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M. HETZEL

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ELECTROMAGNETIC VIBRATING DRIVE

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2 Sheets-Sheet 1

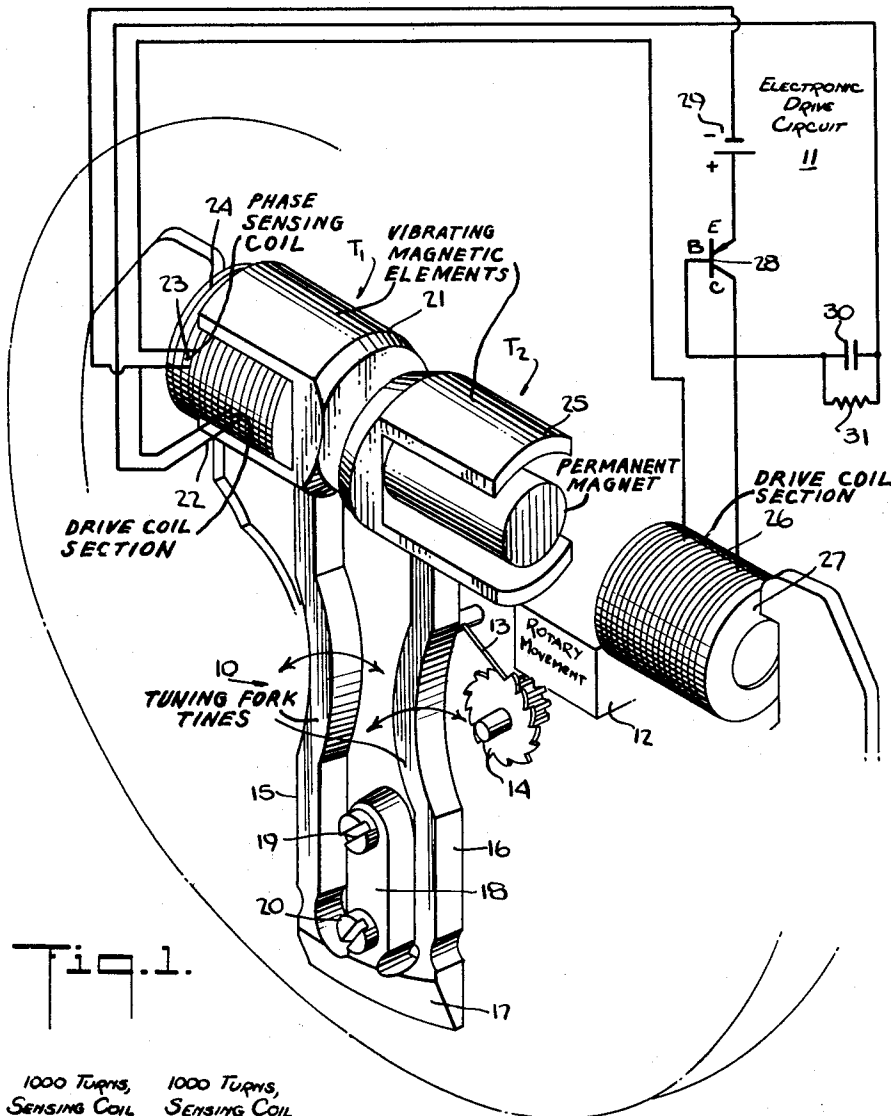


Fig. 1.

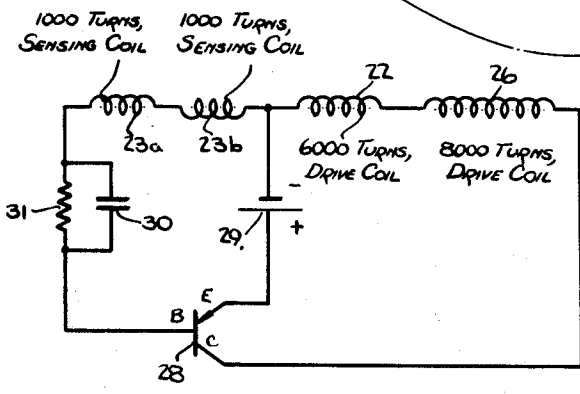


Fig. 2.

INVENTOR.  
 MAX HETZEL  
 BY *Michael Chad*  
 ATTORNEY

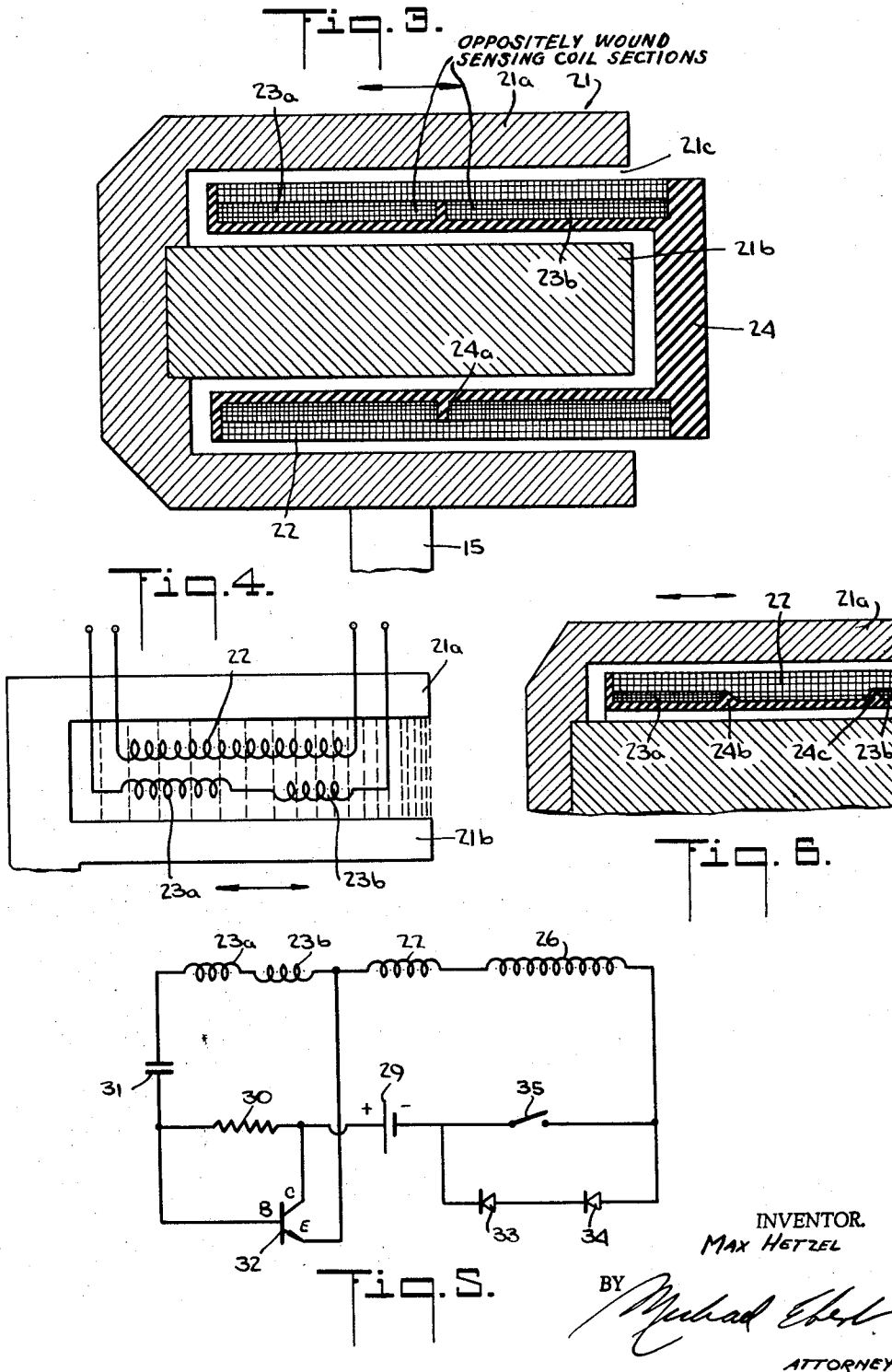
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2 Sheets-Sheet 2



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**ELECTROMAGNETIC VIBRATING DRIVE**

Max Hetzel, New Hyde Park, N.Y., assignor to Bulova Watch Company, Inc., New York, N.Y., a corporation of New York

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9 Claims. (Cl. 318—128)

My invention relates generally to electronically controlled timepieces, and more particularly to improved electromagnetic transducers and transistor drive circuits therefor to actuate a tuning fork timekeeping standard and to convert the vibratory motion of the fork into rotary motion.

In my copending applications Serial No. 665,480, filed June 13, 1957 entitled "Electronically Controlled Timepiece" now issued as Patent 2,971,323, and in Serial No. 584,709, filed May 14, 1956, entitled "Electrical Timepiece" there are disclosed devices making use of a tuning fork having a predetermined natural frequency, the fork being pulsed electromagnetically by means of a battery-operated transistor circuit which excites the fork into vibration and sustains the motion thereof.

This motion is transferred to a rotary gear train by means of a pawl secured to one tine of the fork, the pawl advancing a ratchet or index wheel which drives the train.

The drive circuit for the tuning fork is constituted by a drive coil electromagnetically coupled to the tuning fork and connected to a transistor amplifier whose operation is controlled by a phase-sensing or pick up coil similarly coupled to the tuning fork, the alternating voltage induced in the sensing coil by the vibration of the fork being applied to the transistor to render it conductive periodically and thereby produce drive pulses in the drive coil.

The tuning fork, which is operatively coupled to both coils, in effect acts as a feedback link for the transistor amplifier, and when the amplification factor of the amplifier exceeds the damping of this feedback element, under proper phase conditions the tuning fork is excited into vibration and the oscillation thereof is sustained by the amplifier.

In practical embodiments of this arrangement, it is difficult to separate or isolate the drive coil and pick-up coil transducers and as a consequence electromagnetic or electrostatic coupling between these transducers may lead to a higher degree of feedback than that brought about by the tuning fork. Hence the amplifier will be caused to oscillate parasitically at a frequency determined not by that of the tuning fork but by the unwanted stray feedback. When this occurs, vibration of the tuning fork may cease and the time-piece rendered inoperative.

Such stray coupling is particularly acute in small electronic watch movements where, because of the limited space available, it becomes necessary to combine the sensing coil and a section of the drive coil on one transducer operatively coupled to one tine of the fork, the main section of the drive coil being placed on the second transducer operatively coupled to the other tine. For example, in one form of watch now in commercial use, 6,000 turns of the drive coil as well as 2,000 turns of sensing coil are both wound on one coil form, and the remaining 8,000 turns of drive coil being wound on a second form. Thus while the resultant transducers have the same total number of turns and are therefore of equal size, a strong electromagnetic coupling is developed between the pick-up and drive systems. This gives rise in the circuit to parasitic oscillations having a frequency of several kilocycles.

While one may shunt out these high frequency oscillations with a by-pass capacitor whose reactance is relatively great at the lower frequency of the mechanical os-

cillations, the capacitor also acts to impart a phase shift which, however small, is nevertheless sufficient to bring about a change in timing amounting to an error of some seconds per day. Moreover since the phase shift varies somewhat with temperature, this introduces a further inaccuracy. The shunt capacitor not only impairs the accuracy of the watch, but because of its bulk it adds to the space requirements. This of course is a disadvantage in highly compact watch mechanisms where space is at a premium.

Accordingly, the principal object of my invention is to provide a transducer arrangement for an electronically actuated tuning fork in which feedback between the sensing and drive coils is obviated without the use of shields or a shunt capacitor, thereby avoiding the disadvantages incident to such expedients and improving the accuracy of the timepiece.

More specifically, it is an object of the invention to provide a transducer wherein the sensing coil turns are so arranged and wound relative to the drive coil turns as to preclude unwanted coupling therebetween, without impairing the operative relationship between these coils and the tuning fork.

Also an object of the invention is to provide a transistor circuit for a timepiece of the above-described type which consumes less power and which operates effectively over a greater temperature range.

A further object of the invention is to provide an electronically operated stop watch of high efficiency in which the start and stop delay is but a small fraction of a second.

Briefly stated, these objects are attained by winding the sensing coil along the coil form in two series-connected halves, which are wound in opposing directions, the half sections of the sensing coil being symmetrically arranged with respect to the drive coil winding whereby the transfer inductivity therebetween is effectively zero. The divided sensing coil however is distributed within an annular air gap formed between a cylindrical magnet and a surrounding cup, the flux density in the air gap decreasing progressively as one moves inwardly from the open end of the cup. Hence the voltage induced in the one half of the sensing coil adjacent the open end is substantially greater than in the counterwound other half and the total output voltage of the series-connected halves is relatively large despite the bucking arrangement thereof.

A further significant feature of the invention resides in the use of a grounded collector silicon transistor drive circuit which has an extremely low leakage current, thereby minimizing power losses.

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 drawing, wherein:

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

FIG. 2 is the electrical circuit diagram of the timepiece;

FIG. 3 is a sectional view of one transducer showing the winding arrangement of the pick-up drive coils;

FIG. 4 is the equivalent circuit diagram transducer;

FIG. 5 shows a modified electrical circuit diagram for the timepiece which includes a stop watch arrangement; and

FIG. 6 is a modified coil carrier for the transducer.

Referring now to FIG. 1 of the drawings, the major components of the timepiece are a timekeeping standard constituted by a tuning fork 10 and an electronic drive circuit 11 therefor, and a rotary movement 12 of conventional design including a gear train for turning the hands of the timepiece which may be a clock, a watch or any other timing mechanism such as a time-delayed

switch. Because of the exceptional accuracy of the device, a switching action may be caused to occur within predetermined months, days, hours or minutes or fractions thereof, spaced from a given starting instant. The gear train is driven by means of a pawl 13 connected to one tine of the fork and engaging a ratchet wheel 14 coupled to the rotary movement. The tuning fork has no pivots or bearings and its timekeeping action is therefore independent of the effects of friction.

Tuning fork 10 is provided with a pair of flexible tines 15 and 16 interconnected by a relatively inflexible base 17, the base having an upwardly extending stem 18 secured to the pillar plate of the timepiece 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 first and second transducers  $T_1$  and  $T_2$ . Transducer  $T_1$  is constituted by a magnetic element 21 secured to the free end of tine 15, the element coating with a drive coil 22 and a pick-up or phase sensing coil 23. The two coils are wound in a manner to be later described on an open ended tubular carrier 24 affixed to a sub-assembly mounting form secured to the pillar plate. The second transducer  $T_2$  includes a magnetic element 25 secured to the free end of tine 16 and coating with a drive coil 26 wound by a tubular carrier 27.

The electronic drive circuit 11 comprises a transistor 28, a single cell battery 29 and an R-C biasing network formed by condenser 30 shunted by resistor 31. Transistor 28 which may be of the Germanium junction PNP type, is provided with base, emitter and collector electrodes designated B, E and C, respectively.

The base B is coupled through the R-C network 30-31 to one end of phase sensing coil 23, the other end of which is connected to one end of drive coil section 22. The main drive coil section 26 is connected in series with drive coil section 22 to collector electrode C of the transistor.

Emitter E is connected to the positive terminal of battery 29, the negative terminal thereof being connected to the junction of drive coil 22 and phase-sensing coil 23. Thus battery 29 is connected serially through both drive coils 22 and 26 between the emitter and collector of the transistor, the collector being negative relative to emitter. Battery 29 should be of the type providing a highly stable voltage (i.e., 1.3 volts) for almost the full duration of its useable life.

The interaction of the electronic drive circuit 11 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 operation, an energized pulse applied to the drive coils of the transducers will cause an axial thrust on the associated magnetic element in a direction determined by the polarity of the pulse in relation to the polarization of the permanent magnet therein and to an extent depending on the energy of the pulse. Since the magnetic element is attached to a tine of the tuning fork, the thrust on the element acts mechanically to excite the fork into vibration.

The resultant movement of the magnetic element relative to the fixed coils induces a back E.M.F. in the drive coils and in the case of transducer  $T_1$  in the phase sensing coil as well. Since the magnetic element reciprocates in accordance with the fork motion, the back E.M.F. will take the form of an alternating voltage whose frequency corresponds to the fork frequency. The voltage picked up by the sensing coil is applied to the base of the transistor to control the instant during each cycle when the driving pulse is to be delivered to the drive coils. The behavior of the drive circuit is more fully explained in the above-identified patent applications.

The two transducers are of like design except that transducer  $T_1$  includes a phase-sensing coil 23 as well

as a drive coil 22. The construction and behavior of the transducers is similar to that of a dynamic permanent magnet speaker save that the moving element is the magnet and not the coil.

The invention resides in the arrangement of the sensing coil and drive coil in transducer  $T_1$  and as shown in FIG. 3 magnetic element 21 is constituted by a cylindrical cup 21a, of magnetic material, such as iron, and a permanent magnet rod 21b coaxially mounted therein. Magnet 21b, which may be made for example of Alnico, is supported on the end wall of the cup to provide a magnetic circuit in which the lines of magnetic flux extend across the annular air gap 21c defined by the inner magnet and the surrounding cup.

Magnet rod 21b is a cylinder of uniform circular cross section throughout its length, hence the cross-sectional area of the air gap throughout the length of the cup is also uniform. However, the magnetic field strength is greatest at the mouth of the cup adjacent the free pole of the permanent magnet and is weakest at the base of the cup inasmuch as the flux density progressively diminishes as one moves inwardly from the open end.

As best seen in FIG. 1, cylindrical cup 21a is cut out longitudinally along diametrically opposed planes to form slots. This effects a substantial reduction in transducer dimensions with relatively little flux leakage. The cut-outs act to reduce the space occupied by the cups in depth and they also prevent so-called dash-pot effects resulting from air compression of the magnet and cup assembly.

It will be seen that the fixed tubular carrier 24 is also cylindrical and is received concentrically within the annular air gap 21c in spaced relation both to the magnet rod and the surrounding cup whereby the magnetic element is free to reciprocate axially relative to the fixed coils.

The tubular coil carrier 24 is provided centrally with a circumferential ridge 24a, at the midpoint thereof, to provide separation between two halves of the sensing coil 23, one half 23a being wound on one side of the ridge and the remaining half 23b being wound in a counter direction on the other side. The two halves are connected in series. Wound about the two halves of the sensing coil are the turns of drive coil 22.

In lieu of a single ridge, it is also possible to use a pair of spaced ridges 24b and 24c, centrally located on the carrier and providing a greater separation between coil halves 23a and 23b. The space between the two ridges, as shown in FIG. 6, may be used by the drive coil 22.

The operation of this arrangement is best understood with reference to FIG. 4. It will be seen that the drive coil 22 and the sensing coil halves are magnetically coupled, the two halves being symmetrically disposed relative to the drive coil and inductively coupled thereto. Since however the voltages induced by the drive coil in the sensing coil halves are of equal amplitude and in phase opposition, the voltages buck each other and cancel out.

On the other hand the voltages induced in the sensing coil halves by reciprocal movement of the magnetic elements 21a, 21b, are not of equal amplitude, for the flux density in the air gap area in which coil half 23b lies is far greater than that for coil half 23a. Hence even though the two induced voltages are in phase opposition the resultant output is primarily the voltage induced in coil half 23b and this voltage is sufficient to control the transistor operation in the manner described previously.

While a symmetrical arrangement of the coil halves has been shown in order to reduce the inductive transfer between the sensing coil and drive coil to zero, such symmetry is not essential but preferred since it is only necessary to reduce such feedback substantially to prevent high frequency oscillation. It is to be understood that

the specific number of turns given above are merely by way of example.

In the circuit shown in FIGS. 1 and 2, the arrangement is of the grounded emitter type. In the alternative circuit shown in FIG. 5, the circuit is of the grounded collector type and makes use of a Silicon high common emitter connection current amplification factor transistor amplifier 32. The advantage of the Silicon transistor over the Germanium type is that it is free of leakage current and works well from  $-60^{\circ}$  to  $110^{\circ}$  C. with a power efficiency of 75% and more. This reduces the power consumption of the timepiece and also makes it operative in extremely hot and cold climates without loss of accuracy.

A very reliable start and stop feature can be incorporated in this circuit by the use of two Silicon diodes 33 and 34 interposed between the negative terminal of battery 29 and drive coil 26, the diodes being serially connected and shunted by an on-off switch 35.

In the event the battery voltage applied to the transistor is lowered, a point will be reached at which the resultant amplitude of fork operation and pawl movement is insufficient to advance the ratchet wheel, even though the fork still vibrates. Assuming that the diodes each have a knee voltage of .4 volts, in series the diodes will begin to conduct at .8 volts. With switch 35 open (stop position), the voltage applied to the transistor oscillator is the battery voltage (1.32) minus .8 volts, which will ordinarily reduce the amplitude below the normal amount to a level at which the ratchet wheel will no longer be driven. When the switch is closed, the diodes are shunted out and normal operation is resumed.

Thus the operation of the fork is not arrested when stopping the watch but is only diminished somewhat in amplitude. The gear train however is decoupled from the tuning fork.

While there has been shown what are considered to be preferred embodiments of the invention, it will be appreciated that many modifications may be made therein without departing from the essential spirit thereof expressed in the annexed claims.

What I claim is:

1. An electromagnetically actuated vibrator comprising a vibratory member, a transducer for actuating said member and including a magnetic element attached to said member and vibrating therewith and fixedly supported pick-up and drive coils operatively coupled to said magnetic element, an amplifier coupled to said coils, said coils being inter-linked by said element to provide feedback in said amplifier acting to sustain oscillation therein and cause vibration of said member, said pick-up coil being constituted by two serially-connected portions wound in counter directions to minimize stray coupling between said drive coil and said pick-up coil, said two pick-up portions being symmetrically disposed relative to said drive coil whereby the voltages induced therein by said drive coil effectively balance out, said two pick-up portions being so disposed relative to said vibrating magnetic element whereby the voltages induced therein by movement of said element are of unequal amplitudes.

2. A vibrator, as set forth in claim 1, wherein said

amplifier is constituted by a battery energized transistor, and said vibratory member is a tuning fork.

3. An electronically controlled timepiece comprising a tuning fork, a transducer for actuating said fork and including a magnetic element attached to a tine of said fork and fixed pick-up and drive coils operatively related to said magnetic element, an amplifier coupled to said coils to drive control voltage from said pick-up coil and to apply drive pulses to said drive coil, said coils being linked by said element to provide oscillatory feedback sustaining the vibration of said tuning fork, said pick-up coil being constituted by two serially connected portions wound in counter directions to minimize stray coupling between said drive and pick-up coils, said two pick-up portions being symmetrically disposed relative to said drive coil whereby the voltages induced therein by said drive coil effectively balance out, said two pick-up portions being so disposed relative to said vibrating magnetic element whereby the voltages induced therein by movement of said element are of unequal amplitudes.

4. An electromagnetically-actuated timepiece comprising a tuning fork having a pair of tines, and means actuating said fork including a transducer constituted by a magnetic element attached to one of said tines and formed by a cylindrical cup having a magnetic rod supported coaxially therein to define an annular air gap of uniform cross-section, a fixedly supported coil form received within said air gap, and pick-up and drive coils wound on said form, said pick-up coil being divided into two serially-connected portions wound in counter directions.

5. The arrangement set forth in claim 4, wherein said coils are equal halves symmetrically disposed relative to said drive coil.

6. The arrangement set forth in claim 4, wherein said form is provided with a central ridge to separate the two portions of said pick-up coil.

7. The arrangement set forth in claim 4, wherein said form is provided with a pair of spaced centrally located ridges to separate said two portions of said pick-up coil, the drive coil being wound in the space between said ridges.

8. An electromagnetically-actuated timepiece comprising a tuning fork having a pair of tines, and means actuating said fork including a transducer constituted by a magnetic element attached to one of said tines and formed by a cylindrical cup having a magnetic rod supported coaxially therein to define an annular air gap of uniform cross-section, a fixedly supported coil form received within said air gap, and pick-up and drive coils wound on said form, said pick-up coil being divided into two serially-connected portions wound in counter directions, a battery-operated transistor amplifier connected to said drive coil and said pick-up coil and rendered oscillatory by the feedback through said magnetic element.

9. A device as set forth in claim 8, wherein said transistor amplifier includes a grounded-collector to Silicon NPN transistor.

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