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Watkins

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[54] **SYNCHRONIZED WATCH MOVEMENT**

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[52] **U.S. Cl.** .... **58/28 R;** 58/23 A; 331/116 M

[51] **Int. Cl.** **G04b 1/00**

[58] **Field of Search** .... 318/128, 133, 119, 125, 318/127, 126, 129; 58/23 R, 23 A, 23 AC, 23 D, 23 V, 28 R, 28 A, 28 B; 331/116 R, 116 M, 172

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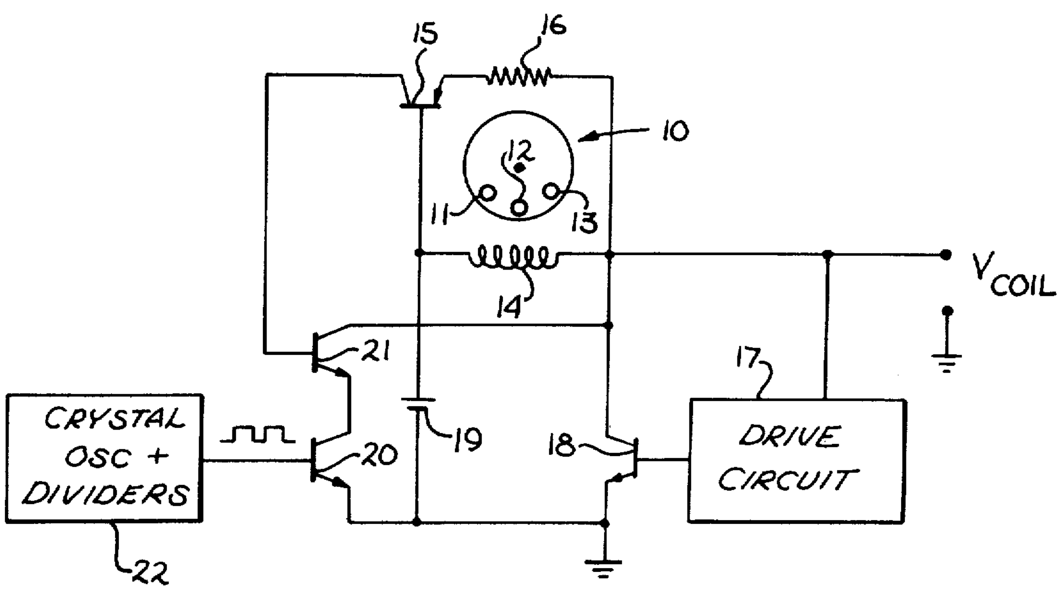
Assistant Examiner—U. Weldon
Attorney, Agent, or Firm—Spensley, Horn & Lubitz

[57] **ABSTRACT**

A synchronized electronic balance wheel watch movement in which the period of the balance wheel is varied by an impulse to the balance wheel, the magnitude of which is a function of the phase difference between the balance wheel and synchronizing pulses derived from a crystal oscillator is disclosed. The synchronization sensing circuit does not draw power from the balance wheel when the amplitude of the balance wheel is diminished, thus, allowing the balance wheel to more quickly regain its full amplitude.

4 Claims, 5 Drawing Figures



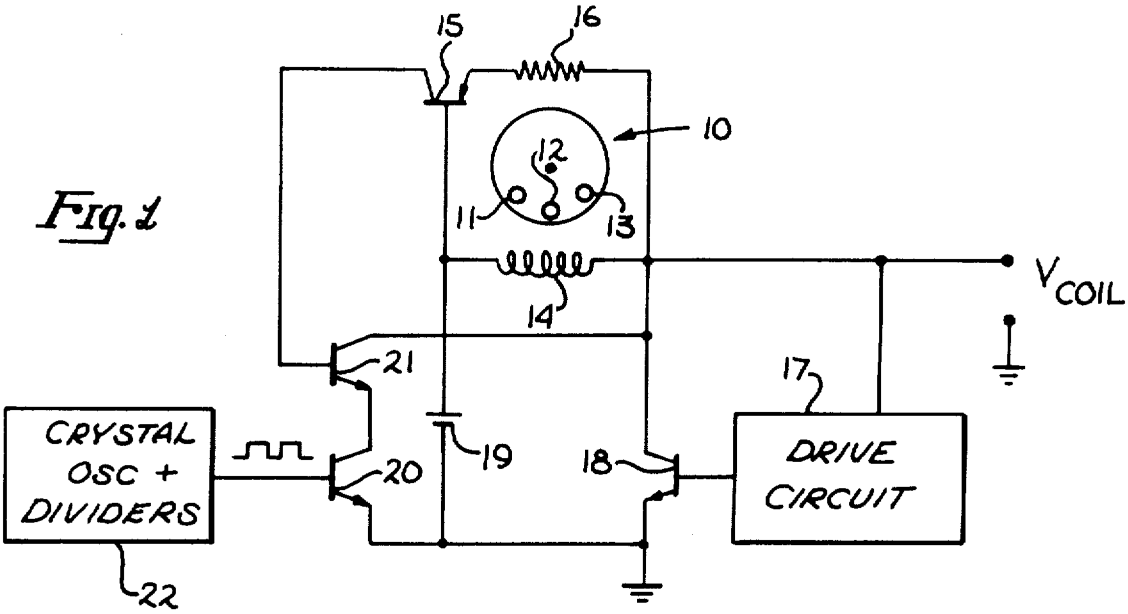

15
16
10
12
11
13
14
VCOIL
21
17
CRYSTAL OSC + DIVIDERS
20
19
18
DRIVE CIRCUIT
22

Fig. 1

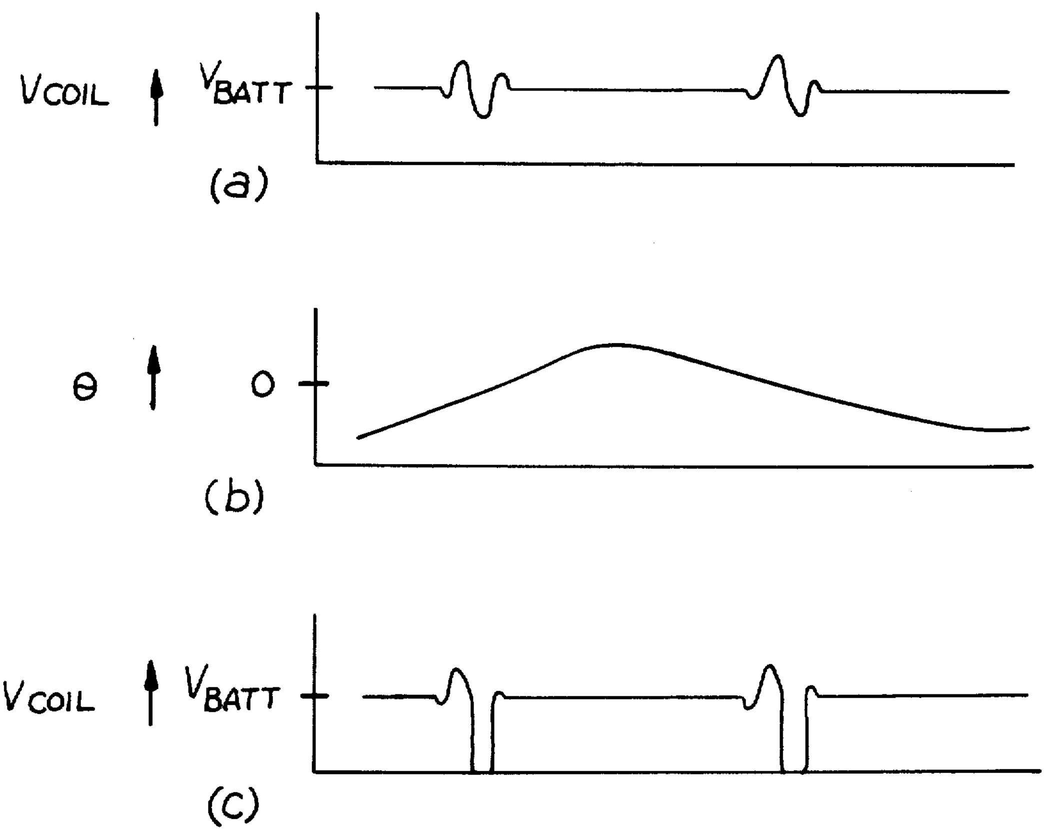

VCOIL
VBATT
(a)
θ
0
(b)
VCOIL
VBATT
(c)

Fig. 2

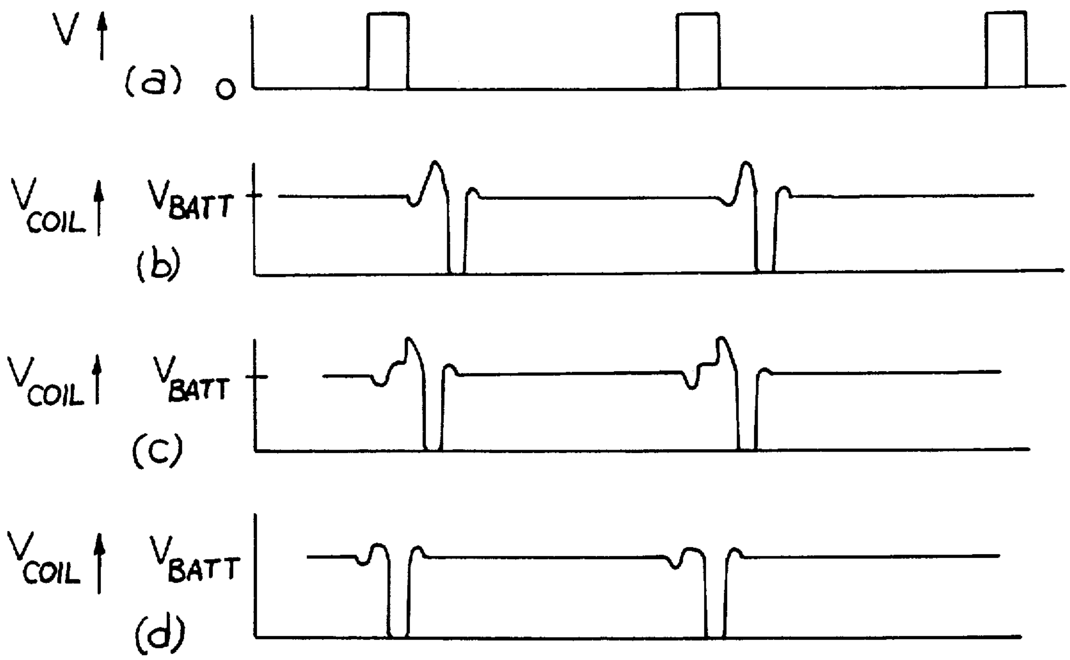


Fig. 3

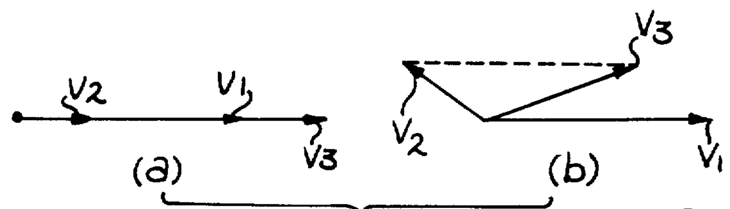


Fig. 4

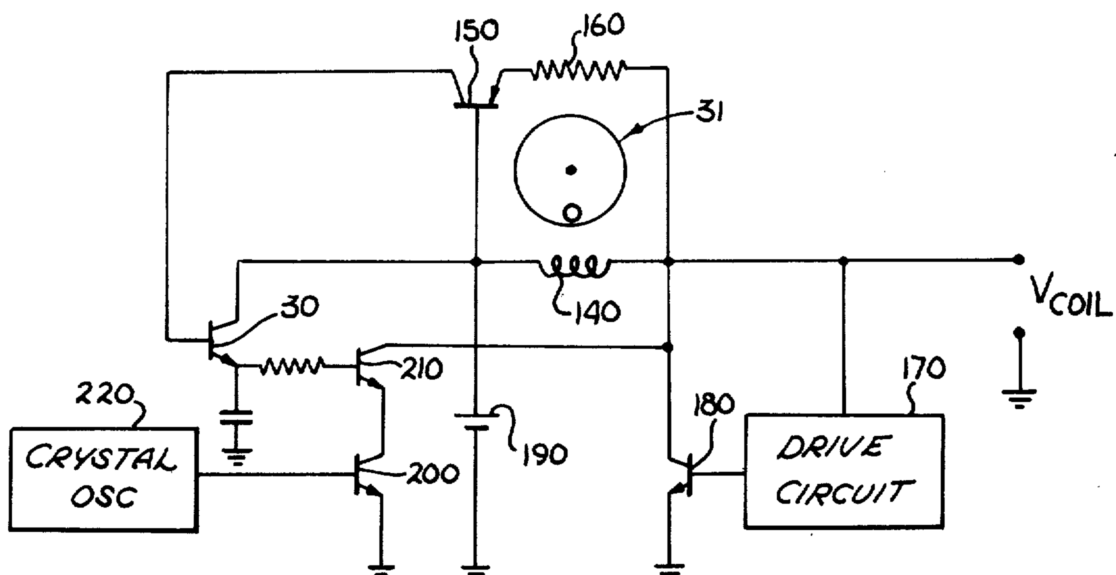


Fig. 5

SYNCHRONIZED WATCH MOVEMENT

BACKGROUND OF THE INVENTION

1. Field of the Invention

This invention relates to horological equipment and more specifically to systems for synchronizing horological mechanical resonators with highly accurate standard frequency sources.

2. Prior Art

In recent years electric watches have become popular and due partly to a demand for more accurate watches their production is increasing rapidly. However, electrically operated watches are not necessarily more accurate than conventional mainspring watches and considerable effort is being expended to find ways of improving the accuracy.

One form of electric watches in production utilizes a tuning fork operating at several hundred hertz as the basic timing element. Production of this watch involved a major development since it represented a complete departure from existing technology; but even some tuning fork watches are not significantly more accurate than the better mainspring type watches.

another approach to the electric watch is to use a more or less conventional balance wheel magnetically driven to provide the time standard. The so-called electronic balance wheel drives a gear train through a pawl and ratchet wheel arrangement directly rather than having the gear train driven by the mainspring and controlled by escapement. This design involves components very similar to the traditional mainspring type watch and has many of the same limitations.

The resonators in both of the approaches described above are required to deliver power and small variations in the load presented by the gear train or in the ambient conditions have an adverse effect on the timekeeping qualities of the watch.

It has been proposed to improve the accuracy of electric watches by synchronizing the tuning fork or electronic balance wheel with the oscillations of a quartz crystal oscillator. Quartz crystal oscillators are known to be exceedingly accurate and stable and therefore it is expected that such synchronization will result in a substantial improvement in accuracy. Synchronization has been accomplished successfully, see e.g., U.S. Pat. Nos. **3,282,042, 3,616,638** and **2,976,470.** In view of the small space available, however, the mere synchronizing of the movement with the crystal oscillations does not dispose of all of the problems. A major problem remaining is to cause the desired synchronization with a minimum of power expenditure.

A typical battery for an electric watch has a voltage of **1.3** to **1.5** volts and will furnish but **200** mah (milliampere-hours of power). Since in order to be practical for a production watch for sale to the general public, a battery must last for a year or more, hence the current drain must be very limited, for example, to an average of **200** ma. This current must not only run the watch but must supply whatever power is required to operate the crystal oscillator and synchronizing means.

The synchronizing scheme of the present invention uses a very limited amount of power beyond that required to drive the balance wheel so that a practical long lasting crystal controlled watch becomes possible.

The watch balance wheel is driven at a slightly higher amplitude than is needed to maintain satisfactory operation and then a small amount of the balance wheel

momentum is removed, as needed, to keep it in synchronism with signals derived from a highly accurate quartz crystal oscillator. The result is a synchronized balance wheel with very little power consumed by the synchronizing system.

SUMMARY OF THE INVENTION

In the presently preferred embodiment of the invention, an electronic balance wheel which carries three magnets is used to drive the watch gear train through a pawl and ratchet mechanism as is conventional in the art. A coil mounted adjacent to the balance wheel is pulsed by a conventional feedback oscillator circuit which causes the balance wheel to oscillate at very nearly its natural frequency. the constants of the system are chosen so that the watch will run slightly fast under all expected conditions of temperature, position, etc. The driven pulses also are slightly higher in amplitude than necessary so that the balance wheel has an excess of momentum in the unsynchronized condition. In the absence of the synchronizing pulses, then, the watch will run satisfactorily even though it will gain time slightly.

A quartz crystal oscillator is included in the watch case with a frequency of oscillation which is an exact multiple of the frequency of oscillation required to keep exact time. Frequency dividers, flip-flops, or other means, are used to reduce the frequency to the required submultiple of the crystal frequency.

This submultiple of the crystal oscillator controls a circuit which effectively shunts the balance wheel driving coil during a portion of the time that the balance wheel magnets are passing the coil and are thereby generating voltage in the coil. The shunting of the coil while it is generating voltage dissipates energy and thus decreases the momentum of the balance wheel. A decrease in the momentum of the balance wheel has the effect of increasing the period of oscillation of the balance wheel for that cycle during which the momentum was decreased. Repetitive shunting of the coil therefore effectively decreases the frequency of oscillation of the balance wheel. The amount of time that the driving coil is shunted and therefore the amount of momentum removed from the balance wheel is a function of the relative phase of the balance wheel with respect to the submultiple of the crystal oscillator with which the watch is to be synchronized. An equilibrium phase angle exists wherein the amount of momentum removed from the balance wheel on each cycle increases the period of the balance wheel just enough to increase its period so that the watch will run in synchronism with the crystal oscillator and keep perfect time.

BRIEF DESCRIPTION OF THE DRAWINGS

FIG. **1** is a circuit diagram of a preferred embodiment of the present invention as applied to a three magnet electronic balance wheel watch.

FIGS. **2***a*, 2*b* and **2***c* show the voltage waveforms generated by the coil uninfluenced by the synchronizing circuit.

FIGS. **3***a*, 3*b*, 3*c* and **3***d* show the voltage waveforms generated by the coil with the synchronizing circuit active.

FIGS. **4***a* and **4***b* are a vector diagram of the velocity of the balance wheel showing the effect of an impulse to the balance wheel.

FIG. 5 is a circuit diagram of an alternate embodiment wherein a single magnet is coupled to the balance wheel.

DETAILED DESCRIPTION OF THE INVENTION

Conventional mainspring watches utilize a spring loaded balance wheel as the basic timing device. The balance wheel controls an escapement which is geared to the hands of the watch indicating the time. The balance wheel receives an impulse on each cycle of motion from the escapement which makes up for any frictional or other losses in the balance wheel and keeps the balance wheel in motion. The conventional design is such that the impulse is imparted to the balance wheel at precisely the rest position of the balance wheel so as to minimize the effects of variation in the magnitude of the impulse on the timekeeping properties of the watch.

In electric watches no escapement is generally used. The basic timekeeping device is still a mass-spring system, either in the form of a tuning fork or a balance wheel similar to that used in mainspring watches, but the gear train leading to the hands of the watch is generally driven by a pawl-ratchet wheel combination rather than an escapement. The impulses to drive the timekeeping element are derived from the motion of the mass and applied magnetically rather than mechanically.

A typical so-called electronic balance wheel carries one or more permanent magnets near the periphery of the wheel which cooperate with a coil mounted adjacent to the wheel so that current in the coil will cause a rotational force on the balance wheel and conversely rotation of the balance wheel will cause voltage to be generated in the coil. Pulses of current in the coil provide the impulses required to keep the wheel in motion. The drive impulses are usually generated by a single transistor oscillator; the balance wheel and coil being the tuned element.

An impulse consists of a force applied to a system for some period of time. When applied to a simple mass spring system, such as a balance wheel, an impulse results in a change of momentum and velocity proportional to the magnitude of the impulse. If the momentum of a simple system which is oscillating with simple harmonic motion is suddenly changed, as by the application of an impulse, the effect is dependent upon the magnitude of the change and when during the cycle the impulse was applied.

This is illustrated in FIG. 4 which depicts the velocity of such a system vectorially. The vector V_1 represents the velocity of the wheel before application of the impulse; V_2 is the velocity change due to the impulse; and V_3 is the velocity of the wheel immediately after the impulse. In FIG. 4*a*, V_1 and V_2 are in phase, that is, the impulse is applied just as the balance wheel goes through its rest position — when the velocity is maximum. The resultant velocity V_3 is seen to be in phase with both V_1 and V_2. It might be thought that the velocity of the wheel will continually increase due to repetitive impulses, but losses in the system limits the amplitude to an equilibrium value. In FIG. 4b, the impulse resulting in V_2 is applied out of phase with V_1, that is, not as the wheel is going through its rest position. It is seen that V_2 is no longer in phase with V_1 and it is easy to see that repetitive impulses at this angle will cause V_3 to decrease. Note that the period can be increased or decreased by proper phasing of the impulse and the effect can be achieved with impulses that either increase or decrease the velocity of the system.

This ability to change the period of a system by judicious adjustment of the momentum of the system during the oscillation forms the basis for the synchronization system here disclosed.

Referring now to FIG. **1** where the circuit of the clock synchronizing system of the present invention is shown as applied to a typical three magnet electronic balance wheel watch. The watch balance wheel is shown schematically, designated by the numeral **10,** and having three magnets **11, 12** and **13** mounted thereon. As the balance wheel swings, the magnetic field surrounding the magnets induces a voltage in coil **14,** mounted on the watch structure adjacent to the balance wheel. The waveform induced by the motion of the balance wheel, unaffected by any synchronization or drive circuits, is shown in FIG. **2***a*.

Referring to FIG. **1**, one terminal of coil **14** is coupled to the base of pnp transistor **15** while the emitter of transistor **15** is coupled to the other terminal of coil **14** through the current limiting resistor **16.** The collector of transistor **15** is coupled to the base of the npn transistor **21.** The collector of transistor **21** is coupled to the other terminal of coil **14** and the drive circuit **17.** The emitter of transistor **21** is coupled to the collector of transistor **20.** The base of npn transistor **20** is coupled to the crystal oscillator and drivers **22** while the emitter is coupled to ground. The emitter of transistor **18** and one terminal of battery **19** are also coupled to ground. The base of transistor **18** is coupled to the drive circuit **17** which the collector of transistor **18** is coupled to the other terminal of coil **14.** The other terminal of battery **19** is coupled to the one terminal of coil **14.**

The power used to sustain the oscillations of balance wheel **10** is obtained from the battery **19.** As the drive circuit **17** detects the movement of the balance wheel **10,** it time gates transistor **18** allowing current to flow through coil **14** so as to reinforce the movement of the balance wheel **10.** This is a technique commonly known and used in the prior art. The transistors **15, 20** and **21** along with resistor **16** and the crystal oscillator and drivers **22** comprise the synchronization circuit which may be added to the standard electronic drive means for balance wheels in some instances in order to synchronize the balance wheel electronically with a crystal oscillator such as crystal oscillator and drivers **22.** In the presently preferred embodiment all the electrical components of FIG. **1** are fabricated as an integrated circuit although in applications where larger circuitry is tolerable such as in clocks, discrete components may be used.

Drive pulses are formed by the drive circuit **17** and applied to the coil **14** through transistor **18** so as to cause the balance wheel **10** to oscillate at very nearly its natural frequency. Methods and circuits for generating drive pulses are old and well known to those skilled in the art and therefore are not discussed in detail here. Examples of such drive circuits are used and explained in U.S. Pat. Nos. **2,971,323; 3,218,793; 3,447,052; 3,098,185;** and **3,616,638.** It should be understood that any suitable means for causing the balance wheel to oscillate at or near its natural frequency could be used in conjunction with the present invention.

The waveform across coil **14**, including the drive pulses, is shown in FIG. *2c*.

The emitter base diode of transistor **15** is connected across coil **14** through resistor **16** and is forward biased during the time that V_{coil} exceeds the voltage of battery **19** by more than the emitter-base voltage.

Transistor **20** operates as an on-off switch in response to a square wave drive at precisely the frequency required for keeping exact time derived from crystal oscillator and amplifier **22.** If at any time when transistor **20** is on, the voltage V_{coil} starts to rise above the battery voltage, the emitter of transistor **15** becomes forward biased as previously mentioned, and current will flow in the collector circuit into the base of transistor **21** so as to effectively limit the voltage V_{coil} to the battery voltage plus the emitter forward voltage drop of transistor **15.** When transistor **20** is off, no such limiting will occur.

The voltage across the coil itself during the limiting action is approximately the base-emitter voltage of transistor **15,** or approximately **0.6** volts. A possible problem which can occur when attempting to synchronize a balance wheel with decelerating impulses as is here done is that too much energy might be removed from the balance wheel by the synchronizing circuit. If this happens, the balance wheel amplitude will drop and if decelerating impulses are continued, watch stoppage may result. By shunting the coil to approximately **0.6** volts instead of a direct short, it can be seen that the circuit of this invention guards against this possible problem. Thus, the invented circuit, but not drawing power from the balance wheel when its amplitudes are small allows the balance wheel to return to normal amplitudes more quickly. If the balance wheel drops in amplitude, so will the coil voltage, and if the voltage drops below **0.6** volts, nor further synchronizing impulses will be imparted to the balance wheel until its amplitude again increases.

The balance wheel, as driven by the drive pulses, oscillates at very nearly the natural frequency of the balance wheel with some equilibrium amplitude which is determined by the magnitude of the driving impulses and the losses of system. The frequency of oscillation is chosen to be slightly higher than the precise frequency of oscillation needed for keeping exact time and the motion of the balance wheel is modified by the effects of the synchronizing drive from crystal oscillator **22** so that exact time is kept.

The balance wheel motion is essentially sinusoidal and can very nearly be described by the equation:

$$a = A \sin 2\pi ft$$

The actual motion deviates slightly from this equation particularly during the time the drive pulses are applied, but the equation nevertheless describes the motion closely enough for the purposes at hand.

If a small impulse is applied to the balance wheel while it is oscillating in accordance with the above equation, the effect will be a change in the amplitude of motion, and if the impulse is applied when the balance wheel is deflected from its at-rest position, a change in the phase of the motion with respect to the motion prior to the impulse; that is, the motion can then be described by the equation:

$$a = A' \sin (2\pi ft \pm \theta)$$

If the impulse is applied repetitively, the equation of motion becomes

$$a = A'' \sin (2\pi ft \pm n\theta)$$

The period of oscillation is thus seen to be either slightly longer or shorter than the original oscillation period depending on the polarity of the impulse. The magnitude and timing of the impulse govern the amount by which the effective period of oscillation is changed.

By utilizing a crystal oscillator and frequency dividers to provide a reference signal at the exact desired frequency, the magnitude of the impulse can be made to automatically compensate for the difference in period between the free oscillation of the balance wheel and the frequency of the crystal oscillator so that the balance wheel oscillates at exactly in synchronous with the submultiple of the crystal oscillator required to keep exact time.

FIG. *3a* shows the waveform applied to transistor **20** which has its repetition rate derived from the crystal oscillator. FIG. *3b* shows the waveform at the coil **14** with the balance wheel not yet synchronized with the crystal oscillator. The watch is operating at a rate determined by the balance wheel period which has purposely been set to be slightly shorter than the crystal derived period. As time increases then the coil waveform will drift to the left with respect to the crystal controlled wave. Eventually the transistor **20** will not be turned off until after the start of the pulse output from the coil **14** as shown in FIG. *3c*. While transistor **20** is on the voltage across the coil **14** is limited to about **0.6** volts by the shunting effect of transistors **20** and **21** as previously explained. The limiting of the coil voltage results in current flow in the coil and a decelerating impulse to the balance wheel. A decelerating impulse to the balance wheel causes a phase shift in the balance wheel motion such that the period is effectively lengthened. As the coil pulses drift to the left due to an insufficiently long period, the magnitude of the decellerating impulse to the balance wheel increases until at some point the impulse becomes sufficient to increase the balance wheel period to equal the period of the crystal derived synchronizing pulses. This is the equilibrium operation point of the watch. The balance wheel will continue to operate in synchronism with the crystal once the equilibrium point is reached.

FIG. *3d* depicts a situation where synchronization has not been achieved but instead of no decelerating impulse to the balance wheel as was the condition in FIG. *3b*, the transistor **20** remains on for the duration of the positive portion of the coil **14** waveform. This provides the maximum decellerating impulse to the balance wheel and the circuit constants must be so chosen that with the maximum deceleration impulse the period of the balance wheel is longer than the crystal derived period and therefore the coil waveform will drift to the right with respect to the crystal derived waveform until the equilibrium condition of FIG. *3c* has been reached.

Illustrative of possible modifications which might be made within the spirit of the present invention is a second preferred embodiment of the invention, the circuit diagram of which appears at FIG. **5.** This embodiment differs from the first preferred embodiment in two substantial respects: first, a single magnet type balance wheel is used in the place of the three magnet type previously explained, and second, an emitter follower stage (transistor **30**) has been added between the coil voltage sensing transistor **150** (transistor **15** of the first embodiment) and one of the shunting transistors **210** (transistor **21** of the first embodiment). Corresponding components to FIG. **1** have been shown in FIG. **5** with a "**0**" added to the number designation used in FIG. **1.**

The added emitter follower stage, transistor **30**, does not change the basic operation of the synchronizing circuit but adds additional gain in the feedback loop to assure that enough current is drawn through the coil **140** to maintain its terminal voltage at the voltage determined by the base-emitter voltage of transistor **150.** The inclusion of transistor **30** does not change the level at which the coil voltage is limited so that if the balance wheel drops in amplitude, the shunting circuitry will be ineffective and does not extract energy from the balance wheel as previously explained.

The single magnet balance wheel **31** comprises a balance wheel as previously described but with only one magnet **32** on its periphery.

The period of the free running balance wheel **31** is slightly shorter than the synchronizing signal as in the previously described embodiment so that eventually a synchronizing pulse will occur during the time a positive pulse is being generated by the coil **140** and the coil **140** is thereafter shunted in the same manner as previously described reducing the momentum of the wheel and thereby shifting the phase of the balance wheel. An equilibrium position will be reached after repeated pulses in which the phase of the balance wheel will be changed an amount on each cycle due to the momentum change so as to maintain synchronism with the crystal oscillator synchronizing signal.

Thus, a synchronization circuit has been disclosed that may in some instances be added to prior art electronically driven balance wheels.

I claim:

1. In an electric timepiece containing a balance wheel and drive means for causing such wheel to oscillate at substantially its natural frequency, an improvement comprising:

a. a coil adjacent such balance wheel and electrically coupled to such drive means;

b. three magnets mounted on such balance wheel whereby at least one positive and one negative polarity voltage pulse is generated in said coil upon each motion of said magnets past said coil;

c. a source of synchronizing waves of precisely controlled frequency;

d. a battery in series with said coil, said battery being coupled such that said negative polarity voltage pulse will increase the voltage across said coil and said battery;

e. circuit means coupled to said source of synchronizing waves for limiting the coil voltage with respect to said negative polarity voltage pulse during the coincidence of said synchronizing waves and said negative polarity voltage pulse comprising:

1. a first transistor having its emitter coupled to said battery and its base coupled to said source of synchronizing waves whereby said coil, said battery and said first transistor present a low impedance to said negative polarity voltage pulse during the time interval of said synchronizing waves;

2. a second transistor of the same generic type as said first transistor having its emitter coupled to the collector of said first transistor and its collector coupled to said coil whereby said coil, said battery and said first and second transistors form a closed series circuit;

3. a third transistor of opposite generic type to said first and second transistors, said third transistor having its base coupled to the junction of said coil and said battery, its collector coupled to the base of said second transistor, and its emitter resistively coupled to the junction of said coil and said second transistor;

whereby the period of oscillation of such wheel is changed so as to substantially match the period of said source of precisely controlled frequency.

2. The improvement as recited in claim **1** where said source of synchronizing waves is controlled by a quartz crystal.

3. The improvement as recited in claim **2** where said first transistor is of the npn type.

4. In an electric timepiece containing a balance wheel and drive means for causing such wheel to oscillate at substantially its natural frequency, an improvement comprising:

a. a coil adjacent such balance wheel and electrically coupled to such drive means;

b. one magnet mounted on such balance wheel whereby one negative polarity voltage pulse will be generated in said coil upon each motion of said magnet past said coil;

c. a source of synchronizing waves of precisely controlled frequency;

d. a battery coupled in series with said coil, said battery being connected such that said negative voltage pulse will increase the voltage across said coil and battery; and

e. circuit means for limiting the coil voltage with respect to said negative voltage pulse during the coincidence of said synchronizing waves and said negative voltage pulse, said circuit means coupled to said source of synchronizing waves and said coil, comprising:

1. a first transistor having its emitter coupled to said battery and its base coupled to said source of synchronizing waves whereby said coil, said battery and said first transistor form a series circuit, said first transistor presenting a low impedance to said negative voltage pulse during the time interval of said synchronizing waves;

2. a second transistor of the same generic type as said first transistor having its emitter coupled to the collector of said first transistor and its collector coupled to said coil whereby said coil, said battery, and said first and second transistors form a closed series circuit; and

3. a third transistor of opposite generic type to said first and second transistors, said third transistor having its base coupled to the junction of said coil and said battery, its collector coupled to the base of said second transistor, and its emitter resistively coupled to the junction of said coil and said second transistor;

whereby the period of oscillation of such wheel is changed so as to substantially match the period of said source of precisely controlled frequency.

* * * * *