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(54) SYNCHRONIZED HOROLOGICAL SYSTEM

(71) We, TIMEX CORPORATION, a Corporation organized under the laws of the State of Delaware, United States of America, of Waterbury 20, Connecticut, United States of America, do hereby declare the invention, for which we pray that a Patent may be granted to us, and the method by which it is to be performed, to be particularly described in and by the following statement:—

The present invention relates to horology and more particularly to an electronic watch movement.

The historical goal of horology has been accurate timekeeping. Time standards have been developed which may be accurate to one part in twenty million, based upon astronomical observations. Even higher accuracy time standards have been proposed and built based upon gas absorption phenomena and radioactive emission. However, these precision instruments have been primarily laboratory instruments, large in size and extremely costly. In contrast, portable watches are much less accurate.

The most accurate watches are still those that are based upon mechanically, or motion, actuated mainsprings which, through a gear train and escapement, drive rotatable hands. But such watches, termed "chronometers", are costly and relatively fragile. Electronic watches, employing a mechanical oscillator having a frequency of 300 to 400 Hz, have been constructed. But they are generally subject to position error, that is, their timekeeping depends upon the position of the watch in relationship to the earth's gravitational field. In addition, such electronic watches have also been fragile and costly. They require a delicate pawl system to transfer the rapid motion of the mechanical vibrator to gears of the watch. There have been various suggestions to replace the pawl system, such as having the motion of the mechanical oscillator interact with a transducer to provide a pulse which either directly, or through divid-

ing circuits, operates a motor. However, that system requires two motors—first the mechanical oscillator and second the motor to drive the gear trains, so that the system utilizes too much power for practical utilization in a watch.

Another system which has been proposed and which has been used in clocks is to utilize a high-frequency piezoelectric crystal oscillator whose frequency is reduced by a series of count-down (dividing) circuits. The output of the dividing circuits is then utilized to drive a motor or to control a driving circuit.

The present invention provides a horological instrument including a high frequency oscillator as the instrument's time base, a frequency dividing circuit connected to the output of said time base and producing a low frequency output, a low frequency mechanical element carrying one of an interacting coil and magnet means and capable of low frequency oscillation, the magnet means establishing at least two magnetic poles of alternately opposite polarities, a drive circuit, the output of said drive circuit being connected to said coil and said drive circuit being connected to and synchronised by the output of said dividing circuit, and time display means operated by said low frequency mechanical element.

The present invention also provides a horological instrument including a high frequency oscillator as the instrument's time base, a frequency dividing circuit connected to the output of said time base and producing a low frequency output, a low frequency mechanical element carrying one of an interacting coil and magnet means and capable of low frequency oscillation, a drive circuit, the output of said drive circuit being connected to said coil and said drive circuit being connected to and synchronised by the output of said dividing circuit, and a time display operated by said low frequency mechanical element,

wherein said drive circuit is a regenerative multivibrator.

The present invention still further provides a horological instrument including a high frequency oscillator as the instrument's time base, a frequency dividing circuit connected to the output of said time base and producing a low frequency output, a low frequency mechanical element carrying one of an interacting coil and two oppositely poled magnets, said element being capable of low frequency oscillation, a regenerative multivibrator drive circuit, the output of said drive circuit being connected to said coil and said drive circuit being connected and synchronised by the output of said dividing circuit to produce a driving pulse for each oscillation of said oscillatory element, and a time display operated by said low frequency mechanical element, wherein the output of said dividing circuit is algebraically added to the back electromotive force induced in said coil by movement thereof relative to said two magnets to produce an actuating pulse, said actuating pulse causing said drive circuit to produce an additional driving pulse on the return movement of said oscillatory element only when its movement is not in synchronisation with the output of said dividing circuit.

The preferred time base is a piezoelectric crystal oscillator which is sufficiently small in size so that it fits within the case of the instrument. The instrument preferably is a watch and the crystal oscillator has a frequency of above 10,000 Hz, for example, 60,000 Hz. A lower frequency is derived from the oscillator output by a frequency divider including a plurality of count-down (dividing) circuits, preferably utilizing solid-state low energy transistors such as metal oxide field effect transistors.

The horological instrument also includes a separate electronic circuit for the driving of a mechanical oscillator. Preferably the oscillator is a balance wheel which carries the coil and which swings through the field of a plurality of magnets which are fixed on a plate of the instrument. The magnets establish three magnetic fields of alternately opposite polarities such as north-south-north poles, although either two or four magnetic fields may alternatively be utilized.

The magnets may be carried by the balance wheel and the coil fixed on the plate of the instrument, but in the preferred system a single coil, carried by the balance wheel, performs the functions of a drive means for swinging the balance wheel, by its interaction with the magnetic fields, and as a pick-up means for timing the driving pulse. The circuitry for driving the balance wheel is known from United States Patent No. 3,046,460, and particularly the circuit of Fig. 4 therein and a suitable physical system of the balance wheel and magnets are also known

from that patent, at Figs. 1—3, 8—10 and 13—16.

The pulses which are derived from the count-down circuits are utilized to synchronize the normal operation of the electronic horological movement. The pulses preferably are at a relatively high rate in relationship to the normal oscillations. For example, the output pulses of the count-down circuits may be at 48 Hz and the normal oscillations of the balance wheel at 3 Hz. This relatively high synchronization rate lessens the number of count-down circuits. The oscillator, i.e., the balance wheel, carries a pin which indexes, either directly or indirectly, by means of a fork mechanism, the first of a series of wheels which rotate the hands of the watch. This type of balance wheel pin take-off system is conventional in watches and has proven to be reliable and rugged by years of useage.

The instrument is highly accurate because of its synchronization with the piezoelectric oscillator. Yet it is: (1) relatively resistant to shocks because of the pin and fork power take-off system of the balance wheel; (2) relatively low in cost because many of the parts (balance wheel, drive circuit, dial train, etc.) may be the same as, or similar to, parts used in relatively inexpensive and only moderately accurate electric watches; and (3) relatively low in power consumption; as the accuracy of the watch is high even without synchronization, its synchronization requires little power.

Other objectives of the present invention will be apparent from the following description of preferred embodiments taken in conjunction with the accompanying drawings, in which:

Fig. 1 is a block schematic diagram of the circuit of an electronic watch according to the present invention;

Fig. 2 is a side cut-away view of the watch;

Fig. 3 is a cross-section view taken along line 3—3 of Fig. 2;

Fig. 4 is a cross-sectional view taken along line 4—4 of Fig. 3;

Fig. 5 is a cross-sectional view of an alternative magnet arrangement;

Fig. 6 is a schematic view of a drive circuit in the present invention;

Figs. 7, 7A and 7B are diagrams utilized in analyzing the drive system;

Fig. 8 is a diagram of the voltage induced in the coil and the current wave forms theoretically produced at the output of the circuit of Fig. 6;

Fig. 9A is a diagram of the fields of the magnets;

Fig. 9B is a diagram illustrating the voltages induced in the coil by those fields;

Figs. 10A and 10B are top plan views of the magnet structure showing the positions

of the coil as it moves through the magnetic fields;

Fig. 11 is a diagram illustrating the combined voltages induced in the coil;

Fig. 12 is a top plan view of a further alternative magnet structure;

Fig. 13 is a diagram of the voltages induced in a coil by the structure of Fig. 12;

Fig. 14 is a top plan view of another magnet structure using two magnets, the drawing showing the positions of the coil as it moves through the magnetic fields;

Fig. 15 is a diagram illustrating the voltages on the forward and return movement of the coil using the two-magnet structure of Fig. 14;

Fig. 16 is a diagram indicating the induced voltages, and their synchronization, during two different return movements of the coil, utilizing the two-magnet structure of Fig. 14; and

Fig. 17 is a diagram illustrating the combined voltages induced in the coil by the two-magnet structure of Fig. 14.

As shown in Fig. 1, the circuitry for the electronic watch consists of a number of sub-circuits. The time base is a high-frequency oscillator 10. Preferably the high-frequency oscillator is an electronic piezoelectric crystal oscillator whose frequency is above 10,000 Hz. The high-frequency pulse rate output from oscillator 10 is divided down by a dividing circuit 11. The dividing circuit 11 may be, for example, a series of flip-flop circuits in tandem. Alternatively, the dividing circuit 11 may be a plurality of relaxation oscillators having selected time constants. For example, the relaxation oscillators may be cascaded in tandem (in series) and divided by ratios of 7:1, 7:1 and 7:1. A signal at the reduced frequency is supplied, by means of line 12, to the drive circuit 13 of the watch. The drive circuit 13 is synchronized by the output of the divider and, even in the absence of synchronization, provides a driving output pulse. The drive circuit supplies drive pulses to a coil 14 which interacts magnetically with a magnet 15. Either the coil 14 or the magnet 15 may be carried by a low frequency mechanical oscillating element.

The low frequency mechanical element is, in a watch, preferably a balance wheel 25 as shown in Figs. 2 to 4. An upper plate 20 and a bottom plate 21 are spaced apart, and a balance wheel staff 22 rotates between a bearing 23 in the upper plate 20 and a bearing 24 in the lower plate 21. The balance wheel staff 22 carries the balance wheel 25. An electric coil 26, of round, trapezoidal or other shape, consisting of many turns of fine wire, is carried by the balance wheel 25. A shunt 27, of soft magnetic material such as steel, is positioned above the balance wheel. The shunt 27 is carried by one of the plate members of the watch. The watch movement

shown in Figs. 2 to 4 provides a low frequency output which operates a time display means (not shown) for example conventional time-indicating hands, in any suitable manner.

A stud 28 is fixed to the plate 20 and a first hairspring 29 has its outer end fixed within the stud 28. The inner end of the hairspring 29 is fixed to a hub fixed on the balance wheel staff 22. There is an electrical connection, for example, by means of a wire, from the hub or spring 29, to one end of the coil 26. A second stud 30 is fixed within insulating material 31 in the upper plate 20. A second hairspring 32 is connected, at its outer end, to the stud 30 and is connected at its inner end to an insulated second hub fixed on the balance wheel staff 22. A wire leads from the hairspring 32 to the opposite end of the coil 26. The coil is thus electrically connected, by means of the hairsprings 29 and 32, to the respective studs 28 and 30. The studs 28 and 30 serve as electrical terminals of the coil.

A magnet structure 33 is positioned below the balance wheel. Preferably the magnet structure is positioned on a lower shunt plate 34, of soft magnetic material, which is fixed to the lower plate 21. The magnet, as shown in Figs. 2, 3 and 4, is preferably a single piece of ceramic magnetic material which is magnetized in the axial direction to form, in effect, three magnets, creating three magnetic fields through which the coil oscillates. As shown, the magnetic poles are arranged at the top face of the magnet North-South-North and at the bottom face (against the bottom shunt) South-North-South.

As shown in Fig. 3, the balance wheel 25 consists of an outer rim portion 35 having a widened portion 36 for poising and counterbalancing. The coil 26 is held between extending arms 37 and 38 which are integral with the spoke 39 of the balance wheel.

In the alternative arrangement of Fig. 5, the coil 26 is carried by the balance wheel 25 beneath the shunt 27. The three magnetic fields are created by three separate magnets 40, 41 and 42, which are axially magnetized to form, at their free top sides, respectively North-South-North poles. The lower shunt is eliminated and the magnets 40, 41 and 42 are fastened directly on the lower plate 21, which is of a non-magnetic material such as brass.

A further alternative construction is to utilize only the two magnets 40 and 41 and not use the magnet 42.

A drive circuit of the watch of the present invention is shown in Fig. 6. The circuit of Fig. 6 is a relaxation oscillator utilizing two complementary transistors. A PNP transistor 50 is connected, through a resistor 53, to the negative terminal of a battery 52. The battery 52 is preferably the power source for all the watch circuits. The collector of transistor 50

is connected, through a resistor 54, to the base of NPN transistor 55. The emitter of the NPN transistor 55 is connected, through a resistor 56, to the negative terminal of the battery 52. The collector of transistor 55 is connected to junction point A and to the coil 26. The opposite end of the coil is connected to the resistor 51. The point A is connected through a capacitor 58 to the base of transistor 50. The synchronization signal is injected on line 59 to the emitter of transistor 50. The coil 26, as previously described, oscillates through the plurality of magnetic fields. The coil performs two functions, namely, it acts as a pick-up (timing) means and as a driving means. When current flows through the coil, the coil causes the physical oscillation of the balance wheel. Movement of the coil into the fields of the magnets causes a back e.m.f., which is utilized to trigger the driving pulses.

The driving circuit of Fig. 6 is preferably triggered by three independent sources, which are as follows: (1) The back e.m.f. induced in coil 26, by its physical motion into the fields of the magnet, acts through capacitor 58 to change the voltage at the base of transistor 50. That change of voltage turns on transistor 50, which turns on transistor 55 and causes current to flow from the battery through the coil 26. A regenerative action causes the duration of the output driving pulse from transistor 55 to be independent of the back e.m.f. After the back e.m.f., in effect, is swamped by the forward current, the forward current will continue for a time period determined by the timing components of the circuit, particularly by the capacitor 58 and the resistor 51. (2) The circuit is independently triggered for the self-starting of the watch. The circuit is self-oscillating, due to the connection of the base of transistor 50 through resistor 53 to the negative terminal of the battery 52. Even in the absence of movement of the balance wheel, a train of pulses will be produced to start such movement. (3) The circuit produces a triggered pulse due to the synchronization pulse received on line 59. The synchronization signal injected on line 59 is added to what would normally be an insufficient amount of back e.m.f. voltage to produce a trigger pulse. The synchronization signal is set so that it alone (in the absence of back e.m.f.) would not be sufficient to trigger the driving circuit.

Consider a mechanical oscillator with some losses (damping), characterised by its undamped natural frequency ω_0 and a damping ratio ζ (ratio of actual to critical damping). If a single short impulse is imparted to the oscillator, it will execute a sinusoidal oscillation at the damped frequency

$$\omega_1 = \omega_0 \sqrt{1 - \zeta^2}$$

with exponentially decaying amplitude. To maintain constant amplitude, a short impulse (duration of impulse short in comparison with the period of oscillation) is applied during each cycle. The point in the cycle, at which the impulse is applied, is important. Only if the impulse occurs at the neutral point (zero displacement, maximum velocity), will the frequency remain at

$$\omega_1 = \omega_0 \sqrt{1 - \zeta^2}$$

If the impulse occurs earlier, the frequency increases; if it occurs later, it decreases. If ψ denotes the phase angle at which the impulse occurs, then, for small values of ψ , the change in frequency is given by:

$$\frac{\Delta\omega}{\omega} = \psi \zeta$$

For example, if $\psi = 3$ degrees = 0.05 radian and

$$\zeta = \frac{1}{20} = 0.01$$

(a value believed to be realistic for a balance wheel), then

$$\frac{\Delta\omega}{\omega} = 0.0005$$

equivalent to 43 seconds/day.

As long as ψ is small (i.e. $\cos \psi$ nearly equal to unity) and the pulse duration is short compared to the period, a pulse of arbitrary shape and duration may be replaced, for purposes of analysis, by an equivalent rectangular pulse of unity height and having the same area as the original pulse (Fig. 7). Two rectangular pulses P_1 and P_2 , occurring at ψ_1 and ψ_2 , and having widths W_1 and W_2 , respectively, may be replaced by a single pulse P_3 which has the same moment about the point $\psi = 0$ as the two original pulses.

$$W_3 = W_1 + W_2$$

$$W_3 \psi_3 = W_1 \psi_1 + W_2 \psi_2$$

$$\psi_3 = \frac{W_1 \psi_1 + W_2 \psi_2}{W_1 + W_2}$$

If pulse P_1 remains constant, and P_2 is varied in width W_2 and/or position ψ_2 , the position of ψ_3 or P_3 is shifted. This is illustrated in Figs. 7A and 7B.

In the watch described above, a coil mounted on the balance wheel passes successively over three magnet poles of alternately

opposite polarity. The voltage induced in the coil as a function of the phase angle is depicted in Fig. 8. The drive circuit (Fig. 6) exhibits regenerative action. When the voltage at point A dips even momentarily below the value V_0 (Figs. 8 and 11), both transistors are turned on and a current pulse is sent through the coil. The current remains on, until the slope of the induced voltage curve reaches a certain positive value.

Without synchronization, only pulse P_1 is present and the watch runs at a rate determined by the constants of the balance wheel. When a sync pulse is injected on line 59, pulse P_2 appears in addition to P_1 . The net effect of both pulses is represented by an equivalent pulse P_3 . It can be seen that P_3 occurs at a negative value of ψ , that is, before the neutral position, and therefore accelerates the watch. Furthermore, the position of P_3 is dependent upon the phase angle ψ , at which the sync pulse is injected. If the watch normally runs slow by a large amount, ψ is nearly -30° , P_2 is wide, and P_3 is shifted to the left. If the watch is only slightly slow, P_2 is narrow and P_3 is almost identical with P_1 . If the watch runs fast, the sync pulse gives rise only to a very narrow (1 microsecond) pulse P_2 which has no effect, and there is no synchronization.

Therefore, the watch is initially made to run somewhat slow (with synchronization) so that introduction of the pulse keeps the balance wheel in step with the sync pulse, which, in turn, is controlled by the crystal oscillator. If, for any reason, synchronization is momentarily lost, the watch continues to run at a slower rate until the sync pulse again occurs in the position shown in Fig. 8. The loss of time at 48 Hz with a 3 Hz balance wheel amounts to about 1/48 of a second.

The three magnets provide North-South-North magnetic fields, shown in Fig. 9A, through which the coil moves. The back e.m.f. voltage is plotted in Fig. 9B wherein it is assumed that the fields are widely spaced apart. In fact, the magnetic fields are closely next to one another so that the back e.m.f. voltages are combined. The various positions of the coil 26 as it moves through the magnetic fields are shown in Figs. 10A and 10B, there being only one magnetic structure but two figures 10A and 10B, only to make the illustration clearer. The positions of the coil at sequential times are I, II, III, IV and V, with III being the central position when the coil is directly over the centre magnet. The forward side of the coil is labelled a and the following side b . Fig. 11 shows the back e.m.f. which is the algebraic addition of the voltages induced in the coil by the magnetic fields. For example, the rising portion labelled $IIa+IIb$ indicates that the voltage rises when the forward side of the coil moves into position IIa and the follow-

ing side of the coil moves into position IIb (the physical position II is shown in Fig. 9A).

The synchronization pulses 71, 72 and 73 occur at a high rate compared to the oscillation of the balance wheel. For example, a synchronization rate of 48 Hz. is preferably employed with a balance wheel oscillating at 3 Hz. Assuming that the balance wheel oscillates 210° in each direction (i.e., a complete swing in both directions of 840°), then

$$\frac{3 \times 840}{48} = \sim 52^\circ$$

which is the spacing of the synchronization pulses. The synchronization pulses 72 and 73 are not of any effect. However, the pulse 71, when algebraically added to the back e.m.f., falls below V_0 (at point 74) and triggers the driving circuit. The driving circuit is again triggered, without the aid of a synchronizing pulse, at point 75. The drive circuit causes a driving pulse to the coil twice in each direction of oscillation, i.e., four times in each full oscillation or 12 times a second utilizing a 3 Hz balance wheel.

If the balance wheel slows down, the triggering, at point 74 in Fig. 11, will still be sufficient, even with the decreased back e.m.f., to trigger the drive circuit and restore the correct velocity of the balance wheel. As mentioned above, the duration of the pulse depends upon the rising induced voltage in the coil attaining a certain positive value. That value is attained sooner, i.e., a shorter pulse width, when the velocity of the balance wheel is too large.

The embodiment of Figs. 12 and 13 utilises at least four magnetic fields. This embodiment again provides for synchronisation which accelerates the balance wheel, and also provides synchronisation which may decelerate the balance wheel.

The embodiment of Fig. 12 utilises four evenly spaced magnets 80, 81, 82 and 83 which are axially poled parallel to the axis of the balance wheel staff. The coil 26 embraces two of the magnet faces simultaneously. The back e.m.f. voltage wave form is shown in Fig. 13. Normally, the synchronous pulse 84 would provide an acceleration to the balance wheel as it occurs before the central line 85. The synchronizing rate is selected so that, should the balance wheel have too high a velocity, a synchronising pulse 84a will occur on the third negative voltage excursion 86 of the wave form. The driving circuit will be turned on at a time which effectively decelerates the balance wheel. Normally, the decelerating synchronising pulse occurs past the negative excursion 86 at 87 and has no effect upon the system. The accelerating synchronous pulse, in the

event that the balance wheel has too high a velocity, occurs at 88, i.e., before the first negative excursion of the wave form, and does not trigger the driving pulse.

- 5 The synchronous system of the present invention permits the watch designer greater freedom in designing the watch. For example (1) the magnets may be placed on the balance wheel and two fixed coils used, one for pick-up and one for driving; (2) the amplitude of
10 oscillation of the balance wheel may be decreased as the balance wheel does not determine the timekeeping; (3) the synchronizing frequency may be selected at an even multiple of the balance wheel.

- 15 In the embodiment of Fig. 14, the magnet 90 is a ferro-electric ceramic magnet fixed to the frame plate or a shunt and having two axially poled zones, although other types of
20 magnets creating two oppositely poled magnetic fields may be used. As seen in the top view of Fig. 14, the magnetic zones are a north magnetic pole 91 and a south magnetic pole 92. This magnet is utilised
25 with the same synchronisation circuit as described in connection with Fig. 1 and may be used with the same physical structure as is described in connection with Figs. 2, 3, 4 and 5. A coil 93 is carried, similarly to the coil
30 26 of Fig. 3, by the balance wheel of the watch. In Fig. 14 the coil 93 is shown in five positions, designated I, II, III, IV and V. In position I, the forward half of the coil is over the north magnet 91. In position III
35 the centre line of the coil coincides with the centre of the magnet 92 (designated IIIb) and the north magnet 91 (designated IIIa). In position IV the coil 93 is principally over the south magnet 92 and in position V the
40 coil 93 has its following side over the south magnet 92.

- The term "forward movement", as used herein, means a clockwise motion, when
45 viewed as in Fig. 14 (looking down on the coil and magnets). The term "return movement" means the counter-clockwise motion. The return movement is illustrated in Fig. 14.

- 50 During the forward movement, a voltage, of the approximate form of waveform 95, shown in Fig. 15A, is induced in the coil. The waveform 95 includes a first rising portion 96, a descending negative going
55 portion 97, which triggers the drive pulse, and a second rising portion 98. The synchronizing pulses, which may be 99 in portion 96, 100 in portion 97, and 101 in portion 98, have no effect. They do not cause any portion of the waveform to be shifted,
60 and do not cause the addition or subtraction of any drive pulses. In other words, the synchronising pulses 99 and 101, algebraically added to the induced voltages 96 and 98 respectively, do not trigger the drive circuit
65 because they do not fall below the negative

going voltage 102 necessary to trigger the drive circuit, and also the synchronising pulse 100 has no effect because the drive circuit has already been triggered by the negative going voltage 97 falling below voltage level 102.

The induced voltage, during the return motion, is utilised to synchronise the watch. That induced voltage 103, shown in Fig. 15B, consists of a first small negative portion 104, a larger positive portion 105, and a second small negative portion 106. None of these are below the trigger voltage line 102 and none, in the absence of a synchronising pulse, would trigger the drive circuit.

Fig. 16 illustrates the induced voltage on the return movement. In Fig. 16A the waveform 103a has, as its first negative portion 104a, a synchronizing pulse 107 algebraically added to it. The combination of pulse 107 and portion 104a is sufficiently negative to fall below the trigger line 102a. The drive circuit is triggered and a current drive pulse is produced. The induced portion 104a, and the resulting drive pulse, occurs when the coil is entering the magnets, i.e., when the coil is in positions I and II (over the N magnet 91) and before the centre line 110. Consequently, the extra added drive pulse, when the coil is in that position, acts to accelerate the coil, the driving force being in the counterclockwise direction, aiding the counterclockwise direction of motion.

The synchronising pulse should, if the balance wheel frequency were exact, occur in portion 105a. Such a synchronising pulse 108 would not have any effect in that it would not cause an extra drive pulse.

As shown in Fig. 16B, the induced waveform 103b, when the coil is too fast, is the same as in the Fig. 16A. However, the synchronising pulse 109 occurs in portion 106b and algebraically adds to that portion, dropping the total voltage below trigger line 102a and thereby triggering the drive circuit. The portion 106b, and the resulting drive pulse, occurs when the coil 93 is over the S magnet 92, in positions IV and V. The drive pulse, when it occurs at an instant when the coil is past the centre line 110 (which is between magnets 91 and 92) acts to retard the return motion of the coil and thereby slows down the balance wheel.

As shown in Fig. 17, the induced waveform on the return movement consists of a first negative portion 104b corresponding to the positions I and II of the coil, a positive portion 105b corresponding to the coil positions IIIa and IIIb, and a second negative portion 106c corresponding to coil position IV and V.

In this embodiment, as in the earlier embodiments, the magnets may be carried by the balance wheel and the coil may be fixed to the base plate. Also, as in the other

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embodiments, the drive circuit is a regenerative multi-vibrator so that any width or shape of input triggering pulse is sufficient to trigger a drive pulse output. Preferably the drive circuit is a relaxation oscillator, or other type of astable multivibrator, using a complementary pair of transistors.

WHAT WE CLAIM IS:—

1. A horological instrument including a high frequency oscillator as the instrument's time base, a frequency dividing circuit connected to the output of said time base and producing a low frequency output, a low frequency mechanical element carrying one of an interacting coil and magnet means and capable of low frequency oscillation, the magnet means establishing at least two magnetic poles of alternately opposite polarities, a drive circuit, the output of said drive circuit being connected to said coil and said drive circuit being connected to and synchronised by the output of said dividing circuit, and time display means operated by said low frequency mechanical element.

2. A horological instrument including a high frequency oscillator as the instrument's time base, a frequency dividing circuit connected to the output of said time base and producing a low frequency output, a low frequency mechanical element carrying one of an interacting coil and magnet means and capable of low frequency oscillation, a drive circuit, the output of said drive circuit being connected to said coil and said drive circuit being connected to and synchronised by the output of said dividing circuit, and a time display operated by said low frequency mechanical element, wherein said drive circuit is a regenerative multivibrator.

3. A horological instrument according to claim 2, wherein the drive circuit produces a main driving pulse for each oscillation of the mechanical element and the output of said dividing circuit is algebraically added to a back electromotive force induced in said coil by said magnet means to produce an actuating pulse, said actuating pulse causing said drive circuit to produce an additional driving pulse.

4. A horological instrument according to claim 3, wherein said actuating pulse occurs before or after a main driving pulse, whereby the drive circuit produces at least two driving pulses for each oscillation of the mechanical element.

5. A horological instrument according to any one of the preceding claims wherein the low frequency mechanical element is a balance wheel fixed on a balance wheel staff, said coil is a single coil and said magnetic means includes three magnets alternately oppositely poled in the axial direction of the balance wheel staff.

6. A horological instrument according to any one of claims 1 to 4, wherein the low frequency mechanical element is a balance wheel fixed on a balance wheel staff, said coil is a single coil and said magnetic means includes four magnets.

7. A horological instrument including a high frequency oscillator as the instrument's time base, a frequency dividing circuit connected to the output of said time base and producing a low frequency output, a low frequency mechanical element carrying one of an interacting coil and two oppositely poled magnets, said element being capable of low frequency oscillation, a regenerative multivibrator drive circuit, the output of said drive circuit being connected to said coil and said drive circuit being connected and synchronised by the output of said dividing circuit to produce a driving pulse for each oscillation of said oscillatory element, and a time display operated by said low frequency mechanical element, wherein the output of said dividing circuit is algebraically added to the back electromotive force induced in said coil by movement thereof relative to said two magnets to produce an actuating pulse, said actuating pulse causing said drive circuit to produce an additional driving pulse on the return movement of said oscillatory element only when its movement is not in synchronisation with the output of said dividing circuit.

8. A horological instrument according to claim 7, wherein the low frequency mechanical element is a balance wheel fixed on a balance wheel staff, said coil is a single coil and said magnets are poled in the axial direction of the balance wheel staff.

9. A horological instrument according to any one of the preceding claims wherein said drive circuit is a relaxation oscillator utilising a complementary pair of transistors.

10. A horological instrument according to any one of the preceding claims wherein said high frequency oscillator is a piezoelectric crystal oscillator.

11. A horological instrument according to claim 10 wherein the frequency of said crystal oscillator is above 10,000 Hz.

12. A horological instrument according to claim 11, wherein the frequency is 60,000 Hz.

13. A horological instrument according to any one of the preceding claims wherein said coil is a single coil carried by the balance wheel.

14. A horological instrument according to any one of the preceding claims wherein the drive circuit is an astable multivibrator.

15. A horological instrument according to any one of the preceding claims further comprising an electric power source.

16. A horological instrument constructed, arranged and adapted to operate substantially

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embodiments, the drive circuit is a regenerative multi-vibrator so that any width or shape of input triggering pulse is sufficient to trigger a drive pulse output. Preferably the drive circuit is a relaxation oscillator, or other type of astable multivibrator, using a complementary pair of transistors.

WHAT WE CLAIM IS:—

1. A horological instrument including a high frequency oscillator as the instrument's time base, a frequency dividing circuit connected to the output of said time base and producing a low frequency output, a low frequency mechanical element carrying one of an interacting coil and magnet means and capable of low frequency oscillation, the magnet means establishing at least two magnetic poles of alternately opposite polarities, a drive circuit, the output of said drive circuit being connected to said coil and said drive circuit being connected to and synchronised by the output of said dividing circuit, and time display means operated by said low frequency mechanical element.

2. A horological instrument including a high frequency oscillator as the instrument's time base, a frequency dividing circuit connected to the output of said time base and producing a low frequency output, a low frequency mechanical element carrying one of an interacting coil and magnet means and capable of low frequency oscillation, a drive circuit, the output of said drive circuit being connected to said coil and said drive circuit being connected to and synchronised by the output of said dividing circuit, and a time display operated by said low frequency mechanical element, wherein said drive circuit is a regenerative multivibrator.

3. A horological instrument according to claim 2, wherein the drive circuit produces a main driving pulse for each oscillation of the mechanical element and the output of said dividing circuit is algebraically added to a back electromotive force induced in said coil by said magnet means to produce an actuating pulse, said actuating pulse causing said drive circuit to produce an additional driving pulse.

4. A horological instrument according to claim 3, wherein said actuating pulse occurs before or after a main driving pulse, whereby the drive circuit produces at least two driving pulses for each oscillation of the mechanical element.

5. A horological instrument according to any one of the preceding claims wherein the low frequency mechanical element is a balance wheel fixed on a balance wheel staff, said coil is a single coil and said magnetic means includes three magnets alternately oppositely poled in the axial direction of the balance wheel staff.

6. A horological instrument according to any one of claims 1 to 4, wherein the low frequency mechanical element is a balance wheel fixed on a balance wheel staff, said coil is a single coil and said magnetic means includes four magnets.

7. A horological instrument including a high frequency oscillator as the instrument's time base, a frequency dividing circuit connected to the output of said time base and producing a low frequency output, a low frequency mechanical element carrying one of an interacting coil and two oppositely poled magnets, said element being capable of low frequency oscillation, a regenerative multi-vibrator drive circuit, the output of said drive circuit being connected to said coil and said drive circuit being connected and synchronised by the output of said dividing circuit to produce a driving pulse for each oscillation of said oscillatory element, and a time display operated by said low frequency mechanical element, wherein the output of said dividing circuit is algebraically added to the back electromotive force induced in said coil by movement thereof relative to said two magnets to produce an actuating pulse, said actuating pulse causing said drive circuit to produce an additional driving pulse on the return movement of said oscillatory element only when its movement is not in synchronisation with the output of said dividing circuit.

8. A horological instrument according to claim 7, wherein the low frequency mechanical element is a balance wheel fixed on a balance wheel staff, said coil is a single coil and said magnets are poled in the axial direction of the balance wheel staff.

9. A horological instrument according to any one of the preceding claims wherein said drive circuit is a relaxation oscillator utilising a complementary pair of transistors.

10. A horological instrument according to any one of the preceding claims wherein said high frequency oscillator is a piezoelectric crystal oscillator.

11. A horological instrument according to claim 10 wherein the frequency of said crystal oscillator is above 10,000 Hz.

12. A horological instrument according to claim 11, wherein the frequency is 60,000 Hz.

13. A horological instrument according to any one of the preceding claims wherein said coil is a single coil carried by the balance wheel.

14. A horological instrument according to any one of the preceding claims wherein the drive circuit is an astable multivibrator.

15. A horological instrument according to any one of the preceding claims further comprising an electric power source.

16. A horological instrument constructed, arranged and adapted to operate substantially



as hereinbefore described with reference to
Figures 1 to 4 and 6 to 11 of the accom-
panying drawings or the said Figures as
modified by Figure 5 or Figures 12 and 13
5 or Figures 14 to 17 of the accompanying
drawings.

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