**Dec. 22, 1964** E. VAN HAAFTEN **3,162,006**

TUNING FORK FOR ELECTRONIC TIMEPIECE

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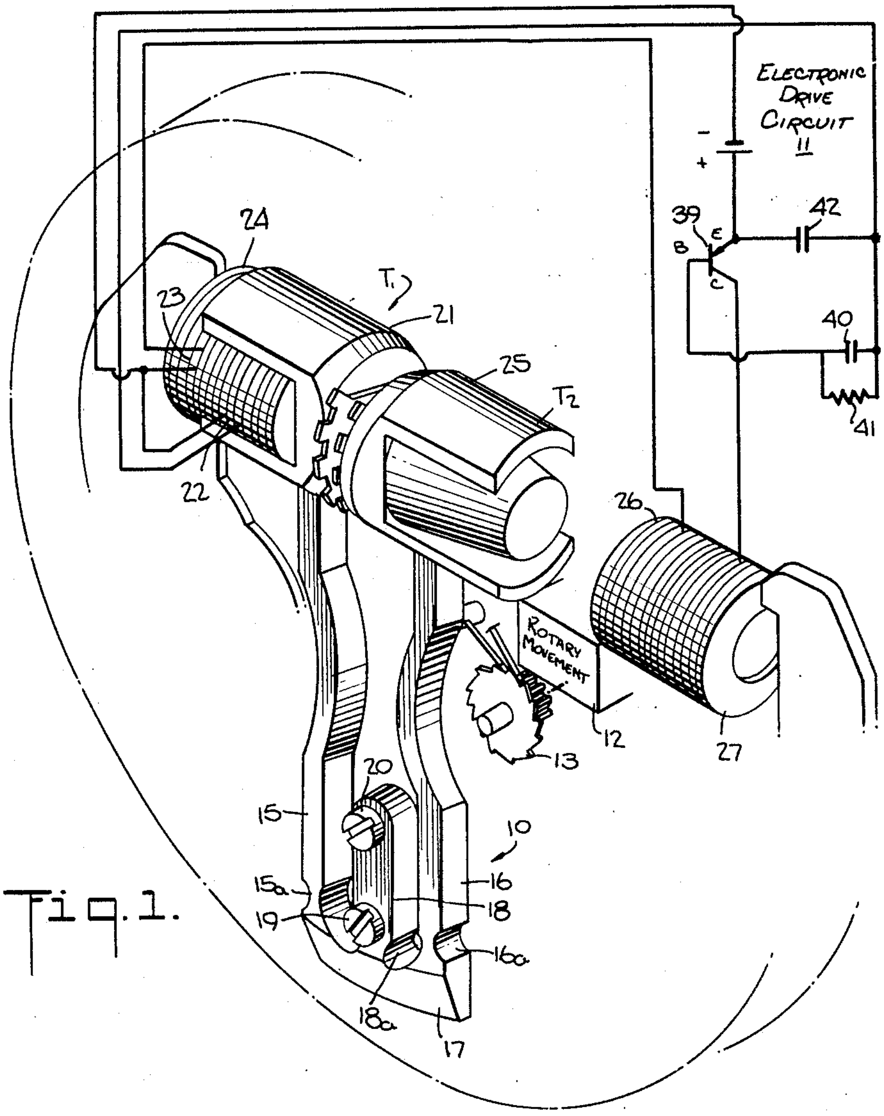

Fig. 1.

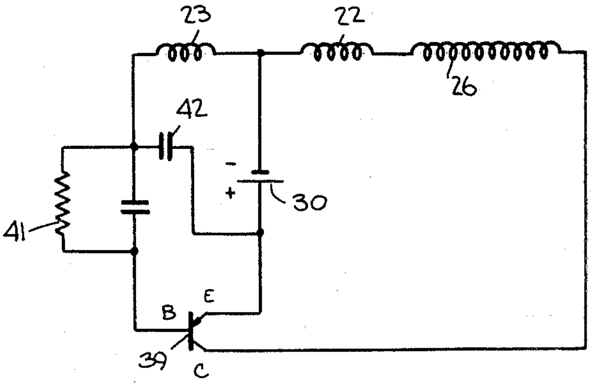

Fig. 2.

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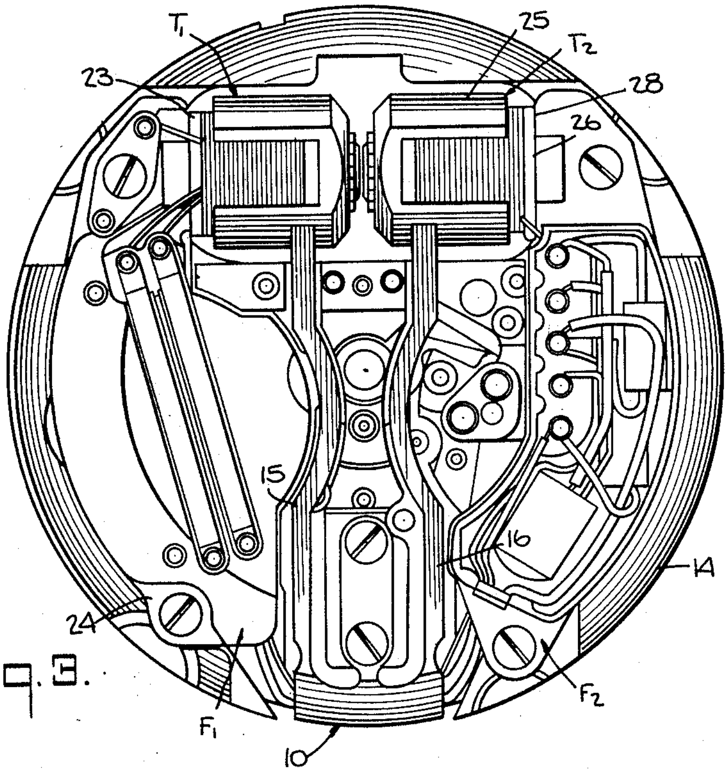

Fig. 3.

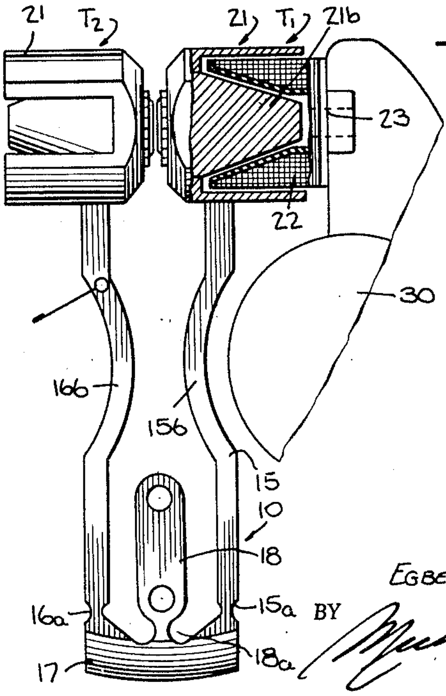

Fig. 4.

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## TUNING FORK FOR ELECTRONIC TIMEPIECE

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Original application Jan. 19, 1961, Ser. No. 89,896. Divided and this application Aug. 19, 1963, Ser. No. 303,020
2 Claims. (Cl. 58—23)

This invention relates generally to electronically-controlled timepieces which incorporate electromagnetically-actuated tuning forks, and more particularly to improved tuning fork structures therefor. This application is a division of the copending application Serial No. 89,896, filed January 19, 1961, now abandoned.

In ordinary electric watches, make-and-break contacts are mechanically operated by the swinging of the balance wheel. Each time these contacts close, battery current flows in a coil or coils to electromagnetically impulse the balance wheel. This mechanically operated make-and-break contact system is subject to wear and also to deterioration and contamination of the delicate contact points which must open and close an electric circuit without fail 216,000 times a day. The slightest sparking will cause rapid deterioration of these contacts and early failure of the watch.

The present invention does away with a balance wheel and escapement as well as make-and-break contacts and makes use of a timekeeping tuning fork which is pulsed electromagnetically by means of a transistor circuit. It constitutes an improvement over timepieces of the type disclosed in the copending applications Serial No. 665,480, filed June 13, 1957, now Patent No. 2,971,323, entitled "Electronically-Controlled Timepiece," and in Serial No. 584,709, filed May 14, 1956, now Patent No. 2,960,817, entitled "Electrical Timepiece."

In said copending applications there are disclosed novel timepieces including a self-sufficient timekeeping standard formed by a tuning fork having a predetermined natural frequency and a battery-energized transistorized drive circuit to sustain the vibratory motion of the fork. This motion is transferred to a rotary movement including the usual gear train and dial pointers by means of a pawl attached to one tine of the fork, the pawl advancing a ratchet wheel which drives the gear train.

The main object of this invention is to provide an improved tuning fork structure for an electronic timepiece of the above-described type having a high degree of stability.

For a better understanding of the invention as well as other objects and further features thereof, reference is made to the following detailed description to be read in conjunction with the accompanying drawings wherein like components in the several figures are identified by like reference numerals.

In the drawings:

FIG. 1 is a schematic representation, in perspective, of the basic components of an electronic timepiece in accordance with the invention.

FIG. 2 shows the electrical circuit diagram of the timepiece.

FIG. 3 is a plan view of the electronic watch movement as seen on the dial side of the watch, and

FIG. 4 is a separate elevational view of the tuning fork structure.

Referring now to the drawing, the major components of a timepiece in accordance with the invention are a timekeeping standard constituted by a tuning fork 10 and an electronic drive circuit 11 therefor, a rotary movement of conventional design including a gear train 12 for turning the hands of the timepiece, and a motion transformer including an index wheel 13 operatively intercoupling the fork 10 and the rotary movement 12 and acting to convert the vibratory action of the fork into rotary motion. The tuning fork has no pivots or bearings and its timekeeping action is therefore independent of the effects of friction.

All of the electrical components of the drive circuit are mounted on two unitized sub-assembly units or modules attached to a disc-shaped metallic pillar plate 14 which may be supported within a watch casing of standard design or within any other type of housing, depending on the use to which the timepiece is put.

Tuning fork 10 is provided with a pair of flexible tines 15 and 16 interconnected by a relatively inflexible base 17, the base being provided with an upwardly extending stem 18 secured to the pillar plate by suitable screws 19 and 20. The central area of the pillar plate is cut out to permit unobstructed vibration of the tines.

The tuning fork is actuated by means of a first transducer $T_1$ constituted by a magnetic element 21 secured to the free end of tine 15, the element coacting with a drive coil 22, and a phase sensing coil 23. Drive coil 22 is wound on an open ended tubular carrier 24 affixed to a sub-assembly mounting form $F_1$ which is secured to pillar plate 14. Coils 22 and 23 may be wound in juxtaposed relation on carrier 24 or the phase sensing coil 23 may be wound over drive coil 22.

A second transducer $T_2$ is provided constituted by a magnetic element 25 secured to the free end of tine 16 and coacting with a drive coil 26 wound on a tubular carrier 27.

The operation of the motion transformer depends upon the tuning fork amplitude remaining within reasonable limits under all conditions of shock, vibration and motion.

As best seen in FIGS. 1 and 2, the electronic drive circuit 11 of the tuning fork comprises a transistor 39, the single cell battery 30 and an R-C biasing network constituted by a condenser 40 shunted by a resistor 41. Transistor 39 is provided with base, emitter and collector electrodes represented by letters B, E and C, respectively.

The base electrode is coupled through the R-C bias network 40–41 to one end of the phase-sensing coil 23, the other end of the coil being connected to one end of the drive coil section 22. The drive coil 26 is connected in a series with drive coil 22 to the collector electrode C of the transistor.

The emitter electrode E is connected to the positive terminal of the battery 30, the negative terminal thereof being connected to the junction of drive coil 22 and phase-sensing coil 23. Thus the battery is connected serially through both drive coils 22 and 26 between the emitter and collector electrodes of the transistor, the collector being negative relative to the emitter.

The transistor is preferably of the germanium junction type, and the polarity of the battery connection is shown as it exists when the transistor is of the PNP type. Obviously for other types of junction and point contact transistors made of such materials as silicon or germanium, the battery connections are arranged in accordance with the particular requirements.

The interaction of the electronic drive circuit and the tuning fork is self-regulating and functions not only to cause the tines to oscillate at their natural frequency, but also to maintain oscillation at a substantially constant amplitude. In practice, the amplitude of oscillation of the tines will be maintained at a substantially constant value or quickly returned to this value in the event of a mechanical disturbance. The electrical behavior of this circuit is set out more fully in the above-identified copending applications.

A tuning fork is a high "Q" mechanical oscillator and will vibrate at a natural frequency determined by the dimensions of the tines and the loading thereon which, in this instance, is determined by the mass of magnetic elements attached to the free ends. The rate at which the timepiece movement is driven is directly proportional to the operating frequency of the vibrator, so that the accuracy of the timepiece may be regulated by predetermining the operative frequency of the tuning fork. In practice, a fork vibrating at 360 cycles per second may be used.

For reasons which will be explained hereinafter, the design of the fork is made such as to provide a constriction 18*a* of reduced section between the stem 18 and the base 17 of the fork. This reduction in mass between the stem and the base of the fork weakens the connection between the fork mounting and the fork tines and provides in effect a flat spring hinge. The flat spring hinge is of sufficient stiffness to maintain the proper alignment of the fork and yet to elastically mount the fork within the watch casing. Each tine 15 and 16 is also provided at its root with a constriction 15*a* and 16*a*, respectively which may be filed to make small adjustments in tine frequency. To economize on space by allowing room within the casing for the electrical energy source provided by a miniature battery cell 30, the intermediate portion 15*b* of tine 13 is bowed inwardly, the arc of the bow being concentric with the circumference of the circular battery wafer. To effect symmetry, the intermediate portion 16*b* of the other tine is likewise bowed, whereby the fork has a knock-kneed appearance.

We shall now consider the reasons for elastically mounting the tuning fork within the casing.

Mechanical oscillators for timekeeping purposes require very stable masses and elasticities. Whether this mechanical oscillator consists of more than two masses elastically coupled in a given frequency range is not important as long as the masses and elasticities remain constant.

The pendulum, balance wheel and reed are two-mass oscillators in which the second mass or inertia is many times and at least "Q" times greater than the first mass. Hence this second mass or inertia, in spite of being unstable, cannot have more influence on the frequency and power of the oscillator than is already determined by the "Q" of this two-mass oscillator.

Quartz crystals, vibratory rods and tuning forks are three-mass oscillators, the third mass being the mounting fixture for the oscillator. This third mass or fixture is unwanted, for it is not constant, particularly in portable devices, such as watches. The fixture mass is also a more or less energy-absorbing element when in touch with nonmetallic parts or when only lightly in contact with other parts.

It may readily be shown that these three-mass oscillators are not as effective as timekeepers when constructed as two-mass oscillators. In a quartz crystal, with its "Q" of one million, if we assume a $\frac{2}{10}$ gram oscillating quartz mass, the fixture mass should be at least 400 pounds; the same being true for the vibratory rod. But in the present instance involving a tuning fork in a watch, with a tuning fork having a 0.5 gram mass and a "Q" of 3,000, the wrist watch case and pillar plate would have to weigh at least three pounds. Obviously this is not feasible.

In a three-mass oscillator, the sum of three vectors of velocity multiplied by mass and angle velocity times

inertia must be zero. In order to bring the fixture vector to zero one must make the other two equal and opposite. In the present tuning fork construction this is substantially accomplished by so connecting the magnetic elements to the parallel tines so that the tines point to the center of gravity of the magnetic elements whereby the velocity vectors of both elements fall into the same line.

However to make the absolute values of velocity times mass equal requires that the natural frequencies of the tines be equal. How accurate this matching of tine frequencies must be depends upon the ratio of the fixture inertia to the inertia of the magnetic element at the foot of the tine. Putting the watch on a hard surface like a glass plate might cause this ratio to exceed 100,000 to 1, so that the frequencies of the tines would then have to be matched accordingly, which means matched to one second. Even with this high matching of the frequencies, we would still have unequal magnet vectors, for the "Q" of the fork is only 3,000.

Since the fork is driven on both sides while power is taken off by the ratchet system from the tine which is driven 25% more (tine 16 in FIG. 1), the mathematical "Q" responsible for such balancing can be estimated to about 10,000 so that it would not be sensible to match the tines more accurately than 10 seconds. In this case, the fixture inertia ratio would still have to be less than 10,000 to 1, which is not possible when for example the watch is laid on a hard surface.

The only practical way to permit the magnets, independently of fixture inertia, to oscillate with equal products of velocity times mass is to mount the entire fork elastically within the watch casing in the manner disclosed above.

The resulting natural frequency of the fork will be the arithmetic mean of the two tine frequencies. Theoretically, the mounting elasticity can be "Q" times stiffer or the tine frequency difference ratio times stiffer than the elasticity of one tine, which of these two numbers is smaller. In practice, the elastic mounting is made much less stiff than this theoretical value in order to have more tolerance in unbalance of the tines frequencies. The sensitivity of the watch to shock is not markedly affected by this elastic mounting. However, the elasticity of the mounting must not be excessive, otherwise the sensitivity of the wrist watch to shock would increase. In practice, the mounting elasticity should be about 10% of the elasticity of one tine, as measured from the cup center. This means that the stem elasticity must be considerably stiffer than the tine elasticity.

The torsional elasticity in the base of the fork takes care of the adverse effect arising when the watch casing is resting on a hard surface. The torsional elasticity is in effect produced by the short tine or stem 18 which couples the fixture of pillar plate 14 to the base 17 of the fork. It is to be noted that the stem mounting is very stiff in the plane normal to the plane of vibration. The advantage of having an upwardly extending stem is that it brings the elastic mounting member as close as possible to the tine feet in order to optimize decoupling for a given mounting elasticity.

While there has been shown what is considered to be a preferred embodiment of the invention, it is to be understood that many changes may be made therein without departing from the essential spirit of the invention as defined in the annexed claims.

What is claimed is:

1. In a timepiece having a mounting plate, a tuning fork structure supported on said plate comprising a pair of tines and a connecting base thereof, a stem integral with said base and extending upwardly therefrom to occupy a position intermediate said tines, and means attaching said stem to said mounting plate, the junction of said stem and said base being constricted to provide a flat spring elastically mounting said fork on said plate.

2. In a timepiece having a mounting plate for support-

ing a gear train operating time indicators, an electromagnetically-actuated tuning fork supported on said plate and operatively coupled to said gear train, said fork being constituted by a pair of tines joined together by a base having an integral stem, said stem extending upwardly from said base and being situated between said tines, said stem being secured to said mounting plate, the junction between said stem and said base being constricted to provide a flat spring elastically to mount said fork on said plate.

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