

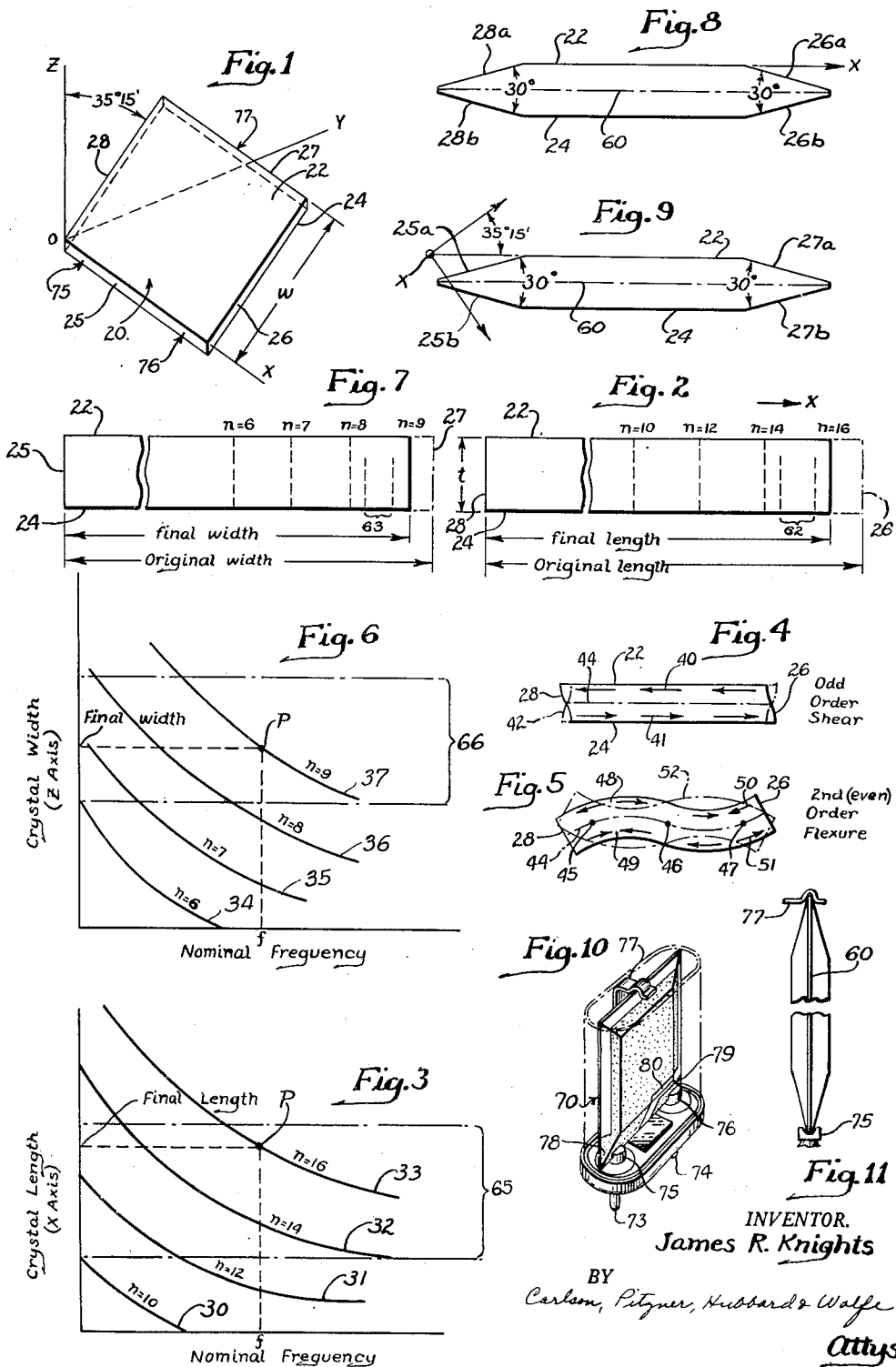
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METHOD OF FINISHING CRYSTALS

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METHOD OF FINISHING CRYSTALS

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The present invention relates to crystals and more particularly to the manufacturing of quartz crystals for vibration in the shear mode.

Experience with quartz crystals has shown that the vibration under applied electrical stress, far from being simple, is complicated by simultaneous movement in various modes and by the effect of coupling between the various modes. For example, the well known AT cut exhibits, in addition to its normal thickness shear mode vibration, movement in extension, flexure and shear along the various axes. In its simplest aspect the extensional mode vibration causes rapid edgewise expansion and contraction of the crystal. Although this is accompanied by changes in thickness of the crystal by reason of elastic coupling, the effect is found in practice to be quite minor and may, in any event, be counteracted by appropriate edgewise clamping of the crystal in the holder.

More important is the vibration which occurs in the flexural mode along the X axis. This consists of bending or bowing of the quartz plate about two or more stationary points or nodes with the length of the centerline remaining unchanged. In the case of very large crystals operating at a low frequency such bending may be of the first order or fundamental having two nodes, or of the second order having three. In the case of AT cut crystals operating at communications frequencies flexural vibrations of much higher order become important and it is with vibrations of roughly the tenth to the sixteenth order that the present disclosure is primarily concerned.

The reason that such high order flexural vibrations are important is that they are of a frequency which is of the same order of magnitude of the nominal frequency of the crystal when the latter is vibrating normally in the desired thickness shear mode. The difficulty is that in crystals as commonly produced high order flexural vibration may occur at a frequency which is the same as that of the shear mode vibration or which lies very close to it. When such flexural vibration is of "even" order such as the tenth, twelfth, fourteenth, etc., the two modes of vibration, occurring slightly out of step, are coupled and interfere with one another. Thus a self-cancelling effect sets in and the activity of the crystal in its desired shear mode vibration is greatly reduced. Many crystals thus become rejects and must be discarded or laboriously tailored in length and width by cut-and-try in an attempt to bring the activity up to the required

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point. Normally this adjustment is made "in the dark" and without knowledge of whether it is the vibration along the length or the width that is causing the trouble. Often so much of the crystal is ground away before high activity is achieved that this serves as a basis for rejection. It is in the case of beveled crystals that the real difficulty arises since any adjustment in lateral dimension must be produced by tapering the crystal equally on both sides of the nodal plane to keep the crystal symmetrical.

Aside from loss of activity there is a disadvantage of coupling which is of equal or even greater importance: the effect on the temperature coefficient. It is well known that an AT cut crystal has a low coefficient which is very desirable. It is not so well appreciated that the coefficient of an AT cut crystal vibrating in X flexure is extremely high. As long as the temperature remains at about the same level as when the crystal was calibrated, the crystal will operate as intended. However, upon a departure in one direction or the other from this value the frequency of flexural vibration will change and, due to coupling with the shear mode, will cause a substantial net change in operating frequency.

As a result of the above it has been found extremely difficult to manufacture crystals economically on a high production basis which are sufficiently uniform in their characteristics to meet the exacting requirements of military and commercial users.

In view of the foregoing it is an object of the present invention to provide a method of producing piezoelectric crystals in which coupling or interference between shear mode vibration and other modes of vibration particularly flexure, is minimized.

It is another object of the invention to provide a method of making quartz crystals which is adapted for the quantity production of stable crystals of uniformly high activity and which substantially eliminates the necessity for rejecting crystals by reason of coupling with undesired modes of vibration.

It is a further object of the invention to provide a method of making crystals for vibration in the thickness shear mode which substantially eliminates flexural vibration at nominal crystal frequency and which insures that any drift in frequency upon changes in temperature is reduced to a minimum. It is a more detailed object to provide a method for preparing active, low drift crystals in quantity which are particularly suited for mounting at the nodal plane.

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Other objects and advantages of the invention will be apparent from the following detailed description taken in connection with the accompanying drawing, in which:

Figure 1 shows a typical blank of AT cut suitable for use in the practice of the present invention.

Fig. 2 is an enlarged edgewise view of a crystal blank adjusted to its final length in the X direction.

Fig. 3 shows a family of curves of the type which are preferably employed in practicing the present method.

Fig. 4 is a diagrammatic view showing the distortion of the crystal caused by odd order vibration in the thickness shear mode.

Fig. 5 is a diagrammatic view showing the distortion caused by second order flexural vibration.

Fig. 6 is a family of curves of the same general type as disclosed in Fig. 3 to facilitate dimensioning the width of the crystal.

Fig. 7 is an enlarged view of a crystal blank cut to the desired width.

Figs. 8 and 9 are edge views of the crystal produced by the present method.

Fig. 10 is a perspective view showing the crystal mounted in a holder and the arrangement of electrodes thereon.

Fig. 11 is a more detailed showing of the manner in which the crystal is gripped in the holder of Fig. 10.

While the invention is susceptible of various modifications I will herein describe in detail only the preferred method. It is to be understood, however, that I do not intend to limit the invention by such disclosure, but aim to cover all modifications and alternative methods falling within the spirit and scope of the invention as expressed in the appended claims.

By way of introduction to the present invention reference is made to the blank of conventional AT cut shown in Fig. 1. The blank designated at 20 has faces 22, 24 of a length l and a width w . The four edges of the crystal are designated 25-28. It will be assumed for the sake of simplicity that the crystal blank has been adjusted to a thickness t to produce a desired nominal frequency of vibration f when vibrating in the thickness shear mode along the X axis. This mode of vibration is also known in the art as high frequency shear vibration. As the discussion proceeds, however, it will be apparent that precise adjustment of thickness to that corresponding to frequency f need not be a first step but may be the final step in the production of the finished crystal.

In accordance with previous practice the crystal, after grinding, is checked for output and then mounted. Low activity crystals are discarded or altered in length or width in an effort to minimize coupling between the thickness shear vibration and the other modes of vibration and thereby improve the operating characteristics. In practicing the present method, however, just the opposite is done: the length of each crystal (along the X axis) is initially adjusted to the worst possible condition, namely that in which an even high-order flexural vibration takes place at the desired shear mode frequency of the crystal. Assuming that the nominal frequency of a crystal is f , then the length is adjusted by grinding or the like so that flexural vibration takes place at some even high order and at the frequency f .

To make this clear, reference will be made to the typical quartz plate of frequency f shown

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in Fig. 2 in which the worst possible lengths are indicated at $n=10$, $n=12$, etc. corresponding to the various possible orders of vibration. In the case of an AT cut crystal such lengths are found using the expression

$$X_f = \frac{53n}{f}$$

where X_f is the dimension along the X axis, n is the order of flexural vibration and f is the nominal frequency of thickness shear vibration. X_f is in units of thousandths of an inch and f is measured in megacycles. Such a formula may be derived purely theoretically knowing the physical properties of the quartz, but it is generally found more suitable to determine the constant, in this case 53, by means of experimental studies well within the capabilities of one skilled in the art.

The constant may vary slightly depending upon a number of factors which include the contour of the blank, the orientation in the holder, the order of the vibration and the loading effect of the electrodes. However, the effect of the latter is generally so small as to make the figure given adequate for most purposes. Possible variation is merely mentioned to emphasize that the determination of the constant per se forms no part of the present invention and it may be refined in accuracy to suit the particular circumstances.

To assist the operator in adjusting the X dimension of the crystal to the point corresponding to maximum coupling, graphs or curves may be used of the type set forth in Fig. 3. Here the abscissa is the nominal frequency of vibration in the shear mode and the ordinate is the dimension of the crystal along the X axis. These curves are plotted using the expression for X_f given above and are of hyperbolic form. In the present instance the most unfavorable X dimension for each nominal frequency may be read directly from one of the curves 30, 31, 32 or 33. Note that curve 33 corresponds to a flexural vibration of the sixteenth order and the curve 32 to a flexural vibration of the fourteenth order. In the practical case these curves are vertically spaced about .070 inch.

In determining which of the curves is to be used the holder dimensions should be taken into consideration. Preferably, horizontal limit lines are inscribed on the curve sheet defining range of dimension, indicated at 65, which may be accommodated. Although the curves labeled $n=14$ and $n=16$ both fall within this range for a frequency f , less edge grinding is necessary if the curve for $n=16$ is used. The frequency f defines a point P on the curve. Proceeding to the left from this point the desired final dimension is quickly and accurately determined. The crystal is then adjusted to the dimension by grinding or the like to form a square edge. Each of the crystals passing along the production line is so treated although it will be understood that the "worst" dimensions obtained from the curve sheet will be different for crystals of different nominal frequency.

While it is known for a fact that even order flexural vibration may seriously interfere with vibration in the thickness shear mode, the reason for coupling between the modes may be more clearly understood by inspection of Figs. 4 and 5 which show the distortion of the crystal blank under first order thickness shear and second order flexural vibration respectively. Under

shear, the top face 22 of the crystal is displaced in one direction, say to the left, as indicated by the arrows 40 while the lower face is displaced in the opposite direction as indicated by the arrows 41. During the second half of the vibration cycle the condition is exactly reversed as indicated by the dot-dash line 42.

Referring more particularly to Fig. 5, second order flexural vibration occurs about the nodal points 45, 46, 47. These points lie on a mid-line 44 which does not change in length as the crystal undergoes flexure. At the left-hand side of the crystal expansion takes place at the top as indicated by the arrows 48 while compression occurs at the bottom as shown by the arrows 49. In the right-hand portion of the crystal the conditions are just reversed as indicated by the arrows 50, 51 respectively. This condition lasts only during the first half of the vibratory cycle; during the second half of the cycle the crystal tends to assume the opposite condition as indicated by the dot-dash outline 52.

Comparing the two figures it will be seen that the distortion caused by first order shear mode vibration and second order flexural vibration is substantially the same. In each case there is a tendency for the upper face to move to the left relative to the lower during the first half cycle of vibration. It will be apparent to one skilled in the art that this general type of distortion, in which the edges 26, 28 are angularly oriented in the same direction, holds true, not only for second order flexure and first order shear, but for all even order flexure and odd order shear vibrations. Such coupling has two disadvantageous effects. In the first place the activity is reduced. This apparently is due to the fact that normal vibration in the two modes respectively will not be exactly in step as pictured in Figs. 4 and 5 but will tend to be out of phase due to small temperature variations and other extraneous effects. This causes a certain amount of cancellation or neutralizing between the modes and consequent reduction in amplitude. As larger changes in temperature occur the flexural vibration departs radically from its original frequency, tending to drag the frequency of the shear mode vibration along with it. This coupling in the case of an AT cut crystal is particularly disadvantageous since it defeats the very thermal stability for which the AT cut was developed.

The above discussion covers the dimensioning in the X direction which is of primary importance. For maximum performance the dimension of the edge lying generally along the Z axis should also be considered. In this direction there is substantially no coupling with flexural vibration; instead Z shear vibration is of importance. In accordance with one of the more detailed aspects of the invention, therefore, the width or Z dimension of the crystal is adjusted to the worst possible condition in a manner analogous to the adjustment of the X dimension. This condition is defined by the expression

$$Z_s = \frac{99.5n}{f}$$

where Z_s is the dimension of the crystal lying generally along the Z axis, n is the order of the Z shear vibration and f is the nominal frequency of vibration in X shear.

In the case of the X flexure coupling, only the high even order vibrations had to be considered since the odd order flexural vibrations do not pro-

duce any appreciable amount of coupling. In connection with the Z shear vibration presently under discussion, the normally encountered orders of vibration are of the same general magnitude as the desired X shear vibration and both the even and odd orders are objectionable from the standpoint of undesired coupling. The various "worst" widths to which the crystal blank is initially adjusted may be obtained from the above expression for Z_s . However, I prefer to make up a chart having a family of curves computed from the Z_s expression for various values of n from which the width of the crystal may be read directly. An example of such a chart is shown in Fig. 6, the curves being designated 34, 35, 36 and 37 corresponding to orders of Z shear vibration of 6, 7, 8 and 9. The use of this chart is completely analogous to that discussed in connection with Fig. 3 except that here the ordinates are in terms of crystal width measured generally along the Z axis. By way of example it will be assumed that for a frequency f a crystal in the desired range of width may be obtained by adjusting the width for a ninth order vibration in Z shear. This determines a point P on the curve $n=9$, and the final width may be read directly along the ordinate. The crystal is then edge-ground to this width, the appearance of the blank after grinding being disclosed in Fig. 7. This step, combined with the foregoing on crystal length, results in a rectangular quartz plate in which X flexure coupling and Z shear coupling are a maximum. The crystal blank thus produced will have extremely poor operating characteristics. The lack of activity and lack of temperature stability will, in the normal case, be so marked as to preclude its use in frequency control applications.

In accordance with the next step of the method the edges of the crystal are beveled, the bevel extending substantially to the nodal plane and with the included angle of the bevel near the edge being relatively sharp. The formation of the bevel is disclosed in Figs. 8 and 9 which show the edge view of the finished crystal in length and width respectively. In Fig. 8 the beveled edges corresponding to the edge 28 are designated 28a, 28b, while those corresponding to the edge 26 have been indicated 25a, 26b. In Fig. 9 the beveled surfaces are designated respectively 25a, 25b and 21a, 21b. Such beveled surfaces are in the present instance flat and are preferably formed by grinding or lapping. As will be seen, they are symmetrically arranged about the nodal plane 60 passing through the center of the crystal. I have found that a bevel on the order of 15 degrees with a 30 degree included angle has a number of beneficial effects. It not only permits gripping on the nodal plane but has been found to convert the effective length and width from the worst possible condition to a condition which reduces the coupling from X flexure or Z shear vibration to an optimum condition thereby permitting vibration in the thickness shear mode to take place substantially independently.

It might be expected that a bevel as sharp as that herein disclosed would have the effect of excessively reducing the effective dimension of the crystal. For example, it might be thought that a sharp bevel would reduce the effective length from that corresponding to a sixteenth order flexural vibration to that corresponding to, say, a fourteenth or twelfth order flexural vibration ($n=14$ or $n=12$ in Fig. 2). Similarly it might be thought that the effective widths would be reduced greatly, say, to that correspond-

ing to a seventh or eighth order Z shear vibration ($n=7$ or $n=8$ in Fig. 7). If this were so the beveled crystal would suffer from the same disadvantages as the blank which was originally tailored to the "worst" dimensions. However, it is found in practice that a bevel on the order of that shown does not reduce the effective length nearly to the extent as might be supposed. Referring to Figs. 2 and 7 it is found that a bevel on the order of 15 degrees reduces the effective length and width so that they fall within the ranges 62, 63 which lie intermediate the undesirable dimensions corresponding to, say, the sixteenth order and fourteenth order flexural vibrations. The effect of this is that the blank 20 which was tailored to the most undesirable condition, after beveling, falls in an extremely favorable condition lying intermediate two adjacent undesirable conditions. The invention is not to be considered limited to a bevel of 15 degrees but would obviously include a bevel adjusted to one side or the other of this value where the result is to produce an effective length falling in the favorable ranges 62, 63.

Another beneficial result brought about by the present invention relates to the activity in the extraneous modes as distinguished from the frequency of the vibration in these modes. As we have seen, the reduction in effective length resulting from beveling acts to prevent coupling, for example with X flexure vibration, by changing the frequency of the latter. It has been found, however, that the activity in the flexural mode is also greatly reduced. The reason for this may be explained by considering the appearance of the crystal along the X axis. The length in this direction is greatest at the nodal plane; this corresponds to a particular frequency of X flexure vibration. On the other hand, the X dimension is a minimum at the crystal faces; this corresponds to a much higher frequency of flexural vibration. Intermediate the two the length varies continuously, each length element tending to vibrate at a different frequency. This produces a substantial amount of cancellation or neutralizing effect so that the crystal becomes exceedingly inefficient as a flexure vibrator. Thus the net flexural vibration which takes place at some "compromise" frequency is at a very low level and the harmful effects of coupling are further minimized.

While it is true that the temperature coefficient for X flexure is extremely high, the fact that the effective length is substantially centered in a safe range makes it necessary for an extremely great temperature change to occur before the frequency of vibration in flexure would approach the nominal frequency of shear mode vibration. Such a condition would not occur within the conceivable temperature variation encountered in practical use. This again is contrasted with crystals produced by conventional techniques, in which the variation with temperature is a matter of conjecture until the crystal is finally tested rather than being predictable. The present method accordingly enables drift specifications to be drawn even tighter with assurance that they can be consistently met.

In a production line setup the simplicity of the scheme is apparent. It is merely necessary for the operator to observe the desired frequency of the crystal in thickness shear mode vibration and then by means of graphs similar to those shown in Fig. 3 and Fig. 6 to read off the length and width determined by one of the curves lying within the desired dimensional ranges 65, 66. A curve

is selected which is slightly less than the respective dimensions of the unfinished blank. The crystal may be reduced to a thickness corresponding to thickness shear vibration at frequency f either as a preliminary step or as a final step. If desired, the crystal may be lapped or etched to a frequency slightly higher than the desired frequency as a step preliminary to beveling and then loaded with silver, say by evaporation, after beveling to lower the frequency precisely to the desired value.

A crystal manufactured as outlined is ideally suited for mounting in a holder which grips the crystal in compression in the Z direction along the nodal plane. An example of such a holder will be seen in Fig. 10, the finished crystal being indicated at 70. The holder 71 includes a base 72 having prong terminals 73, 74 making contact with a pair of insulated crystal supports 75, 76. The latter are notched as shown in Fig. 11 and the crystal is pressed therein by a spring finger 77 which may be fastened to the base by any desired means. The faces of the crystal are coated with evaporated silver to form electrodes 78, 79 which are "wrapped around" the lower edge of the crystal and separated from one another by a diagonal strip 80 for contact with the respective supports 75, 76. Conductive cement is preferably applied in the grooves. Such amount effectively damps many of the lesser extraneous modes of vibration while leaving the faces of the crystal free to vibrate in the desired thickness shear mode.

While the above disclosure has described the method in connection with AT cut crystals it will be understood that the invention is by no means limited thereto but would include application to BT and other cuts, the primary difference being the use of different constants in setting up the graphs and tailoring for the "worst" condition prior to beveling.

I claim as my invention:

1. The method of finishing piezoelectric crystals for vibration in the thickness shear mode which includes the steps of adjusting the crystal blank to predetermined thickness so that it vibrates in the shear mode at a corresponding desired frequency, adjusting the lateral dimensions of said blank so that the crystal would tend to vibrate in flexure at said frequency with an even order of vibration, and then beveling the edges of the crystal to inhibit said even order flexural vibration.

2. The method of finishing piezoelectric crystals for vibration in the thickness shear mode which includes the steps of adjusting the crystal blank to predetermined thickness so that it vibrates in the shear mode at a corresponding frequency, adjusting the lateral dimensions of said blank so that the crystal would tend to vibrate in flexure as said frequency with an even order of vibration and then beveling the edges of the crystal substantially to the nodal plane to inhibit any tendency for said crystal to vibrate flexurally as said even order.

3. The method of manufacturing piezoelectric crystals for vibration in the thickness shear mode which includes the steps of adjusting the crystal blank to predetermined thickness so that it vibrates in the shear mode at a corresponding frequency, adjusting the lateral dimensions of said blank so that the crystal would tend to vibrate in flexure at said frequency with an even order of vibration, and then beveling the edges of the crystal substantially to the nodal plane to inhibit even order flexural vibration at said frequency,

the included angle of said bevel being approximately 30 degrees.

4. The method of manufacturing piezoelectric crystals for vibration at a desired frequency in the thickness shear mode which includes the steps of adjusting a lateral dimension of said blank so that the crystal would tend to vibrate in flexure along said dimension at the desired frequency with an even order of vibration, and then beveling the edges of the crystal corresponding to said lateral dimension to inhibit even order flexural vibration at said frequency.

5. The method of preparing piezoelectric crystals for vibration in the thickness shear mode which includes the steps of adjusting the crystal blank to predetermined thickness so that it vibrates in the shear mode at a corresponding desired frequency, adjusting the lateral dimensions of said blank so that the crystal tends to vibrate in flexure at said frequency with an even order of vibration, beveling the edges of the crystal to inhibit even order flexural vibration at said frequency, and then mounting said crystal by gripping the opposed beveled edges lying parallel to the direction of shear mode vibration of said crystal.

6. The method of preparing piezoelectric crystals for vibration in the thickness shear mode which includes the steps of adjusting an AT cut crystal blank to predetermined thickness so that it vibrates in the shear mode at a corresponding desired frequency, adjusting the lateral dimensions of said blank so that the crystal would tend to vibrate in flexure at said frequency with an even order of vibration, beveling the edges of the crystal to substantially the nodal plane to inhibit even order flexural vibration at said frequency and then mounting said crystal for oscillation by gripping the crystal at its nodal plane.

7. The method of preparing piezoelectric crystals for vibration in the thickness shear mode at a predetermined frequency which includes the steps of adjusting a lateral dimension of said blank so that the crystal would tend naturally to vibrate in flexure at said frequency with an even order of vibration, and then beveling the edges of the crystal toward the nodal plane not only to permit gripping at the nodal plane but to reduce the effective lateral dimension of the crystal, said beveling being carried to such a degree that the effective lateral dimension lies between the adjusted lateral dimension and the dimension corresponding to the next lowest even order of vibration.

8. The method of preparing piezoelectric crystals for vibration in the thickness shear mode which includes the steps of adjusting the crystal blank to predetermined thickness so that it vibrates in the shear mode at a corresponding frequency, adjusting the lateral dimensions of said blank so that the crystal may vibrate in

flexure at said frequency with an even order of vibration, beveling the edges of the crystal to inhibit vibration in flexure at said frequency and then gripping said crystal for oscillation by engaging opposed beveled edges to apply gripping pressure generally along the Z axis of said crystal.

9. The method of preparing piezoelectric crystals for vibration in the thickness shear mode at a desired nominal frequency which includes the steps of adjusting the X dimension of the crystal blank so that the crystal tends to vibrate in X flexure at said frequency with an even order of vibration, adjusting the dimension of said blank so that the crystal tends to vibrate in the shear mode at said frequency, and then beveling the edges of the crystal symmetrically about the nodal plane with an included angle of approximately 30 degrees to inhibit both X flexure and Z shear vibration at said nominal frequency.

10. The method of preparing piezoelectric crystals for vibration at a desired nominal frequency which is a function of the thickness of the crystal which includes the steps of adjusting the length of the crystal blank so that the crystal tends to vibrate at said frequency in a mode which is dependent upon the length of the crystal, adjusting the width of the crystal blank so that the crystal tends to vibrate at said frequency in a mode which is dependent upon the width of the crystal, and then beveling the entire periphery of the crystal to decrease the effective length and width thereby to inhibit vibration in said modes at said nominal frequency.

11. The method of preparing piezoelectric crystals for vibration in the thickness shear mode at a desired nominal frequency which depends upon the thickness of the crystal which includes the steps of adjusting the dimension of the crystal blank along the X axis so that the crystal tends to vibrate in X flexure at said frequency with a high even order of vibration, adjusting the dimension of the crystal blank lying generally along the Z axis so that the crystal tends to vibrate in Z shear, and then beveling the periphery of the crystal to the nodal plane, the included angle of the beveling being such as to inhibit vibration at said desired frequency in X flexure and Z shear at said nominal frequency.

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