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(54) 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 quartz crystal vibrators and in particular, although not so restricted, to tuning fork type quartz crystal vibrators.

According to one aspect of the present invention there is provided a quartz crystal vibrator mounted within a casing by way of mounting means having a thermal expansion coefficient or thermal expansion coefficients which, relative to the thermal expansion coefficient or thermal expansion coefficients of the material of the casing and relative to the thermal expansion coefficient or thermal expansion coefficients of the quartz crystal material of the vibrator, are such that the thermal expansion of the casing, the mounting means and the vibrator causes no, or substantially no stresses, to be generated in the vibrator.

In one embodiment said mounting means comprises two spaced apart mounting members.

Said vibrator may be secured to and may span the space between the mounting members.

In another embodiment, said mounting means may comprise a mounting member spaced apart from a portion of the casing, said vibrator being secured to and spanning the space between the mounting member and said portion of the casing.

Said casing may be made of ceramic material.

Said mounting means may be made of metal.

According to a further aspect of the present invention there is provided a wristwatch having a 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 tuning fork type quartz crystal vibrator;

Figure 2 is a view of a rear surface of a vibrator of Figure 1;

Figure 3 illustrates the relationship between the physical axes of the vibrator of Figure 1 and the crystallographic axes thereof;

Figure 4 illustrates the operation of the vibrator of Figure 1;

Figure 5 is a perspective view of a tuning fork type quartz crystal vibrator for use with the present invention;

Figure 6 is a view of a rear surface of the vibrator of Figure 5;

Figure 7 illustrates the relationship between the physical axes of the vibrator of Figure 5 and the crystallographic axes thereof;

Figure 8 illustrates the operation of the vibrator of Figure 5;

Figure 9, consisting of Figures 9-*a* and 9-*b* illustrates a theoretical casing for a tuning fork type quartz crystal vibrator;

Figure 10, consisting of Figures 10-*a*, 10-*b*, 10-*c* and 10-*d*, illustrate one embodiment of a casing of a tuning fork type quartz crystal vibrator according to the present invention;

Figure 11, consisting of Figure 11-*a*, 11-*b* and 11-*c*, illustrates another embodiment of a casing of a tuning fork type quartz crystal vibrator according to the present invention;

Figure 12, consisting of Figures 12-*a*, 12-*b* and 12-*c*, illustrates a still further embodiment of a casing of a tuning fork type quartz crystal vibrator according to the present invention; and

Figure 13 shows, schematically, a practical form of a tuning fork type quartz crystal vibrator according to the present invention.

Figure 1 is a perspective view of a conventional tuning fork type quartz crystal vibrator produced, by a photochemical etching technique from an NT-cut quartz crystal plate several tens of microns in thickness. Electrodes 2, 3 are provided on a front surface of the vibrator and are connected to respective terminals 6, 7 by bonding wires 4, 5.

An electrode 9 (Figure 2) is provided on a rear surface of the vibrator 1. The vibrator 1 is adhered to a mounting structure 8 which also acts as a terminal block for the electrode 9 since it is in electrical contact with a portion 10 of the electrode 9. The vibrator 1 may be adhered to the mounting structure 8 using, for example, solder or conductive paste.

Figure 3 illustrates the relationship between the physical axes of the vibrator 1 and the crystallographic axes of the quartz crystal material of the vibrator. An angle α indicates a first rotation and an angle β a second rotation. The angles α and β are between 0° and 10°, and 55° and 70° respectively. When an electric potential is applied to the electrodes 2, 3, 9, electric fields 11, 12, as shown in Figure 4, are produced and these cause the vibrator 1 to vibrate. In Figure 4, the angle α is set at 0° for simplicity of illustration. The vibrator 1 may be made with a relatively small size and can be mass produced easily. However, as shown in Figure 4, only components 13, 14 of electric fields 11, 12 in the direction of the X-axis are involved in causing the vibrator to vibrate. When the angle β is relatively large, the dynamic impedance of the vibrator is relatively high since it is inversely proportional to $\cos^2\beta$. Furthermore, to be stable over a relatively wide temperature range, the vibrator should have a zero frequency-temperature coefficient at room temperature. If the frequency-temperature coefficient is to be zero at 20°C., the angle β needs to be about 75° and this causes the dynamic impedance of the vibrator to be as high as several megohms, which is not practical.

Figure 5 is a perspective view of a tuning fork type crystal quartz vibrator 15 for use with the present invention. A vibrator 15 is formed for a quartz crystal plate, as shown in Figure 7, by a photochemical etching technique. An angle γ is between 0° and 10°. Electrodes 16, 17 are formed on a front surface of the vibrator and electrode 26, 26 are formed on a rear surface as shown in Figure 6. As shown in Figure 8, electric fields are applied to the vibrator so that they are parallel to the X-axis. Accordingly, the dynamic impedance of the vibrator is about 50 kilo-ohms, being considerably smaller than the dynamic impedance of the vibrator of Figure 1. The frequency-temperature coefficient of the vibrator 15 is zero between 20°C and 40°C and is, in the main, determined by the angle γ. Thus the vibrator has a good performance and a relatively small size and consequently may be used to advantage in wristwatches. However, it is necessary to connect a pair of leads not only to the electrodes 16, 17 on the front surface of the vibrator but also to the electrodes 25, 26 on the rear surface. Thus the vibrator cannot be mounted in the conventional manner and in particular cannot be adhered to an electrically conductive mounting structure, such as the mounting structure 8 of Figure 1. As shown in Figure 5, a mounting structure 24 is made of electrically insulating material and has two spaced apart electrically conductive films 18, 19 thereon. The electrodes 27, 28 are adhered to the conductive films 18, 19 by, for example, solder. The electrodes 16, 27 are electrically connected together and to a terminal pin 22 by a bonding wire 20. The electrodes 17, 28 are electrically connected together and to a terminal pin 23 by a bonding wire 21.

Conventional tuning fork type quartz crystal type vibrators have been housed in metallic casings. In order to reduce the size of an oscillator circuit consisting of such a vibrator and an integrated driving circuit, it has now been found advantageous to house the vibrator and the integrated driving circuit in a casing made of electrically insulating material, e.g. ceramic material. Such a casing has the advantage that electrical connections to external circuitry may pass outwards of the casing without fear of short circuiting which would otherwise occur if the casing were made of metal.

Figure 9, which consists of Figures 9-*a* and 9-*b*, illustrates a theoretical casing 29 of a tuning fork type quartz crystal vibrator. The casing 29 is made of ceramic material and is provided with a stepped portion 30 on which two spaced apart metallic films 31 are deposited and subsequently sintered. The metallic films 31 are electrically connected to the outside of the casing by means passing through a wall of the latter. Figure 9-*b* illustrate a vibrator 32 mounted on the casing 29 of Figure 9-*a*. If the casing 29 is made of a ceramic material which has an expansion coefficient of about 7×10^{-6}/°C and the quartz crystal material of the vibrator has an expansion coefficient of about 13×10^{-6}/°C, there is a tendency for cracks to develop in the vibrator when it cools from the temperature which it is soldered to the metallic films 31, due to a relatively large tensile stress developed in the vibrator as a result of the difference of expansion coefficients. However, there is no ceramic material which has a sufficiently high expansion coefficient, together with the various other necessary characteristics, to prevent this happening. Thus the casing 29 is not commercially practical.

Figure 10, consisting of Figures 10-*a*, 10-*b*, 10-*c* and 10-*d* illustrates a casing 13 of a tuning fork type quartz crystal vibrator according to the present invention. As shown in Figures 10-*a*, the casing 33 which is made of ceramic material, has a stepped portion 34 on which is formed two spaced apart metallic films 35 which are sintered. A metallic plate 36 is subsequently provided on,

be similar to the vibrator 15 of Figure 5, is mounted so as to span the plates 45. In this embodiment the effects of shock to the casing, which might otherwise damage the vibrator, are reduced or prevented, by virtue of the resiliency of the plates 45. The plates 45 have an expansion coefficient which is less than the expansion coefficients of the material of the casing and of the quartz crystal material of the vibrator.

Referring now to Figure 13, there is shown, schematically, a practical form of a tuning fork type quartz crystal vibrator, according to the present invention. A casing 46 has a stepped portion 47 on which the metallic film portions 48 are formed. The integrated circuit 49 is connected to the film portions 48 by bonding wires 50. Connections between external circuitry and the integrated circuit 49 are effected by metallized portions 51. A tuning fork type quartz crystal vibrator 52, which may be similar to the vibrator 15 of Figure 5, is mounted in the casing in the manner illustrated in any one of Figures 10 to 12. As shown clearly in Figure 13, the integrated circuit 49 and the vibrator 52 are housed and assembled in a compact manner in the casing 46.

The embodiments of the present invention as described above have the advantage that the vibrators have improved shock resistance and so may be used to advantage in wrist watches.

WHAT WE CLAIM IS:—

1. A quartz crystal vibrator mounted within a casing by way of mounting means having a thermal expansion coefficient or thermal expansion coefficients which, relative to the thermal expansion coefficient or thermal expansion coefficients of the material of the casing and relative to the thermal expansion coefficient or thermal expansion coefficients of the quartz crystal material of the vibrator, are such that thermal expansion of the casing, the mounting means and the vibrator causes no, or substantially no stresses, to be generated in the vibrator.

2. A quartz crystal vibrator as claimed in claim 1 in which said mounting means comprises two spaced apart mounting members.

3. A quart crystal vibrator as claimed in claim 2 in which said vibrator is secured to and spans the space between the mounting members.

4. A quartz crystal vibrator as claimed in claim 1 in which said mounting means comprises a mounting member spaced apart from a portion of the casing, said vibrator being secured to and spanning the space between the mounting member and said portion of the casing.

5. A quartz crystal vibrator as claimed in any preceding claims in which said casing is made of ceramic material.

6. A quartz crystal vibrator as claimed in any preceding claim in which said mounting means are made of metal.

7. A quartz crystal vibrator substantially as herein described with reference to and as shown in Figures 10 to 13 of the accompanying drawings.

8. A wristwatch having a quartz crystal vibrator as claimed in any preceding claim.

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and in contact with, each metallic film 35 (Figure 10-*b*), the plates 36 being out of contact with one another and adhered to the respective films 35 using, for example, a brazing alloy. As shown in Figure 10-*c*, a vibrator 37, such as that shown in Figure 5, is adhered to the two plates 36 so as to span them. In Figure 10-*d*, which is a sectional view of Figure 10-c, the distance l_1 is the minimum distance between plates 36, and a distance l_2 is the minimum distance between the two films 35. As clearly shown, each plate 36 is fixed to the casing 33 only at one end, and the other end of each plate is fixed to the vibrator so that each plate can expand or contract independently or substantially independently of the step portion 34. Thus, if the dimension l_1 and l_2 are suitably chosen, the temperature changes to which the vibrator is subjected do not generate stresses therein to any substantial degree. Thus, if with a temperature change ΔT the minimum distance between the plates changes by the same amounts as the vibrator then:

$$l_2\alpha_Q\Delta T-(l_2-l_1)\alpha_M\Delta T=l_1\alpha_Q\Delta T$$

$$\therefore(\alpha_Q-\alpha_M)l_1=(\alpha_Q-\alpha_M)l_2$$

where,

α_Q is the linear expansion coefficient of the ceramics material of the casing,

α_Q is the linear expansion coefficient of the quartz crystal material of the vibrator; and

α_M is the linear expansion coefficient of the metallic plate 36.

For simplification, the variation of the linear expansion coefficients with temperature has been ignored. If, for example,

$$\alpha_C=7\times10^{-6}/°C$$
$$\alpha_Q=13\times10^{-6}/°C$$
$$\alpha_M=5\times10^{-6}/°C$$

then

$$l_1:l_2=1:4.$$

The above calculation is of a theoretical nature, and it is assumed that those parts of the plates 36 adhered to the films 35 and to the vibrator 36 expand as do the remainder of the plates. However, this assumption is not strictly correct and in practice the plates 36 expand or contract with a given temperature rise more than they would do if they were not fixed. Accordingly, although in practice, the minimum distance between the plates 36 on a given temperature rise is slightly more than indicated above, the area of the contact between the plates and the films on the one hand, and the vibrator on the other hand, is relatively so small that, even though the above assumption is made, no appreciable stress will occur in the vibrator for a given temperature change.

It will be appreciated that by means of the arrangement shown in Figure 10, the effect on the vibrator of the difference between the expansion coefficient of the material of the casing and the expansion coefficient of the quartz crystal material of the vibrator, can be minimised if two metallic plates 36, for example of Kovar (Trade Mark) having a smaller expansion coefficient than the material of the casing and a smaller expansion coefficient than the quartz crystal material of the vibrator, are used to mount the vibrator on the casing. The result of this arrangement is as if the vibrator were directly mounted on a casing having the same or substantially the same expansion coefficient as the material of the vibrator.

In Figure 10 the plates 36 are metallic but, if desired, they may be made of electrically insulating material having a suitable expansion coefficient with a coating thereon of a metal.

Figure 11, consisting of 11-*a* to 11-*c* illustrates another embodiment of a casing of a tuning fork type quartz crystal vibrator according to the present invention. The casing, which is made of ceramics material, has a stepped portion 38 on which is formed two metallic films 39, 40 which are not in the same plane. A metallic plate 41 (Figure 11-*c*) is adhered to the metallic film 39, the difference between the plane of the metallic films 39, 40 being the same or substantially the same as the thickness of the plate 41. A tuning fork type quartz crystal vibrator 42, which may be similar to the vibrator of Figure 5, is mounted so to stand on the metallic film 40, and the plate 41. As clearly shown in Figure 11-*c*, although only one plate 41 is used, the same effect is achieved by the casing 33 of Figure 10 can be obtained, assuming that the dimensions and expansion coefficients involved are suitably chosen, and in particular assuming that the expansion coefficient of the plate 41 is less than the expansion coefficient of the material of the casing and the expansion coefficient of the quartz crystal material of the vibrator.

Figure 12, consisting of Figures 12-*a*, 12-*b* and 12-*c* illustrates another embodiment of a casing 43 of a tuning fork type quartz crystal vibrator according to the present invention. As shown in Figure 12-*a* the casing 43 has two spaced apart raised portions 44 to each of which is secured a metallic plate 45. The plates 45 overhang the respective raised portions 44 in the direction of each other. Each raised portion 44 has a metallic film 44′ thereon to which the respective plate 45 is secured by means of, for example, soldering or brazing. A tuning fork type quartz crystal vibrator 43′, which may

be similar to the vibrator 15 of Figure 5, is mounted so as to span the plates 45. In this embodiment the effects of shock to the casing, which might otherwise damage the vibrator, are reduced or prevented, by virtue of the resiliency of the plates 45. The plates 45 have an expansion coefficient which is less than the expansion coefficients of the material of the casing and of the quartz crystal material of the vibrator.

Referring now to Figure 13, there is shown, schematically, a practical form of a tuning fork type quartz crystal vibrator, according to the present invention. A casing 46 has a stepped portion 47 on which the metallic film portions 48 are formed. The integrated circuit 49 is connected to the film portions 48 by bonding wires 50. Connections between external circuitry and the integrated circuit 49 are effected by metallized portions 51. A tuning fork type quartz crystal vibrator 52, which may be similar to the vibrator 15 of Figure 5, is mounted in the casing in the manner illustrated in any one of Figures 10 to 12. As shown clearly in Figure 13, the integrated circuit 49 and the vibrator 52 are housed and assembled in a compact manner in the casing 46.

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2. A quartz crystal vibrator as claimed in claim 1 in which said mounting means comprises two spaced apart mounting members.

3. A quart crystal vibrator as claimed in claim 2 in which said vibrator is secured to and spans the space between the mounting members.

4. A quartz crystal vibrator as claimed in claim 1 in which said mounting means comprises a mounting member spaced apart from a portion of the casing, said vibrator being secured to and spanning the space between the mounting member and said portion of the casing.

5. A quartz crystal vibrator as claimed in any preceding claims in which said casing is made of ceramic material.

6. A quartz crystal vibrator as claimed in any preceding claim in which said mounting means are made of metal.

7. A quartz crystal vibrator substantially as herein described with reference to and as shown in Figures 10 to 13 of the accompanying drawings.

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