreement with this formula will oscillate at but one useful thickness-mode frequency, i. e., the frequency dictated jointly by the thickness of the element and by the constant peculiar to its particular type of cut.

From the above formula it is obvious that the higher the frequency, the thinner the crystal. The difficulties attendant the cutting and finishing of very thin crystal elements or "plates" impose limits as to the frequencies possible of practical achievement. While quartz crystal plates have been cut so thin that they will oscillate at a frequency as high as fourteen megacycles such plates are regarded in the art as "museum pieces". The thinnest crystals now commercially available will oscillate at a frequency no higher than substantially eight megacycles and such crystals are so fragile that they have very little power handling capacity.

Accordingly, a principal object of the present invention is to provide a quartz piezo-electric element which will oscillate efficiently at frequencies heretofore impossible of practical achievement.

Another object of the invention is to provide a quartz piezo-electric element which will oscillate

late at a frequency higher than that of prior art elements of similar thickness.

Another object of the invention is to produce a piezo-electric element which will oscillate vigorously at any of several harmonically related frequencies.

Another object is to provide a method of so cutting a quartz crystal element that it will oscillate at the fundamental frequency dictated by its "standard" thickness-mode frequency constant and which will also oscillate at a thickness-mode frequency which is an odd multiple of such fundamental frequency, and this too without "driving" the crystal.

The methods employed in preparing crystals in accordance with this invention and further objects and advantages to be attained in carrying out the invention will be more readily understood from the following description taken in connection with the accompanying drawing, in which

Fig. 1 is a cross-sectional view of a quartz piezo-electric element having a convex-spherical electrode face, the degree of curvature being exaggerated,

Fig. 2 is a partly diagrammatic perspective view illustrative of the manner of manufacturing a crystal blank with a convex-spherical electrode face,

Fig. 3 is a view in perspective of a section of a mother crystal illustrative of one manner of orientating a blank to be finished in accordance with the present invention,

Fig. 4 is a plan view of a mother crystal with certain of its axes marked as an aid to a clear understanding of the system of orientation followed in producing certain other types of crystal plates to which the invention is applicable,

Fig. 5 shows in outline and in perspective a piece of natural quartz having a section cut and divided to provide a rough bar having top and bottom surfaces lying in planes which are normal to the Z (optic) axis and its long edges parallel to a W (reference) axis which is 25° removed from an X (electric) axis,

Fig. 6 is an elevational view showing the position of two blanks cut from the bar of Fig. 5. One of these blanks is tilted towards parallelism with the plane of a major apex surface of the mother crystal and the other toward parallelism with the plane of a minor apex surface of the mother crystal,

Fig. 7 shows the left-hand blank of Fig. 6 removed and trimmed, but not finished; the

plane of projection being perpendicular to the plane of the paper,

Fig. 8 shows the right-hand blank of Fig. 6 removed and trimmed, but not finished,

Fig. 9 is an elevational view of a section of a mother crystal illustrative of other angles of orientation of crystal blanks, prior to being finished in accordance with the invention,

Fig. 10 is a cross-sectional view through a crystal element having electrode surfaces of duplicate convex-spherical contour.

Thickness-mode crystal elements of the prior art are in the form of plates (which may be square, round, polygonal, rectangular or other shape) having duplicate, parallel, flat electrode-surfaces. The objects of the present invention are simply achieved by so finishing a quartz blank that it will have at least one convex, or convex-spherical electrode surface. Where the element is of bi-convex-spherical contour, the radius of curvature of each electrode surface must be substantially exactly the same. Because of the difficulties incident to the grinding or lapping duplicate curved surfaces the preferred manner of carrying the invention into effect is to provide the crystal blank with one convex-spherical electrode surface and one substantially optically-flat electrode surface. A cross-sectional view through the middle of such an element is shown in Fig. 1. Here "a" designates the optically flat electrode surface and "b" the opposite, convex-spherical electrode surface. Optimum performance of crystals cut in accordance with the invention is ensured with an element wherein the dimension at its thickest point (i. e., the center) is substantially no more than two ten-thousandths of an inch (.0002") greater and substantially no less than one ten-thousandth of an inch (.0001") greater than its thickness at its thinnest points, i. e., adjacent its edges. The same limits obtain where, as in Fig. 10, the element is of bi-convex-spherical contour. Crystal elements whose curvature is greater or less than that above set forth will usually fail to exhibit the desired harmonic-frequency response, though in some cases the fundamental and a single odd-harmonic frequency may be achieved.

In manufacturing the element of Fig. 1, the preferred practice is to start with a blank of a thickness slightly greater than that required to achieve the desired fundamental thickness-mode frequency. (As in prior art thickness-mode crystals, the length and breadth dimensions are usually unimportant.) One of the major surfaces of the blank is selected as a reference face and this face ("a", Figs. 1 and 2) is ground and lapped until it is substantially optically flat and the element is of the required thickness. By "optically flat", as this term is herein used, is meant approximately within two one-hundred-thousandths of an inch (.00002"). This optically flat surface "a" is then preferably given a finish to a degree which may be defined as "one step removed from a polish".

The thickness of the blank at this stage in its manufacture will be understood to be uniform. The unfinished surface of the blank is then placed in contact with a flat surface having an abrasive film thereon. Force is applied, as with the fingers, adjacent each corner (as indicated by the arrows in Fig. 2) and the blank moved over the abrasive material with a circular or figure-eight movement. Since no force is applied to the center of the blank and since the quartz is relatively flexible the edges of the blank will be sub-

jected to the greater abrasive action whereby this surface ("b", Fig. 1) will assume a convex-spherical contour. Frequent tests at this stage should be made to determine the oscillating characteristics of the element. When the desired characteristics are achieved, the last treated surface "b" should preferably be given a finish similar to that given the other electrode surface, "a".

The crystal element is now ready for use, for example, as an oscillator. When tested even in a non-regenerative circuit the element will usually be found to oscillate, selectively, at its fundamental thickness-mode frequency and at one or several other frequencies which are odd-numbered multiples of its fundamental frequency. Thus, if the thickness of the element (at the point of maximum thickness) is such as to endow the element with a fundamental thickness-mode frequency of, say, eight megacycles, it will, alternatively, respond to a frequency of 24 megacycles, and 40 megacycles, and 56 megacycles, and even higher odd-multiple frequencies. The element will, of course, respond even more vigorously if it is included in a regenerative circuit.

Blanks whose major surfaces are orientated in any of several known ways may be employed in carrying the invention into effect. Thus, as indicated in Fig. 3, a so-called "Y-cut" blank may be employed. In this figure, 3 designates generally a section or slab cut at right angles to the Z (optic) axis of a mother crystal, and 5 designates a blank whose major surfaces are parallel to an X (electric) axis and perpendicular to a Y (crystallographic) axis. The cut of this blank is that described in Tillyer Patent No. 1,907,613. A blank cut in accordance with the Tillyer disclosure will possess a thickness-mode constant (K) of substantially 77.8. When finished in accordance with the present invention, it will also possess a frequency constant of substantially 233.4, and of 389 and other higher odd multiples of the fundamental constant (77.8).

Y-cut quartz crystals inherently possess a positive temperature coefficient of frequency. British Patent No. 457,342 (1936) to Samuel A. Bokovoy and Charles F. Baldwin discloses a system of orientating crystal blanks whereby they exhibit a zero or other low temperature coefficient of frequency. Blanks cut in accordance with the Bokovoy and Baldwin invention may likewise be employed in carrying the present invention into effect.

This desired operating characteristic obtains, in accordance with the Bokovoy and Baldwin disclosure, by reason of a rotation or inclination of the major surfaces of the element about any of certain $Y+\theta$ axes. Each of these $Y+\theta$ axes is normal to a W-axis, which W-axes lie in the X-Y plane, i. e., in a plane normal to the Z-axis. The direction of rotation or "tilt" is away from parallelism with the Z-axis and may be toward parallelism with the plane of a major or a minor apex face of the mother crystal. The range of frequency constants (K) for crystals cut in accordance with this earlier filed case is substantially 66.5 to 68.2 for blanks tilted towards a minor apex face and substantially 88 to 100 for blanks tilted towards a major apex face. The exact constant for a given blank is dependent upon the W-axis selected as a reference axis. A blank cut in accordance with this earlier invention and finished in accordance with the present invention will possess additional frequency constants which, like the previously described Y-

cut crystal, are odd multiples of the fundamental constants above given.

The blanks of Figs. 6, 7, 8 and 9 are typical of the Bokovoy and Baldwin disclosure and may be finished in accordance with the present invention with one (or both) convex-spherical electrode surfaces, in which case, they will respond to, and oscillate at, a fundamental frequency which is a function of its thickness dimension and also at one or more odd harmonic thickness-mode frequencies.

Since the Bokovoy and Baldwin invention involves a system of orientation in which (a) the major and minor apex surfaces of the mother crystal are employed as reference planes and (b) certain W-axes and (c) certain $Y+\theta$ axes are employed as reference axes, it is first necessary to identify these planes and axes.

As to (a), referring to Figs. 4 and 5 of the drawing, and having in mind that all unbroken quartz crystals are uniformly shaped hexagonal bi-pyramids, it will be seen that certain of the terminal faces of the quartz extend to the apex of the pyramid. These surfaces are designated "M" and are the major apex surfaces. Those terminal surfaces which do not touch the apex are designated "N" and are the minor apex surfaces of the mother crystal.

As to (b), Fig. 4 is marked to show an electric, X-axis and an adjacent mechanical or crystallographic Y-axis. The optic or Z-axis, marked in Fig. 5, is perpendicular to the plane of projection in Fig. 4. The W-axes lie between an X-axis and an adjacent Y-axis in the X-Y plane, i. e., in a plane normal to the Z-axis. In Fig. 4, but one W-axis is marked. It forms a W-angle of 25° with that X-axis which is designated X-X.

As to (c), there is a $Y+\theta$ axis for each W-axis, each is normal to its W-axis and normal to the Z-axis. It is about a $Y+\theta$ axis that the element is rotated or tilted to achieve a desired temperature coefficient of frequency and frequency constant.

In order to produce a quartz piezo-electric blank or plate having a predetermined low temperature coefficient, a suitable angle of orientation (angle W) with respect to an X-axis, and a coordinated angle representing the inclination of the electrode (i. e., "top" and "bottom") faces, must be chosen. This latter angle will be referred to generally as the "V-angle" and more specifically as the "V^m angle" or the "Vⁿ angle" as determined by the direction of rotation, i. e., whether towards parallelism within the plane of a major apex surface (M) or a minor apex surface (N) of the mother crystal.

It is not deemed essential to a complete disclosure of the present invention to illustrate every possible way of cutting a "zero temperature coefficient blank" to be finished in accordance with the present invention. Accordingly, but four such blanks are illustrated in Figs. 5 to 9, inclusive.

Referring first to Fig. 5, a section 10, say one inch thick, is first sliced from the body of the mother crystal; the thickness dimension of this section is parallel to, and the length-breadth dimensions normal to the Z-axis. A bar 12 is then cut from the section 10, preferably at the exact W-angle selected as a reference axis. In the illustrated embodiment, the long dimensions of the bar 12 coincide with a W-axis which is 25° removed from that X-axis (and hence 5° removed from that Y-axis) marked in both Figs. 4 and 5.

Referring to Figs. 6, 7 and 8, the blanks 14 and 16 from which the finished elements are to be formed are then sliced from bar 12 at either a V^m angle or a Vⁿ angle dictated by the temperature coefficient desired. The electrode faces of blank 14, as shown, have been rotated substantially 35.5° (the V^m angle) about its $Y+\theta$ axis in a direction away from parallelism with the Z-axis toward parallelism with the plane of that minor apex surface of the mother crystal which is designated N1 in Fig. 4. (In Fig. 5, N1 is opposite the major apex surface designated M1.) This 35.5° V^m angle is disclosed in the referred to Bokovoy and Baldwin British patent as the precise angle required to achieve a zero temperature coefficient of frequency—when the selected W-axis forms a W-angle with an X-axis of 25° .

The electrode faces of blank 16 of Figs. 6 and 8 have been rotated substantially 47° (the V^m angle) about its $Y+\theta$ axis in a direction away from parallelism with the Z-axis towards parallelism with the plane of that major apex surface of the mother crystal which is designated M1 in Figs. 4 and 5.

The blanks 18 and 20 of Fig. 9 have been cut from a bar whose long edges are parallel to a Y-axis, i. e., at a 30° W-axis. The Vⁿ angle of blank 18 is substantially 35° and the V^m angle of blank 20 is substantially 47.5° .

Assuming, for purposes of illustration, that the element to be ground and lapped from blank 14 is to respond to a fundamental thickness-mode frequency of, say, 2 megacycles, then since

$$t \text{ (thickness)} = \frac{K^n}{f} \quad \begin{matrix} \text{(frequency constant)} \\ \text{(frequency in megacycles)} \end{matrix} \quad (35)$$

and Kⁿ (as disclosed in British Patent 457,342) for a zero temperature coefficient of frequency crystal having a W angle = 25° and a Vⁿ angle = 35° equals 67; therefore

$$t = \frac{67}{2}$$

or, solved, t = substantially 33.5 thousandths of an inch.

The frequency constant K for blank 16 of Figs. 6 and 8 is substantially 97. If this blank 16 is to respond to a fundamental thickness-mode frequency of, say, 8 megacycles, then, applying the same formula,

$$t = \frac{97}{8}$$

which, solved, shows the thickness dimension required to achieve an 8 megacycle, zero temperature coefficient, V^m type crystal is substantially 12.125 thousandths of an inch.

The fundamental thickness-mode frequency constant of blank 18 of Fig. 9 is, substantially 66.5 and the K value of blank 20 of this figure is substantially 100. Obviously, these constants K being known, these blanks 18 and 20 may be made of any thickness necessary to achieve a desired fundamental thickness-mode frequency.

These dimensions having been determined, it remains only to grind the blanks to the required thickness dimensions and to subject them to the lapping process described in connection with Fig. 2 so that an electrode surface, or both of them, will be of convex-spherical contour, as shown in Figs. 1 and 10. When so finished, these elements will possess not only the previously mentioned fundamental thickness-mode frequency constants (K) but also additional constants which are odd multiples of said fundamental frequency constants. These elements will be found incapable

ble of oscillating at even-numbered harmonic frequencies, but will respond vigorously to frequencies which are odd-numbered multiples of their fundamental thickness-mode frequency.

- 5 Although certain specific ways and means for accomplishing the objects of the invention have been set forth, it is to be understood that they have been given for the purpose of explaining the inventive concept and should not be construed as limitations to the scope of the invention. 10 Neither is it to be understood that any statements herein made in regard to dimensions or to value or relationship between frequency constants, angles of orientation, etc., are other than close approximations. The invention, therefore, 15 is not to be limited except insofar as is necessitated by the prior art and by the spirit of the appended claims.

What is claimed is:

- 20 1. A quartz piezo-electric element adapted to respond to a fundamental frequency which is a function of its thickness dimension, said element having at least one curved electrode surface, the departure of said surface from optical flatness 25 being substantially no more than two ten-thousandths of an inch whereby said element will respond to a second thickness-mode frequency which is harmonically related to said first mentioned frequency.
- 30 2. A quartz piezo-electric element adapted to respond to a fundamental frequency which is a function of its thickness dimension, said element having at least one convex surface, the departure of said convex surface from optical flatness 35 being substantially no more than two ten-thousandths of an inch whereby said element will

respond to a second thickness-mode frequency which is an odd-numbered multiple of said first mentioned frequency.

3. The invention as set forth in claim 2 wherein said element contains an electric (X) axis 5 and said convex surface extends along said electric (X) axis.

4. The invention as set forth in claim 2 wherein said element contains a $Y+\theta$ axis, said $Y+\theta$ axis being normal to a W-axis which lies from 10 0° to 30° removed from an electric (X) axis in a plane normal to the optic (Z) axis, and said convex surface extends along said $Y+\theta$ axis.

5. Method of manufacturing a quartz piezo-electric element capable of oscillating at a fundamental thickness-mode frequency and at least 15 one other frequency which is an odd-numbered multiple of said fundamental frequency, said method comprising cutting a flat surfaced blank of a thickness substantially that required to 20 achieve said fundamental thickness-mode frequency and then reducing the thickness of the blank adjacent the periphery thereof by not more than substantially two ten-thousandths of 25 an inch.

6. Method of achieving fundamental and harmonically related frequencies in a piezo-electric element which comprises forming a quartz crystal blank dimensioned to respond to the desired fundamental frequency, reducing its di- 30 mensions between its electrode faces adjacent the periphery thereof to render said blank capable of responding to a harmonically related frequency, and then vibrating said crystal at the particular frequency desired. 35

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