Feb. 11, 1941. F. W. SMALTS 2,231,483

ART OF CUTTING AND MOUNTING PIEZOELECTRIC CRYSTAL ELEMENTS

Filed May 31, 1939

Fig. 1.

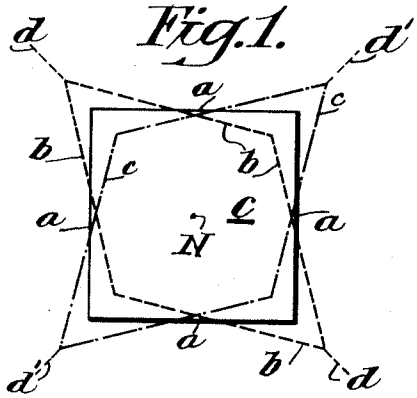


Fig. 3.

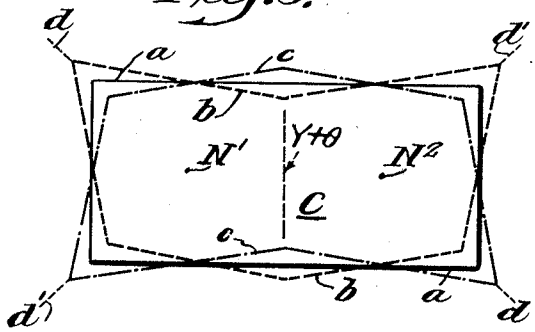


Fig. 2

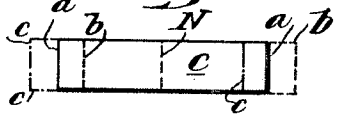


Fig. 4.

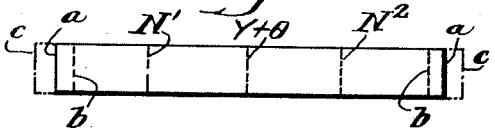


Fig. 5.

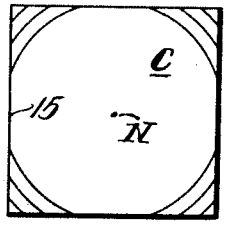


Fig. 6.

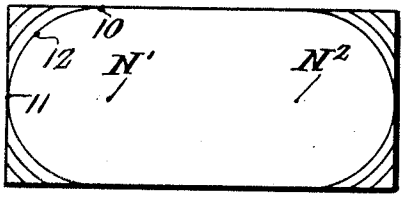


Fig. 8.

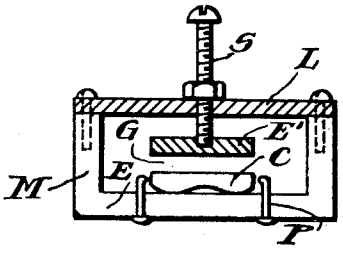
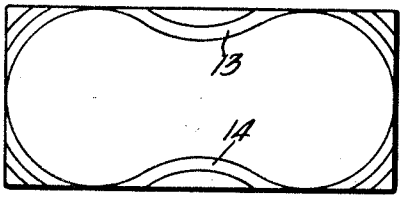


Fig. 7.



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Patented Feb. 11, 1941 2,231,483

UNITED STATES PATENT OFFICE

2,231,483

ART OF CUTTING AND MOUNTING PIEZOELECTRIC CRYSTAL ELEMENTS

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Application May 31, 1939, Serial No. 276,667

9 Claims. (Cl. 171—327)

My present invention relates to the art of cutting and mounting piezoelectric crystal elements and has for its principal object to minimize the damping effect which necessarily obtains due to friction between the crystal and the electrode surface upon which it is mounted.

It is known to those skilled in the art to which my invention appertains that there are lines or axes of zero movement in piezoelectric crystals and that when a crystal element is clamped along such an axis it will be damped to a lesser extent than it would be if the clamping force were to be applied at some other point.

Some crystal elements, depending upon their orientation, are so sensitive in their oscillating performance that even when the clamping force is applied along a nodal axis the amplitude of oscillation will be so highly damped as to seriously impair the usefulness of the crystal. In such cases, and indeed wherever the greatest possible amplitude of vibration is desired, it has been the practice to employ a simple air gap holder wherein the crystal is simply laid without any clamping force upon a surface provided with pins or other protuberances which serve to limit the range of movement of the crystal thereover.

As disclosed in U. S. Patent No. 2,139,998 to Herbert A. Clarke, it is important that the retaining pins employed in air gap holders be so positioned with respect to the crystal that they will in no wise inhibit its normal oscillatory movement. Thus, as disclosed in the said patent, where the crystal element is of a type wherein the maximum oscillatory movement is along its diagonals, it is important that the retaining pins be disposed remote from the corners so that the crystal is free to alternately expand and contract along its said diagonals. Clarke further points out that if the crystal is permitted to vibrate against a straight pin sufficient friction may be created to inhibit maximum performance; he accordingly recommends the use of inverted L-shape retaining members having rounded ends which are directed inwardly toward the center of each minor face of the crystal element.

My present invention is predicated upon an appreciation of the fact that the prior art, as exemplified by the Clarke patent, recognizes but one factor as inhibiting maximum amplitude of vibration of crystals mounted in so-called air gap holders (i. e. the friction occasioned by the crystal vibrating in contact with its retaining members) whereas there is a second factor which presents a different and important problem which, as far as I am aware, has not heretofore been successfully solved. This "second," but by no means less important problem is that of minimizing the damping effect due to friction between the crystal and the electrode or electrodes upon which it is supported.

It would appear, theoretically at least, that this problem is susceptible of two solutions, to wit: (1) by so shaping the electrode upon which the crystal rests that it will contact the crystal only adjacent its nodal axis or area of minimum activity, and (2) by so shaping the crystal that it will contact the electrode only adjacent its said area of minimum activity.

The first mentioned method, however, is objectionable since, if the crystal is mounted without clamping pressure upon an electrode which is provided with one or more risers, it will move laterally thereover so that at one moment the crystal may be supported at a point of minimum activity and at another moment at a point of maximum activity. Obviously, if the crystal is clamped along its edges to prevent such lateral movement the advantage of reduced friction adjacent its bottom surface is lost. Further, if the crystal can tilt or rock on its support then changes in capacitance may affect the stability of oscillation of the crystal. Even if the above difficulties did not obtain, the objection remains that it would be necessary to machine the electrodes in innumerable sizes and patterns to accommodate the infinite variety of crystal types, shapes and sizes.

On the other hand, in attempting to achieve the objects of the invention by shaping the crystal one encounters not only the difficulty of maintaining the frequency which is characteristic of the original blank, but also the fact that indiscriminate removal of the crystalline structure adjacent the several zones of maximum activity may result in an element which will either refuse to oscillate, or one which will oscillate less vigorously than the uniformly shaped crystals of the prior art.

The manner in which these last mentioned difficulties are overcome will be apparent and the invention itself will be best understood by reference to the following specification and to the accompanying drawing, wherein

Figure 1 is a diagrammatic plan view and Figure 2 is a diagrammatic side elevational view of a square "V-cut contour-mode" piezoelectric quartz crystal, illustrating the manner in which such crystals vibrate;

Figure 3 is a diagrammatic plan view and Figure 4 is a diagrammatic side elevational view

of an oblong "V-cut contour-mode" crystal illustrating the manner in which such oblong crystals vibrate;

Figure 5 is a plan view of the bottom surface of the square quartz piezoelectric element of Figs. 1 and 2 when finished in accordance with the principle of the invention;

Figures 6 and 7 show the invention as applied to oblong crystal elements; and

Figure 8 is an elevational view of the crystal of Fig. 7 mounted in a simple air gap type of holder.

While my invention will be described as applied to contour-mode crystal elements which have been orientated in the manner generally described in British Patent 457,342 (1936), pages 10 to 12, (U. S. application Serial No. 71,388, filed March 28, 1936, to Baldwin and Bokovoy) and more specifically described in U. S. Patents 2,111,383 and 2,111,384 to Bokovoy, it is to be understood that the invention is not necessarily limited to the so-called "V-cut" crystals there described; the disclosure in this respect being merely illustrative for purposes of explaining the inventive concept.

In carrying my invention into effect it is first necessary to determine the zones or areas of maximum and minimum activity of the crystal. This may be done simply by sprinkling the crystal, or an electrode upon which the crystal is mounted, with lycopodium powder, then vibrating the crystal, and finally observing the pattern which the powder assumes as a result of the crystal vibration. As is well known in the art, the areas of the crystal upon which the lycopodium powder is concentrated are zones of minimum activity and, conversely, the areas of least powder concentration define the zones of maximum activity. In cases where the powder is projected over the edges of the crystal, opposite results are obtained.

It has been found, in the case of the contour-mode crystals described in the above-identified disclosures, that there are zones of maximum activity adjacent the corners of both square and oblong crystal elements. The manner in which such crystals vibrate is indicated in Figs. 1 to 4, inclusive.

Referring particularly to Figs. 1 and 2 wherein the solid lines *a* define a major or electrode face of a square V-cut contour mode crystal, C, when it is in the "idle" position, i. e. either when it is not in use or at a moment of zero displacement. During one-half of a complete cycle of vibration the crystal expands along one diagonal, say diagonal *d*, and a complementary contraction takes place along the other diagonal, *d'*. During the next half cycle the crystal contracts as measured along *d* and expands as measured along *d'*. In Fig. 1 the shape of the crystal at the maximum of its expanding movement along *d* is indicated by the broken lines *b*, and the shape of the crystal at the maximum of its expanding movement along diagonal *d'* is shown by the dot-and-dash boundary lines *a*. Similar lines in Fig. 2 represent this movement as viewed along a minor surface of the crystal. There is a "line of zero movement" or "nodal axis" N which extends through the thickness or "$Y+\theta$" dimension from opposite mid-points on the major faces of the crystal.

It will be apparent from an inspection of Figs. 3 and 4 that oblong crystals of similar orientation vibrate in much the same manner as the square crystal of Figs. 1 and 2, that is to say, there is a zone of maximum activity adjacent each of its four corners. In this case, however, there are also zones of maximum activity substantially midway between the adjacent corners. Considering this oblong crystal C to be made up of two halves which are separated by the line Y—Z in Fig. 3 then each half section has a nodal axis, N^1, N^2, respectively. These two axes each have zero motion with respect to their respective crystal sections, but may move slightly with respect to each other. Thus, since this oblong crystal as a whole has no centrally located point which exhibits zero activity it is necessary to make use of the areas immediately surrounding the points (N^1 N^2) of minimum activity in mounting the crystal. In order to accomplish this the bottom surface of the crystal is cut away at its zones of maximum piezoelectric activity so that the crystal rests solely on its areas of minimum activity.

If the crystal blank is cut to the dimensions required to achieve a desired frequency prior to being finished in accordance with the principle of my invention then the depth of the cut away portions should be limited to a few (say, one to five) one-hundred-thousandths of an inch so that there will be no appreciable alteration in the desired frequency. It is of course possible, however, to start with a blank having dimensions slightly greater than that required to achieve the desired frequency and then, after the blank has been treated in accordance with my invention, its dimensions may be further reduced by grinding the top surface or side edges of the crystal as determined by the particular type or orientation of the blank.

The cutting away of the zones of maximum activity may be accomplished by lapping the blank on a surface on which an abrasive has been spread, in which case pressure may be applied manually to the top of the blank at its zones of maximum activity. In the case of the oblong crystal of Figs. 3, 4, 6 and 7 it is sometimes sufficient to cut away only the corner zones as indicated in Fig. 6 although, usually, optimum performance is obtained when the intermediate edge zones are also reduced in thickness, as shown in Fig. 7.

As a result of my experience in cutting and operating numerous crystal elements in accordance with my invention I have formulated certain standards which when carefully followed ensure maximum amplitude of vibration. By way of example, I have determined that it is desirable to limit the dimensions of a given cut away portion of the crystal and to make the corresponding cut away areas of duplicate contour. Uniformity in this respect can be simply achieved by inspecting the blanks between successive stages of the grinding operation by means of monochromatic light projected upon an optically flat glass plate which is laid upon the cut away face of the blank. In testing by this method it is merely necessary to count the number of Newtonian rings which appear at one cut away area and to so grind the other areas of maximum activity that the same number of rings appear at each of said areas.

In connection with the above it is preferable in the case of both square and oblong crystals to limit the number of Newtonian rings adjacent the cut away corners to three, as indicated by the curved lines in Figs. 5, 6 and 7. Another specific rule which may be followed to advantage in the case of the oblong crystals of Figs. 6 and 7 is this: the distance from the point 10,

where the innermost Newtonian ring (or arc) becomes tangent to the long side of the crystal, to the nearest end should preferably not be less than $L/8$ or greater than $L/4$, and the distance from the point 11 where the said Newtonian ring becomes tangent to the end of the crystal to the nearest long edge should preferably be not less than $W/4$ or greater than $W/2$. As previously indicated the space between the point 12 and the corner of the crystal should preferably show not less than one nor more than three Newtonian rings.

When the crystal is finished in the manner shown in Fig. 7 the pattern of the central cut away areas 13, 14 should preferably exhibit no more than two Newtonian rings and the area embraced by these cut away portions should preferably be no greater than $W/4$.

In the case of the square crystal of Fig. 5, the innermost of the Newtonian rings should preferably intersect a side edge of the crystal at a point 15 no further removed from the midpoint of that side edge than one-half the distance between said midpoint and the corner adjacent which said Newtonian ring appears.

I have found that as a general rule the activity of the crystal will increase with the degree of polish, not only on the bottom face which contacts the electrode but also on the other faces as well. Best results have been achieved when the bottom surface was polished to a high degree with American Optical Company polishing compound M–310 (rouge). The other surfaces should preferably be finished with an abrasive not coarser than M–304, care being taken to avoid allowing the abrasive to dry on and become embedded in the surface of the crystal. Other manufacturing precautions that should be taken are listed below:

(1) The two electrode faces of the crystal should be kept substantially parallel. I have noted that if the deviation from parallelism is in the direction of the longer dimensions of an oblong crystal its activity may be appreciably impaired. If, however, the departure from parallelism occurs in the direction of the shorter dimensions, the decrease in activity is hardly noticeable when a gravity top plate is employed as the second electrode but becomes quite serious when the crystal is mounted in a fixed air gap holder.

(2) Care should be taken in finishing the edges and corners of the blank. It is preferable that all of the horizontal and vertical edges be rounded, not beveled, so as to produce a smooth junction between adjacent surfaces.

(3) The bottom electrode upon which the crystal vibrates should be flat. The departure from optical flatness should be very small, being zero in the direction of concavity and for best results not deviating more than a few one-hundred-thousands of an inch toward convexity. To keep the friction between the crystal and its electrode at a minimum, the electrode should be given a finish approaching what is known as a "mirror finish."

In Fig. 8 the crystal of Fig. 7 is shown mounted in a simple airgap holder comprising a metal casing M which is provided with an insulating cover L and a flat bottom inner surface which surface E constitutes an electrode supporting surface for the crystal C. As previously described, the crystalline corner and intermediate edge zones of maximum piezoelectric activity have been cut away so that the crystal contacts the electrode surface at its areas of minimum activity whereby the friction and hence the damping which is incident to the operation of the crystal is minimized. The second or top electrode shown at E^1 is preferably circular and may be secured to a screw S to permit of various adjustments of the air-gap G which exists between its surface and the top face of the crystal. The pins P which are provided to limit the range of movement of the crystal over the surface of E are preferably mounted remote from the corners of the crystal in the manner set forth in the previously identified patent to Clarke.

Various modifications of my invention will suggest themselves to those skilled in the art. It is to be understood therefore that the foregoing is to be interpreted as illustrative and not in a limiting sense except as required by the prior art and by the spirit of the appended claims.

What I claim is:

1. A piezoelectric crystal element having bottom and top faces each embracing zones of maximum and minimum activity, said element having its bottom surface partially cut away adjacent a zone of maximum piezoelectric activity whereby to reduce the friction incident to the operation of said crystal when it is mounted with its said bottom face in contact with a flat supporting surface.

2. The invention as set forth in claim 1 wherein the reduction in thickness of said cut away portion is of the order of a few one-hundred-thousandths of an inch.

3. A piezoelectric crystal element comprising substantially rectangular top and bottom faces each of which has corner zones of maximum piezoelectric activity, said element having its bottom face cut away adjacent its said corner zones whereby to reduce the friction incident to the operation of said crystal when it is mounted with its said bottom face in contact with a flat supporting surface.

4. The invention as set forth in claim 3 and wherein each of said cut away corner zones exhibit the same number of Newtonian rings.

5. A piezoelectric crystal element comprising oblong top and bottom faces each of which has corner zones and intermediate edge zones of maximum piezoelectric activity, said element having its bottom face partially cut away adjacent its said corner and intermediate zones whereby to reduce the friction incident to the operation of said crystal when it is mounted with its said bottom face in contact with a flat supporting surface.

6. A piezoelectric element comprising a substantially square crystalline body having a central nodal axis which extends between the top and bottom faces of said body, said faces having corner zones of maximum activity, and having its said bottom face partially cut away adjacent its said corner zones, said cut away zones exhibiting Newtonian rings at different radial distances from said nodal axis, the innermost of said Newtonian rings intersecting a side edge of said crystal at a point no farther removed from the midpoint of said side edge than one-half the distance between said midpoint and the corner adjacent which said Newtonian rings appear.

7. A piezoelectric element comprising an oblong crystal having at least two nodal axes which extend between the top and bottom faces of said crystal, said faces having corner zones of maximum piezoelectric activity and having its bottom face partially cut away adjacent its said corner zones, said cut away zones exhibiting Newtonian

rings at differential radial distances from the nearer of said nodal axes, the innermost of said Newtonian rings intersecting a long edge of said crystal at a point no nearer its cut away corner than one-eighth of the dimension of said long edge and no farther from said corner than one-quarter of said dimension.

8. The invention as set forth in claim 7 wherein said innermost Newtonian ring intersects a short edge of said oblong crystal at a point no nearer its said cut away corner than one-quarter of the dimension of said short edge and no farther from said corner than one-half of said dimension.

9. In combination, a piezoelectric element and a substantially flat electrode upon which said element rests, the bottom face of said crystal embracing zones of maximum and minimum piezoelectric activity and having a portion of its said bottom face cut away adjacent a zone of maximum activity whereby to reduce the friction between said face and said flat electrode, and a second electrode supported in spaced relation with respect to the top surface of said crystal element.

FRANKLIN W. SMALTS.