SPECIFICATION

Contour vibration mode piezo-electric resonator

The present invention relates to a contour vibration mode piezo-electric resonator, e.g. a miniature quartz resonator.

Recently, a tuning fork type flexural quartz resonator has become used as a frequency standard of a wrist watch. The frequency-temperature characteristic of the tuning fork type flexural quartz resonator is constituted by a quadratic curve, and it is therefore difficult, when using such a resonator, to achieve highly precise and stable frequency in a wide temperature range. Therefore, a titanium acid barium condenser, the capacitance of which varies according to temperature, is employed for temperature compensation, thereby making it possible to achieve high precision in a quartz wrist watch. In this case, however, the precision of the quartz wrist watch is limited because the temperature compensation condenser should be adjusted to the optimum value of the temperature characteristic of the quartz resonator, and the capacitance of the temperature compensation condenser changes with the passage of time.

Consequently, consideration has been given to the use of an AT-cut quartz crystal wrist watch having a cubic frequency-temperature curve as a means of overcoming the above-mentioned disadvantage. In the case of an AT-cut quartz resonator, however, there are many spurious vibrations other than the thickness shear vibration which is used for the frequency standard, and the spurious vibrations injuriously affect the various characteristics of the resonator. Accordingly, in order to separate the spurious vibrations from the major vibration (thickness shear vibration), the quartz crystal plate has to have optimum dimensions and an optimum cut angle, and exceedingly high precision is therefore required. Up to the present time, however, the above requirements have not been achieved because in actual manufacture the number of man-hours used has been too high and the yield, i.e. the number of usable resonators produced, has been too low. It is, moreover, particularly difficult to meet this requirement in the case of a minature AT-cut quartz resonator for use in a wrist watch. Furthermore, there has not previously been proposed a satisfactory way of supporting the resonator which prevents the spurious vibrations being changed by the support, prevents deterioration of the CI (crystal impedance), and ensures sufficient shock resistance.

By reason of the above-mentioned problems, little use has been made of a wrist watch incorporating an AT-cut quartz resonator as the frequency standard.

On the other hand, a GT-cut resonator also has a cubic frequency-temperature curve. The GT-cut resonator is scarcely used at present and has never been used for a wrist watch.

For instance, the conventional rectangular GT-cut quartz crystal plate having a standard frequency of 100KHz is rather large, i.e. its length, width and thickness are respectively 38.4, 32.9 and 3.0 mm. Moreover, since the cut angle of the GT-cut resonator is specific, the resonator must be produced from a large quartz crystal plate and consequently the cost of the GT-cut quartz crystal resonator is very high. Furthermore, since the GT-cut quartz crystal resonator is large, it has to be supported by the so-called "multi-points" supporting method, i.e. by fixing from 4 to 8 supporting wires to from 2 to 4 portions on each of the major surfaces of the resonator (and thus on 4 to 8 portions in all) and at the nodal points of the quartz crystal plate taking its strength into account. Moreover, masses of solder must be provided on the supporting wires at the positions where the leakage of vibration energy of the resonator is at a minimum.

According therefore to the present invention there is provided a contour vibration mode piezo-electric resonator comprising a contour vibration mode piezo-electric resonator comprising a rectangular vibrating portion having opposed relatively short sides and opposed relatively long sides, the vibrating portion being integrally connected to at least one supporting portion by way of a respective bridge portion, the or each supporting portion comprising a resilient portion which is connected to the vibrating portion by way of the said bridge portion, a vibration attentuation portion which is integrally connected to the resilient portion, and a fixing portion which is adapted to be fixed to a support member, the fixing portion being integrally connected to or forming at leat a part of the vibration attenuation portion, and wherein the relationship between the width W of each of the short sides of the vibrating portion, the width W_0 or the or each bridge portion, and the length L_1 and the width W_1 of the or each resilient portion is represented by:

$$0.015 \leqq (W_0/W) \leqq 0.200, \text{ and}$$

$$5 \leqq (L_1/W_1) \leqq 25$$

The resonator may be made by etching.

The or each bridge portion may be provided substantially at the centre of the respective resilient portion.

The or each supporting portion may have an opening therethrough which is surrounded by the respective connected together resilient and vibration attenuation portions.

The or each resilient portion may extend substantially parallel to the relatively short sides of the vibrating portion.

Preferably, at least a part of the or each vibration attenuation portion extends substantially parallel to the respective resilient portion.

Metallic electrode films are preferably provided on each of the opposite major surfaces of the vibrating portion and supporting portions(s).

The electrode films may be removed from the vicinity of the bridge portion(s) or may be thicker in said vicinity.

The or each supporting portion is preferably provided substantially at the centre of a said relatively short side of the vibrating portion.

The or each fixing portion is preferably provided substantially at the centre of the vibration attenuation portion.

The relationship between the width W_1 of the or each resilient portion, the width W_2 of the or each vibration attenuation portion, the space W_3 between the or each resilient portion and the respective vibration attenuation portion may be represented by

$$0.3 \leqq (W_1/W_2) \leqq 1.2$$

$$W_1 \leqq 1.5\, W_0$$

$$0.2 \leqq (W_1/W_3) \leqq 2.0.$$

The relationship between the relatively long sides L and relatively short sides W of the vibrating portion may be

$$0.8 \leqq (W/L) = 1.0.$$

The resonator is preferably made from a quartz crystal Y plate rotated around the X axis through an angle of 45° to 65°, the Y plate being further rotated through an angle of ± (40° to 50°) in a plane parallel to the major surfaces thereof.

The or each fixing portion may be fixed and sealed to a supporting member which is provided on a case which houses the resonator, the or each fixing portion being electrically connected to the supporting member.

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

Figures 1 and 2 show means for supporting a conventional GT-cut quartz resonator,

Figure 3 is a plan view showing a conventional GT-cut quartz resonator comprising supporting portions and a vibrating portion made in one piece,

Figures 4 and 5 are diagrammatic views showing how a resonator according to the present invention may be cut,

Figure 6 shows a relationship between the ratio of the sides of the resonator and the frequency of a resonator,

Figures 7(a), (b) and (c) show samples of various resonators not in accordance with the present invention,

Figures 8 and 9 show embodiments of the resonator according to the present invention,

Figures 10(a), (b) and (c) illustrate the principle of the resonator according to the present invention,

Figures 11(a), (b), (c) and (d) are respectively plan views showing other embodiments of a resonator according to the present invention,

Figures 12 and 13 show a further embodiment of a resonator according to the present invention,

Figure 14 is a simplified diagrammatic view of a resonator according to the present invention to show the disposition of certain metal parts thereof,

Figure 15 illustrates the distribution of displacement of a resonator according to the present invention,

Figures 16 and 17 show still further embodiments of a resonator according to the present invention,

Figure 18 is a perspective view showing a resonator according to the present invention,

Figure 19 is a sectional view showing how the resonator of Figure 18 may be supported,

Figure 20 shows a frequency-temperature characteristic,

Figure 21 shows another way of supporting a resonator according to the present invention,

Figures 22 and 23 are respectively a plan view and a sectional view showing yet another embodiment of a resonator according to the present invention,

Figures 24, 25 and 26 illustrate the manufacturing method of a resonator and capsule thereof according to the present invention,

Figure 27 is a sectional view showing the manner in which a resonator according to the present invention is mounted, and

Figures 28 and 29 show the principle of the supporting structure used to support a resonator according to the present invention.

The "multi-points" supporting method which is mentioned above is illustrated in Figure 1 which

shows a known construction. As shown in Figure 1, a quartz crystal plate 1 is supported by fixing it to respective ends of supporting wires 2, such as headed wires or the like, and connecting the opposite ends of the supporting wires 2 to supporting rods 3. In this case, silver points are fixed by a burning technique to support positions of the quartz crystal plate 1 and then the supporting wires 2 are fixed at right angles to the silver points by providing conical masses of solder 5*a*. The said opposite ends of the supporting wires 2 are electrically connected to a substrate 6 (and so to external circuits) by the supporting rods 3 which are fixed to the supporting wires 2 by solder 5*b*. The supporting wires 2 should be adjusted so that the peaks of the conical masses of solder 5*a* serve as nodes of vibration at the vibration frequency. Accordingly, the positions of solder "balls" or masses 4 are adjusted, in the Figure 1 construction so that the peaks of the conical masses of solder 5*a* serve as nodes of vibration of the supporting wires. This difficult process has to be followed for all the supporting wires 2. Further, the possibility of reducing the dimension of the GT-cut quartz resonator in the thickness direction is limited since there is a possibility that the conical masses of solder 5*a* can become welded together when the positions of the solder "balls" 4 are adjusted, and consequently the construciton uses excessive space.

By way of an improvement of the construction of Figure 1, a miniature GT-cut resonator having a length, a width, and a thickness of respectively 8.03 mm, 9.37 mm and 0.65 mm can be used to reduce the number of the supporting wires, as shown in Figure 2.

The known construction shown in Figure 2 is similar to that of Figure 1 in that each of the supporting wires 2 is fixed to the centre of the respective major surfaces of the quartz crystal plate 1. In this construction, however, although the number of supporting wires 2 is smaller than that of Figure 1 and the adjustment of the solder balls 4 is simplified, the space occupied is the same.

As illustrated above, the conventional supporting wire construction shown in Figures 1 and 2 has the disadvantage that the assembly of the quartz resonator is difficult and yield thereof is poor. Moreover, a rather large space is required so that a quartz resonator assembled by this supporting wire construction could never have been used in a wrist watch, since a quartz resonator for use in a wrist watch necessitates the ability to mass produce and miniaturise it.

In order to overcome the disadvantages of the supporting wire construction, the vibrating portion and the supporting portion of a known quartz resonator can be made in one piece as shown in Figure 3. In this case, a quartz crystal plate is easily supported and miniaturized by providing a supporting portion 12 near the nodal line of a vibrating portion 11. The vibrating portion 11 and the supporting portion 12 are made in one piece by etching from a GT-plate. The length, width and thickness of the vibrating portion 11 are respectively 4.9 mm, 4.2 mm and 0.04 mm, and the frequency thereof is 780KHz. The supporting portion 12 is connected to the vibrating portion 11 near a nodal line 15 and is fixed on a supporting member (not shown) at a portion indicated by oblique lines. Simultaneously an electrode film 13*a* on the obverse surface and an electrode film 13*b* on the reverse surface of the vibrating portion 11 are connected to an external circuit. Although the Figure 3 construction is superior to the supporting wire construction of Figures 1 and 2 in that it is simpler and can be mass produced, the supporting portion 12 is unduly large.

Thus, although the quartz crystal plate shown in Figure 3 can be miniaturised to a greater extent than the quartz crystal plate shown in Figures 1 and 2, an excessive space is needed because of the large supporting portion 12, whereby the quartz crystal plate shown in Figure 3 is not suitable for use in a wrist watch. Further, since the vibration energy of the vibrating portion 11 is transmitted to the supporting member even if dimensions and shape of the supporting portion are as good as possible, a leakage of vibration occurs and, as a result, there is an increase in CI, a deterioration of pressure resistance, and a variation in the frequency-temperature characteristics. Moreover, the resilient coupling of the length vibration and the width vibration which controls the characteristics of the GT-plate changes by reason of the provision of the supporting portion 12, and as a result the characteristics of the quartz resonator change.

Figures 4 and 5 show the cut angle of a preferred contour vibration mode quartz resonator according to the present invention, whose X-axis, Y-axis and Z-axis respectively denote the electrical axis, mechanical axis and optical axis of the quartz crystal plate, where the use of a prime (') denotes that the resonator has been rotated. A Y plate quartz crystal plate 20 has been rotated through angle ϕ of 45° to 65° around the X-axis in Figure 4, and is rotated through an angle $\theta = \pm$ (40° to 50°) inside the major surfaces (X—Z) planes) in Figure 5.

According to vibration analysis in two dimensions, the following relationships of each of the constituents of the elastic constant of the quartz crystal are represented at follows:

(1) $$C'_{11} = C'_{33},\ C'_{15} = C'_{35}$$

(2) $$C'_{11},\ C'_{33},\ C'_{13} \gg C'_{15},\ C'_{35}$$

where ' (prime) denotes the value to which the coordinate is transformed. Further, since C'_{55} is negligible when taking the piezo electric constant into account, it is noted that the longitudinal vibration in the directions of the X'-axis and the Z''-axis are excited when the plate thickness is sufficiently thin. By the above-mentioned relationships, Hook's Law in Two-Dimensional Problems (X—Z'' planes) is represented by:

$$X_X = C'_{11}x_x + C'_{13}x_z,\ Z_Z = C'_{13}z_x + C'_{11}z_z,$$

where X_X, x_x: longitudinal stress and strain in the X-axis direction
Z_Z, z_z: longitudinal stress and strain in the Z axis direction
x_z, z_x: shearing strains in the Z"—X' plane.

Consequently the characteristic of the resonator is affected by the elastic constant of two longitudinal vibrations and the above mentioned relationships will be shown in Figure 6.

In Figure 6 the side ratio r denotes the dimensional ratio of the short side to the long side of the plate, where the dimension of the short side is constant and the dimension of the long side is changed. Figure 6 shows that the short side vibration frequency 22 and the long side vibration frequency 23 are coupled in a region 24. In Figures 4 to 6, use is made of a conventional GT-cut quartz crystal plate in which $\psi = 51.5°$, $\theta = 45°$ and r = 0.85. When the frequency-temperature characteristic is calculated by the frequency equation obtained by the vibration analysis while using ψ, θ and r as parameters, excellent frequency-temperature characteristics are realized in a wide range of these parameters.

The above-mentioned result is a very important one for a resonator which consists of a vibrating portion and a supporting portion which are integrally connected by way of bridges. That is to say, since the value obtained by the theoretical calculation is the one obtained in free vibration, the boundary condition is different when the resonator consists of the vibrating portion and the supporting portions made in one piece, with the result that there is a shift in the values of parameters ψ, θ, and r which give excellent frequency-temperature characteristics. Taking the above fact into account, it is very convenient that excellent frequency-temperature characteristics are realized in a wide temperature range. Further, even if the quartz resonator is a miniature one, i.e. the short side of the vibrating portion is less than 5 mm, there is a possibility that the values of the parameter may shift through various causes. In this respect the above mentioned feature is advantageous.

The range of each of the parameters theoretically calculated by the above explanations is $\psi = 40°$ to 70°, $\theta = 40°$ to 50° and r = 0.80 to 1.00.

Resonators (not in accordance with the present invention) and having the supporting portions of various shapes as shown in Figure 7(a), 7(b) and 7(c) were manufactured by way of experiment and the following new facts were found.

In Figures 7(a), 7(b) and 7(c) there is shown a resonator 21 consisting of supporting portions 25 and a vibrating portion 26, made in one piece. Although Figures 7(a), 7(b) and 7(c) show typical embodiments, it is to be noted that various kinds of supporting portions having various dimensions and shapes were used in the experiment. Further, the resonator was supported by the supporting wire construction as shown in Figure 2. By combining each of the parameters, a quartz resonator having excellent frequency-temperature characteristics and a low CI was produced when the following parameters were combined:

$\psi = 45°$ to 65°

$\theta = \pm$ (40° to 50°)

r = 0.8 to 1.00

In greater detail, since the effective constituent of the resonator is the electric field in the direction of the Y-axis, the constituent becomes small if ψ becomes large and the driving efficiency is reduced. But when $\psi < 65°$ the quartz resonator is not influenced by the electric field in the direction of Y-axis so much, and there is scarcely any difference between the present embodiment and the conventional type with respect to CI. Although the resonator is mainly etched when the vibrating portion and the supporting portions are made in one piece, the quartz crystal has the property that the Y-direction thereof is scarcely etched because of its anisotropy, and it takes a long time to etch the resonator when $\psi < 45°$. (The etching liquid is a mixture of hydrofluoric acid and ammonium fluoride). The experiment shows that the optimum ψ value is given by the expression $45° \leqq \psi \leqq 65°$. As regards θ, θ is not necessarily 45° as mentioned before, and various characteristics of the quartz resonator are not affected much by θ. The tolerance of θ is the same as the tolerance given by theoretical calculation: $40° \leqq r \leqq 50°$. Lastly, with respect to the frequency-temperature characteristic, if the value r is in the range of 0.80 to 1.00 when ψ and θ are in the above mentioned range, an excellent frequency-temperature characteristic is produced regardless of the dimensions and shapes of the supporting portions. (r = W/L in Figures 7(a), 7(b) and 7(c)).

As mentioned above, each of the parameters (ψ, θ, r) given by the experiment using the embodiments shown in Figures 7(a), 7(b) and 7(c) are included in the range of the parameters given by the preceding theoretical calculation. Consequently, the value of parameters is confirmed both experimentally and theoretically.

The facts show that a resonator having various shapes of supporting portions satisfies any required specification by combining each of the parameters suitably, whereby there is wide freedom in designing a resonator.

An embodiment of a contour vibration mode miniature quartz resonator according to the present invention using the parameters mentioned above will now be illustrated.

Figure 8 shows an embodiment of a contour vibration mode miniature quartz resonator according to the present invention, and Figure 9 shows the dimensions of the parts of Figure 8. A contour vibration mode quartz resonator 21 consists of a vibrating portion 26 and two elongated supporting portions 25 made in one piece by etching. Each of the parameters ϕ, θ and r are within the range of the above mentioned parameters and are suitably combined to improve the frequency-temperature characteristics.

The maximum width of the short side W of the resonator is less than 5 mm and the thickness thereof is less than 200 μm. The value of the thickness t is newly found experimentally and theoretically by reason of the fact that the greater the thickness of the resonator, the greater is the ease with which it can be etched, and the more the frequency-temperature characteristic is adversely affected by the tendency for there to be elastic coupling of the two longitudinal vibrations. Each supporting portion 25 comprises a resilient portion 30 which is connected to and receives the vibration of the vibrating portion 26 by way of a respective bridge portion 31. Each supporting portion also comprises a vibration attenuation portion 28 connected at both ends to the respective resilient portion 30 by connecting portions 29, and a fixing portion 27 provided at the centre of the vibration attenuation portion 28 and fixed to a supporting member or the like (not shown in Figure 8). The width of the bridge portions 31, the width of the resilient portions 30, the width of the vibration attenuation portions 28, the distance between each resilient portion 30 and the respective vibration attenuation portion 28, and the length of the resilient portions 30 are respectively W_0, W_1, W_2, W_3 and L_1.

The principle of the embodiments of Figures 8 and 9 will be illustrated in conjunction with Figure 10.

Figure 10 shows one quarter of the Figure 8 construction along a line of symmetry. Figure 10(a) has been drawn to a slightly larger scale so as to enable the condition of the resonator when not vibrated to be easily understood (provided that the dimensional ratio is arbitrarily chosen). Figures 10(a), 10(b) and 10(c) are drawn to a larger scale so that the distribution of displacement obtained by the vibration analysis of the longitudinal vibration in the Z" axis direction and the longitudinal vibration in the X'-axis direction by the Finite Element Method can be easily understood. Two chain dot lines shows the position after displacement and the solid lines show the position before displacement.

As shown, the long side vibration and the short side vibration at the vibrating portion 26 are not respectively disturbed, in other words, the long side and the short side vibrate freely. Although the resilient portions 30 are directly connected to receive the vibrations of the vibrating portion 26 and are considerably displaced, the displacement at the vibration attenuation portions 28 is exceedingly small and the amount of displacement is at its minimum at the fixing portions 27.

Thus, the contour vibration mode quartz resonator provided with the supporting portion or portions according to the present invention is effective since the disturbance of mode at the vibrating portion and leakage of vibration to the supporting member and the like is quite small.

According to theoretical calculations, the short side vibration (in the direction of the X'-axis) results in a better frequency-temperature characteristic than the long side vibration (in the direction of the Z"-axis). Accordingly, it is better to provide the supporting portions 25 at the short side of the vibrating portion 26 than at the long side thereof. That is to say, it is better not to provide the supporting portions at the long side since they alternate the short side vibration.

If the analysis of vibration by the Finite Element Method is pursued further, it is found that the longitudinal direction of the elongated supporting portions 25 in Figure 8 is substantially parallel to the short side of the resonator. This is advantageous since excessive space is not necessary if the supporting portions 25 are provided on the short side as mentioned above.

Examining the optimum shape of the resonator by the Finite Element Method analysis, the disturbance of mode of the vibrating portion 26 and the leakage of vibration (caused by the vibration at the fixing portions 27) is prevented if the following relationships of each of the dimensions W_0, W_1, W_2, W_3, L_1 and the like in Figure 9 are satisfied. Namely, when each of the dimensions is changed by the Finite Element Method, the mode of the vibrating portion 26 and the vibrating condition of the supporting portions 25 are examined as follows.

(1) If the relationship between the width W of the vibrating portion 26 and the width W_0 of the bridge portions 31 is represented by $0.015 \leqq (W_0/W) \leqq 0.200$, then the shape of the supporting portions 25 which is required to prevent the disturbance of mode of the vibrating portion and the increase in distortion of the bridge portions 31 can be determined.

(2) If the width W of the resilient portions 30, the width W of the vibration attenuation portions 28, and the width W between each resilient portion 30 of the respective vibration attenuation portion 28 satisfy the following equations:

$$0.3 \leqq (W_1/W_2) \leqq 1.2, W_1 \leqq 1.5.W_0\ 0.2 \leqq (W_1/W_3) = 2.0$$

when $0.015 \leqq W_0/W \leqq 0.200$, the variation of mode of the vibrating portion 26 and the leakage of vibration are substantially prevented.

Referring in more detail to the leakage of vibration, when the amount of the maximum displacement at the vibrating portion 26 is 1.0 mm, the displacement of the fixing portion is less than 1

$\times 10^{-3}$ mm. (In this case, according to the calculation, the difference of frequency between the situation where the fixing portion 27 is fixed and the situation where the fixing portion 27 is free is substantially within 1PPM). That is to say, the displacement of the fixing portion 27 can be made almost zero by giving suitable values to W_1, W_2, W_3, W_0 and L_1, and as a result the leakage of vibration to the supporting member and the like is prevented.

(3) If the relationship between the length L_1 of the vibration attenuation portions 28 (which, in Figure 8, is the same as the length of the resilient portions) to the width W_1 of the resilient portions is $5 \leqq (L_1/W_1) \leqq 25$, it is effective to prevent the disturbance of mode at the vibrating portion in combination with the relationship given in (1) above.

(4) In order to prevent the leakage of vibration, the fixing portions 27 should be at the centre of the vibration attenuation portions 28, taking the symmetry of the resonator into account.

Applying the above-mentioned results to the construction shown in Figure 8, an excellent resonator can be produced without disturbance of the mode of the vibrating portion and without leakage of vibration. If the short side width W of the vibrating portion and without leakage of vibration. If the short side width W of the vibrating portion 26 is less than 5 mm, an adequate characteristic is realized by providing small supporting portions 25. Moreover, there is considerable design freedom in producing a resonator of a desired size.

Figures 11(a) to 11(d) show further shapes of the supporting portion or portions 25 of the contour vibration mode miniature quartz resonator according to the present invention. In the drawings, the supporting portion 25 made in one piece with the vibrating portion 26 by way of the bridge portion 31 consists of the resilient portion 30, the connecting portion 29, the vibration attenuation portion 28 and the fixing portion 27. Each of the parameters ϕ, θ, r and the plate thickness have the values discussed above.

Figure 11(a) shows an embodiment in which there is a supporting portion 25 only one one side; Figure 11(b) shows an embodiment in which the resilient portion 30 and the vibration attenuation portion 28 are connected by only one connecting portion 29; Figure 11(c) shows an embodiment provided with three connecting portions 29; and Figure 11(d) shows an embodiment in which the fixing portion 27 and the vibration attenuation portion 28 are constituted by the same part.

Figure 12 shows another embodiment of the contour vibration mode quartz resonator according to the present invention, and Figure 13 shows a sectional view taken on the line A—A. The relationship between the vibrating portion 26 and the supporting portion 25 of the resonator 21 of Figures 12 and 13 is the same as described above with reference to Figures 4 to 11. Metal electrode films 33*a*, 33*b*, e.g. of Au and the like, are disposed on both major surfaces of the resonator 21, and the films are disposed on the surfaces of both the vibrating portion 26 and the supporting portions 25. The electrode films 33*a* on the obverse surface of the vibrating portion 26 and of the supporting portions 25 are connected by way of one of the bridge portions 31, and the electrode films 33*b* on the reverse surface of the vibrating portion 26 and the supporting portions 25 are connected by way of the other bridge portion 31.

In the above-mentioned construction, the fixing portions 27 of the resonator are mechanically and electronically connected simultaneously to a lead terminal and a supporting member (not shown) which are electrically connected to an external circuit (the oscillating circuit) by sealing materials such as solder or the like, thus making mass production easy. In order to make sure that the mounting of the resonator is reliable, the metal electrode films 33*a* and 33*b* disposed on both surfaces of the resonator are electrically connected to metal parts 34*a* and 34*b*, (Figure 14) e.g. of Au and the like disposed on certain portions of the supporting portions 25 (or also on whole surfaces of the supporting portions 25). The metal parts 34*a*, 34*b* are produced by spattering metal powder on the supporting portions 25 in a circular motion.

The distribution of displacement in the long side direction (Z″-direction) of the resonator according to the present invention may be investigated by the analysis of Finite Element Method in the same way as in Figures 10(a) to 10(c). Figure 15 is the analyzed result of distribution of displacement showing one quarter of the resonator represented by the relative displacement when the maximum displacement is 1.0 mm.

As indicated in Figure 15, the displacement of the vibrating portion 26 corresponds substantially to a sine curve having an A portion near each bridge portion 31 which is distorted, and the abrupt change of the distortion is observed. In order to prevent the effects of the distortion, the electrode film is removed near the bridge portion as shown in Figure 16, or the thickness of the electrode film is increased near the bridge portion as shown in Figure 17.

In Figure 16, the electrode film 33 disposed on the vibrating portion 26 is removed at portions 36*a*, 36*b* in the vicinity of the bridge portions 31 so as to reduce the effect of electrical polarization caused by abnormal distortion.

In Figure 17, the electrode film 33 disposed on the vibrating portion 26 and the supporting portions 25 is thicker at portions 37*a* and 37*b* in the vicinity of the bridge portions 31, whereby to prevent the distortion. By the method mentioned above, the effect of the distortion illustrated in Figure 15 is prevented.

It is to be noted that the resonator need not be a quartz resonator whose supporting portion has

the shape and dimensions given above, but may also be applied to other contour vibration mode piezo electric resonators.

Figures 18 and 19 are general views of the resonator according to the present invention, and Figure 20 and Table 2 show each of the characteristics.

In Figures 18 and 19, the resonator has each of the parameters $\psi = 56$, $\theta = 45°$ and $r = 0.88$, and the short wide W and the thickness are respectively substantially 1.4 mm and 80 μm.

Each of the dimensions illustrated in Figure 9 is shown in Table 1 below.

The resonator case is composed of three plates 40, 41 and 42 in Figures 18 and 19. The plate 40 at the middle layer and the plate 42 at the upper layer are provided with holes of suitable size to thereby provide a void portion inside the capsule, and a stepped portion to support the resonator 21 is made by the plates 40 and 42. The fixing portion 27 of the resonator 21 is directly fixed to the stepped portion. Then the electrode lead films 38*a* and 38*b*, e.g. of Au or the like, are disposed on the surface of the stepped portion where the resonator is supported and fixed by evaporation, printing or the like, and the electrode lead films 38*a* and 38*b* are lead to a part of the lower surface of the plate 41 by way of the external side surfaces of the plates 40 and 41. The resonator 21 is set on the plate 40 so that the fixing portion 27 of the resonator contacts the Au films 38*a* and 38*b* disposed on the plate 40 and is fixed by electro-conductive sealing materials 47*a* and 47*b*, such as solder or the like, and at the same time is electrically connected to the exciting electrode films 33*a* and 33*b* disposed on opposite sides of the resonator 21. As will be clearly understood from Figure 19, the electrode lead films 38*a* and 38*b* are electrically connected to the exciting electrode film 33*a* disposed on the obverse surface of the resonator 26 and to the exciting electrode film 33*b* disposed on the reverse surface of the resonator 26 respectively. When an alternating voltage is applied to the Au films 38*a* and 38*b* so that the Au films 38*a* and 38*b* have a different polarity, an electric field in the direction of the plate thickness is applied to the vibrating portion of the resonator 21, whereby the resonator 21 vibrates. The vibration characteristic of the resonator assembly measured by the transmission method will be as shown in Table 2, and the frequency-temperature characteristics thereof will be shown in Figure 20.

In Table 2, Ro is an equivalent series resistance, Lo is an equivalent inductance, Co is an equivalent capacitance, and the number of resonators experimented with was 10. As will be clearly understood from the result of the experiment, each of the characteristics and the supporting structure is excellent even through the resonator is of miniature size.

TABLE 1

	dimension (mm)
W	1.6
L	1.41
W_0	0.12
W_1	0.08
W_2	0.10
W_3	0.08
L_1	0.92

TABLE 2

	KHz frequency	Ω R_0	(H) L_0	(fF) C_0
$\bar{x}$	2,265	80	1.76	2.80
σ	—	25	0.01	0.02

$\bar{x}$ denotes mean value.

σ denotes the standard deviation.

By way of another embodiment, guide members 50 were provided at the ends of the fixing portions 27, as shown in Figure 21. A complete description of Figure 21 is not provided since the portions thereof other than the guide members 50 are substantially the same as in Figures 18 and 19. The guide members 50 are made in one piece with fixing portions 27*a*, 27*b* and are inserted into holes

in a ceramic plate 42, the fixing portions 27*a*, 27*b* being automatically positioned by the guide members 50 when the resonator 21 is placed in position. Since the fixing portions 27*a*, 27*b* of the supporting portions 25*a*, 25*b* are scarcely displaced by the vibrations, the guide members 50 do not adversely affect the characteristic of the resonator. If necessary, the guide members 50 may be removed from the fixing portions 27*a*, 27*b* by notching necked portions 51 in the fixing portions 27*a*, 27*b* after the fixing portions 27*a*, 27*b* have been fixed by solder 47*a*, 47*b*. Since the resonator of Figure 21 can easily be positioned with the aid of the guide members 50, the construction of Figure 21 can be more easily assembled automatically than that of Figures 18 and 19.

Figures 22 and 23 show another embodiment of the present invention, wherein the supporting member is made of the same piezo-electric material is the resonator. Figure 22 is a plan view and Figure 23 is a section taken on the line A—A' of Figure 22. The vibrating portion 26 and the supporting portions 25 of the resonator 21 of Figure 22, which are made in one piece by way of the bridge portions 31*a* and 31*b*, have a predetermined cut angle and dimensions. The fixing portions 27*a*, 27*b* of the supporting portions 25 are provided with frame portions 21*a* of predetermined width surrounding the resonator 21, and an Au film 60, of about 2 μm in thickness, is disposed on both sides of the frame portions 21*a*. A base 62 is made of the same piezo-electric material as the resonator 21. An Au film (not shown) disposed on the obverse surface of the base 62 and an Au film (not shown) disposed on the reverse surface of the frame portions 21*a* are adhered to each other by way of solder or the like to thereby fix and seal the base 62 and the resonator 21 to each other. A vacuum sealing cap 61 is made of the same piezo-electric material as the resonator. An Au film (not shown) is disposed on the cap 61 and is adhered to the corresponding Au film 60 disposed on the frame portions 21*a* by way of solder or the like. Exciting electrodes 33*a* and 33*b*, disposed on the major surface of the resonator 21, are lead out and protrude from the frame portions 21*a*, the cap 61 being fixed on the frame portions 21*a* as it is. The cap 61 is omitted from Figure 22. The cap 61 and the base 62 are etched respectively to provide a void portion in which the resonator 21 is sealed. In order that this embodiment can be more easily understood, the assembly of the resonator will be described with reference to the resonator shown in Figures 24, 25, and 26. Three piezo electric plates respectively shown in Figures 24, 25 and 26 are treated in a batch process by a photo lithographic technique. Figure 25 shows a number of piezo-electric plates 62 arranged in a row and connected by way of connecting portions 75, the plates 62 and connecting portions 75 being simultaneously formed on a frame 74 by a photographic and etching technique from a piezo electric plate wafer 73. Thereafter portions 63*a* are etched from a few to several tens μ in depth and Au films 60*b* are disposed around the portions 63*a* by evaporation. Subsequently the unit comprising the vibrating portion 26, the supporting portions 25 and the frame portions 21*a* is formed in one body as shown in Figure 24, and a plurality of such units are arranged in a row on the frame 71 by way of the connecting portions 75, this assembly being formed from a piezo-electric plate wafer 70 by way of the above-mentioned techniques. The input and output electrode films 33*a* and 33*b* and an Au film 60*a* are then disposed on the resonator by spattering and evaporation.

After the above-mentioned process, caps 61 are fabricated from a piezo-electric plate wafter 76 shown in Figure 26 and are connected to a frame 77 by way of connecting portions 78. A portion 63*b* from a few to severals tens μ in depth and an Au film 60*c* are disposed on one side of each cap 61 by half etching. The three piezo-electric plates are assembled to overlap one another as shown in Figure 23. By applying heat and pressure to the Au films 60*a*, 60*b* and 60*c* which are disposed on the respective piezo-electric plates which overlap one another and are soldered together, the three piezo-electric plates are simultaneously sealed together. These assemblies of three piezo-electric plates are then separated from each other by lightly breaking the connecting portions 72, 75 and 78 at the end of the process.

Thus the embodiments shown in Figures 22, 23, 24, 25 and 26 are effective to permit mass production and a reduction in cost since the assembly of the resonator is not only simplified but also a number of cases containing the resonators can be made simultaneously in the same process.

Further, since both ends of the resonator are supported, the flexure caused by shock is small and it is therefore scarcely necessary to provide much space in the case. Moreover, since the resonator is not necessarily set on the frame, the space in the width direction (the space between the resonator and the inner wall of the case) can be very small, to enable the resonator to be miniaturized.

Figure 27 shows an embodiment of a resonator mounted on a supporting member such as a resilient plate spring.

The thickness of the resonator should desirably be reduced since it is made by a photo-lithographic technique. However, if this is done there is a fear that the resonator can be broken, or that if the resonator is mounted on elastic material and is subjected to shock, there will be a large frequency change by reason of the bending power applied to the resonator when the flexibility of the elastic material at the opposite ends of the resonator is different. In the embodiment shown in Figure 27, which aims to eliminate the above-mentioned disadvantages, the flexibility of the supporting material at the opposite ends of the resonator is always most equal. The exciting electrodes are omitted in Figure 27 for simplification purposes. The resonator 21 is enclosed by the steps of sealing a copper glass 82 into a cylindrical base 81 made of copper, introducing plate lead terminals 83*a*, 83*b* made of copper material through the cylindrical base 81, and introducing under pressure the lead terminals 83*a*, 83*b* and copper

glass 82 into a cylindrical cap 80 made of nickel silver. The resonator 21 is fixed to the lead terminals 83*a* and 83*b* by electro-conductive sealing material 84*a*, 84*b*, such as a solder, at fixing portions 27*a*, 27*b* provided at the ends of supporting portions 25*a* and 25*b*.

The lead terminals 83*a*, 83*b* are electrically connected to the exciting electrodes of the resonator 21 and to the external circuit, but said exciting electrodes are omitted since the principle is the same as in the embodiments shown in Figures 18, 19, 22 and 23.

Each of the lead terminals is designed so that the flexibility of the lead terminal 83*a* at the fixing point of the fixing portion 27*a* and the flexibility of the lead terminal 83*b* at the fixing point of the fixing portion 27*b* are substantially equal. A portion 85 at the end of the lead terminal 83*a* is provided so as to allow the flexibility of the latter to be adjusted.

The flexibility of the lead terminals will now be examined. If the lead terminal is regarded as a cantilever having a load mounted on the end thereof, the flexibility yl of the end of the lever is represented (using symbols as shown in Figure 28). as follow:—

$$y_1 = \frac{P}{3EI} l^3 = \frac{Pl}{3E} \cdot \frac{12}{bt^3} = \left(\frac{4P}{E}\right) \cdot \left[\frac{1}{b}\left(\frac{l}{t}\right)^3\right] \qquad (1)$$

where E is Youngs modulus and P is a concentrated load. Accordingly, the flexibility of the end of the cantilever is adjusted by changing the length l, the width b and the thickness t. The equation (1) shows that the simplest method to adjust the flexibility of the load terminal is to change the value of l/t. Further, if a load is mounted on the middle of the lever, the flexibility y_2 of the end of the lever is represented as follows:

$$y_2 = \frac{Pa^2}{6EI}(3l - a) = \frac{P}{6E} a^2 \cdot (3l - a) \cdot \frac{12}{bt^3} = \left(\frac{2P}{E}\right) \cdot \left[\frac{1}{bt^3} \cdot a^2 (3l - a)\right] \qquad (2)$$

provided that *a* is the length from the supporting point to the loaded point as shown in Figure 29. y_2 changes in dependence upon the loaded position and the dimensions of the lever. P in equations (1) and (2) can be changed by adding an additional load (e.g. the portion 85 shown in Figure 27). Thus there are various methods of changing the flexibility not necessarily referred to here. From the above it will be seen that one can add the additional load as shown in Figure 27, one can change the dimensions of the lead terminals, one can equalize the length from the copper glass to the fixing portions and one can change each of the dimensions.

The embodiments of the present invention described above have the following features.

(1) The resinator has an excellent and stable characteristic (the variation in the characteristic is small) since the supporting structure ensures that the energy loss is at a minimum.

(2) The shock resistance is excellent since the resonator can be rigidly supported because of its small energy loss.

(3) The resonator can have a small energy loss even if the supporting portions are small. Since the supporting portions are provided at the short sides of the vibrating portion, the resonator is easily miniaturized.

(4) As will be clear from features (1) and (2), the assembly of the resonator is easy and mass production is possible.

(5) Each of the dimensions (W_1, W_2, W_3, W_0 and L_1) of the supporting portions can be varied, within the limits set by the inequalities mentioned above, so there are many possible designs.

(6) A quartz resonator of desired characteristics can be produced since the degree of freedom of the cut angle and the dimensional ratio is large.

(7) A resonator having excellent frequency temperature characteristics can be produced by suitably combining the cut angle and the dimensional ratio after the shape and the dimensions of the supporting portions have been decided.

(8) The disturbance of mode of the vibrating portion which is produced when the supporting portions and the vibrating portion are made in one piece is easily removed by changing the electrode composition as necessary.

(9) When two supporting portions are provided at opposite ends of the vibrating poriton, the amount of flexure caused by shock is small, and the case of the resonator can be exceeding small for the reason indicated at feature (3) above.

CLAIMS

1. A contour vibration mode piezo-electric resonator comprising a rectangular vibrating portion having opposed relatively short sides and opposed relatively long sides, the vibrating portion being integrally connected to at leat one supporting portion by way of a respective bridge portion, the or each supporting portion comprising a resilient portion which is connected to the vibrating portion by way of the said bridge portion, a vibration attenuation portion which is integrally connected to the resilient portion, and a fixing portion which is adapted to be fixed to a support member, the fixing portion being

glass 82 into a cylindrical cap 80 made of nickel silver. The resonator 21 is fixed to the lead terminals 83*a* and 83*b* by electro-conductive sealing material 84*a*, 84*b*, such as a solder, at fixing portions 27*a*, 27*b* provided at the ends of supporting portions 25*a* and 25*b*.

The lead terminals 83*a*, 83*b* are electrically connected to the exciting electrodes of the resonator 21 and to the external circuit, but said exciting electrodes are omitted since the principle is the same as in the embodiments shown in Figures 18, 19, 22 and 23.

Each of the lead terminals is designed so that the flexibility of the lead terminal 83*a* at the fixing point of the fixing portion 27*a* and the flexibility of the lead terminal 83*b* at the fixing point of the fixing portion 27*b* are substantially equal. A portion 85 at the end of the lead terminal 83*a* is provided so as to allow the flexibility of the latter to be adjusted.

The flexibility of the lead terminals will now be examined. If the lead terminal is regarded as a cantilever having a load mounted on the end thereof, the flexibility yl of the end of the lever is represented (using symbols as shown in Figure 28). as follow:—

$$y_1 = \frac{P}{3EI} l^3 = \frac{Pl}{3E} \cdot \frac{12}{bt^3} = \left(\frac{4P}{E}\right) \cdot \left[\frac{1}{b}\left(\frac{l}{t}\right)^3\right] \qquad (1)$$

where E is Youngs modulus and P is a concentrated load. Accordingly, the flexibility of the end of the cantilever is adjusted by changing the length l, the width b and the thickness t. The equation (1) shows that the simplest method to adjust the flexibility of the load terminal is to change the value of l/t. Further, if a load is mounted on the middle of the lever, the flexibility y_2 of the end of the lever is represented as follows:

$$y_2 = \frac{Pa^2}{6EI}(3l - a) = \frac{P}{6E} a^2 \cdot (3l - a) \cdot \frac{12}{bt^3} = \left(\frac{2P}{E}\right) \cdot \left[\frac{1}{bt^3} \cdot a^2 (3l - a)\right] \qquad (2)$$

provided that *a* is the length from the supporting point to the loaded point as shown in Figure 29. y_2 changes in dependence upon the loaded position and the dimensions of the lever. P in equations (1) and (2) can be changed by adding an additional load (e.g. the portion 85 shown in Figure 27). Thus there are various methods of changing the flexibility not necessarily referred to here. From the above it will be seen that one can add the additional load as shown in Figure 27, one can change the dimensions of the lead terminals, one can equalize the length from the copper glass to the fixing portions and one can change each of the dimensions.

The embodiments of the present invention described above have the following features.

(1) The resinator has an excellent and stable characteristic (the variation in the characteristic is small) since the supporting structure ensures that the energy loss is at a minimum.

(2) The shock resistance is excellent since the resonator can be rigidly supported because of its small energy loss.

(3) The resonator can have a small energy loss even if the supporting portions are small. Since the supporting portions are provided at the short sides of the vibrating portion, the resonator is easily miniaturized.

(4) As will be clear from features (1) and (2), the assembly of the resonator is easy and mass production is possible.

(5) Each of the dimensions (W_1, W_2, W_3, W_0 and L_1) of the supporting portions can be varied, within the limits set by the inequalities mentioned above, so there are many possible designs.

(6) A quartz resonator of desired characteristics can be produced since the degree of freedom of the cut angle and the dimensional ratio is large.

(7) A resonator having excellent frequency temperature characteristics can be produced by suitably combining the cut angle and the dimensional ratio after the shape and the dimensions of the supporting portions have been decided.

(8) The disturbance of mode of the vibrating portion which is produced when the supporting portions and the vibrating portion are made in one piece is easily removed by changing the electrode composition as necessary.

(9) When two supporting portions are provided at opposite ends of the vibrating poriton, the amount of flexure caused by shock is small, and the case of the resonator can be exceeding small for the reason indicated at feature (3) above.

CLAIMS

1. A contour vibration mode piezo-electric resonator comprising a rectangular vibrating portion having opposed relatively short sides and opposed relatively long sides, the vibrating portion being integrally connected to at leat one supporting portion by way of a respective bridge portion, the or each supporting portion comprising a resilient portion which is connected to the vibrating portion by way of the said bridge portion, a vibration attenuation portion which is integrally connected to the resilient portion, and a fixing portion which is adapted to be fixed to a support member, the fixing portion being

integrally connected to or forming at least a part of the vibration attenuation portion, and wherein the relationship between the width W of each of the short sides of the vibrating portion, the width W_0 of the or each bridge portion, and the length L_1 and the width W_1 of the or each resilient portion is represented by:

$$0.015 \leqq (W_0/W) \leqq 0.200, \text{ and}$$

$$5 \leqq (L_1/W_1) \leqq 25$$

2. A resonator as claimed in claim 1 in which the resonator is made by etching.

3. A resonator as claimed in claim 1 or 2 in which the or each supporting portion is provided substantially at the centre of a said relatively short side of the vibrating portion.

4. A resonator as claimed in any preceding claim in which the or each bridge portion is provided substantially at the centre of the respective resilient portion.

5. A resonator as claimed in any preceding claim in which the or each supporting portion has an opening therethrough which is surrounded by the respective connected together resilient and vibration attenuation portions.

6. A resonator as claimed in any preceding claim in which the or each resilient portion extends substantially parallel to the relatively short sides of the vibrating portion.

7. A resonator as claimed in any preceding claim in which at least a part of the or each vibration attenuation portion extends substantially parallel to the respective resilient portion.

8. A resonator as claimed in any preceding claim in which the relationship between the width W_1 of the or each resilient portion, the width W_2 of the or each vibration attenuation portion and the space W_3 between the or each resilient portion and the respective vibration attenuation portion is represented by

$$0.3 \leqq (W_1/W_2) \leqq 1.2,$$

$$W_1 \leqq 1.5 \times W_0, \text{ and}$$

$$0.2 \leqq (W_1/W_3) \leqq 2.0$$

9. A resonator as claimed in any preceding claim in which the relationship between the relatively long sides L and the relatively short sides W of the vibrating portion is represented by:

$$0.8 \leqq (W/L) < 1.0$$

10. A resonator as claimed in any preceding claim in which the resonator is made from a quartz crystal Y plate rotated around the X axis through an angle of 45° to 65°, the Y plate being further rotated through an angle of ± (40° to 50°) in a plane parallel to the major surfaces thereof.

11. A resonator as claimed in any preceding claim in which metallic electrode films are provided on each of the opposite major surfaces of the vibrating portion and supporting portion(s).

12. A resonator as claimed in claim 11 in which the electrode films are removed from the vicinity of the bridge portion(s) or are thicker in said vicinity.

13. A resonator as claimed in any preceding claim in which the or each fixing portion is fixed and sealed to a supporting member which is provided on a case which houses the resonator, the or each fixing portion being electrically connected to the supporting member.

14. A resonator substantially as hereinbefore described with reference to and as shown in any of Figures 8, 9, 11(a), 11(b), 11(c), 11(d), 12 and 13, 16—19 and 21—27.

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