May 30, 1967 KAZUO ISHIKAWA ET AL 3,322,016

ADDED MASS TYPE CIRCULAR TUNING FORK

Filed June 12, 1964

2 Sheets-Sheet 1

Fig. 1

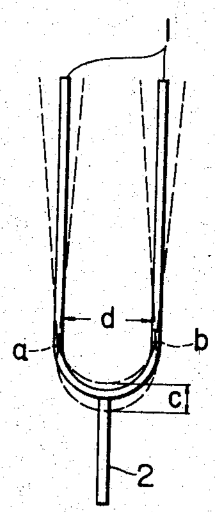


Fig. 2

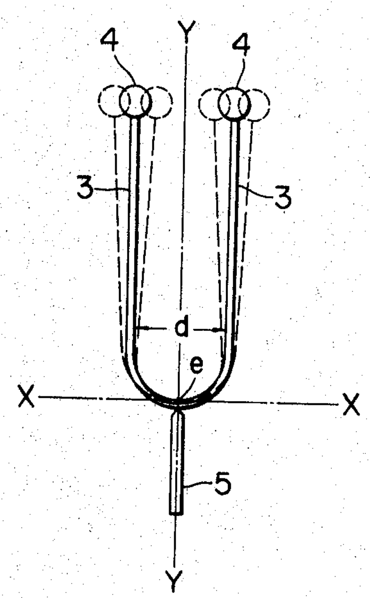


Fig. 3

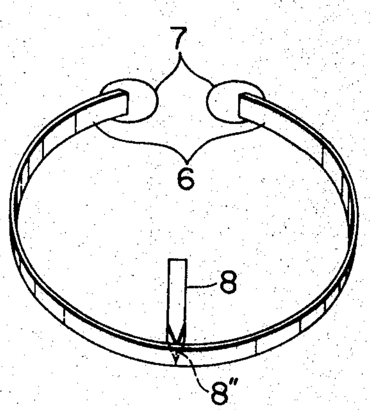
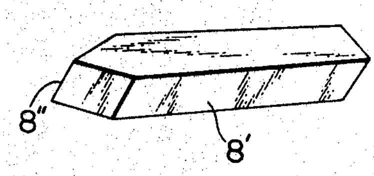


Fig. 4



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2 Sheets-Sheet 2

Fig. 5

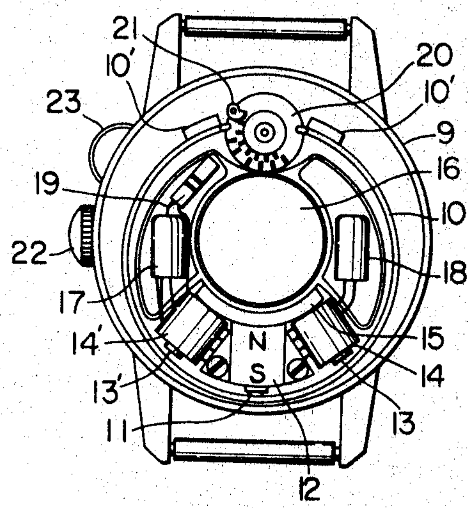


Fig. 6

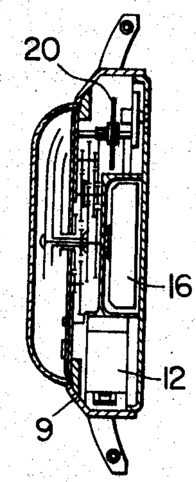


Fig. 7

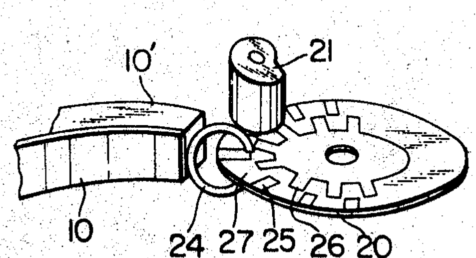
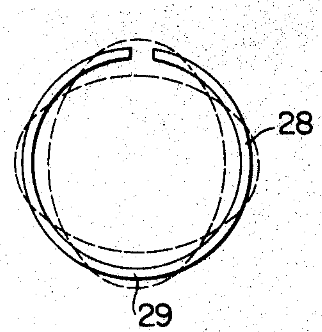


Fig. 8



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1

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ADDED MASS TYPE CIRCULAR TUNING FORK

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The portion of the term of the patent subsequent to Nov. 9, 1982, has been disclaimed and dedicated to the Public
6 Claims. (Cl. 84—457)

This invention relates to mechanical oscillators suitable for use as time keeping oscillators in such small timepieces as, for example, watches.

Conventional time keeping oscillators for this type of use have generally used balance wheels and, more recently, tuning forks.

However, the balance wheel has certain disadvantages as for timepiece applications in that its frequency is small, that its oscillating part has a frictional bearing part, that the quality facor Q of he balance wheel itself is very small. Consequently no high time keeping accuracy can be expected of the conventional timepiece using the balance wheel. When a tuning fork is to be fitted in the mechanism of a smaller timepiece, its size and shape are restricted by the gear train and other parts in the mechanism. Therefore, it has been very difficult to reasonably arrange both tuning fork and gear train in a small space. Thus, when such tuning fork and gear train are to be arranged in a limited space, the structure of the tuning fork will become so complicated as to be difficult and costly to manufacture.

The main object of the present invention is to eliminate the above mentioned disadvantages by making the conventional U-shaped tuning fork of circular configuration so as to provide an oscillator which can be reasonably arranged in a limited small space, specifically in a smaller timepiece mechanism together with the gear train and other parts required to form the mechanism.

Another object of the present invention is to provide such an oscillator of a high quality factor Q.

A further object of the present invention is to provide an oscillator which is simpler in the structure than the conventional tuning fork and is adapted to mass-production.

The present invention will be understood with reference to the following description and drawings of embodiments of the present invention. The accompanying drawings shall now be explained.

FIGURE 1 is a plan view illustrating the oscillating mode of a conventional tuning fork.

FIGURE 2 is a plan view illustrating the oscillating mode and structure of a tuning fork having a weight secured to each of both free ends.

FIGURE 3 is a perspective view illustrating an embodiment of the present invention.

FIGURE 4 is a perspective view illustrating the supporting part of a tuning fork according to the present invention.

FIGURE 5 is a plan view of a watch as an embodiment using an added mass type circular tuning fork according to the present invention.

FIGURE 6 is a sectional side view of the same watch shown in FIGURE 5.

FIGURE 7 is an enlarged perspective view of the magnetic coupling arrangement at each tip of the circular tuning fork in the watch of FIGURE 5.

FIGURE 8 is a plan view illustrating the oscillating mode of an annulus oscillator.

2

In FIGURE 1, there is shown a substantially U-shaped tuning fork made of a resilient material and having a supporting part **2** secured to the bottom part of both tines **1** of the tuning fork. Points *a* and *b* are nodal points of oscillation produced when the tuning fork oscillates, and the base portion of the fork between the nodal points oscillates with an amplitude *c*.

First of all, this oscillating mode shall be explained. As is well known, a conventional tuning fork will vibrate with symmetrical oscillating motions shown by the broken lines in FIGURE 1, with the points *a* and *b* as nodal points. Therefore, the supporting part **2** is not secured in the place where the nodal points of the tines of the tuning fork are produced, but is secured at the point of maximum amplitude *c* of the base portion of the fork. Therefore, as the distance *d* between the opposed tines expands, the amplitude *c* of the base portion will become larger, the energy leaking out of the supporting part **2** secured to said base portion will decrease, and the quality factor Q of the tuning fork will decrease. It is generally well known that, if the distance *d* between the tines of said tuning fork is made as small as possible, a tuning fork of a high quality factor Q will be obtained.

In FIGURE 2, there is shown a tuning fork having a weight **4** secured to the tip of each of both tines **3**. A supporting part **5** is secured to the base portion of the fork.

It has been generally considered that the two nodal points *a* and *b* will be produced in two positions spaced away from the supporting part **2** as a center, even in the tuning fork having the weight **4** secured to the tip of each of both tines **3**. However, it has now been discovered that the tuning fork having the weight **4** at the tip of each of both tines **3** as is illustrated in FIGURE 2 can be designed to have an oscillating mode quite different from that of a tuning fork having no weight **4** as is illustrated in FIGURE 1. This is an entirely new discovery. In the following specification, the tuning fork having the weight **4** secured to the tip of each of both tines **3** shall be referred to as an "added mass type" tuning fork so as to be distinguished from the tuning fork having no added weights.

As mentioned above, it has been discovered that the added mass type tuning fork illustrated in FIGURE 2 will show an oscillating mode different from that of the ordinary tuning fork illustrated in FIGURE 1. The oscillating mode of the added massed type tuning fork is shown by the dotted lines in FIGURE 2. In the oscillating ordinary tuning fork, the nodal points of the oscillation are distributed to the two spaced points *a* and *b* but, in the added mass type tuning fork constructed in accordance with this invention, said nodal points *a* and *b* will converge so close to a point *e* that the nodal points of the oscillation can be considered to be produced at only one point *e*. This unexpected phenomenon has been confirmed by the results of experiments in which the tuning fork according to the present invention illustrated in FIGURE 3 and the conventional annulus illustrated in FIGURE 8 of the same frequency were oscillated with the same amplitude. It was found that the amplitude of the supporting part (8″ in FIGURE 3) of the tuning fork according to the present invention was less than ⅙ of that of the conventional annulus.

The degree of convergence of the two nodal points is determined by the ratio of the mass of the weight attached to each tip to the equivalent mass of both tines; the larger the ratio, the higher the degree of convergence. In an added mass type tuning fork in which the mass of said weight is so large that said equivalent mass of the tines can be neglected as compared with it (in such case, the frequency of this tuning fork will naturally reduce and its value will be less than 500 cycles/second), both nodal points *a* and *b* have been found to converge so close to each other as to be considered substantially one point.

When the weight is secured to the free end of each of the tines so that the nodal points are converged to one point as mentioned above, the following advantages are obtained:

(1) As the nodal points are converged to one point, the supporting part **5** may be secured to the nodal point and the amplitude *c* in the supporting part is minimized. Consequently, the oscillating energy of the tuning fork leaking out through the supporting part will decrease and the quality factor Q of the tuning fork will increase.

(2) The energy consumed within the tine by the oscillating motion of the tuning fork will quickly increase with increase in the strain per unit volume of the resilient material forming the tine. Therefore, if the distance *d* between the bottom parts of both tines, where the strain is a maximum, is made larger, said strain per unit volume will be reduced with attendant reduction in the energy loss within the tines. That is to say, the quality factor Q of the tuning fork can be made higher by making the distance *d* between the bottom parts of both tines larger.

As explained above, in the added mass type tuning fork provided by this invention there is no fear that the amplitude *c* of the supporting part will increase when the distance *d* between both tines **3** expands. Therefore, when the strain is distributed as uniformly as possible within the resilient material so that the strain per unit volume produced within said material may be made smaller, the quality factor Q of the tuning fork will be made higher.

FIGURE 3 illustrates an added mass type circular tuning fork embodying the present invention. Thus, the tines **6** of a substantially circular tuning fork made of a resilient material have weights **7** secured to the tips thereof. A supporting part **8** is secured to the central part of the fork midway between the ends of the two tines **6**. As the tines **6** of the tuning fork form a smooth arc, the strain is distributed more uniformly than in the conventional U-shaped tuning fork. Therefore, the strain per unit volume is reduced and the quality factor Q of said tuning forks increased.

Further, in case the tuning fork is to be used in a limited space as in a watch, both circular tines of the tuning fork can be arranged along the case, and the gear train required for the watch mechanism and the electric parts to excite said tuning fork can be contained in the circular space enclosed with both tines and those members can be very reasonably arranged.

The use of a tuning fork embodying this invention in a watch shall be explained with reference to FIGURES 5, 6 and 7. Thus, a case **9** houses a circular tuning fork **10** having an added mass **10'** secured to each tip of the fork tines. A supporting part **11** is provided in the central part of the arcuate length of the circular tuning fork. A permanent magnet **12** for the exciting circuit is secured at one end to the above mentioned supporting part **11**, and thus forms part of the supporting structure for the fork. The electronic drive system for the tuning fork includes a driving coil **14** wound on an iron core **13** for a tuning fork, and a detecting coil **14'** wound on an iron core **13'**. An arcuate yoke **15** arranged to be concentric with said circular tuning fork, is secured at its center to the permanent magnet **12** with the iron cores **13** and **13'** secured to the respective ends of the yoke so that a closed magnetic circuit may be formed with the central portion of the circular tuning fork **10**. The electronic circuit is completed by a mercury battery **16** arranged inside the above mentioned yoke **15**, a transistor **17**, a condenser **18**, and a resistor **19**. Said transistor, condenser and resistor are contained in the annular space between the circular tuning fork and the mercury battery. **20** is a rotary disk or escape wheel **21** is an eccentric cam for adjusting the frequency of the tuning **10**. Said rotary disk **20** is rotatably fitted between the magnetic poles of small permanent magnets **24** secured to the respective tips of the above mentioned circular tuning fork. **23** is a starting knob. **25** is an outer magnetic path of said rotary disk **20**. **26** is an inner magnetic path of the same. **27** is a nonmagnetic part of the same. Conventional gears driven by the rotation of said rotary disk, such as a second hand gear, minute hand gear and hour hand gear are arranged inside the circular tuning fork as illustrated in FIGURE 6.

In the electric circuit in FIGURE 5, if the battery **16** is connected, the tuning fork **10** will begin to oscillate due to driving impulses from the exciting circuit consisting of the driving coil **14**, transistor **17**, detecting coil **14'**, condenser **18** and resistor **19**. Each tine of said tuning fork will oscillate alternately toward and away from each other. Its amplitude will be a maximum at the tip. The permanent magnet **24** at the tip will reciprocate approximately linearly on the rotary disk **20** around the supporting part **11** as a center. This reciprocating motion will be converted to a rotary motion of the rotary disk **20** by the magnetic force interposed between the permanent magnet **24** and the rotary disk **20** and said rotary disk **20** will continue to rotate as synchronized with the frequency of the circular tuning fork **10**.

Further, as the speed adjusting cam **21** is an eccentric cam, by varying its rotating angle, the attraction by the leaking magnetic flux of the permanent magnet **24** can be varied so that the frequency may be regulated to adjust the rate of movement of the time-indicating elements of the watch.

Thus, when the circular tuning fork according to the present invention is used as a time keeping oscillator for a small timepiece such as a watch, the electric parts and gears can be contained inside the arcuate tines, so that the space can be used most effectively and the mechanism made small and thin.

As already explained with reference to FIGURES 2 and 3, in the added mass type tuning fork provided by this invention, the nodal point of the oscillation will be produced only at the point *e* at the center of the base of the tuning fork. Therefore, it can be easily seen that if the tuning fork is supported at said point *e*, the energy leaking out of the supporting part will be a minimum. As can be seen from FIGURE 2, if the tuning fork is supported in the resilient part of the tines, spaced away from the center point *e* in the direction of the X axis, the motion of the tines in the direction of the Y axis will be restricted by the supporting part, the energy escaping from the supporting part will increase and the quality factor Q of the tuning fork will decrease. However, it will not restrict the above mentioned oscillation at all to make the connecting part of the supporting part large in the direction intersecting at right angles with the U-shaped plane of said tuning fork without increasing the connecting area in the direction of the X axis. Therefore, the connecting area between the tine and supporting part of the tuning fork can be increased without reducing the quality factor Q.

Increasing the connecting area is very important to the tuning fork. That is to say, by increasing said connecting area, the mechanical strength of the connection can be increased and a tuning fork which withstands impact and oscillation can be obtained. Further, when the tuning fork is manufactured by integrally forming both tines of a resilient material in the form of a pipe or ribbon and welding the supporting part to the fork as by electric welding, the heat capacity of the tip of the supporting part which is pressed against the tuning fork will be so much smaller than that of the fork that the tip of the supporting part will be melted, but the part of the tuning fork pressed against the tip will not be melted and therefore it is difficult to achieve perfect electric welding. However, this defect can be eliminated by providing the supporting part with a wedge-shaped tip according to the present invention. This method of making tuning forks is much more adapted to mass production and contributes more to the reduction of cost than the conventional method of cutting a tuning fork of any desired shape out of a block of resilient material.

The supporting elements **8** and **8'** in FIGURES 3 and 4, respectively, illustrate the wedge-shaped end portions described above. In FIGURE 3, **6** designates the tines of a tuning fork made of a resilient material. **8** is a tuning fork supporting part made of a round bar welded at its wedge-shaped edge **8''** to the base portion of the tuning fork. Sain supporting part **8** is made by working the round bar to be wedge-shaped at one end to increase the above mentioned welding area.

FIGURE 4 illustrates a wedge-shaped supporting part **8'** made of a square bar having a wedge-shaped end portion **8''** to be welded to the tuning fork.

The added mass type circular tuning fork provided by this invention is similar in shape to a conventional annulus (an example of which is illustrated in FIGURE 8) but is quite different from the conventional annulus in the oscillating mode and performance. This difference between them shall be described below.

FIGURE 8 illustrates an example of conventional annulus. In FIGURE 8, **28** is an oscillating part made of a resilient material adapted to be supported at a point **29**.

The conventional annulus can be made smaller and produced more easily than a tuning fork. But, as it has a defect fatal to timekeeping oscillators in that its quality factor Q is small, it has not been widely used. That is to say, its quality factor Q is low because, as shown by the dotted lines in FIGURE 8, where the amplitude in the longitudinal direction in the annulus is the smallest, the amplitude in the lateral direction will be the largest and, conversely, where the amplitude in the lateral direction is the smallest, the amplitude in the longitudinal direction will be the largest. This is quite different from the oscillating mode of the added mass type circular tuning fork according to the present invention.

Thus, in the conventional annulus, there is no nodal point or stationary point suitable to support it. Therefore, even if the annulus is supported at a point symmetrical to the slit of the innulus and the annulus (it is considered to be most desirable to support the annulus at this point), that will be the point of the largest amplitude in the longitudinal direction and therefore the oscillating energy of the annulus escaping out of the supporting part will be so large that the value of the quality factor Q will be only about half as great as that of the inventive added mass type circular tuning fork.

According to the present invention, the tine parts are formed of arcuate segments of a circular resilient material, a weight is secured to the tip of each tine, and the tuning fork is supported very close to the nodal point produced when the tuning fork is excited. Consequently, there is provided a tuning fork whereby, even in a small timepiece mechanism, the gear train and other parts required to form the mechanism can be reasonably arranged in an extremely small space. Moveover, the tuning fork can be provided with a high Q without impairing the mechanical strength. Further, by the method of forming the tine parts of the circular tuning fork by cutting a resilient material in the form of a ribbon or pipe and securing a wedge-shaped supporting part to it as by electric welding, the tuning forks can be economically manufactured in large quantities.

What is claimed is:

1. An added mass tuning fork comprising the combination of a circular tuning fork comprising a split circular annulus made of a resilient material with the split forming a pair of opposed curved tines adapted to vibrate alternately toward and away from each other at a predetermined natural frequency of vibration, a pair of added masses one of which is mounted on one of said curved tines and the other of which is mounted on the other of said tines, said masses being symmetrically located with respect to each other and to said fork, said tuning fork and said added masses being adapted to converge the nodal points of the vibratory motion of said tuning fork

at substantially a single point midway between the ends of said tines, and a supporting member secured to said tuning fork at said point where the nodal points of the vibratory motion are converged.

2. An added mass tuning fork comprising the combination of a circular tuning fork comprising a split circular annulus made of a resilient material with the split forming a pair of curved tines adapted to vibrate alternately toward and away from each other at a predetermined natural frequency of vibration, a pair of added masses one of which is mounted on one of said curved tines and the other of which is mounted on the other of said tines, said masses being symmetrically located with respect to each other and with respect to said tuning fork, the ratio of the mass of said added masses to the mass of said tines being adapted to converge the nodal points of the vibratory motion of said tuning fork at substantially a single point midway between the ends of said tines, and a supporting member secured to said tuning fork at said points where the nodal points of the vibratory motion are converged.

3. An added mass tuning fork comprising the combination of a circular tuning fork comprising a split circular annulus made of a resilient material with the split forming a pair of opposed outwardly curved tines adapted to vibrate alternately toward and away from each other at a predetermined natural frequency of vibration, a pair of added masses at least one of which comprises a permanent magnet mounted on one of said curved tines with the other of said masses being mounted on the other of said tines, said masses being symmetrically located with respect to each other and with respect to said fork, the ratio of the mass of said added masses to the mass of said tines being adapted to converge the nodal points of the vibratory motion of said tuning fork at substantially a single point midway between the ends of said tines, and a supporting member secured to said tuning fork at said point where the nodal points of the vibratory motion of the tuning fork are converged.

4. An added mass type tuning fork comprising the combination of a supporting member, a circular tuning fork comprising a split circular annulus made of a resilient material with the split forming a pair of opposed outwardly curved tines adapted to vibrate alternately toward and away from each other at a predetermined natural frequency of vibration, said tuning fork being connected to said supporting member at a point diametrically opposed from said split, a pair of magnetic masses one of which is mounted on the end of one of said curved tines and the other of which is mounted on the other of said tines so as to form two pairs of opposed magnetic poles adapted to follow the vibratory motion of said tuning fork, said magnetic masses being symmetrically located with respect to each other and with respect to said fork, said tuning fork and said magnetic masses being adapted to converge the nodal points of the vibratory motion of said tuning fork at substantially a single point midway between the ends of said tines, and a rotary member forming a plurality of radially extending, circumferentially spaced magnetic elements disposed between said pairs of magnetic poles for rotating said rotary member in accordance with the frequency of vibration of said tuning fork.

5. An added mass tuning fork comprising the combination of a circular tuning fork comprising a split circular annulus made of a resilient material with the split forming a pair of opposed curved tines adapted to vibrate alternately toward and away from each other at a predetermined natural frequency of vibration, a pair of added masses one of which is mounted on one of said curved tines and the other which is mounted on the other of said tines, said masses being symmetrically located with respect to each other and with respect to said tuning fork, the ratio of the mass of said added masses to the mass of said tines being adapted to converge the nodal points of the vibratory motion of said tuning fork at substantially a single point, and a supporting member secured to said tuning fork at said point where the nodal points of the vibratory motion of the tuning fork are converged, said supporting member being connected to said tuning fork along a line of contact extending perpendicularly to the plane of the vibratory motion of said fork.

6. An added mass type tuning fork comprising the combination of a supporting member having a wedge-shaped end portion, a circular tuning fork comprising a split circular annulus made of a resilient material with the split forming a pair of curved tines adapted to vibrate alternately toward and away from each other at a predetermined natural frequency of vibration, said tuning fork being connected to the leading edge of the wedge-shaped end portion of said supporting member at a point diametrically opposed from said split, a pair of added masses one of which is mounted on one of said curved tines and the other of which is mounted on the other of said tines, said masses being symmetrically located with respect to each other and with respect to said fork, said tuning fork and said added masses being adapted to converge the nodal points of the vibratory motion of said

tuning fork at substantially a single point midway between the ends of said tines.

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