

PATENT SPECIFICATION

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(54) IMPROVEMENTS IN OR RELATING TO TEMPERATURE COMPENSATED ELECTRIC TIMEPIECES

(71) We, KABUSHIKI KAISHA SUWA SEIKOSHA, a Corporation of Japan 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 temperature compensated electric timepieces of the kind having a crystal oscillator as the time standard thereof.

The invention seeks to provide the crystal oscillator of such a watch with improved simple and compact temperature compensating means for maintaining the time standard oscillator frequency substantially constant, despite temperature variations, over a usefully wide range, at a desired value. An important object of the invention is to provide such temperature compensation and also frequency adjusting means for the crystal oscillator by means of a single element which serves both to maintain the frequency substantially constant despite ambient temperature changes and to permit the value of that frequency to be manually adjusted. The invention offers the advantages — very important for watches such as wrist watches where space is limited — of great compactness and efficiency as regards power consumption, no electric power being required for achieving temperature compensation.

According to this invention the crystal oscillator of a timepiece having said crystal oscillator as the time standard thereof is temperature compensated by means of a manually adjustable temperature compensating condenser the dielectric of which is made of a ferro-electric substance and which is adapted to present a temperature coefficient which changes from positive to negative in the ambient temperature range for which said oscillator is intended said condenser serving both for temperature compensation and

manual adjustment of the time standard frequency.

Preferably said dielectric substance is BaTiO_3 .

The temperature compensating condenser may be continuously adjustable and may have a fixed electrode on one side of a dielectric plate of ferro-electric substance and a movable electrode on the other side thereof.

However, the condenser may be variable in steps and in preferred constructions of this nature there is, on one side of the dielectric of the condenser, a relatively large electrode in capacitative relationship with a plurality of separate electrodes on the other side thereof, means being provided for adjusting the capacity by switch selection of the separate electrodes brought into circuit. The separate electrodes may be of different progressively increasing areas and switch selection may be effected by a movable contact arm adapted to be moved to connect with any one of them or they may be individually alike and switch selection effected by a contact arm adapted to be moved to connect with any desired number (from one upwards) of said separate electrodes simultaneously.

Preferably the electrodes of the condenser are in the form of fired-on metal coatings (e.g. of silver) on a dielectric substrate.

The invention is illustrated in and explained on connection with the accompanying drawings in which:—

Figures 1 and 2 are diagrams of conventional known temperature compensated crystal oscillators as at present used in electric watches,

Figures 3 and 4 are diagrams of time standard temperature compensated frequency adjustable oscillators for use in timepieces in accordance with this invention,

Figures 5a and 5b are mutually perpendicular schematic representations of one form of temperature compensating adjustable condenser suitable for use in carrying out this

invention and providing continuous adjustment of frequency, and

Figures 6 and 7 show forms of temperature compensating adjustable condenser for use in carrying out this invention and providing stepped adjustment of frequency.

Referring to Figure 1 this shows a known temperature compensated crystal oscillator as at present commonly used as the time standard of an electric watch. It comprises a temperature compensating element C_t connected in series with the crystal X and constituted by an element such as thermistor or a capacitor the capacity of which is arranged in known manner to vary with temperature. This temperature compensating element is a device which is constructionally separate from and used in the watch and is hermetically sealed (as the other parts of the oscillator usually are) and is designed and dimensioned to vary its capacity with temperature in such manner as to ensure that a predetermined oscillator frequency (f_0) is maintained as nearly as possible constant despite ambient temperature changes thereby ensuring a substantially temperature-independent "rate" for the watch. The rate can be adjusted by adjusting an adjustable condenser C_s also in series with the crystal. Since the oscillator forms the time standard of the watch it is possible to obtain accurate time-keeping, substantially independent of temperature, by adjusting C_s to bring f_0 accurately to a predetermined substantially constant value. In the known oscillator circuit shown T_r is a transistor, L an inductance (the watch driving coil) which is the load thereof, R is the base resistance for the transistor and B is a battery.

Figure 2 shows another known circuit which needs little further description over that already given for Figure 1. In Figure 2, X is again the crystal, C_t the temperature compensating condenser and C_s the frequency adjusting condenser. The transistor, here referenced T is shown as a field effect transistor (F.E.T.), R_1 , R_2 and R_3 being the usual circuit resistances associated therewith. B is again the battery.

Figure 3 is a circuit diagram of an improved oscillator for use as the time standard of a watch in accordance with this invention. Here X is again the crystal but instead of the two separate condensers C_t and C_s of Figures 1 and 2 there is only a single condenser C_{ts} (a preferred construction for which will be described later) which performs the two functions of temperature compensation and rate adjustment. In Figure 3 the amplifier block referenced AMP represents the rest of the circuit which, except for the substitution of C_{ts} for C_t and C_s is as in Figure 1.

Figure 4 shows another time standard oscillator circuit for use in a watch in accordance with this invention. It needs no further description beyond that it is like Figure 2

except for the substitution of the single condenser C_{ts} for the two condensers C_t and C_s of Figure 2.

The condenser C_{ts} (Figure 3 or Figure 4) has a dielectric made of a ferro-electric substance such as the ceramic material $BaTiO_3$. The ferroelectric substance is a recently developed mixture containing barium or strontium and the temperature of its Curie point can be chosen at any desired value by suitably selecting the ratio of mixing. If the ambient temperature becomes higher than the Curie point, a condenser with a dielectric of $BaTiO_3$ exhibits a negative temperature characteristic. If the ambient temperature is below the Curie point and increases from a low value to the Curie point temperature, the capacity of the condenser increases and if the ambient temperature rises still further increasing above the Curie point temperature the capacity of the condenser reduces.

The performance of the ferroelectric substance changes strikingly when the temperature exceeds the Curie point and one this happens it is difficult to regain the original performance exhibited at temperatures below the Curie point. If the temperature is increased from low to high through the Curie point and then brought back again from high to low, the original dielectric constant is not regained. In other words a hysteresis effect is exhibited. However experiment has shown — and in particular an experiment in which the temperature was repeatedly cycled over a range about twice as large as a practical operating temperature range for a watch ($-20^\circ C \sim +80^\circ C$) — that a condenser with a ferroelectric substance as its dielectric can be used satisfactorily in an oscillator as diagrammatically represented in Figure 2.

In general, the temperature-frequency characteristics of a crystal oscillator as represented in Figure 3 or 4 is a parabola, with its peak point at or near the temperature at which the condenser C_{ts} is of zero temperature coefficient at which point the temperature constancy of frequency is a minimum. Accordingly, in carrying out this invention the condenser C_{ts} is so designed that the said peak point occurs at about $20^\circ C$, said condenser exhibiting zero temperature coefficient at about this temperature. If this is done, the ferroelectric dielectric chosen being one having its Curie point at about $20^\circ C$ a high degree of frequency independence of temperature is obtained even although the Curie point temperature may be exhibited and good practical results are obtained.

Figure 5 shows one form of continuously variable condenser for the condenser C_{ts} . Referring to Figure 5, the dielectric of the condenser is a semi-circular plate 1 of $BaTiO_3$ with a metal rotor electrode 2 (for rate adjustment) on one side and a fixed electrode 3 (not shown in Figure 5a) on the other. By

adjusting electrode 2 rotationally a desired substantially constant value of f_0 can be obtained. The parts of this condenser need not be shaped as shown in Figure 5 and by suitably choosing the shapes, in accordance with principles well known in condenser practice generally, desired different laws of variation of capacity with rotation of the rotatable electrode can be obtained.

10 In the form of condenser shown in Figure 6 silver electrodes 10a, 10b, 10c, 10d and 10e are fired on a substrate of BaTiO_3 referenced 12 the areas of these electrodes being different in size. 13 is a brush contact by which connection can be made to any of these electrodes. There is a fired-on silver back electrode, which does not appear in Figure 6 covering the whole rear (i.e. rear as viewed in Figure 6) surface of the substrate 12.

20 In the form of condenser shown in Figure 7 a coating of silver is fired on one side (that which appears in Figure 7) of the substrate 12 of BaTiO_3 and this coating is radially cut to form a number of similar sector shaped electrode 14a, 14b and so on. A broad angled sector shaped brush 15 provides connection to these electrodes and, as will be apparent it is possible, by rotation of the brush 15 to bring one, two or any other number of the electrodes 14a, 14b into circuit in dependence upon the position of the said brush. A back electrode, which does not appear in Figure 7, is provided as in the case of Figure 6.

35 The step by step adjustable condensers of Figures 6 and 7 have the advantage that a desired maximum capacity can be obtained with a small physical size of condenser because the electrodes, being fired on to the dielectric, make intimate contact therewith and the front and rear electrodes are thus brought very close together being spaced apart only by the thickness of the substrate which can be made quite thin. These constructions thus overcome the difficulty of obtaining relatively large capacity with relatively small size in a condenser in which the dielectric is a sintered material such as BaTiO_3 . By providing an adequate number of electrodes on one side of the substrate any practically desirable smallness of individual capacity steps can be obtained.

55 The space available in a quartz crystal watch, and in particular a wrist watch, is very limited and the invention is of great advantage for such watches inasmuch as it substitutes one component for two and therefore enables a very compact temperature compensated quartz crystal oscillator to be made.

WHAT WE CLAIM IS:—

1. An electric timepiece having a crystal oscillator as the time standard thereof, wherein said oscillator is temperature compensated by means of a manually adjustable temperature compensating condenser the dielectric of which is made of a ferro-electric substance and which is adapted to present a temperature coefficient which changes from positive to negative in the ambient temperature range for which said oscillator is intended, said condenser serving both for temperature compensation and manual adjustment of the time standard frequency.

2. A timepiece as claimed in claim 1 wherein said dielectric substance is BaTiO_3 .

3. A timepiece as claimed in claim 1 or 2 wherein said condenser has a fixed electrode on one side of a dielectric plate of ferro-electric substance and a movable electrode on the other side thereof.

4. A time piece as claimed in any of the preceding claims wherein the condenser is in series with the crystal in the circuit of the oscillator.

5. A timepiece as claimed in any of the preceding claims wherein the condenser is adjustable in steps.

6. A timepiece as claimed in claim 5 wherein the condenser has, on one side of the dielectric thereof, a relatively large electrode in capacitative relationship with a plurality of separate electrodes on the other side thereof, means being provided for adjusting the capacity by switch selection of the separate electrodes brought into circuit.

7. A timepiece as claimed in claim 6 wherein the separate electrodes are of different areas and switch selection means constituted by a movable contact arm adapted to be moved to connect with any one of them are provided.

8. A timepiece as claimed in claim 6 wherein the separate electrodes are individually alike and switch selection is effected by a contact arm adapted to be moved to connect with any desired number of said electrodes simultaneously.

9. A timepiece as claimed in any of claims 5 to 8 wherein the electrodes of the condenser are in the form of fired-on metal coatings on a dielectric substrate.

10. A timepiece as claimed in any of the preceding claims wherein the condenser is substantially as herein described and illustrated in Figure 6 or Figure 7 of the accompanying drawings.

adjusting electrode 2 rotationally a desired substantially constant value of f_0 can be obtained. The parts of this condenser need not be shaped as shown in Figure 5 and by suitably choosing the shapes, in accordance with principles well known in condenser practice generally, desired different laws of variation of capacity with rotation of the rotatable electrode can be obtained.

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The step by step adjustable condensers of Figures 6 and 7 have the advantage that a desired maximum capacity can be obtained with a small physical size of condenser because the electrodes, being fired on to the dielectric, make intimate contact therewith and the front and rear electrodes are thus brought very close together being spaced apart only by the thickness of the substrate which can be made quite thin. These constructions thus overcome the difficulty of obtaining relatively large capacity with relatively small size in a condenser in which the dielectric is a sintered material such as BaTiO_3 . By providing an adequate number of electrodes on one side of the substrate any practically desirable smallness of individual capacity steps can be obtained.

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2. A timepiece as claimed in claim 1 wherein said dielectric substance is BaTiO_3 .

3. A timepiece as claimed in claim 1 or 2 wherein said condenser has a fixed electrode on one side of a dielectric plate of ferro-electric substance and a movable electrode on the other side thereof.

4. A time piece as claimed in any of the preceding claims wherein the condenser is in series with the crystal in the circuit of the oscillator.

5. A timepiece as claimed in any of the preceding claims wherein the condenser is adjustable in steps.

6. A timepiece as claimed in claim 5 wherein the condenser has, on one side of the dielectric thereof, a relatively large electrode in capacitative relationship with a plurality of separate electrodes on the other side thereof, means being provided for adjusting the capacity by switch selection of the separate electrodes brought into circuit.

7. A timepiece as claimed in claim 6 wherein the separate electrodes are of different areas and switch selection means constituted by a movable contact arm adapted to be moved to connect with any one of them are provided.

8. A timepiece as claimed in claim 6 wherein the separate electrodes are individually alike and switch selection is effected by a contact arm adapted to be moved to connect with any desired number of said electrodes simultaneously.

9. A timepiece as claimed in any of claims 5 to 8 wherein the electrodes of the condenser are in the form of fired-on metal coatings on a dielectric substrate.

10. A timepiece as claimed in any of the preceding claims wherein the condenser is substantially as herein described and illustrated in Figure 6 or Figure 7 of the accompanying drawings.



* C L H S *

11. A time piece as claimed in claim 1
having a time standard crystal oscillator sub-
stantially as herein described with reference
to Figures 3 and 4 of the accompanying draw-
ings.

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