

PATENT SPECIFICATION

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(54) FLEXURAL QUARTZ CRYSTAL VIBRATOR

(71) We, KABUSHIKI KAISHA SUWA SEIKOSHA, a Japanese body corporate, of 3-4, 4-chome, Ginza, Chuo-ku, Tokyo, Japan, do hereby declare the invention, for which we pray that a patent may be granted to us, and the method by which it is to be performed, to be particularly described in and by the following statement:—

This invention relates to flexural quartz crystal vibrators e.g. for timepieces such as wrist watches.

In recent years, the technology of electronic wrist watches has developed considerably and quartz crystal wrist watches are now being manufactured. Such quartz crystal wrist watches have quartz crystal vibrators as their time standard. Conventional quartz crystal vibrators utilise the flexural mode of vibration and are of the free-free-bar type or the tuning fork type. Conventional vibrators are cut from natural quartz crystal material using a diamond wheel cutter or a supersonic or ultrasonic technique. Recently, chemical techniques, e.g. photo-etching techniques, have been used in the manufacture of vibrators such as disclosed in Japanese Patent Publication No. 48-3575.

According to one aspect of the present invention there is provided a flexural quartz crystal vibrator having electrodes on only one face thereof.

The vibrator may be made from a plate of quartz crystal material which is obtained by firstly rotating a X-cut plate about X-axis through an angle between 0° and 10° and by secondly rotating the X-cut plate about an imaginary axis, generated by the Y-axis as a result of the first rotation, through an angle between 70° and 90°.

Preferably the vibrator is 0.5 millimetres or less in thickness.

The vibrator may be formed from a or the plate of quartz crystal material by a photo-etching technique.

The vibrator is optionally provided with a metallic film on a portion thereof which portion, in operation of the vibrator, does

not vibrate, the said film being provided to assist in securing the vibrator to a mounting structure.

In the preferred embodiment the vibrator is a tuning fork vibrator.

According to a further aspect of the present invention there is provided a timepiece including a flexural quartz crystal vibrator as recited above.

The invention is illustrated, merely by way of example, in the accompanying drawings, in which:—

Figure 1 is a perspective view of a conventional flexural quartz crystal vibrator of the tuning fork type;

Figure 2 is a cross-section taken on the line 2—2 of the vibrator of Figure 1;

Figure 3 is a perspective view of another type of conventional flexural quartz crystal vibrator of the tuning fork type;

Figure 4 is a cross-section taken on the line 4—4 of the vibrator of Figure 3;

Figure 5 is a perspective view of a flexural quartz crystal vibrator according to the present invention of the tuning fork type;

Figure 6 is a cross-section taken on the line 6—6 of the vibrator of Figure 5;

Figure 7, consisting of Figures 7(a) and 7(b) shows, in perspective, another embodiment of a flexural quartz crystal vibrator according to the present invention; and

Figure 8, consisting of Figures 8(a) and 8(b) shows, in perspective, a further embodiment of a flexural quartz crystal vibrator according to the present invention.

Figure 1 is a perspective view of a conventional flexural quartz crystal vibrator of the tuning fork type generally designated by the reference numeral 1. Figure 2 is a cross-section of the vibrator 1 taken on the line 2—2. The vibrator has two electrodes 2, 3 which are provided on all the faces thereof except the end faces. The electrical, mechanical and optical axis of the quartz crystal material of the vibrator are indicated by axis X, Y, Z respectively. In Figure 2, an angle α shown in Figure 1 is

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0° for the sake of simplicity. The vibrator is made from a Z-cut plate of quartz crystal material rotated through an angle α about the X-axis the angle α being between 0° and 10° and usually about 5°.

If a positive voltage is applied to the electrode 3 and a negative voltage is applied to the electrode 2, the electric field shown by the arrows in Figure 2 are produced. The components of the electric fields in the direction of the X-axis causes the quartz crystal material of the vibrator to become strained. Considering one of the tines of the vibrator, the component of the electric fields in the direction of the X-axis (as seen in Figure 2) of the axis of the tine is in the opposite direction to the component of the electric fields in the direction of the X-axis to the right (again as seen in Figure 2) of the axis of the tine. Thus, one side of the tine is in tension and the other side of the tine is in compression. Thus symmetrical flexural vibration of the vibrator 1 will result when an alternating current is applied between the electrodes 2, 3.

The advantage of a vibrator of this type is that it can be easily connected to an oscillating circuit (not shown) because its dynamic impedance is low and that it can contribute to high precision time keeping when it is used in a wrist watch because the point of zero temperature coefficient of the temperature-resonance frequency characteristics is near to room temperature. On the other hand, a vibrator of this type has the following disadvantage. As clearly shown in Figure 1, electrodes must be provided on all except the end faces and these electrodes are of a complex shape making manufacture difficult and making it impossible to reduce the thickness of the vibrator in the direction of the Z-axis below 0.5 millimetres. As a result, when a flat plate of quartz crystal material is to be formed into the shape of a tuning fork, this must be done using a diamond wheel cutter or a supersonic or ultrasonic technique and a photo-etching technique cannot be used. The techniques that can be used to form this type of conventional vibrator impose limits upon its miniaturisation.

Figure 3 is a perspective view of a NT-cut conventional flexural quartz crystal vibrator 4 of the tuning fork type, formed by a conventional chemical technique. Figure 4 is a cross-section of the vibrator of Figure 3 taken on the line 4—4 of Figure 3. In Figure 4 the thickness of the vibrator has been exaggerated relative to its width and an angle α shown in Figure 3 is set at 0° for the sake of simplicity.

A pair of spaced apart electrodes 5, 6 are disposed on opposite faces of the vibrator. The electrodes 5 are electrically connected

as also are the electrodes 6. As in Figures 1 and 2, the electrical, mechanical and optical axes of the quartz crystal material of the vibrator are indicated by the axes X, Y, Z respectively. The vibrator 4 is formed from a plate obtained by rotating a X-cut plate of quartz crystal material through angle α to the X-axis and through an angle β to the Y-axis which is an imaginary Y-axis generated by the rotation through the angle α . The angle α is usually between 0° and 10° and the angle β is usually between 50° and 70° or between -50° and -70° (i.e. between 290° and 310°). As is clearly shown in Figures 3 and 4 a vibrator of this type has electrodes on only one pair of opposite faces and so it can be formed from a relatively thin plate of quartz crystal material. Accordingly, a vibrator of this type has the advantage that it can be formed by a chemical technique, e.g. a photo-etching technique, resulting in a relatively small sized vibrator and in particular a relatively thin vibrator which can be mass-produced. On the other hand, a vibrator of this type has the following disadvantage. If positive and negative voltages are applied to the electrodes 5, 6 respectively, electric fields indicated by reference numerals 7, 8 in Figure 4 are produced within the quartz crystal material. Components 9, 10 of the electric fields 7, 8 respectively in the direction of the X-axis cause strain of the quartz crystal material. An alternating current applied to the electrodes 5, 6 will cause the vibrator to perform symmetrical flexural vibrations for the same reasons as described with reference to Figures 1 and 2. The components 9, 10 however, are extremely small compared to the electric fields 7, 8 since the former is related to the latter by the cosine of the angle β . Consequently, the vibrator has a relatively high dynamic impedance. This dynamic impedance has been found theoretically and practically to be inversely proportional to $\cos^2\beta$. When β is 70° the dynamic impedance increase 8.5 times compared to the case where β equals 0°. When β equals 75° the dynamic impedance increases 15 times compared to the case where β equals 0° and when β equals 90° the dynamic impedance is infinity. As the point of zero temperature coefficient of the temperature-resonance frequency characteristics increases with increase in the angle β , the point of zero temperature coefficient is relatively low because the angle β is generally 70° since otherwise the dynamic impedance will become unacceptably high. Thus a vibrator of this type is unsuitable for timepieces because its dynamic impedance is too high and the flexion point temperature is too low even though the vibrator is advantageous

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from the point of view of size and the fact that it may be mass-produced.

As mentioned above in detail, the conventional vibrator of Figures 1 and 2 has the advantage that its dynamic impedance is relatively low and the flexion point temperature is relatively high but the disadvantage that it is difficult to miniaturise especially to make thin and it cannot be made by chemical technique. On the other hand, the conventional vibrator of Figures 3 and 4 has the advantage that it can be made relatively thin easily and that it can be made by a chemical technique but the disadvantage that its dynamic impedance is relatively high and its point of zero temperature coefficient is relatively low. Conventionally the two types of vibrator were considered to be different since the methods of applying the electric fields are dissimilar. But in view of the similarity in the angles α and β , the two types of vibrator may be regarded as one. That is to say, the angle α of both types of vibrator is between 0° and 10° and for a conventional vibrator of the type illustrated in Figures 1 and 2 the angle β is 90° whereas the angle β for a conventional vibrator of the type illustrated in Figures 3 and 4 is between 50° and 70° or between -50° and -70° .

The following embodiments of the present invention have the advantage of the conventional vibrators as described above with their disadvantages.

Figure 5 is a perspective view of one embodiment of a flexural quartz crystal vibrator 11 according to the present invention and Figure 6 is a cross-section thereof taken on the line 6—6 of Figure 5. In Figure 6 an angle α shown in Figure 5 is set at 0° for the sake of simplicity. Two spaced-apart electrodes 12, 13 are disposed on one and the same face of the vibrator. No electrodes are provided on the opposite face of the vibrator although that face may have a deposited metal film (not shown) thereon to secure or assist in securing the vibrator to a mounting structure (not shown).

The electrical, mechanical and optical axes of the quartz crystal material of the vibrator are indicated by the axes X, Y, Z respectively. The vibrator is formed from a plate obtained by rotating a X-cut plate of quartz crystal material through an angle α about the X-axis and then through an angle γ through the Y'-axis which is an imaginary axis generated by the Y-axis on rotation to the angle α . Z' is an imaginary Z-axis generated by the rotation through the angle α . The angle α is between 0° and 10° and the angle γ is between 70° and 90° or between -70° and -90° i.e. between 290°

and 270° in which range advantageous temperature characteristics are obtained.

If positive and negative voltages are applied to the electrodes 12, 13 respectively, the electric fields indicated by the arrows in Figure 6 are produced within the quartz crystal material. Thus strains are produced in each tine of the vibrator and if an alternating current is applied between the electrodes, the vibrator will perform symmetrical flexural vibrations. The components of the electric field in the direction of the X-axis are greater than in the conventional vibrator of Figures 4 and 5 so that the vibrator of Figure 6 has a lower dynamic impedance than the vibrator of Figures 4 and 5. Since electrodes are provided on only one face of the vibrator, the vibrator may have a thickness of 0.5 millimetres or less in the direction of the Z-axis. Therefore, a chemical technique, e.g. a photo-etching technique, can be used in the manufacture of the vibrator of Figure 6 and consequently its size can be reduced still further.

One method of manufacturing the vibrator shown in Figures 5 and 6 is as follows. First a chrome layer is deposited on the front and rear faces of a relatively thin plate of quartz crystal material and then a gold layer is deposited on the chrome layer, the chrome layer being provided to reinforce the connection between the quartz crystal material and the gold layer. A photo-resist is applied to the gold layer and exposed to light through a photomask so that the photo-resist which remains has the external shape of the vibrator. The plate is then steeped in an etching liquid which eats into the parts of both the chrome layer and the gold layer not covered by the photo-resist. Thus the plate now has on its front and on its rear faces a chrome layer and a superposed gold layer having the external shape of the vibrator. The plate is then steeped in a solution of hydrofluoric acid which eats into the quartz crystal material not covered by the chrome and gold layers which serve as an etching mask: the result is that the plate now has the shape of a tuning fork. The vibrator is completed by forming the electrodes from the chrome and gold layers on the front face of the vibrator.

If this technique is applied to the conventional vibrator shown in Figures 1 and 2, it will be necessary also to deposit chrome and gold layers on the opposed faces of the tines after the plate has been etched into the shape of a tuning fork, and this is found to be impractical. On the other hand, since the vibrator according to the present invention is shown in Figures 5 and 6 as electrodes on only one face, the

technique described above is well suited to its manufacture.

Figure 7, consisting of Figures 7(a) and 7(b), shows, in perspective, another embodiment of a quartz crystal vibrator 14 according to the present invention, Figure 7(a) being a front view thereof and Figures 7(b) being a rear view thereof. Two pairs of electrodes 15, 16 are formed on the front face of the vibrator. The electrodes of each pair of electrodes 15 are electrically connected together by an electrical connection and the electrodes of each pair of electrodes 16 are electrically connected together. A portion 19 of each electrode is provided to enable adjustment of the resonant frequency of the vibrator. On the rear face of the vibrator a metallic film 20 is deposited to facilitate securing of the vibrator to mounting structure (not shown). The vibrator 14 is vibrated using the same principle as described above in relation to the vibrator of Figures 5 and 6. The resonance frequency of the vibrator is adjusted by irradiating the portions 19 of each electrode 15 with a laser beam to evaporate part of the metal thereof. The electrodes 15, 16 have enlarged portions 17, 18 respectively to which lead wires (not shown) are connected to connect the vibrator to external circuitry (not shown). Four such enlarged portions are provided to reduce the possibility that the vibrator should be inoperable due to a cut in one of the electrical connections between the electrodes of each pair being formed during manufacture of the vibrator. The vibrator is formed by a photo-etching technique and, if there is a small scratch on the face of the quartz crystal material this could result in such a cut being produced in one of the electrical connections between the electrodes of each pair.

As mentioned above the vibrator may be secured to the mounting structure, e.g. a block holder, by way of the metallic film 20 which is formed simultaneously with the electrodes by the photo-etching technique. The metallic film 20 is provided on the base portion of the vibrator and since this base portion does not vibrate with the times, the metallic film 20 never affects the electric fields in the quartz crystal material although it does tend to increase the inter-electrode capacitance, etc.

Figure 8, consisting of Figures 8(a) and 8(b) shows, in perspective, another embodiment of a flexural quartz crystal vibrator 21 according to the present invention, Figure 8(a) being a front view thereof and Figure 8(b) being a rear view thereof. Three electrodes 22, 23, 24 are provided on the front face of one of the tines of the vibrator and electrodes 25, 26,

27 are provided on the front face of the other tine. The electrodes 22 to 27 have respective enlarged portions 28 to 33 to which lead wires (not shown) are connected to connect the vibrator to external circuitry. Each tine has a portion 34 to enable adjustment of the resonant frequency of the vibrator. On the rear face of the vibrator there is a metallic film 35 to facilitate securing of the vibrator to mounting structure (not shown). The portion 34 and the metallic film 35 are similar to the portion 19 and the metallic film 20 of the vibrator of Figure 7.

The vibrator may be made as a two-terminal vibrator by electrically connecting the electrodes 22, 24, 25, 27 together as a set and by electrically connecting the terminals 23, 26 together as a set and applying alternating current between the two sets.

Alternatively, the vibrator may be made a three-terminal vibrator by electrically connecting electrodes 22, 24, 25, 27 to ground and applying an alternating current to the electrodes 23, 26.

Again the vibrator may be made a three-terminal vibrator by electrically connecting electrodes 22, 24 and 26 to ground, electrically connecting electrodes 25, 27 together as a set and applying alternating current between this set and the electrode 23.

In a further alternative, the vibrator may be made a three-terminal vibrator by electrically connecting electrodes 23, 26 to ground, connecting the electrode 22 as a driving electrode and electrically connecting the electrodes 24, 25, 27 together as an output terminal.

It will thus be appreciated that the electrodes 22 to 27 may be connected in any desired manner to suit a particular application of the vibrator.

The present invention can be applied to a free-free-bar flexural quartz crystal vibrator or any other type of flexural quartz crystal vibrator and not merely flexural quartz crystal vibrators of the tuning fork type such as those described above.

Quartz crystal vibrators similar to those described above, are also described and claimed in the following co-pending Applications filed with the present Application:

Application No. 16169/74 (Serial No. 1460636),

Application No. 16202/74 (Serial No. 1460639), and

Application No. 16170/74 (Serial No. 1460638).

Parts of the disclosures of these Applications are incorporated herein by way of reference.

Flexural crystal vibrators according to

the present invention may, if desired, be made from a plate of quartz crystal material in a similar manner to that described in connection with the conventional vibrator of Figures 3 and 4.

WHAT WE CLAIM IS:—

1. A flexural quartz crystal vibrator having electrodes on only one face thereof.

2. A vibrator as claimed in Claim 1 made from a plate of quartz crystal material which is obtained by firstly rotating a X-cut plate about the X-axis through an angle between 0° and 10° and by secondly rotating the X-cut plate about an imaginary axis, generated by the Y-axis as a result of the first rotation, through an angle between 70° and 90°.

3. A vibrator as claimed in Claim 1 which is 0.5 millimetres or less in thickness.

4. A vibrator as claimed in any preceding claim formed from a or the plate of quartz crystal material by a photo-etching technique.

5. A vibrator as claimed in any preceding claim provided with a metallic film on a portion thereof which portion, in operation of the vibrator, does not vibrate, the said film being provided to assist in securing the vibrator to a mounting structure.

6. A vibrator as claimed in any preceding claims in which the vibrator is a tuning fork vibrator.

7. A flexural quartz crystal vibrator substantially as herein described with reference to and as shown in Figures 5 to 8 of the accompanying drawings.

8. A timepiece including a vibrator as claimed in any preceding claim.

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the present invention may, if desired, be made from a plate of quartz crystal material in a similar manner to that described in connection with the conventional vibrator of Figures 3 and 4.

WHAT WE CLAIM IS:—

1. A flexural quartz crystal vibrator having electrodes on only one face thereof.

2. A vibrator as claimed in Claim 1 made from a plate of quartz crystal material which is obtained by firstly rotating a X-cut plate about the X-axis through an angle between 0° and 10° and by secondly rotating the X-cut plate about an imaginary axis, generated by the Y-axis as a result of the first rotation, through an angle between 70° and 90°.

3. A vibrator as claimed in Claim 1 which is 0.5 millimetres or less in thickness.

4. A vibrator as claimed in any preceding claim formed from a or the plate of quartz crystal material by a photo-etching technique.

5. A vibrator as claimed in any preceding claim provided with a metallic film on a portion thereof which portion, in operation of the vibrator, does not vibrate, the said film being provided to assist in securing the vibrator to a mounting structure.

6. A vibrator as claimed in any preceding claims in which the vibrator is a tuning fork vibrator.

7. A flexural quartz crystal vibrator substantially as herein described with reference to and as shown in Figures 5 to 8 of the accompanying drawings.

8. A timepiece including a vibrator as claimed in any preceding claim.

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