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(54) VIBRATOR UNIT

(71) We, KABUSHIKI KAISHA DAINI SEIKOSHA, a Japanese Company, of 31-1, 6-chome, Kameido, Koto-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 vibrator units.

Conventional thickness shear type piezoelectric crystal vibrators are made by a mechanical technique, e.g. machining, and so they are usually made disc-shaped. However, such a disc-shaped vibrator has relatively large dimensions which make it unsuitable for use in wrist watches.

Recently, rectangular-shaped vibrators have been developed to overcome this problem, but the energy losses in support members for the vibrator are very large. Thus if a rectangular-shaped vibrator is miniaturised, the performance is found to be inadequate. Moreover, the support members resonate or sub-vibrate with the vibrator so that the frequency-temperature characteristics are inferior.

According to the present invention there is provided a vibrator unit comprising a thickness shear type crystal vibrator having a plurality of electrodes, the vibrator being formed from a laminar plate obtained by firstly rotating a Y-cut plate through an angle between 0° and 25° about the Z axis and by secondly rotating the plate about an imaginary axis generated by the X-axis as a result of the first rotation, through an angle between −30° and −45° said electrodes being mounted on faces which are greater in size than the other faces and which are parallel to an imaginary axis generated by the Y-axis by said first and second rotations to apply an electric field in the direction of said latter imaginary axis.

The vibrator unit may include further electrodes mounted on faces which are perpendicular to the imaginary axis generated by the Y-axis by said first and second rotations.

The electrodes are preferably shaped by an etching technique.

Preferably the thickness of the vibrator in the direction of the mechanical axis is determined by a mechanical technique and thereafter the vibrator and support means are formed by an etching technique.

The vibrator unit may be formed integrally from the same piece of material as support means.

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

Figure 1 is a plan view of one form of conventional thickness shear type crystal vibrator;

Figure 2 shows a side view of a conventional vibrator unit;

Figure 3 illustrates the cutting angle of a conventional thickness shear type crystal vibrator;

Figure 4 shows the electric field direction in a conventional thickness shear type crystal vibrator;

Figure 5 illustrates the cutting angle of one embodiment of a thickness shear type crystal vibrator of a vibrator unit according to the present invention;

Figure 6 shows the electric field direction in one embodiment of a thickness shear type crystal vibrator according to the present invention;

Figure 7 illustrates a modification of the vibrator of Figures 5 and 6;

Figure 8 shows a cutting angle of another form of thickness shear type crystal vibrator

of a vibrator unit according to the present invention;

Figure 9 illustrates a thickness shear type crystal vibrator cut in the manner shown in Figure 8;

Figure 10 consists of a plan view and a side view of a yet further embodiment of a vibrator unit according to the present invention;

Figure 11 illustrates the cutting angle of a thickness shear type crystal vibrator forming part of the vibrator unit of Figure 10; and

Figure 12 illustrates the vibrator of Figure 11 in greater detail.

In Figure 1 there is illustrated a conventional thickness shear type crystal vibrator 1 carrying electrodes 2 on opposite faces thereof. The vibrator 1 is disc-shaped and has the disadvantage that it is of relatively large size. Figures 3 and 4 illustrate the vibrator of Figure 1 in greater detail.

Figure 2 illustrates a conventional modification of the vibrator 1, the modified vibrator being rectangular in shape. The vibrator of Figure 2 has the disadvantage that support members S therefor resonate or sub-vibrate and the frequency-temperature characteristics are poor. However, the vibrator of Figure 2 has the advantage over the vibrator of Figure 1 that it is of relatively small size. The support members S are relatively thin and so a vibrator unit composed of the vibrator of Figure 2 and the support members S is not particularly resistant to external shocks. In addition, the vibrator unit has to be made to a high degree of accuracy to minimise the effects of resonance or sub-vibration already discussed.

In summary, therefore, conventional vibrator units are unsatisfactory when used as time standards in wrist watches because of their size, their liability to damage as a result of external shocks, their resonance or sub-vibration problems and their relatively poor frequency-temperature characteristics.

Referring to Figures 5 and 6 there is shown one embodiment of a thickness shear type crystal vibrator of a vibrator unit according to the present invention.

The vibrator is cut from a laminar plate obtained by firstly rotating a Y-cut plate through an angle $\theta_2°$, where θ_2 is between 0° and 25°, about the Z-axis and subsequently rotating the Y-cut plate through an angle $\theta_3°$, where θ_3 is between −30° and −45°, about the X′-axis which is an imaginary axis generated, together with the Y′-axis, by the first rotation through $\theta_2°$. The second rotation generates the Z′-axis from the Z-axis and the Y″-axis from the Y′-axis. The X-axis of the material of the vibrator 1′ is the electrical axis, the Y-axis is the mechanical axis and the Z-axis is the optical axis. The vibrator 1′ has faces 1a (Figure 6) which are parallel to the Y″-axis.

Electrodes A_1, A_2, B_1, B_2 are mounted on the faces 1a. When the electrodes A_1, B_1 receive a positive potential and the electrodes A_2, B_2 receive a negative potential an electric field (shown in broken lines) which is parallel to the Y″-axis is generated within the material of the vibrator. On the other hand, when the electrodes A_1, B_1 receive a negative potential and the electrodes A_2, B_2 receive a positive potential, an electric field (shown in solid lines) which is also parallel to the Y″-axis is generated within the material of the vibrator. Thus when an alternating potential is applied to the electrodes A_1, B_1, A_2, B_2, electric fields alternating in direction and parallel to the Y″-axis are generated within the material of the vibrator to cause thickness shear vibrations.

The frequency of vibration of the vibrator 1′ is determined by the thickness in the direction of the Y″-axis. Since the thickness in the direction of the Y″-axis may be freely chosen, the vibrator 1′ may have any desired frequency of vibration.

Figure 7 shows a modification of the vibrator 1′ where, in addition to the electrodes A_1, A_2, B_1, B_2, electrodes C_1, C_2 are provided on side faces which are parallel with the Z′-axis.

The cutting angle of another form of thickness shear type crystal vibrator 10 for a vibrator unit is shown in Figure 8 and the vibrator itself is shown in Figure 9. The vibrator 10 is formed from a laminar plate obtained by rotating a Y-cut plate through $\theta_3°$, where θ_3 may be 38°, about the X-axis. The vibrator 10 has opposite faces 11a extending in the direction of the Y′-axis, and opposite faces 11b which extend in the direction of the Z′-axis, the faces 11a having larger dimensions than the faces 11b. Electrodes A_3, A_4, B_3, B_4 are formed on the faces 11a and electrodes C_3, C_4 are formed on the faces 11b. Electrodes A_3, B_3, C_3 are electrically connected together to the same potential and electrodes A_4, B_4, C_4 are electrically connected together to the same potential which is of opposite polarity to the potential applied to the electrodes A_3, B_3, C_3. The electric field generated in the material of the vibrator causes it to perform thickness shear vibrations.

The frequency of vibration of the vibrator 10 is determined by its thickness in the direction of the Y′-axis. Thus to form the vibrator 10 with a precise frequency of vibration, it is necessary to ensure that the thickness in the direction of the Y′-axis is accurately a predetermined thickness. The thickness in the direction of the Y′-axis may

be freely chosen so that the vibrator 10 has a desired frequency of vibration.

A further embodiment of a vibrator unit according to the present invention is illustrated in Figures 10 to 12. A thickness shear type crystal vibrator 21 is made from a laminar plate obtained by rotating a Y-cut plate through $\theta_5°$, where θ_5 may be between 30° and 45° and preferably about 38°, about the X-axis. The vibrator 21 has opposite faces 21a which are parallel to the Y'-axis and faces 21b which are parallel to the Z'-axis. The faces 21a have larger dimensions than the faces 21b. Electrodes A_5, A_6, B_5, B_6 are mounted on the faces 21a. When the electrodes A_5, B_5 receive a positive potential and the electrodes A_6, B_6 receive a negative potential an electric field is generated in the material of the vibrator in the direction of the Y'-axis. On the other hand, when the electrodes A_5, B_5 receive a negative potential and the electrodes A_6, B_6 receive a positive potential an electric field (shown in solid lines) which is also in the direction of the Y'-axis is generated within the material of the vibrator. Thus when an alternating potential is applied to the electrodes A_5, B_5, A_6, B_6 electric fields alternating in direction and parallel to the Y'-axis are generated within the material of the vibrator, to cause the vibrator to produce thickness shear vibrations.

The frequency of vibration of the vibrator is determined by the thickness in the direction of the Y'-axis and so may be made any desired frequency by suitable choice of the thickness.

As shown in Figure 10 the vibrator 21 is integral with a support member 23 which extends in the direction of the Y'-axis and which is connected to the vibrator 21. The vibrator 21 and the support member 23 are formed as a unit by an etching technique to reduce or prevent resonance or sub-vibration of the support member 23. Thus the vibrator unit shown in Figure 10 is especially suitable for use in wrist watches.

The vibrator units according to the present invention and described above have better performance than conventional vibrator units and may be made of ultra-small size.

WHAT WE CLAIM IS:—

1. A vibrator unit comprising a thickness shear type crystal vibrator having a plurality of electrodes, the vibrator being formed from a laminar plate obtained by firstly rotating a Y-cut plate through an angle between 0° and 25° about the Z-axis and by secondly rotating the plate about an imaginary axis generated by the X-axis as a result of the first rotation, through an angle between −30° and −45° said electrodes being mounted on faces which are greater in size than the other faces and which are parallel to an imaginary axis generated by the Y-axis by said first and second rotations to apply an electric field in the direction of said latter imaginary axis.

2. A vibrator unit as claimed in Claim 1 including further electrodes mounted on faces which are perpendicular to the imaginary axis generated by the Y-axis by said first and second rotations.

3. A vibrator unit as claimed in Claim 1 or 2 in which the electrodes are shaped by an etching technique.

4. A vibrator unit as claimed in any preceding claim in which the thickness of the vibrator in the direction of the mechanical axis is determined by a mechanical technique and thereafter the vibrator and support means are formed by an etching technique.

5. A vibrator unit as claimed in any preceding claim in which the vibrator unit is formed integrally from the same piece of material as support means.

6. A vibrator unit substantially as herein described with reference to and as shown in Figures 5 to 12 of the accompanying drawings.

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A further embodiment of a vibrator unit according to the present invention is illustrated in Figures 10 to 12. A thickness shear type crystal vibrator 21 is made from a laminar plate obtained by rotating a Y-cut plate through $\theta_5°$, where θ_5 may be between 30° and 45° and preferably about 38°, about the X-axis. The vibrator 21 has opposite faces 21a which are parallel to the Y'-axis and faces 21b which are parallel to the Z'-axis. The faces 21a have larger dimensions than the faces 21b. Electrodes A_5, A_6, B_5, B_6 are mounted on the faces 21a. When the electrodes A_5, B_5 receive a positive potential and the electrodes A_6, B_6 receive a negative potential an electric field is generated in the material of the vibrator in the direction of the Y'-axis. On the other hand, when the electrodes A_5, B_5 receive a negative potential and the electrodes A_6, B_6 receive a positive potential an electric field (shown in solid lines) which is also in the direction of the Y'-axis is generated within the material of the vibrator. Thus when an alternating potential is applied to the electrodes A_5, B_5, A_6, B_6 electric fields alternating in direction and parallel to the Y'-axis are generated within the material of the vibrator, to cause the vibrator to produce thickness shear vibrations.

The frequency of vibration of the vibrator is determined by the thickness in the direction of the Y'-axis and so may be made any desired frequency by suitable choice of the thickness.

As shown in Figure 10 the vibrator 21 is integral with a support member 23 which extends in the direction of the Y'-axis and which is connected to the vibrator 21. The vibrator 21 and the support member 23 are formed as a unit by an etching technique to reduce or prevent resonance or sub-vibration of the support member 23. Thus the vibrator unit shown in Figure 10 is especially suitable for use in wrist watches.

The vibrator units according to the present invention and described above have better performance than conventional vibrator units and may be made of ultra-small size.

WHAT WE CLAIM IS:—

1. A vibrator unit comprising a thickness shear type crystal vibrator having a plurality of electrodes, the vibrator being formed from a laminar plate obtained by firstly rotating a Y-cut plate through an angle between 0° and 25° about the Z-axis and by secondly rotating the plate about an imaginary axis generated by the X-axis as a result of the first rotation, through an angle between −30° and −45° said electrodes being mounted on faces which are greater in size than the other faces and which are parallel to an imaginary axis generated by the Y-axis by said first and second rotations to apply an electric field in the direction of said latter imaginary axis.

2. A vibrator unit as claimed in Claim 1 including further electrodes mounted on faces which are perpendicular to the imaginary axis generated by the Y-axis by said first and second rotations.

3. A vibrator unit as claimed in Claim 1 or 2 in which the electrodes are shaped by an etching technique.

4. A vibrator unit as claimed in any preceding claim in which the thickness of the vibrator in the direction of the mechanical axis is determined by a mechanical technique and thereafter the vibrator and support means are formed by an etching technique.

5. A vibrator unit as claimed in any preceding claim in which the vibrator unit is formed integrally from the same piece of material as support means.

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