SPECIFICATION

Thickness-shear mode piezo-electric vibrator

The present invention relates to a thickness shear mode piezo-electric vibrator such as an AT-cut quartz vibrator, or a BT-cut quartz vibrator.

A quartz vibrator generally operates in a fundamental main vibration and in many spurious vibrations. If the frequency of the fundamental main vibration is adjacent to the frequency of a spurious vibration, there is a risk that the quartz vibrator will operate in the spurious vibration or will be influenced by the spurious vibration.

According, therefore, to the present invention, there is provided a thickness-shear mode piezo-electric vibrator having an electric or X axis and comprising a piezo-electric member formed of a meterial which can vibrate both in a fundamental main vibration and in a spurious vibration, opposite surfaces of the piezo-electric member being provided with driving electrodes one of which has a blank central portion, the blank central portion being relatively narrow in the direction of the X axis of the vibrator at the central part of the piezo-electric member at which the electric charge of the fundamental main vibration is concentrated, and being relatively wide in the said direction on opposite sides of said central part at which components of the electric charge of the spurious vibration are concentrated.

Preferably, the maximum distance through which the blank central portion extends in the Z axis direction is substantially greater than the maximum distance through which the blank central portion extends in the X axis direction.

The blank central portion may be part-circular in shape. The blank central portion may have edge portions which divide the respective driving electrode into two parts.

The blank central portion preferably extends throughout the whole of the part of the piezo-electric member at which the electric charge of the spurious vibration is concentrated but does not extend throughout the whole of the part of the piezo-electric member at which the electric charge of the fundamental main vibration is concentrated.

The other driving electrode may be elongated in the direction of the X axis.

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

Figure 1 is a front elevation of a known AT-cut quartz vibrator in which there is indicated by a dotted line the electric charge I of the fundamental main vibration of the vibrator.

Figure 2 is a graph illustrating the distribution about the Z axis of the electric charge of the fundamental main vibration of the vibrator shown in Figure 1.

Figure 3 is a front elevation of a known AT-cut quartz vibrator in which there is indicated by dotted lines the electric charge II of a spurious vibration of the vibrator,

Figure 4 is a graph illustrating the distribution about the Z axis of the electric charge of the spurious vibration of the vibrator shown in Figure 3,

Figure 5 is an equivalent circuit diagram of a quartz vibrator,

Figure 6 is a front view of an AT-cut quartz vibrator according to one embodiment of the present invention, there being indicated by a dotted line in Figure 6, the electric charge I of the fundamental main vibration of the vibrator.

Figure 7 is a rear view of the vibrator shown in Figure 6, there being indicated by dotted lines the electric charge II of a spurious vibration of the vibrator,

Figure 8 is a front view of an AT-cut quartz vibrator according to another embodiment of the present invention, and

Figure 9 is a rear view of the vibrator shown in Figure 8.

A quartz vibrator generally operates in a fundamental main vibration (I) and in many spurious vibrations (II). If the frequency of the fundamental main vibration I is adjacent to the frequency of a spurious vibration II, the quartz vibrator may operate in the spurious vibration or may be influenced by the spurious vibration,. For example an AT-cut thickness-shear mode quartz vibrator whose fundamental frequency I is about 4.2MHz can operate in a spurious vibration II whose frequency is about 4.6MHz. This fundamental main vibration I is indicated in Figure 1 by a dotted line, while Figure 2 shows the distribution of the electric charge of this fundamental main vibration I about the Z axis in Figure 2. The spurious vibration II is shown by dotted lines in Figure 3, while Figure 4 shows the distribution of the electric charge of this spurious vibration II about the Z axis. As will be seen from Figures 1 and 2, the fundamental main vibration I is constituted by a positive electric charge which is concentrated at the control part of the quartz member. Moreover, as will be seen from Figures 3 and 4, the spurious vibration II is constituted by a positive component of the electric charge which is concentrated at the central part of the quartz member, and two negative components of the electric charge which are concentrated on opposite sides of the positive component with respect to the Z axis. This distribution of the electic charge is substantially equal to the distribution of the vibration energy.

The object of the present invention is therefore to provide a piezo-electric vibrator whose driving electrodes are so shaped that the vibrator can be easily operated in the fundamental main vibration but in which it is difficult for it to operate in a spurious vibration.

In Figures 6 and 7 there is shown a thickness-shear mode quartz crystal vibrator according to the present invention which comprises a quartz member 1 formed of a material which can vibrate both in a fudamental main vibration I and in a spurious vibration II, a front driving electrode 2 and a rear driving electrode 4 which are provided on opposite surfaces of the quartz member 1. The rear driving electrode 4 has a part-circular blank central portion 3, the maximum distance through which the blank central portion 3 extends in the Z axis direction being substantially greater than the maximum distance

through which the blank central portion extends in the X axis direction. The front driving electrode 2, which is usually of a circular shape as shown, may be formed on a surface of the quartz member 1 by evaporation or by some other method. The rear driving electrode 4 which is provided with the blank central portion 3, may be formed on the other surface of the quartz member 1 by evaporation or by some other method.

The blank central portion 3 has a special shape. That is to say, the parts of the blank central portion 3 which correspond to components IIB and IIC of the electric charge of the spurious vibration II are relatively wide in the direction of the X axis, as indicated at W_1, and the part of the blank central portion 3 which corresponds to the electric charge of the fundamental main vibration I, that is the central portion of the quartz vibrator, is relatively narrow in the direction of the X axis, as indicated at W_2. In other words, the shape of the blank central portion 3 is narrow at the centre part of the quartz member 1 and wide on the right and left hand sides of this centre part with respect to the Z axis. As will be seen, the blank central portion 3 extends throughout the whole of the part of the quartz member 1 at which the electric charge of the spurious vibration II is concentrated, but does not extend throughout the whole of the part of the quartz member 1 at which the electric charge of the fundamental main vibration I is concentrated. The blank central portion 3 has edge portions 3*a*, 3*b* which divide the rear driving electrode 4 into two parts. The edge portions 3*a* and 3*b* correspond to supports for a mask (not shown) which may be employed when the rear driving electrode 4 is formed by evaporation so as to produce the blank central portion 3. However, if the blank central portion 3 is made in the rear driving electrode 4 by a suitable method, the edge portions 3*a* and 3*b* are not necessary.

As stated above, the central part of the blank central portion 3 is narrow, as indicated at W_2, i.e. the central portions of the rear driving electrode 4 project into the blank central portion 3. In other words, the right and left hand parts of the blank central portion 3 which correspond with the right and left hand components of the electric charge of the spurious vibration are wide as indicated at W_1, the electrode material being absent or removed here over a wide area. Thus the quartz vibrator of Figures 6 and 7 operates efficiently in the fundamental main vibration, but does not easily operate in the spurious vibration.

In Figure 5 there is shown an equivalent circuit of a quartz vibrator comprising an inductance L, a motional capacitance Cm, a crystal resistance R, and a capacitance C. A quartz vibrator according to the present invention can have an improved Q-value, a much reduced motional capacitance Cm, but a somewhat increased crystal resistance R. In the quartz vibrator according to the present invention the stray capacitance is hardly affected by the decrease in the motional capacitance Cm, while the stability of the frequency can be improved. Furthermore, since one of the driving electrodes, that is the rear driving electrode, does not have an electrode film in the central portion of the quartz member where the vibration displacement is large, there is little change in the frequency of the quartz vibrator with age. Moreover, the frequency can be efficiently adjusted by using an additional mass since the other driving electrode, that is the front driving electrode, has an electrode film in the central portion of the quartz member where the vibration displacement is large.

In the embodiment of the invention described above, it is necessary that the front driving electrode 2 should have an electrode film at least throughout the portion at which the electric charge of the fundamental main vibration is concentrated as shown by the dotted line in Figure 6. But it is also desirable that the front driving electrode 2 should be a large circular electrode as shown in Figure 6 so as to ensure good values of the crystal resistance R and the motional capacitance Cm.

A further embodiment of the present invention is shown in Figures 8 and 9 in which a front driving electrode 12, which is elongated in the direction of the X axis, is formed on a surface of a quartz member 11 by evaporation or by some other method. The front driving electrode 12 may, as shown, have projections 12*a* and 12*b* which extend from a substantially circular electrode in the direction of the X axis, as indicated in Figure 8. Alternatively, the front driving electrode 12 may be shaped as an ellipse which is elongated in the direction of the X axis. A rear driving electrode 14, having a blank central portion 13, is formed on the opposite surface of the quartz member 11, and may have the same shape as that shown in Figure 7.

When a voltage is applied to the front driving electrode 12 and to the rear driving electrode 14, the quartz vibrator shown in Figures 8 and 9 operates efficiently in the fundamental main vibration, but does not easily operate in the spurious vibration. Furthermore, the motional capacitance Cm and the crystal resistance R shown in the equivalent diagram of Figure 5 are improved by virtue of the fact that the front electrode 12 has projections 12*a*, 12*b* in the direction of the X axis. That is to say, the crystal resistance R decreases considerably, but the motional capacitance Cm increases only a little. Because the rear driving electrode 14 is long in the direction of the X axis, there is a large measure of overlap between the front driving electrode 12 and the rear driving electrode 14.

CLAIMS

1. A thickness-shear-mode piezo-electric vibrator having an electrical or X axis and comprising a piezo-electric member formed of a material which can vibrate both in a fundamental main vibration and in a spurious vibration, opposite surfaces of the piezo-electric member being provided with driving electrodes one of which has a blank central portion, the blank central portion being relatively narrow in the direction of the X axis of the vibrator at the central part of the piezo-electric member at which the electric charge of the fundamental main vibration is concentrated, and being relatively wide in the

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through which the blank central portion extends in the X axis direction. The front driving electrode 2, which is usually of a circular shape as shown, may be formed on a surface of the quartz member 1 by evaporation or by some other method. The rear driving electrode 4 which is provided with the blank central portion 3, may be formed on the other surface of the quartz member 1 by evaporation or by some other method.

The blank central portion 3 has a special shape. That is to say, the parts of the blank central portion 3 which correspond to components IIB and IIC of the electric charge of the spurious vibration II are relatively wide in the direction of the X axis, as indicated at W_1, and the part of the blank central portion 3 which corresponds to the electric charge of the fundamental main vibration I, that is the central portion of the quartz vibrator, is relatively narrow in the direction of the X axis, as indicated at W_2. In other words, the shape of the blank central portion 3 is narrow at the centre part of the quartz member 1 and wide on the right and left hand sides of this centre part with respect to the Z axis. As will be seen, the blank central portion 3 extends throughout the whole of the part of the quartz member 1 at which the electric charge of the spurious vibration II is concentrated, but does not extend throughout the whole of the part of the quartz member 1 at which the electric charge of the fundamental main vibration I is concentrated. The blank central portion 3 has edge portions 3*a*, 3*b* which divide the rear driving electrode 4 into two parts. The edge portions 3*a* and 3*b* correspond to supports for a mask (not shown) which may be employed when the rear driving electrode 4 is formed by evaporation so as to produce the blank central portion 3. However, if the blank central portion 3 is made in the rear driving electrode 4 by a suitable method, the edge portions 3*a* and 3*b* are not necessary.

As stated above, the central part of the blank central portion 3 is narrow, as indicated at W_2, i.e. the central portions of the rear driving electrode 4 project into the blank central portion 3. In other words, the right and left hand parts of the blank central portion 3 which correspond with the right and left hand components of the electric charge of the spurious vibration are wide as indicated at W_1, the electrode material being absent or removed here over a wide area. Thus the quartz vibrator of Figures 6 and 7 operates efficiently in the fundamental main vibration, but does not easily operate in the spurious vibration.

In Figure 5 there is shown an equivalent circuit of a quartz vibrator comprising an inductance L, a motional capacitance Cm, a crystal resistance R, and a capacitance C. A quartz vibrator according to the present invention can have an improved Q-value, a much reduced motional capacitance Cm, but a somewhat increased crystal resistance R. In the quartz vibrator according to the present invention the stray capacitance is hardly affected by the decrease in the motional capacitance Cm, while the stability of the frequency can be improved. Furthermore, since one of the driving electrodes, that is the rear driving electrode, does not have an electrode film in the central portion of the quartz member where the vibration displacement is large, there is little change in the frequency of the quartz vibrator with age. Moreover, the frequency can be efficiently adjusted by using an additional mass since the other driving electrode, that is the front driving electrode, has an electrode film in the central portion of the quartz member where the vibration displacement is large.

In the embodiment of the invention described above, it is necessary that the front driving electrode 2 should have an electrode film at least throughout the portion at which the electric charge of the fundamental main vibration is concentrated as shown by the dotted line in Figure 6. But it is also desirable that the front driving electrode 2 should be a large circular electrode as shown in Figure 6 so as to ensure good values of the crystal resistance R and the motional capacitance Cm.

A further embodiment of the present invention is shown in Figures 8 and 9 in which a front driving electrode 12, which is elongated in the direction of the X axis, is formed on a surface of a quartz member 11 by evaporation or by some other method. The front driving electrode 12 may, as shown, have projections 12*a* and 12*b* which extend from a substantially circular electrode in the direction of the X axis, as indicated in Figure 8. Alternatively, the front driving electrode 12 may be shaped as an ellipse which is elongated in the direction of the X axis. A rear driving electrode 14, having a blank central portion 13, is formed on the opposite surface of the quartz member 11, and may have the same shape as that shown in Figure 7.

When a voltage is applied to the front driving electrode 12 and to the rear driving electrode 14, the quartz vibrator shown in Figures 8 and 9 operates efficiently in the fundamental main vibration, but does not easily operate in the spurious vibration. Furthermore, the motional capacitance Cm and the crystal resistance R shown in the equivalent diagram of Figure 5 are improved by virtue of the fact that the front electrode 12 has projections 12*a*, 12*b* in the direction of the X axis. That is to say, the crystal resistance R decreases considerably, but the motional capacitance Cm increases only a little. Because the rear driving electrode 14 is long in the direction of the X axis, there is a large measure of overlap between the front driving electrode 12 and the rear driving electrode 14.

CLAIMS

1. A thickness-shear mode piezo-electric vibrator having an electrical or X axis and comprising a piezo-electric member formed of a material which can vibrate both in a fundamental main vibration and in a spurious vibration, opposite surfaces of the piezo-electric member being provided with driving electrodes one of which has a blank central portion, the blank central portion being relatively narrow in the direction of the X axis of the vibrator at the central part of the piezo-electric member at which the electric charge of the fundamental main vibration is concentrated, and being relatively wide in the

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said direction on opposite sides of said central part at which components of the electric charge of the spurious vibration are concentrated.

2. A vibrator as claimed in claim 1 in which the maximum distance through which the blank central portion extends in the Z axis direction is substantially greater than the maximum distance through which the blank central portion extends in the X axis direction.

3. A vibrator as claimed in claim 1 or 2 in which the blank central portion is part-circular in shape.

4. A vibrator as claimed in any preceding claim in which the blank central portion has edge portions which divide the respective driving electrode into two parts.

5. A vibrator as claimed in any preceding claim in which the blank central portion extends throughout the whole of the part of the piezo-electric member at which the electric charge of the spurious vibration is concentrated but does not extend throughout the whole of the part of the piezo-electric member at which the electric charge of the fundamental main vibration is concentrated.

6. A vibrator as claimed in any preceding claim in which the other driving electrode is elongated in the direction of the X axis.

7. A thickness-shear mode piezo-electric vibrator substantially as hereinbefore described with reference to and as shown in Figures 6 and 7 or in Figures 8 and 9 of the accompanying drawings.

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