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(72) Inventor MOTOYOSHI SAKAMOTO

(54) A VIBRATOR FOR AN ELECTRIC TIMEPIECE

(71) We, KABUSHIKI KAISHA SUWA SEIKOSHA, a Japanese company, 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 a vibrator for an electric timepiece. More particularly, but not exclusively, the invention relates to a vibrator of relatively low frequency, i.e. of a frequency between several tens of cycles per second and several hundreds of cycles per second.

It is known that, so far as reliability is concerned, a tuning fork of high Q value is much better than a balance wheel of low Q value for use in an electric timepiece, but on the other hand a low frequency balance wheel can be arranged to give zero position error which is not achievable with a tuning fork. Moreover, in a tuning fork for a watch the construction and manufacture of the device for converting the oscillation of the tuning fork to rotation of a rotary part is difficult because of the high frequencies involved.

The present invention seeks to provide a vibrator for an electric timepiece which has a vibrator or oscillator substantially free from position error and in which manufacture of the converting device from oscillation to rotation is not unduly complicated.

According to the present invention, there is provided a vibrator for an electric timepiece comprising an inertia body formed by masses disposed at the ends of an arm, and a spring connected to said arm at a point intermediate the ends of the latter, the arrangement being such that, in operation, the inertia body oscillates, relatively to the spring in a plane about the point of connection with the spring and has a centre of gravity disposed at a distance between one-third and one half of the length of the spring from

the said point of connection between the spring and the inertia body.

Preferably the vibrator includes a pair of symmetrically disposed inertia bodies, said spring being substantially U-shaped to provide a pair of spring legs, each spring leg being connected to one of said inertia bodies at a point intermediate the masses of the respective inertia body, each said point of connection being at a distance between one-third and one-half of the length of the spring leg from the centre of gravity of the inertia body.

The scope of the invention also includes an electric timepiece having a vibrator as set forth above.

The invention will now be described, merely by way of example, with reference to the accompanying drawings, in which:—

Figure 1 is a schematic view of a known U-shaped vibrator,

Figures 2 and 3 are schematic diagrams explaining the principle of the present invention,

Figures 4A, 4B and 4C are respective diagrams explaining the effect of the gravitational field on a vibrator according to this invention,

Figures 5A and 5B represent an experimental vibrator for verifying the principles of the present invention, shown respectively in plan view and side elevation,

Figures 6A and 6B are graphs of the experimental values obtained with the apparatus of Figures 5A and 5B,

Figures 7A and 7B are respectively a plan and an elevational view of a vibrator used as a time base in an electric timepiece according to an embodiment of the present invention,

Figure 8 is a plan view of an electric timepiece provided with a vibrator in accordance with the present invention,

Figure 9 is a circuit diagram associated with the timepiece of Figure 8,

Figure 10 is another embodiment of a

vibrator for use in an electric timepiece in accordance with the present invention, and

Figure 11 is an electric circuit diagram showing the circuit associated with the vibrator of Figure 10.

Referring now to the drawings, Figure 1 shows a conventional substantially U-shaped vibrator having masses 1 positioned at the ends of a substantially U-shaped spring 2 in the form of a tuning fork. It is well-known that the centre of rotation of each mass 1 lies at about one third of the overall length of the spring 2 from the respective mass 1 and that the frequency of this tuning fork vibrator varies in accordance with its position in a gravitational field.

Referring now to Figure 2, a rotary inertia body includes a bar or arm 3, shown as having masses 4 and 5 at its ends, which masses are respectively denoted by the reference letters m_1 and m_2 . The centre of gravity of this arrangement is designated by the reference letter G. A spring 2 is fixed on a plate 6 at one end a and its other end is connected to the bar or arm 3 at a point b which is intermediate the end masses 4 and 5 and is at a distance h from the centre of gravity G. The length of the spring 2 is denoted by the reference letter L and the positions of the X and Y axes are shown by arrows. The vibrator comprising parts 3, 4 and 5 will in operation oscillate about an axis of symmetry M shown in chain-dotted lines, and broken lines shown an extreme position of the rotary inertia body. However, in the full-line position of the inertia body the arm or bar 3 makes an angle θ with the axis of symmetry M.

For the vibrator according to Figure 2 position error in the gravitational field can be eliminated by two methods as follows: firstly by causing the centre of gravity of the rotary inertia body to coincide with the centre of rotation, or secondly by causing the centre of gravity G to move rectilinearly and normally to the axis Y, that is to say along the axis X.

When the centre of gravity G coincides with the centre of rotation, clearly gravitational forces will have no effect on the restoring force of the spring and the position error is therefore eliminated. However, in practice it is impossible to adopt this method because in a vibrator as shown in Figure 2 there is no fixed centre of rotation. This can be understood better from Figure 3 from which the masses 4 and 5 have been eliminated and only the spring 2 is considered. When a moment of force acts on the spring 2, the latter will deform into a substantially circular arc with radius R. At an instant when the displacement of the centre of gravity G at the distance h from the connection point b in the direction of the X axis and the Y axis is Δx and Δy respec-

tively, the following equations can be written:

$$\Delta x = R(1 - \cos \theta) - h \sin \theta \quad (1)$$

$$\Delta y = h(\cos \theta - 1) + (L - R \sin \theta) \quad (2)$$

$$R = \frac{L}{\theta} \quad (3) \quad 70$$

$$\cos \theta = 1 - \frac{\theta^2}{2!} + \frac{\theta^4}{4!} - \frac{\theta^6}{6!} + \dots \quad (4)$$

$$\sin \theta = \theta - \frac{\theta^3}{3!} + \frac{\theta^5}{5!} - \dots \quad (5)$$

Omitting terms of θ to the third or higher powers and substituting the equations (3), (4) and (5) in equations (1) and (2), we obtain

$$\Delta x = \theta \left(\frac{L}{2} - h \right) \quad (6)$$

$$\Delta y = \theta^2 \left(\frac{L}{6} - \frac{h}{2} \right) \quad (7)$$

As θ is very much smaller than 1 radian, the error caused by the omission of the higher powers of θ is extremely small. As shown in equations (6) and (7), there is no point where both Δx and Δy become zero simultaneously except when $\theta=0$.

Referring now to Figures 4A, 4B and 4C, and assuming that the length of the spring 2 is infinite and that the locus of motion of the centre of gravity G is a straight line, it can be seen that where the axis of symmetry for the oscillation, namely the axis Y, lies parallel to the direction of the gravitational forces shown by the arrow g (Figures 4A and 4B), the gravitational forces do not produce a moment, and thus no frequency variations will occur. However, in Figure 4C a case is shown where the axis of vibration is inclined to the direction of the gravitational forces g by an angle α . The effects on the frequency of the moment of gravitational forces are of equal quantity or magnitude on either side of the axis of vibration and so therefore they cancel each other out and have no effect on frequency. From equations (6) and (7) the locus of motion of the centre of gravity is given by equation (8).

$$y = \frac{2(3h - L)x^2}{3(L - 2h)^2} \quad (8) \quad 105$$

To make this motion rectilinear, the numerator in the above equation must be equal to zero which gives

$$3h - L = 0 \therefore h = \frac{L}{3} \quad (9)$$

- 5 Thus the equation (9) represents the condition for eliminating the position error in the vibrator.

In practice, both the moments and bending forces affect the spring 2 and the equation (9) is not satisfied entirely. Practical experience shows that for eliminating the position error h must lie between $\frac{L}{3}$ and

$$\frac{L}{2}$$

- 15 As an experimental verification of the foregoing, the apparatus shown in Figures 5A and 5B is used in which the rotary inertia body consisting of arm 3 with masses 4 and 5 and the spring 2 is shown. A pin 7 connects the inertia body to the spring 2 and a pin 8 connects the spring 2 to a base plate 6. It is found that the position error varies sinusoidally when the vibrator shown in Figures 5A and 5B changes its position. Referring to Figure 6A, several sinusoidal curves are shown with different values of the parameter h in mm., the abscissa being the angle α as referred to in Figure 4C, while the ordinate is the position error n which is

functionally related to $\frac{\Delta_f}{f}$ where f is the

- 30 natural frequency and Δ_f is the frequency error. As can be seen from Figure 6A, n has a maximum at two positions corresponding to the mass 4 being above and below the mass 5.

- 35 Figure 6B represents the relation between h and n , and the graph of Figure 6B was obtained with an oscillator of the type shown in Figures 5A and 5B having a spring length L of 47.5 mm and a natural frequency of 16.7 cycles per second. From the graph in Figure 6B it can be derived that the position error is eliminated only when h is equal to 16 mm. Of course, the slope of the line and the point at which it intersects the X axis will vary in accordance with the variations in the mass and length of arm of the rotary inertia body and the length of the spring.

- 45 In Figure 5A a line M denotes the axis of symmetry of the inertia body and when this axis coincides with the centre of rotation of the body, it is necessary to make the centre of gravity G lie on the axis M to make the position error zero. The above experimental result shows that the position error can be eliminated when the centre of gravity G of

the inertia body is situated on the axis of symmetry M. A vertical line passing through the centre of gravity G intersects the centre line K of the spring 2 approximately one-third of the effective length L of the spring 2 from the free end b of the spring, as shown in Figure 5B. The arm 3 is connected to the spring 2 at the free end b of the spring by a pin 7.

Figures 7A and 7B show an embodiment of a standard oscillator of an electric timepiece in accordance with the present invention and including two oscillators 1, 1' joined together, each oscillator having an arm 3, 3' with masses at the ends 4, 4' and 5, 5' connected by springs 2, 2' with pins 8 connecting the springs to a base plate 6. The oscillators are fixed on the plate 6 symmetrically about an axis Z and oscillate in the same oscillating plane. Pins 7, 7' show respectively the locations of the connections between the respective springs 2, 2' and the arms 3, 3', the pins 7, 7' being at points on the arms 3, 3' corresponding to the point b in Figure 2.

Turning now to the embodiment shown in Figures 8 and 9, there is shown an electric timepiece incorporating a vibrator or oscillator as shown in Figures 7A and 7B for use as a time base. The oscillator comprises a U-shaped spring having respective spring legs 2, 2' connected by respective pins 7, 7' to arms 3, 3' respectively, of two inertia bodies. Each inertia body has masses 4, 5 and 4', 5' respectively at the ends of its arms 3, 3'. Each of the masses 4, 4' is in the form of a cylindrical cup of magnetic material having a permanent magnet fixed centrally therein. Respective coils 9, 9' are located in the annular space between the wall of each cup-shaped mass 4, 4' and the central magnet, the coil 9 serving as a detection coil, and the coil 9' serving as a drive coil. Both arms 3, 3' are joined by the spring legs 2, 2' to the plate 6 at a point corresponding to point a in Figure 2 and of course the pins 7, 7' are at points corresponding to point b of Figure 2. Oscillation of this oscillator is transformed to rotational movement of a ratchet wheel 10 by means of a spring 13 having a pawl 11, the spring 13 being connected to the arm 3' of the oscillator. Another spring 16 is fixed by a pin 15 to the watch plate and carries a pawl 14 for preventing reverse rotation of the ratchet wheel 10.

Rotation of the ratchet wheel 10 is transmitted to a second-hand wheel 18 by means of a pinion 17 mounted rigidly and coaxially on the ratchet wheel 10 to rotate therewith. The second-hand wheel 18 carries a second-hand 19, but description of the gear trains from the second-hand wheel 18 to the hour wheel, etc., are not given here because they are all well-known in themselves.

In a practical embodiment, the ratchet

wheel 10 is driven by one pitch for every oscillation of the oscillator and if the frequency of this oscillator is arranged to be 60 cycles per second, the number of teeth of the ratchet wheel to be 300 and the pitch to be 50 microns, an outer diameter of 5 mm is obtained for the ratchet wheel with twelve rotations per minute. If now the gear ratio between the ratchet wheel and the second-hand wheel is one to twelve, the second-hand wheel 18 can be in direct engagement with the pinion of the ratchet wheel 10.

In Figure 8 a battery direct current source is shown at 20, connected to an electric circuit 21 which is indicated by a block in Figure 8 and shown in more detail in Figure 9. One pole of the battery 20 is earthed on the watch plate 6 through a contact blade 22 and a fixed screw 23. In the circuit of Figure 9, the battery 20, the detecting coil 9 and the drive coil 9¹ are shown as being connected in a drive circuit comprising capacitor 24 and fixed resistor 25 and an amplifier transistor 26.

In the embodiment of Figures 8 and 9 the oscillator is driven electromagnetically, but instead a piezo-electric drive arrangement is also possible, and this is shown in Figures 10 and 11.

The oscillator of Figure 10 comprises a piezo-electric element 27 for detecting the deformation of the legs 2, 2¹, with a piezo-electric element 27¹ for causing the spring legs 2, 2¹ to bend. The piezo-electric element 27¹ is fed by a signal amplified in an amplifier circuit 28 shown in a block form in Figure 10 and shown in more detail in Figure 11. As can be seen, the circuit includes a transistor 29, a biasing resistor 31, a D.C. power source 32 and a transformer 30 for impedance matching. The spring legs 2, 2¹ are connected to respective arms 3, 3¹ of the two inertia bodies by pins 7, 7¹ located as described with reference to Figure 8, at points corresponding to point *b* in Figure 2.

It should be realized that the positions of the piezo-electric elements 27 and 27¹ are not limited to the example shown in Figure 10 and may be placed practically anywhere along the length of the spring legs, provided that the latter can be given sufficient deformation at that location.

It should be understood that although the illustrated embodiments of the invention show the spring in the form of a leaf or

plate spring, it can in fact be of any form, e.g. in the form of a beam of uniform strength.

The illustrated embodiments of the present invention provide a low frequency vibrator for an electric timepiece suitable to provide a watch with low position error.

The present application is divided from Application No. 60389/69 (Serial No. 1,293,159) in which there is claimed in claim 1: "A vibrator for an electric timepiece comprising an inertia body formed by masses disposed at the ends of an arm, and a spring connected between a base and said arm, the arrangement being such that the said body, in operation, oscillates symmetrically in a plane about an axis lying in the said plane and its centre of gravity undergoes substantially rectilinear displacement in said plane and in a direction normal to said axis."

WHAT WE CLAIM IS:—

1. A vibrator for an electric timepiece comprising an inertia body formed by masses disposed at the ends of an arm, and a spring connected to said arm at a point intermediate the ends of the latter, the arrangement being such that, in operation, the inertia body oscillates, relatively to the spring in a plane about the point of connection with the spring and has a centre of gravity disposed at a distance between one-third and one-half of the length of the spring from the said point of connection between the spring and the inertia body.

2. A vibrator as claimed in claim 1 wherein the vibrator includes a pair of symmetrically disposed inertia bodies, said spring being substantially U-shaped to provide a pair of spring legs, each spring leg being connected to one of said inertia bodies at a point intermediate the masses of the respective inertia body, each said point of connection being at a distance between one-third and one-half of the length of the spring leg from the centre of gravity of the inertia body.

3. An electric timepiece including a vibrator as claimed in Claim 1 or Claim 2.

J. MILLER & CO.,
Agents for the Applicants,
Chartered Patent Agents,
262 High Holborn,
London, W.C.1.



wheel 10 is driven by one pitch for every oscillation of the oscillator and if the frequency of this oscillator is arranged to be 60 cycles per second, the number of teeth of the ratchet wheel to be 300 and the pitch to be 50 microns, an outer diameter of 5 mm is obtained for the ratchet wheel with twelve rotations per minute. If now the gear ratio between the ratchet wheel and the second-hand wheel is one to twelve, the second-hand wheel 18 can be in direct engagement with the pinion of the ratchet wheel 10.

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WHAT WE CLAIM IS:—

1. A vibrator for an electric timepiece comprising an inertia body formed by masses disposed at the ends of an arm, and a spring connected to said arm at a point intermediate the ends of the latter, the arrangement being such that, in operation, the inertia body oscillates, relatively to the spring in a plane about the point of connection with the spring and has a centre of gravity disposed at a distance between one-third and one-half of the length of the spring from the said point of connection between the spring and the inertia body.

2. A vibrator as claimed in claim 1 wherein the vibrator includes a pair of symmetrically disposed inertia bodies, said spring being substantially U-shaped to provide a pair of spring legs, each spring leg being connected to one of said inertia bodies at a point intermediate the masses of the respective inertia body, each said point of connection being at a distance between one-third and one-half of the length of the spring leg from the centre of gravity of the inertia body.

3. An electric timepiece including a vibrator as claimed in Claim 1 or Claim 2.

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