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(54) A 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 decribed in and by the following statement:—

This invention relates to flexural quartz crystal vibrators e.g. for timepiece 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 of 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 made from a plate of quartz crystal material which is 0.5 millimetres or less in thickness and which is cut in a plane obtained by firstly rotating the plane of a X-cut plate about the X-axis through an angle between 0° and 10° and by secondly rotating the plane of 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°.

The quartz crystal vibrator may have electrodes on only one surface thereof.

The quartz crystal vibrator may be 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 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 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 is a cross-section taken on the line 8—8 of the vibrator of Figure 7.

Figure 1 is a perspective view of a conventional quartz crystal vibrator of the tuning fork type and is 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 axes of the quartz crystal material of the vibrator are indicated by axes X, Y, Z respectively. In Figure 2 an angle α shown in Figure 1 is 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 fields 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 to become strained. Considering one of the tines of the vibrator, the com-

ponent of the electric fields in the direction of the X-axis to the left (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 flexion point temperature 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 quartz crystal vibrator 4 of the tuning fork type fromed 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 exagerated 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 an angle α to the X-axis and through an angle β to the Y^1-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 only has electrodes on 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 increases 8.5 times compared to the case where β equal 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 flexion point temperature of the temperature-resonance frequency characteristics increases, with increase in the angle β, the flexion point temperature is relatively low because the angle β is generally 70°, since otherwise the dynamic impedance would 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 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 its 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 a 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 flexion point temperature 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 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 advantages of the conventional vibrants as described above without their disadvantages.

Figure 5 is a perspective view of one embodiment of a flexural quartz crystal vibrator 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 to an angle α about the X-axis and then to an angle γ to the Y^1-axis which is an imaginary Y-axis generated by the Y-axis on rotation through the angle α. Z^1 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 at each tine of the vibrator and if an alternating current is applied between the electrodes, the vibrator will perform symmetrically flexural vibrations. The components of the electric fields in the direction of the X-axis are greater than in the convention 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. Furthermore, 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.

Figure 7, consisting of Figures 7(a) and 7(b), is a perspective view of another embodiment of a flexural quartz crystal vibrator 14 according to the present invention. Figure 7(a) is a front view of the vibrator and Figure 7(b) is a rear view thereof. Figure 8 is a cross-section taken on the line 8—8 of Figure 7(a). The vibrator 14 is formed in the same manner as the vibrator of Figure 5, a pair of electrodes 15, 16 being provided on its front face and electrodes 17 to 20 being provided on its rear face. This embodiment of the present invention differs from that shown in Figure 5 in that electrodes are provided on opposite faces of the vibrator, those on the rear face forming two pairs.

The electrodes 15, 17 and 20 are connected together to form a first set and the electrodes 16, 18, 19 are connected together to form a second set. When a voltage is applied across the two sets, the electric fields shown by arrows in Figure 8 are produced within the quartz crystal material, and when an alternating current is applied between the sets of electrodes, the vibrator will perform symmetrical flexural vibrations. Furthermore, as the electric fields have a larger component in the direction of the X-axis than the electric fields produced in the vibrator of Figures 5 and 6, the vibrator 14 is energised more effectively and it has a lower dynamic impedance than the vibrator of Figures 5 and 6. In the above embodiment, the electrodes 15, 17, 20 and the electrodes 16, 18, 19 are connected together to form a two terminal vibrator. However, a filter may be formed which filter consists of a driving electrode and a pair of detecting electrodes, the former being the electrodes 15, 16 and the latter being the electrodes 17, 20 and the electrodes 18, 19 respectively.

A two output filter may be formed consisting of the electrodes 15, 16 as a pair of driving electrodes, the electrodes 17, 18 as one pair of detecting electrodes, and the electrodes 19, 20 as the other pair of detecting electrodes.

It will be appreciated that the present invention can be applied to any quartz crystal vibrator of the tuning fork type and also to quartz crystal vibrators of the free-free-bar type.

Quartz crystal vibrators similar to or identical with those described above, are also described and claimed in the following copending applications filed with the present application:

Application No. 16170/74 (Serial No. 1,460,638).

Application No. 16201/74 (Serial No. 1,460,637).

Application No. 16202/74 (Serial No. 1,460,639).

The disclosures of these applications are incorporated herein by way of reference.

WHAT WE CLAIM IS:—

1. A flexural quartz crystal vibrator made from a plate of quartz crystal material which is 0.5 millimetres or less in thickness and which is cut in a plane obtained by firstly rotating the plane of a X-cut plate about the X-axis through an angle between 0° and 10° and by secondly rotating the plane of 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°.

2. A quartz crystal vibrator as claimed in claim 1 having electrodes on only one surface thereof.

3. A quartz crystal vibrator as claimed in claim 1 or 2 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.

4. A quartz crystal vibrator as claimed in any preceding claim in which the vibrator is a tuning fork vibrator.

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

6. A timepiece including a flexural quartz crystal vibrator as claimed in any preceding claim.

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Application No. 16202/74 (Serial No. 1,460,639).

The disclosures of these applications are incorporated herein by way of reference.

WHAT WE CLAIM IS:—

1. A flexural quartz crystal vibrator made from a plate of quartz crystal material which is 0.5 millimetres or less in thickness and which is cut in a plane obtained by firstly rotating the plane of a X-cut plate about the X-axis through an angle between 0° and 10° and by secondly rotating the plane of 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°.

2. A quartz crystal vibrator as claimed in claim 1 having electrodes on only one surface thereof.

3. A quartz crystal vibrator as claimed in claim 1 or 2 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.

4. A quartz crystal vibrator as claimed in any preceding claim in which the vibrator is a tuning fork vibrator.

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

6. A timepiece including a flexural quartz crystal vibrator as claimed in any preceding claim.

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