Dec. 2, 1969 YOSHIKIYO FUTAGAWA ET AL 3,481,138

DRIVE FOR A BALANCE IN AN ELECTRIC TIMEPIECE

Filed May 8, 1967 4 Sheets-Sheet 1

FIG. 1

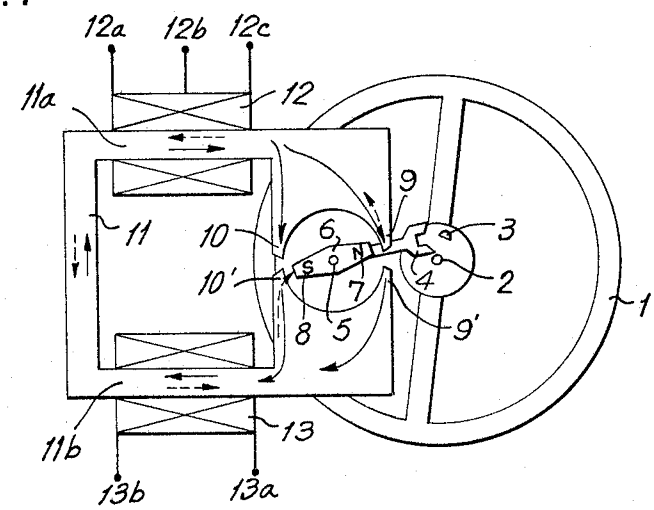

FIG. 2

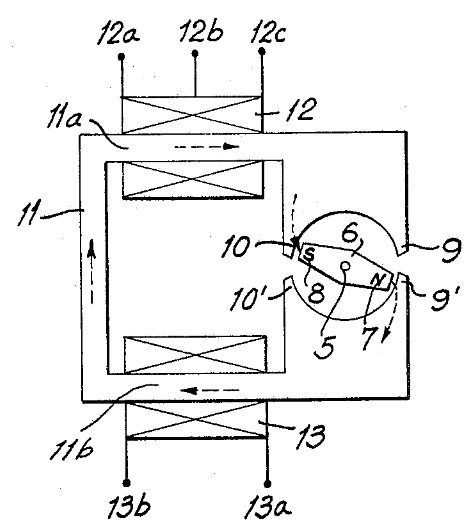

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FIG. 3

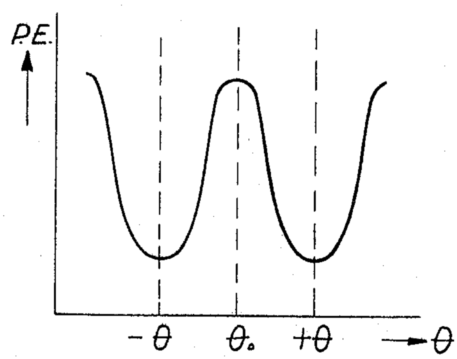

FIG. 4
PRIOR ART

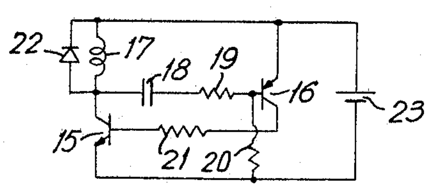

FIG. 5

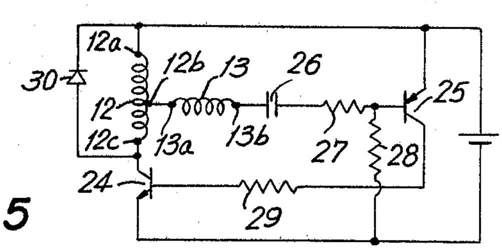

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FIG. 6

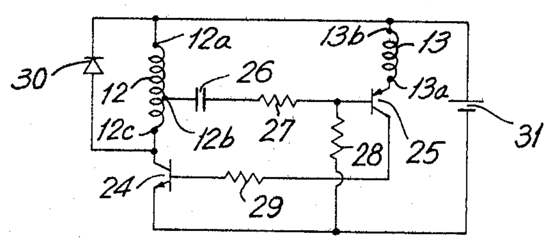
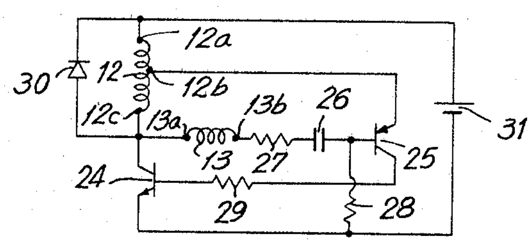


FIG. 7



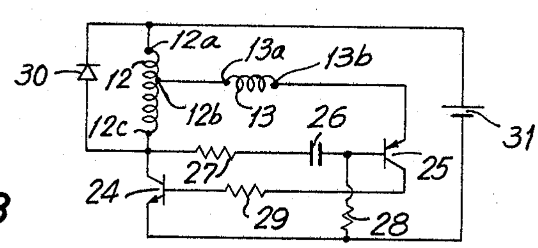


FIG. 8

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DRIVE FOR A BALANCE IN AN ELECTRIC TIMEPIECE

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FIG. 9A

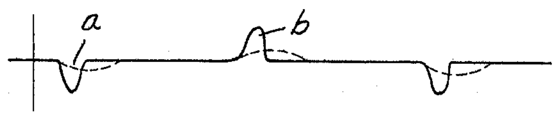


FIG. 9B

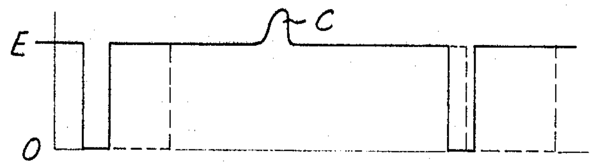


FIG. 9C

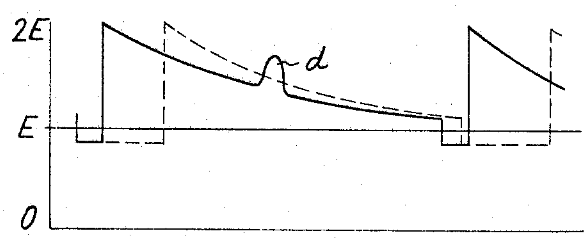


FIG. 10A

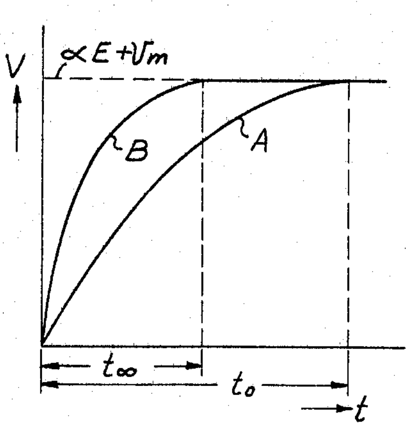
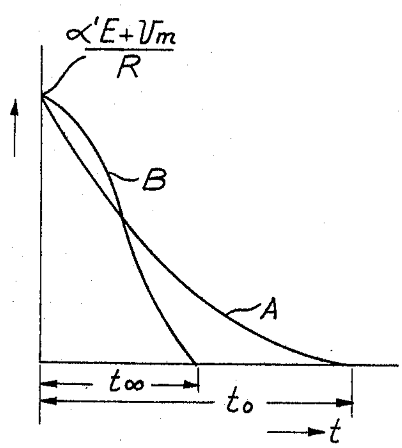


FIG. 10B



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United States Patent Office

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3,481,138
DRIVE FOR A BALANCE IN AN
ELECTRIC TIMEPIECE

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Claims priority, application Japan, May 10, 1966, 41/29,296
Int. Cl. G04c *3/04*
U.S. Cl. 58—28 6 Claims

ABSTRACT OF THE DISCLOSURE

An electric timepiece is provided having an oscillator circuit which provides a pulse output which facilitates self-excited oscillation of the balance wheel and control of the balance oscillation, in an electromechanical transducer wherein the balance wheel is engaged only near the center of the balance oscillation by an anchor and is arrested at a stable point during this engagement of the balance wheel. The oscillator circuit provides a large amount of energy to the balance wheel at the start of the balance oscillation period than the energy applied thereto in the stable state of oscillation, by providing an electrical pulse having a pulse width which is wider at the start of the balance oscillation than in the stable state of oscillation. The amplitude of the balance oscillation is controlled by having the output energy of the electromechanical transducer be a function of the amplitude of the balance oscillation.

The present invention relates to an electric timepiece, and more particularly to an electric timepiece utilizing an oscillator circuit for driving the electric timepiece whereby the pulse output of the oscillator enables self-excited oscillation and amplitude control of the balance wheel, with the electromechanical transducer employed for driving the balance wheel engaging the balance wheel only near the center of the balance oscillation and rendered stationary at a stable point during the oscillation.

In electric timepieces, e.g., wristwatches, it is desired that in order to maintain synchronism, that the balance wheel itself does not constitute an element of the transducer, and accordingly, there is provided an anchor operative with an electromechanical converter.

In such electric timepieces, it is desired to decrease the moment of inertia of the anchor which has a permanent magnet, and to make its construction relatively simple. Furthermore, in order to prevent leakage of magnetic flux in the magnetic circuits, the yoke is commonly disposed very close to the permanent magnet. However, in such instances, the permanent magnet is required to overcome a peak of potential energy due to the variations in permeance of the magnetic circuit. Accordingly, it is necessary to supply a sufficiently large force to the balance wheel at the start of the oscillation period, when the balance wheel is at the stationary state and has no stored energy, while the aforementioned energy peak is effective to prevent the anchor from abnormal vibration which may be caused by outer disturbances when the balance wheel is oscillating.

Thus, it is desired to supply a large amount of energy to the balance wheel only at the start of the oscillation, and a small amount of energy thereto sufficient to maintain the balance oscillation when the balance wheel is in the stable state of oscillation. If this is not done, the balance wheel is subject to a phenomena known as "knocking."

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It is accordingly an object of the present invention to provide an electric timepiece having a transducer, wherein a relatively large amount of energy is applied to the balance wheel at the start of the oscillation period and a reduced amount of energy is applied thereto in the stable state of oscillation.

Another object of the present invention is to provide an electric timepiece comprising an oscillator circuit which has a reduced power consumption in the stable state of oscillation while maintaining self-excited oscillation of the balance wheel.

A further object of the present invention is to provide an electric timepiece having an oscillator circuit which supplies to the transducer, pulses having a larger pulse width at the start of the balance oscillation than the pulse width in the stable state of oscillation.

Yet, another object of the present invention is to provide an electric timepiece wherein the amplitude of the balance oscillation is automatically controlled by the output energy of the transducer.

In accordance with the principles of the present invention, there is provided an electric timepiece having an oscillator circuit whereby the transducer which drives the balance wheel and detects the motion thereof near the center of the oscillation period, with the transducer engaging the balance wheel and increasing its rotative force. Furthermore, there is supplied to the transducer an electric pulse having a wide pulse width at the start of the balance oscillation and a pulse of narrow width when the balance wheel is in the stable state of oscillation, to thereby allow the balance wheel to overcome a peak of energy at the start of the oscillation period.

The novel features believed to be characteristic of this invention are set forth with particularity in the appended claims. The invention itself, however, both as to its organization and advantages thereof, may best be understood by reference to the following description taken in connection with the accompanying drawings wherein:

FIG. 1 depicts an electromechanical time piece transducer for maintaining balance oscillations in an electric timepiece which may be utilized with the novel oscillator of the present invention.

FIG. 2 shows the electromechanical transducer of FIG. 1 including the magnetic circuits set up therein.

FIG. 3 is a graphical representation of the variation of potential energy of the permanent magnet in the transducer shown in FIG. 1, with variation in the rotary angular position of said permanent magnet.

FIG. 4 is a schematic circuit depiction of a conventional oscillator utilized for driving the electromechanical transducer of FIG. 1.

FIG. 5 is a schematic circuit depiction of an oscillator in accordance with the principles of the present invention, in one embodiment thereof.

FIG. 6 is a schematic circuit depiction of an oscillator in accordance with the principles of the present invention, in a second embodiment thereof.

FIG. 7 is a schematic circuit depiction of an oscillator in accordance with the principles of the present invention, in a third embodiment thereof.

FIG. 8 is a schematic circuit depiction of an osecillator in accordance with the principles of the present invention, in a fourth embodiment thereof.

FIG. 9A is a waveform diagram of the induced voltage generated in the driving coil and detecting coil of the electromechanical transducer of FIG. 1.

FIG. 9B is a waveform diagram of the voltage on the collector of transistors **24** in the embodiments of FIGS. 5–8.

FIG. 9C is a waveform diagram of the voltage on the base of the controlling transistor in the embodiments of FIGS. 5 to 8.

FIGS. 10A is a waveform diagram of the variation in voltage with time on the charging condenser in the embodiments of FIG. 5–8.

FIG. 10B is a waveform diagram of the variation in current with time in the charging condenser of the embodiments of FIGS. 5–8.

Referring to FIG. 1, an electromechanical transducer for maintaining the balance oscillation is shown to comprise a balance wheel **1**, oscillating about its axis **2**, and impulse pin **3** mounted on balance wheel **1**, including an anchor **4** connected to its arbor **5**. The balance wheel system of FIG. 1 is thus seen to comprise many of the standard components found in known mechanical watches.

A permanent magnet **6** having north and south magnetic poles **7** and **8** respectively has rigidly connected thereto to anchor **4**. A yoke **11** is provided having magnetic poles **9, 9', 10, 10'** to provide a magnetic circuit surrounding permanent magnet **6**. As shown in FIG. 1, magnetic pole **9** is disposed opposite to the north pole **7** of permanent magnet **6** with pole **10'** disposed opposite to the south pole **8** of permanent magnet **6**. A driving coil **12** having input terminals **12**_a_, **12**_b_, and **12**_c_, is wound about arm **11**_a_ of yoke **11**, and detecting coil **13**, having output terminals **13**_a_ and **13**_b_ is wound about arm **11**_b_ of yoke **11**. Driving coil **12** and detecting coil **13** may be connected so the magnetic flux through the yoke **11** generated by each are added, by connecting terminal **12**_c_ and terminal **13**_a_ and providing a current path from terminal **12**_a_ or terminal **13**_b_. Although not shown in FIG. 1, a well known mechanism for driving the trainwheel of the timepiece may be utilized for the anchor **4**.

The operation of the electromechanical transducer of FIG. 1 is as follows. Permanent magnet **6** is repulsed by magnetic poles **9** and **10'** and is attracted by magnetic poles **9'** and **10**, whereby there is applied thereto a rotative moment to cause rotation if the current pulse applied to the driving coil is sufficiently wide to generate the magnetic flux pattern as show by the solid line arrows in yoke **11** in FIG. 1.

When anchor **4** engages impulse pin **3** the moment of balance wheel **1** adds to its force, and if a large enough force is applied to anchor **4**, balance wheel **1** leaves anchor **4**, while permanent magnet **6** moves from the direction of magnetic poles **9, 10'** to the direction of magnetic poles **9'** and **10** and is stationary there. Due to the restorative force of the hair spring, the balance wheel shortly thereafter takes its original position to again engage with anchor **4** near the center of oscillation of balance wheel **1**, with permanent magnet **6** then returning to the position of stability i.e. from the direction of magnetic poles **9'** and **10**, to that of magnetic poles **9** and **10'**, due to the conservative energy of balance wheel **1**.

If thereafter, driving coil **12** has applied thereto a driving current which generates a magnetic flux opposite in direction to the previous magnetic flux direction, permanent magnet **6** is repelled to the opposite direction by magnet poles **9'** and **10**, and is attracted by magnetic poles **9** and **10'**, which accelerates the rotative moment of magnet **6** to add force to the rotative moment of balance wheel **1** to take the original position, i.e. in the direction of magnetic poles **9** and **10'**. Accordingly, by providing an alternating current to driving coil **12** in synchronism with the period of balance wheel **1**, the added force is applied to balance wheel **1** and it reaches its usual amplitude when the lost energy is equal to the supplied energy. Permanent magnet **6** is rotated by virtue of the moment applied by the driving current and the conservative energy of balance wheel **1**, whereby the magnetic flux flowing from north pole **7** to south pole **8** of permanent magnet **6** is switched from the solid line flux lines of FIG. 1 to the dotted line flux lines of FIG. 2. Thus, the direction of the flux lines is changed from the magnetic circuit running from north pole **7**, through magnetic pole **9**, yoke **11**, magnetic pole **10'** to south pole **8**, to the direction shown by dotted line in FIG. 2, i.e. from north pole **7** through magnetic pole **9'**, yoke **11** and magnetic pole **10** to the south pole.

Due to the change in magnetic flux in yoke **11**, an induced voltage is generated in driving coil **12** and detecting coil **13**, the direction of the induced voltage being opposite to that of the driving current. If the direction of the driving current is opposite to that of the induced voltage, the electro-magnetic energy is converted into mechanical energy and adds force to balance wheel **1**. The above mentioned induced voltage also acts as a synchronous signal for the electric circuit of the time piece in accordance with the present invention, with the width of the induced voltage waveform corresponding approximately to the duration of the engagement of anchor **4** with impulse pin **3** of balance wheel **1**. The waveform of the above mentioned induced voltage is shown in FIG. 9A, wherein the lower half of the waveform is an induced voltage corresponding to the rotation of permanent magnet **6** from the direction of magnetic poles **9** and **10'** to the magnetic poles **9'** and **10**. The upper half of the waveform b is an induced voltage corresponding to the rotation of the permanent magnet **6** from the direction of magnetic poles **9'** and **10** to the magnetic poles **9** and **10'**. As the amplitude of oscillation of balance wheel **1** is increased, the duration of engagement with anchor **4** decreases, while at the same time the rotative velocity of permanent magnet **6** and the change of magnetic flux are increased, causing the induced voltage to be increased as shown by the dotted line with respect to the solid line in FIG. 9A. It will be noted that with respect to the balance wheel **1**, as shown in FIG. 1, permanent magnet **6** when united with anchor **4** makes the magnetic poles opposite to that of north pole **7** and south pole **8** generate a magnetic force of inverse polarity, and is attracted and stands stationary in either direction of magnetic poles **9** and **10'** or **9'** and **10** during almost the complete period of the balance oscillation. Accordingly, the relation to the tuning angle θ of permanent magnet **6**, and its magnetic potential energy is represented by the curve shown in FIG. 3, wherein $-\theta_1$ is the turning angle of the current magnet **6** when in the position of FIG. 1 it is stationary in alignment with magnetic poles **9** and **10'**, $+\theta_1$ corresponding to the turning angle of FIG. 2 wherein it is stationary and aligned with magnetic poles **9'** and **10**, with θ_0 corresponding to the turning angle when the permanent magnet **6** is balanced by the attraction forces of magnetic poles **9** and **10**, and **9'** and **10'**, i.e. north pole **7** being situated near the center of the gap between magnetic poles **9** and **9'** and south pole **8** being equidistant between magnetic poles **10** and **10'**.

As shown in FIG. 3, there is a peak of magnetic potential energy occurring within the turning angle of $2\theta_1$ of anchor **4**. Accordingly in the stable state of oscillation of the balance wheel where the amplitude is large, the conservative energy of the balance wheel must be sufficiently larger than the value of the aforementioned peak of magnetic potential energy. In the stable state of oscillation, when balance wheel **1** moves anchor **4** and permanent magnet **6** through the angle of $-\theta_1$ to $+\theta_1$, balance wheel **1** loses energy in order to overcome the peak at angle θ_0 when approaching from the direction of $-\theta_1$, and conversely receives energy when going in the direction from angle θ_0 to angle $+\theta_1$, accordingly maintaining no loss of energy of the balance wheel **1**. However, when the conservative energy of balance wheel **1** is smaller, at the beginning of oscillation, it will not have sufficient momentum to overcome the aforementioned peak of magnetic potential energy and will stall. In order to overcome the aforementioned peak of energy, the transducer will require to have applied thereto an electrical pulse of sufficient height or width. However, since the output voltage of the voltage source i.e. battery in an electric wrist watch is quite low, it is preferable to provide an oscillator circuit which can widen the width of the pulse, since it is generally difficult to generate a pulse having a large amplitude.

If the anchor 4 of the transducer shown in FIG. 1, engages the balance wheel during most of the oscillating period of balance wheel 1 at the start of the oscillation period, the oscillator circuit can supply the additional force to the balance wheel 1 effectively to provide an electrical pulse of sufficient width to the transducer. However, as the amplitude of the balance wheel 1 reaches that of the stable state of oscillation, the duration of the engagement between balance wheel 1 and anchor 4 is shortened, and accordingly even if the oscillator circuit provides a sufficiently wide electrical pulse to the transducer, it will be of no avail, and accordingly it is necessary to narrow the applied pulse width.

In FIG. 1, in order to add force to the balance wheel 1, the electrical current flowing in driving coil 12 was alternating to generate an alternating magnetic flux in yoke 11. However, if it is possible to add sufficient force to balance wheel 1 by means of a unidirectional driving current in driving coil 12, it will also be possible to maintain the oscillation of balance wheel 1 by having balance wheel 1 return to the position where it drives anchor 4 by the conservative energy of balance wheel 1 to synchronize with the oscillation of balance wheel 1, i.e. the oscillator circuit may supply sufficient force to balance wheel 1 once balance wheel 1 has commenced its oscillatory motion. Hereafter, there will be described various electrical oscillator circuits for providing an electrical pulse in synchronism with the period of the balance oscillation for maintaining oscillation of the balance wheel. Such oscillator circuits generally comprise a simple transistor amplifier having the transducer driving coil in the collector circuit and the detecting coil in the base circuit, an astable transistor blocking oscillator having a time constant capacitor for controlling the period of oscillation, together with a time constant resistor connected to the base terminal of the transistor, or may include a monostable or astable oscillator circuit comprising a pair of transistors of similar or opposite polarity. It should be noted however that in the case of a simple amplifier, if the induced voltage in the detecting coil, generated by the balance oscillation is not sufficient, the transistor will not be switched on, and it will be impossible to start the balance oscillation from a stand still.

In such blocking oscillator circuits, the "on" time of the transistor i.e. the width of the pulse, is determined by the self inductance of the driving coil and the detecting coil and the mutual inductance and resistance of these coils. Since the magnetic circuits in the transducer as shown in FIG. 1, are generally open in one part of the yoke, the inductance will be small and accordingly the width of the pulse will be narrow. It is noted that in such a transducer, the pulse width will be widened if the amplitude of oscillation of the balance wheel is increased, but it is impossible for such transducers to provide self excited oscillation.

In the aforementioned monostable oscillator circuits comprising a pair of transistors of the same polarity, the transistor also will not be switched "on" without generating the induced voltage in the coils as hereinabove described. Also, in the case of the astable oscillators, even if the initial pulse width can be widened, to enable the oscillation to start from a stand still, the electrical power consumption will be disadvantageously substantially increased since either of the two transistors will be switched "on" in the stable state of oscillation.

As pointed out above, it is thus impossible for any of the conventional oscillator circuits briefly described above, to provide the features of self starting together with minimum power consumption. FIG. 4 shows such a conventional oscillator having an astable oscillator circuit including a pair of complementary transistors of opposite polarity, 15 and 16, with transistor 15 being used for driving and transistor 16 used for controlling. The negative induced voltage, as shown in FIG. 9A is generated in driving coil 17 in accordance with the motion of the balance wheel, to render controlling transistor 16 "on." By adding this voltage to controlling transistor 16, the timing circuit comprising charging condenser 18, and resistor 19, controlling transistor 16, resistor 21 and driving transistor 15 is thus rendered into the "on" state. Once in the "on" state, the collector current of transistor 16 which is also the base current of driving transistor 15 flowing through resistor 21 renders driving transistor 15 "on." When transistor 15 is rendered "on," the collector voltage of transistor 15 drops driving controlling transistor 16 further into the "on" condition by virtue of the positive feed back action in this circuit. When driving transistor 15 is switched "on" and is driven into the saturated condition, battery source 23 provides a driving current to the driving coil opposing the induced voltage to supply energy to the balance wheel. The charging current of the aforementioned charging circuit comprising capacitor 18 and resistor 19 flows from the positive terminal of battery 23 through the emitter to base circuit of controlling transistor 16, resistor 19, charging capacitor 18, the collector to emitter circuit of driving transistor 15 returning to the negative terminal of battery source 23, which charging current gradually decreases to sharply cut off controlling transistor 15 and driving transistor 16 by virtue of the aforementioned positive feed back action.

In the aforementioned "on" state, if the discharge time constant of capacitor 18 is a little longer than the balance period, the circuit will be switched "on" when the induced voltage is generated in accordance with the motion of the balance wheel in the next moment. Accordingly, in the conventional oscillator circuit shown in FIG. 4, it is possible to control the transducer so as to supply sufficient energy which is synchronized with the period of the balance oscillation. However, the pulse width of the generated electrical pulse is determined by time constant capacitor 18 and charging resistor 19, i.e. the charging voltage added to capacitor 18 is only that of battery source 23, with the final value of the charging voltage on capacitor 18 being the output voltage of battery source 23. Thus, in the case of adding force to the balance wheel by means of the transducer as shown in FIG. 1, since it is impossible to start the balance oscillation without providing a sufficiently wide pulse at the start of the balance oscillation, the values of time constant capacitor 18 and resistor 19 are fixed in order to widen the pulse width sufficiently for the oscillator circuit shown in FIG. 4. However, in such a case, even if the balance oscillation does reach the stable amplitude, after disengagement of the balance wheel the oscillator circuit will supply the reactive electrical energy to the transducer. In the case of the small batteries utilized in wrist watches, this action will shorten the battery life, and accordingly becomes a very serious disadvantage in practical use. Diode 22, as shown in FIG. 4 functions to absorb the energy of the driving coil which is at the trailing end of the electrical pulse.

Referring to FIG. 5, there is shown a first embodiment of an oscillator circuit in accordance with the principles of the present invention, wherein the above mentioned disadvantages of the conventional oscillator circuit of FIG. 4, and the like, are avoided. The oscillator of FIG. 5 includes a positive feed back circuit comprising intermediary terminal 12*b* of driving coil 12, detecting coil 13 as shown in FIG. 1, charging condenser 26, and charging resistor 27, the base to collector circuit of controlling transistor 25, resistor 29, the base to collector circuit of driving transistor 24 and terminals 12*c* and 12*b* of driving coil 12, in the aforementioned sequence. A charging circuit for time constant capacitor 26 is seen to comprise the positive terminal of battery source 31, emitter to base circuit of controlling transistor 25, resistor 27, time constant capacitor 26, detecting coil 13, intermediate terminals 12*b* and 12*c* of driving coil 12, the collector to emitter circuit of driving transistor 24, and the negative terminal of battery source **31** in the aforementioned order. A discharge circuit is seen to comprise the positive terminal of battery source **31**, terminal **12***a* of driving coil **12**, intermediate terminal **12***b*, detecting coil **13**, time constant capacitor **26**, resistor **27**, time constant resistor **28** (which provides a period of oscillation a little longer than that of the balance wheel), and the negative terminal of battery suorce **31**, in the aforementioned sequence. The embodiment of FIG. 5, in accordance with the principles of the present invention, is thus seen to comprise an astable oscillator circuit utilizing an NPN transistor **24** and a PNP transistor **25** as the controlling transistor including a diode **30** connected across the terminals of driving coil **12** in order to absorb the energy which is stored in driving coil **12** which is generated at the lagging edge of the driving coil pulse.

In the oscillator circuit of FIG. 5, since it comprises an astable circuit it will oscillate even when balance wheel **1** is not oscillating to provide an output pulse to driving coil **12** having a particular pulse width. If this output pulse is sufficient to overcome the peak of potential energy shown in FIG. 3, as discussed above, to provide sufficient energy to anchor **6**, the amplitude of oscillation of the balance wheel will be increased, resulting in an induced voltage generated in driving coil **12** and detecting coil **13**. Since in the embodiment of FIG. 5, the oscillator circuit is arranged so that the voltage induced across terminals **12***a* and **12***b* is added to the induced voltage in detecting coil **13**, this induced voltage will bring transistor **24** to the conductive state more stably even before controlling transistor **25** is switched on, to provide an electrical pulse to driving coil **12** to add more force to the balance wheel. Thus, the oscillator circuit of FIG. 5 synchronizes its pulse output with the oscillating period of the balance wheel, thereby adding energy to the balance wheel.

The oscillator of the present invention, shown in FIG. 5, is thus seen to be advantageous over the conventional oscillator such as that depicted in FIG. 4 in the following manner. The oscillator of FIG. 5 generates an electrical pulse of sufficient width at the start of the balance wheel oscillation which is independent of the amplitude of the balance wheel oscillation; and when the balance wheel attains a particular amplitude, the width of the generated electrical pulse becoming narrower to become a function of the amplitude of the balance wheel oscillation. Thus, in the conventional oscillator arrangement as shown in FIG. 4, the electrical pulse width is equal to the charging time which is determined by charging condenser **18** and resistor **19** which is substantially constant, whereas in the oscillator circuit of the present invention as shown in FIG. 5, the sufficiently long charging time of the charging capacitor at the start of the balance oscillation determines the width of the output pulse which in turn is controlled by the induced voltage generated in the detecting coil which is inserted in the charging circuit of the charging capacitor when the amplitude of the balance wheel oscillation is increased.

The following is a description of the action of the electromotive force which tends to charge capacitor **26**, after conduction, in the oscillator circuit of FIG. 5. When driving transistor **24** is saturated after conduction of the circuit, the voltage on **12***b* may be represented by αE, where E is the voltage of battery source **31**, and α is the ratio of the number of windings between terminals **12***a* and **12***c* to the number of windings (i.e. winding resistance) between terminals **12***b* and **12***c*. Accordingly the electromotive force which tends to charge capacitor **26** is the sum of the difference between the voltage E of the power source **31** and the voltage αE at terminal **12***b*, the relationship being given by Equation 1 below, wherein V is the induced voltage on detecting coil **13**, and the voltage generated in the detecting coil by virtue of the mutual inductance with driving coil **12** being V*m*.

$$E-\alpha E+V+Vm=\alpha' E+V+Vm \quad (1)$$

where $\alpha'=1-\alpha$.

The impedance Z as seen from both ends of charging condenser **26** when the circuit of FIG. 5 is "on," comprises with a combined inductance of driving coil **12** and detecting coil **13**, the resistance of the coil winding wire, resistor **27**, saturation resistance of the collector to emitter path of driving transistor **24**, and the saturation resistance between the base to emitter path of controlling transistor **25**. However, if the value of resistor **27** is larger than that of the other impedances, the impedance Z will be substantially resistive and approximately equal to R. Furthermore, if Zm is not too large than the expression $\alpha' E+Vm$ may be considered constant during the duration of the electrical pulse. V*m* is generated by the mutual inductance of the driving coil and the detecting coil, but in the transducer as illustrated in FIG. 1, the magnetic yoke circuit is opened in a portion thereof, and accordingly the inductance is extremely small. Accordingly, at the start of the balance oscillation when the induced voltage is not generated, the charging voltage V and current through capacitor **26** may be represented by Formulas 2 and 3 as follows.

$$V=(\alpha' E+Vm)\left(1-e^{-\frac{t}{CR}}\right) \quad (2)$$

$$I'=\frac{\alpha' E+Vm}{R}e^{-\frac{t}{CR}} \quad (3)$$

where C is the capacitance of capacitor **26** and *t* being the charging time.

The above Equations 2 and 3 are graphically depicted by curves A in FIGS. 10A and 10B. As indicated by Equations 2 and 3 above, the charging time constant is approximately RC. Since the charging current through capacitor **26** causes controlling transistor **25** to be switched "on" if the value of resistor **27** is increased, the charging time constant will become longer, and it will thereby be possible to maintain the controlling transistor **25** in the "on" state for a long period of time, whereby driving transistor **24** can supply a sufficiently wide pulse to driving coil **12**. Initially the pulse width is increased in order to increase the amplitude of the balance oscillation to the desired amplitude, but as the balance oscillation amplitude increases, the induced voltage will also increase, and the controlling transistor **25** will be triggered even before the conduction period due to the time constant and the electrical circuit can be synchronized with the balance oscillation period.

Furthermore, when the induced voltage is generated, the charge on the charging condenser varies, i.e. the final voltage charge on charging condenser **26** changes from $\alpha' E+Vm$ to $\alpha' E+Vm+V$, and when the induced voltage is removed, the charge on charging condenser **26** returns to the value of $\alpha' E+Vm$. Since the increase in the balance oscillation amplitude causes an increase in the charging current, the charging voltage will rapidly increase, to shorten the time required to reach the final voltage $\alpha' E+Vm$. Accordingly, the charging current will rapidly decay, and the conduction time of controlling transistor **25** will be reduced, since the charging current is the base current of controlling transistor **25**, and the pulse width will accordingly become narrower. Thus, if the induced voltage becomes large as compared with $\alpha' E+Vm$, charging capacitor **26** is already charged to $\alpha' E+Vm$ when V is removed, the charging will immediately stop, for the final charging voltage is $\alpha' E+Vm$, and the pulse width will be narrowed. Since the width of the induced voltage pulse is approximately equal to the time that anchor **4** and balance wheel **1** are in engagement, and the pulse width of the pulse applied to driving coil **12** is controlled as to be equal to the width of the aforementioned induced voltage pulse, when balance wheel **1** reaches its amplitude corresponding to the final voltage, the additional force to balance wheel **1** may be added most effectively. Conversely, in the event that the amplitude of the balance oscillation is reduced due to an outer disturbance, as the induced voltage is reduced, the pulse width of the electrical pulse is widened, and this action tends to restore the original amplitude. Thus, in the embodiment of FIG. 5 of the present invention, the charging time of charging condenser **26** is a function of the amplitude of the balance oscillation.

Referring to FIGS. 10A and 10B, the variation of the charging voltage and current when the induced voltage V is generated is shown by curves B, wherein the pulse width varies from *to* to $t\infty$, where $to > t\infty$.

Referring to FIGS. 9B and 9C, the dotted line curves therein correspond to the state wherein there is little or no induced voltage as indicated by the dotted line curve in FIG. 9A. In the stable state of oscillation, the balance oscillation, the balance oscillation amplitude is large, and in the case that the induced voltage is large, as shown by the solid line curve of FIG. 9A, the pulse width of the voltage on the base of controlling transistor **25**, and that of the voltage on the collector of driving transistor **24**, i.e. the electrical pulse width, becomes narrower as shown by the solid line in FIGS. 9B and 9C.

Furthermore, curve C in FIG. 9B, and curve D of FIG. 9C are variations of the induced voltage *b* caused by the motion of the balance wheel, wherein in FIG. 9A $\alpha'=1$.

Intermediate terminal **12***c* is provided in order to permit the variation of the pulse width by making the induced voltage V comparable with $\alpha'E+Vm$ based on the condition that the voltage of the power source is α'E. If the voltage of power source **31** is very low, the same effect may be obtained when terminal **13***a* of detecting coil **13** is connected directly to the collector of driving transistor **24**.

In FIG. 6, there is shown a second embodiment of an oscillator in accordance with the principles of the present invention, which is of similar configuration to the arrangement of FIG. 5, with the exception that the detecting coil **13** is connected between the emitter of controlling transistor **25** and the positive terminal of battery source **31**. Accordingly waveform of the voltage on the base of the controlling transistor **25** as shown in FIG. 9C is slightly modified, while retaining the same charging characteristic for charging capacitor **26**.

FIG. 7 illustrates a third embodiment of the present invention, which is substantially similar to the arrangement of FIGS. 5 and 6, with the electromotive forces which provide the charge for charging capacitor **26** being essentially similar to those in FIGS. 5 and 6, with the exception that the electromotive force due to the voltage E of battery source **31** is not α'E but rather αE.

Referring to FIG. 8, there is shown a fourth embodiment of an oscillator in accordance with the principles of the present invention, which is in many respects similar to the previously described embodiments of FIGS. 5–7 with the exception that detecting coil **13** is connected to intermediate terminal **12***b* and the emitter of controlling transistor **25**, but otherwise remains essentially similar to the above described embodiments of FIGS. 5–7.

In the embodiment of FIGS. 5–8, the charging resistor **27** has the same controlling effect since it is not in series with the group comprising battery source **31**, driving coil **12** and the collector to emitter path of driving transistor **24**.

Thus, as shown above, the oscillators of FIGS. 5–8, in accordance with the principles of the present invention, provide an electric time piece which may be self excited even when it is necessary to overcome a large peak of potential energy, as shown in FIG. 3 in order to maintain the balance oscillation, wherein the amplitude of the balance oscillation is automatically controlled, and where the power consumption in the stable state of oscillation is substantially decreased.

It is understood that, although the oscillators of the present invention, which have been described in conjunction with the electromechanical transducer of FIG. 1, are not limited in application thereto, but are also adaptable for use in other electromechanical transducers for time pieces which must overcome a peak of potential energy at the start of the oscillation. Furthermore, although an NPN transistor was shown as the driving transistor, and a PNP transistor shown as the controlling transistor, in the embodiments of FIGS. 5–8, it is understood that the transistor types may be reversed.

What is claimed:

1. An electric timepiece comprising a rotatably mounted, oscillatable balance wheel; electro-mechanical transducer means for driving said balance wheel, said electro-mechanical transducer means including mechanical means engaging said balance wheel in the region of the center of the oscillatory path of said balance wheel for applying rotative force to said balance wheel and for displacement in response to the rotative motion of said balance wheel, and magnetic circuit means for applying displacing force to said mechanical means in response to a pulse of magnetic flux applied thereto for driving said balance wheel, and for having a magnetic flux induced therein in response to the displacement of said mechanical means responding to the rotative motion of said balance wheel; and a stable oscillator circuit means having a driving coil in the output of said oscillator circuit means, coupled with said magnetic circuit means to impart said pulse of magnetic flux thereto in response to the output of said oscillator, charging circuit means for controlling the period of oscillation of said oscillator, and a detecting coil coupled with said magnetic circuit means for generating a detecting voltage in response to said induced flux and disposed in series connection with said charging circuit means with the polarity of said induced voltage such that the pulse width of said displacing flux applied to said magnetic circuit means by said driving coil narrows as said detecting voltage increases.

2. An electric timepiece as defined in claim **1**, wherein said oscillator circuit includes a driving transistor having said driving coil serially connected to its collector; a controlling transistor; and a coupling resistor interconnecting the collector of said controlling transistor to the base of said driving transistor, said charging circuit means including a charging capacitor and a charging resistor in series arrangement.

3. An electric timepiece as defined in claim **2**, wherein said driving coil has a pair of end terminals and an intermediate terminal, said detecting coil having a pair of end terminals, said detecting coil end terminals serially interconnecting said driving coil intermediate terminal and said charging circuit means, the other end of said charging circuit means being connected to the base of said controlling transistor, said driving coil end terminals being connected respectively to the collector of said driving transistor and the emitter of said controlling transistor.

4. An electric timepiece as defined in claim **2**, wherein said driving coil has a pair of end terminals and an intermediate terminal, said charging circuit means interconnecting said driving coil intermediate terminal and the base of said controlling transistor, one of said driving coil end terminals being connected to the collector of said driving transistor, said detecting coil interconnecting said controlling transistor emitter and the other of said driving coil end terminals.

5. An electric timepiece as defined in claim **2**, wherein said driving coil has an intermediate terminal connected to the emitter of said controlling transistor, said detecting coil and charging circuit means being in series connection interconnecting the collector of said driving transistor and the base of said controlling transistor.

6. An electric timepiece as defined in claim **2**, said driving coil having an intermediate terminal, said charging circuit means interconnecting the collector of said driving transistor and the base of said controlling transistor, said detecting coil interconnecting the emitter of said controlling transistor and said driving coil intermediate terminal.

References Cited

UNITED STATES PATENTS

2,986,683 5/1961 Lau et al. -------------- 58—23

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