

SPECIFICATION

Electronic timepiece

- 5 This invention relates to electronic timepieces. 5
- According to the present invention there is provided an electronic timepiece including: a stepping motor consisting of a stator, a drive coil and a rotor; drive means for applying a pulsiform driving signal to the stepping motor; detecting means for detecting when the load on the stepping motor is such that the driving signal is incapable of causing the rotor to rotate stepwise and for detecting when the stepping motor is subjected to the influence of an external alternating magnetic field; and varying means for increasing the pulse width of the pulses of the driving signal in response to detection that either the driving signal is incapable of causing the rotor to rotate or the stepping motor is subjected to the influence of an external alternating magnetic field, one or more additional driving pulses being generated to cause the rotor to rotate. 10
- 15 Preferably the detecting means includes a rotation detecting means for detecting that the driving signal is incapable of causing the rotor to rotate stepwise by detecting the voltage induced in the coil by oscillations of the rotor after each driving pulse has terminated. 15
- Preferably the detecting means includes a magnetic field detecting means for detecting the presence of an external alternating magnetic field by detecting the voltage induced thereby in the coil.
- 20 In one embodiment the magnetic field detecting means includes switching means for alternately connecting a relatively low impedance element and a relatively high impedance element across the coil. 20
- The electronic timepiece may include comparator means for comparing the voltage produced across the relatively high impedance element with a reference voltage to produce an indication of the strength of the external magnetic field.
- 25 The varying means, in one embodiment of the present invention, are such that pulses with larger and larger pulse widths are applied to the rotor when the driving signal is incapable of causing the rotor to rotate until a given pulse width is reached which causes the rotor to rotate. Thus the electronic timepiece may include counter means which causes the varying means to produce a predetermined number of pulses of said pulse width which causes the rotor to rotate, the varying means then reducing said pulse width. 25
- 30 The detecting means is preferably arranged to inhibit detection that the load on the stepping motor is such that the driving signal is incapable of causing the motor to rotate stepwise when it is detected that the stepping motor is also subject to the influence of an external alternating magnetic field. 30
- The invention is illustrated, merely by way of example, in the accompanying drawings, in which:-
- 35 *Figures 1(A) and 1(B)* are a perspective view of a conventional stepping motor for an electronic timepiece according to the present invention and a driving waveform thereof; 35
- Figure 2* is a plan view of a magnetic core of a stepping motor in a magnetic field;
- Figure 3* shows schematically the current waveform occurring in the stepping motor of *Figure 1(A)*;
- Figure 4* is a driving/detecting circuit of an electronic timepiece according to the present invention;
- Figure 5* is a characteristic curve of magnetic proof characteristics and pulse widths for alternating current;
- 40 *Figure 6* shows schematically the waveform of driving pulses of a conventional correction pulse system; 40
- Figure 7* is a circuit diagram of a driving/detecting circuit of another electronic timepiece according to the present invention;
- Figure 8* is a timing chart showing one example of a signal at each point of *Figure 7*;
- Figure 9* is a timing chart showing another example of a signal at each point of *Figure 7*;
- 45 *Figure 10* shows curves of response of detection voltage and rotation angle of the rotor; 45
- Figure 11* shows curves showing differences between rotation angle and detection voltage in a rotation condition and a non-rotation condition of the rotor;
- Figure 12* is a waveform of the detection voltage of an electronic timepiece according to the present invention;
- 50 *Figure 13* is a symbol of a N-channel transistor; 50
- Figure 14* is an equivalent circuit of the N-channel transistor of *Figure 13*;
- Figure 15* is an equivalent circuit diagram of part of an electronic timepiece according to the present invention;
- Figure 16(A)* is an enlarged drawing of part of the voltage waveform of *Figure 12*;
- 55 *Figure 16(B)* is a waveform of a detection voltage of an alternating current magnetic field detection device of an electronic timepiece according to the present invention; 55
- Figure 16(C)* shows schematically a switching effect of an electronic timepiece according to the present invention;
- Figure 17* is a characteristic curve of torque relative to pulse width;
- 60 *Figure 18* is a drawing of the waveform of driving pulse of a correction driving system of an electronic timepiece according to the present invention; 60
- Figure 19(A)* is a plan view of an electronic timepiece according to the present invention;
- Figure 19(B)* is a block diagram of an electronic timepiece according to the present invention;
- Figure 20(A)* is a circuit diagram of a driving/detection circuit of *Figure 19(B)*;
- 65 *Figure 20(B)* is a circuit diagram of one embodiment of a control circuit of *Figure 19(B)*; 65

Figure 21(A) is a timing chart showing one example of an output of a waveform combining circuit of Figure 19(B);

Figure 21(B) is a circuit diagram of one embodiment of a control circuit whose input is shown in Figure 21(A):

Figure 22(A) is a timing chart showing another example of an output of a waveform combining circuit of Figure 19(B); and

Figure 22(B) is a circuit diagram showing an embodiment of a control circuit whose inputs are as shown in Figure 22(A).

Figure 1(A) shows a conventional stepping motor for either a conventional electronic timepiece or an electronic timepiece according to the present invention. Figure 1(B) illustrates the waveform of a conventional pulsiform driving signal applied to the stepping motor of Figure 1. When a driving pulse of the signal of Figure 1(B) is applied to a coil 3 of the stepping motor of Figure 1(A), a stator 1 is magnetised and a rotor 2 is rotated stepwise through 180° by repulsion and attraction of the permanent magnetic poles of the rotor 2 and magnetic poles generated in the stator.

The pulse width of the conventional driving signal is selected to ensure that the stepping motor operates in all conditions of the timepiece. Thus the pulse width for most of the time must be greater than actually required to accommodate the load on the stepping motor when a calendar mechanism is advanced, the internal resistance of a battery, and a voltage drop when the battery nears the end of its useful life. Using a pulse width which is greater than that actually required for most of the time wastes power and so it has been proposed to drive the stepping motor with a driving signal whose pulse width is sufficient for most of the time and to provide a detecting circuit which detects the rotation condition (that is the condition in which the rotor rotates stepwise) and the non-rotation condition (that is the condition when the pulse width of the pulses of the driving signal is incapable of causing the rotor to rotate stepwise) of the rotor. This detecting circuit provides a correction drive signal with conventional pulse widths when the rotor is judged to be in the non-rotation condition.

The rotation and non-rotation conditions of the rotor can be determined effectively by measuring the difference in electrical characteristics between the rotation and the non-rotation condition by means of a detector. To provide a separate detector to detect the rotation and non-rotation conditions of the rotor increases cost, and affects miniaturisation and reduction of thickness of the electronic timepiece which is especially important when the electronic timepiece is a watch.

Figure 3 shows the current waveform of a conventional stepping motor. In Figure 3, section "a" represents the time for which a driving pulse is applied to the coil 3 and section "b" represents the time for which current is generated after the driving pulse has terminated, current being induced in section "b" due to oscillation of the rotor. Waveform b_1 shown in Figure 3 is generated when the pulse width is sufficient to cause the rotor to rotate by one step and waveform b_2 is generated when the pulse width is insufficient to do so.

A driving/detecting circuit of an electronic timepiece according to the present invention is illustrated in Figure 4(A) and comprises inverters 4, 5 each consisting of an N-channel field effect transistor and a P-channel field effect transistor, the coil being connected between the outputs of the inverters. When a driving pulse is applied to the coil 3 and has terminated, the coil 3 is short-circuited by the inverters. Then, a current as shown in section "b" of Figure 3 is generated by oscillation of the rotor, the waveform b_1 being produced in the rotation condition and the waveform b_2 being generated in the non-rotation condition. Thus a voltage which is the product of the ON resistance of a driving transistor and a current generated by oscillation of the rotor is produced. This generated voltage is converted into a voltage in the same sense via a transmission gate and compared with a base or reference voltage and peak voltage by a comparator 6. When the rotor is determined in the non-rotation condition, a correction driving signal is produced. When an electronic timepiece is placed in an external alternating magnetic field, a voltage is induced in the coil 3 and this voltage is impressed as external noise on a detection signal when the rotation and non-rotation conditions of the rotor are determined by the voltage induced as a result of oscillation of the rotor. Thus detection of the rotation and non-rotation conditions is liable to error and so the timekeeping of the timepiece becomes faulty.

Figure 5 is a graph of anti-alternating current magnetic characteristics and pulse widths of a stepping motor. Since an electronic timepiece is required to have low electric power consumption the driving pulse width of the driving signal must be as short as possible. Anti-magnetic characteristics are reduced as a result of reducing the pulse width and so in order to use the driving circuit of Figure 4(A) for a watch or other electronic timepiece it must be provided with better than normal anti-magnetic characteristics. Although the driving circuit of Figure 4(A) results in a saving of current it is necessary to add a shield plate to produce the necessary anti-magnetic characteristics and such detracts from the miniaturisation of the watch and increases cost.

In the present embodiment of the invention the voltage induced in the coil 3 of the stepping motor of Figure 1(A) when the rotor does not rotate is used to determine not only when the load on the stepping motor is such that the driving signal is incapable of causing the rotor to rotate stepwise but also for detecting when the stepping motor is subject to the influence of an external alternating magnetic field. Thus a separate detecting element, such as a Hall effect element or a magneto resistive element, is not required to detect the external alternating magnetic field.

Figure 2 is a typical drawing of a coil and a magnetic core 7 of a stator placed in an external magnetic field. A stator used for a stepping motor of an electronic timepiece and in particular an electronic watch normally has slender form. Therefore, the external magnetic field is concentrated in the magnetic core 7 so the flux density in the magnetic core 7 is about ten times the flux density of the external magnetic field although this depends to some extent on the exact shape of the stator.

A voltage v induced in the coil 3 of the stepping motor of Figure 1(A) by an external alternating magnetic field is given by:

$$v = -n \cdot d\phi/dt \dots (1)$$

where n is the number of turns of the coil 3 and ϕ is the flux in the magnetic core 7.

Table 1

material of magnetic core 7	45 permalloy
length of magnetic core 7	12 mm
cross-sectional dimension(s) of magnetic core 7	0.8 mm × 0.8 mm
number of turns of the coil 3	10,000 turns

Supposing that the flux density in the magnetic core 7 is one hundred times that of the external alternating magnetic field when the magnetic core 7 and coil 3 are as shown in the above Table, the flux of the magnetic core is given by:

$$\phi = 100 \times S \times B \times \sin\omega t \dots (2)$$

in which the flux density B (gauss) is the peak value of the flux density of the external alternating magnetic field and S is the cross-sectional area of the core.

From equations (1) and (2) and Table 1

$$\begin{aligned} v &= -100 \times n \times S \times B \times \omega \times \cos\omega t \\ &= -100 \times 1 \times 10^4 \text{ (turns)} \times 0.64 \times 10^{-6} \text{ (m}^2\text{)} \times B \times 10^{-4} \text{ (wb/m}^2\text{)} \\ &\quad \times 2\pi \times 50 \text{ (Hz)} \times \cos\omega t \\ &= -0.02 \times B \cos\omega t \text{ [v]} \end{aligned}$$

Therefore, if the flux density B of the external alternating magnetic field is 2 gauss, v is $-0.04 \cos\omega t$ [v]. Thus to detect the external magnetic flux density and to control the driving pulses offered to the stepping motor a voltage of this order generated in the coil 3 must be detected. Therefore it is necessary to amplify the voltage induced across the coil 3 as described hereinafter.

In Figure 4 the detection of the external alternating magnetic field is performed by detecting the voltage induced in the coil 3 by means of a voltage comparator.

In Figure 4(B) the gate of a P-channel electric field effect transistor (4a or 5a) and the gate of a N-channel electric field effect transistor (4b or 5b) are separate from each other, while, in Figure 4(A), the gate of the P-channel electric field effect transistor and the gate of the N-channel electric field effect transistor are coupled with each other to constitute an ordinary inverter. In Figure 4(B) each pair of transistors (4a and 4b, 5a and 5b) constitutes a 3-stage inverter. Namely the output voltage of the 3-stage inverter which is connected to the terminal of the coil 3 has three stages VDD, ground and infinity. The last stage occurs when both transistors 4a and 4b become OFF together. The terminal of the coil is suddenly cut off by means of the 3-stage inverter when the induced current flows through the drive coil. Therefore the induced voltage is amplified.

When the electronic timepiece is in an external alternating magnetic field, the stepping motor can be driven with a pulse width defined by a peak 8 or a plateau 9 (Figure 5) to improve anti-magnetic characteristics.

Figure 6 is a driving pulse timing chart where a indicates a normal driving pulse, b indicates the time when rotation of the rotor is detected, c is a correction pulse when the rotor is not rotated by the pulse a , b' is a rest period of the rotor and d is a magnetic field detecting period. When it is detected that the electronic timepiece is in an external alternating magnetic field during the period d a driving pulse e having a longer pulse width than the pulse a and the pulse c is provided to a coil 3.

Reference will now be made to a second embodiment of an electronic timepiece according to the present invention in which improvements are made, relative to the first embodiment, regarding information relating to the rotation and non-rotation conditions of the rotor.

Figure 7 illustrates a driving/detecting circuit of an electronic timepiece according to the present invention. In this embodiment it is not necessary to provide an amplifier to amplify the voltage induced in the coil 3 by the external alternating magnetic field but rather a high impedance detecting element is

intermittently connected into the circuit. Thus the circuit of Figure 7 can be constructed as an integrated circuit very easily and so cost is not increased substantially; only the size of the conventional integrated circuit of the electronic timepiece is slightly increased and yet stability of operation is ensured.

The driving/detecting circuit of Figure 7 comprises P-MOSFET gates 10, 12 and N-MOSFET gates 11, 13 forming inverters similar to the inverters 4, 5 in Figure 4(A). Output terminals 18, 19 of the inverters are connected to a coil 3 and a high impedance detecting element, i.e. a detecting resistor 16 via gates 14, 15. A connecting point 20 of the detecting resistor 16 is connected to an input terminal of a binary value logic element 17 having a predetermined threshold voltage.

Figure 8 shows the input signals at each gate of the driving/detecting circuit. A driving pulse is applied to the coil during period T_1 . As only the gate 10 and the gate 13 are ON, current flows from a power source as shown by an arrow 21. Supposing that only gates 14, 13 are ON during period T_2 , a closed loop 22 comprising the coil 3 and the detecting resistor 16 is formed.

If the voltage induced in the coil 3 due to rotation of the rotor 2 is e , the combined internal resistance of the coil 3, the gate 14 and the gate 13 is r , the resistance of the detecting resistor 16 is R , then a voltage V_{20} at the point 20 is:

$$V_{20} = eR/(R + r), \text{ if } R \gg r, V_{20} = e$$

Therefore, if $R \gg r$, V_{20} can be considered to be the induced voltage of the coil.

Figure 10 shows one example of the voltage V_{20} when the detecting resistor 16 is 50 k Ω , the resistance of the coil 3 is 2.8 k Ω and the latter has 9800 turns, and the stepping motor is almost in a non-load condition.

Figure 10 also shows the rotational angle relative to the induced voltage waveform. As the load on the stepping motor increases, the peak of the induced voltage falls gradually and the result is that the period for which the rotor oscillates increases.

Figure 11 shows the waveform of the voltage V_{20} and rotation angle of the rotor at the time of maximum load and overload by means of curves *a* and *b* respectively.

In the case of maximum load, initial rotation of the rotor is slow and as there is virtually no oscillation after each step of rotation there is little or no irregularity of the induced voltage. At the moment of overload, a high peak voltage in the negative direction as shown by curve *b* is induced as the rotor comes back to the starting position.

There are many ways and means of discriminating between the rotation and non-rotation condition of the rotor from the induced voltage waveform but the best way, it has been found, is to detect the existence of a peak *q* shown in Figure 10 for simplicity and certainty.

A detection operation is performed after several milliseconds from the application of the driving pulse to avoid mistaking the peak *p* for the peak *q*. The voltage induced by the free oscillation of the rotor produces a first peak *p* even when the rotor has failed to rotate so that the first peak *p* is not suitable for the detection of the rotor rotation. However, the peak *q* is clear when the rotor is free of load but does not appear when the rotor is subject to an excess load. Thus the second peak *q* is suitable for the detection of the rotor rotation. However, the peak *q* almost disappears when the rotor is subject to a limiting or maximum load. Therefore the detection circuit regards the rotor as having failed to rotate although actually it has. This is not the matter of importance, because the correction pulse which is produced in this case cannot effect rotation of the rotor. In other words after a drive pulse has rotated the rotor, the succeeding correction pulse having the same polarity as the drive pulse cannot drive the rotor and is harmless.

Following is now a discussion of switching intermittently a high impedance detecting element and a low impedance element after the driving pulse has been applied. Just after the drive pulse is applied to the stepping motor, gates 10, 12, 14 and 15 become OFF and gates 11 and 13 become ON (see Figure 7). Then the drive coil 3, gates 11 and 13 constitute a first closed loop that is a "braking circuit". When an individual pulse is applied to the gates 11, 14, the gate 11 becomes OFF and the gate 14 becomes ON and the other gates are unchanged. Therefore the drive coil 3, gate 12, the detecting resistor 16 and gate 13 constitute a second closed loop that is also a "braking circuit". Thus individual pulses successively switch from the first closed loop to the second closed loop. These first and second closed loops are switched during a braking period T_2 (Figure 9) of the rotor. Figure 9 is a timing chart of this action. By operating the above circuit an abrupt change of current occurs in the braking circuit. However, the induced current flowing through the coil 3 cannot follow the abrupt switching so there appears a transient phenomenon determined by the time constant $\tau = L/R$ where L is the inductance of the coil 3 and R is the resistance of the detecting resistor 16.

Then, the voltage generated across the detecting resistor 16 is several millivolts in the braking circuit shown in Figure 4(A). But in Figure 7, since the coil tends to maintain a current during the braking period, the peak voltage $2v$ is generated across the detecting resistor 16 which has relatively high resistance, at the instant of change in the braking circuit. Thereafter this voltage decreases with said time constant τ and becomes as shown by the voltage waveform in Figure 10. The resulting voltage waveform is shown in Figure 12.

A preferable feature of the present invention consists in the amplification of a voltage which is induced by the stepping motor in the braking period only by changing the resistance value of the circuit which executes braking of the rotor. The peak voltage *q* shown in Figure 10 is about 0.4 volts.

The logic element 17 shown in Figure 7 can be composed of an inverter which is an element of the simplest C-MOS composition. In this embodiment, the design of a binary logic element for detection is

38

difficult when the resistance of the detecting resistor 16 is too small since the detection signal is low. Moreover, if the resistance of the detection resistor 16 is more than a given value, the detecting voltage does not increase because electric power generation is constant. Accordingly, it has been found from experiment with a stepping motor whose coil has an inductance of 11 henries and a DC resistance of $3k\Omega$, when a braking circuit is switched on at a frequency of 1 msec. and a 50% duty cycle after application of a driving pulse, a peak voltage 1.5v appears at the detecting resistor 16 if its resistance is more than $20k\Omega$. When the load applied to the rotor reaches 90% of the limit load, the detecting circuit already puts out a detection signal indicative of non-rotation under the condition that a comparator incorporated in the detecting circuit has a threshold voltage 0.5v.

- 10 According to the above described method, normal drive pulses having short pulse width are usually applied to the stepping motor and a correction drive pulse is applied thereto as soon as the detecting circuit puts out the detection signal indicative of non-rotation. If this method is applied to a low electric power drive system, very stable operation is obtained and circuit constitution can be simplified. Only a gate circuit for pulse composition is made a little more intricate and there is slight enlargement of the integrated circuit. Furthermore, the operation of the driving/detecting circuit is very stable because it does not contain condensers but only a detecting resistor whose tolerance is large and because the latter is an analogue element and all the other components are digital elements.

- 20 Referring now to the operation of amplification of a signal by switching between a loop of high resistance and a loop of low resistance. Figure 13 is an N-channel transistor. Figure 14 is an equivalent circuit diagram thereof. A switch 40 is caused to switch ON and OFF by a gate signal applied to terminal G. Reference numeral 39 represents ON resistance of the gate and reference numeral 41 represents a diode between a substrate S and a drain D connected by a P-N junction. A condenser 42 represents the sum total of the capacitance of the P-N junctions between the substrate and the drain, capacity between the drain and the gate, a pad capacity and a suspended or stray capacity etc.

- 25 An equivalent circuit of the driving/detecting circuit of Figure 7 is shown in Figure 15 and a battery is assumed to be a condenser of large capacity and acting as an ideal power source.

- A voltage V represented by a battery 43 is produced by the external magnetic field or oscillation of the rotor. A coil 44 of the motor has an inductance of L henries and an internal resistance 45 of $r\Omega$. Reference numeral 47 represents a loop selecting switch and reference numeral 46 represents the ON resistance $rN\Omega$ of the N gate of Figure 14.

However, the resistance $rN\Omega$ may be neglected because it is small compared to the resistance 45 of the coil. Reference numeral 48 represents parasitic capacitance of the N-gate and P-gate and is the sum of the parasitic capacitance of the N-gate and the parasitic capacitance of the P-gate 22 and is C-farad.

- Reference numeral 49 is a detecting resistance $R\Omega$. Reference numerals 50, 52 are parasitic diodes between the substrate and the drain of the N-gate and the P-gate and reference numeral 51 represents a drive battery, for example, a silver battery used for watches, whose output V_D is generally 1.57v.

An output voltage at a terminal 53 serves as a detecting voltage V_R and is applied to a voltage detecting element. Responses as the selecting switch 47 is changed based on the equivalent circuit of Figure 15 are theoretically as follows:

(i) $a^2 > b$

$$V_R = E \left[1 - \left\{ \frac{1}{\omega} \left(a - \frac{DL}{r} b \right) \sinh \omega t + \cosh \omega t \right\} e^{-at} \right]$$

(ii) $a^2 = b$

$$V_R = E \left[1 - \left(1 + at - \frac{DL}{r} bt \right) e^{-at} \right]$$

(iii) $a^2 < b$

$$V_R = E \left[1 - \frac{1}{\omega} \left(a - \frac{DL}{r} b \right) \sin \omega t + \cos \omega t \right] e^{-at}$$

where

$$a = \frac{1}{2} \left(\frac{r}{L} + \frac{1}{CR} \right), \quad b = \frac{r+R}{LCR}$$

$$E = \frac{R}{R+r} V_D, \quad \omega = \sqrt{4a^2 - bL}, \quad D = 1 - e^{-\frac{r}{L} t_0}$$

where t_0 is the connection period of the low resistance loop and t represents time.

The waveform of the detection voltage V_R is shown in Figure 16(A). From calculations based on one embodiment of the present invention, the time for V_R to reach peak voltage is about 13 msec., the peak voltage being 4.2v so magnification is about 42 under the following conditions:

- 5 $L = 11$ henries, $C = 75$ pF, $R = 150$ k Ω , $r = 2.8$ k Ω , $V_0 = 0.1$ V, $t_0 = \infty$.

Therefore, amplification of the detection signal is performed easily without using an amplifier to amplify an analogue signal. However, it has been assumed above that $t_0 = \infty$ that is the time for which the low resistance loop is maintained is limitless. However, in practice, the high resistance loop and the low resistance loop operate alternately. The time taken for the high resistance loop to reach constant voltage is relatively short but time taken for the low resistance loop to reach constant voltage is relatively long.

In the case of the high resistance loop the detecting voltage V_R becomes substantially constant in about 0.2 msec. and in the case of the low resistance loop the time constant thereof is obtained by $\tau = L/r = 3.9$ msec. Therefore, if the low resistance loop is maintained for 3.9 msec, only 63% of the constant voltage value is obtained.

- 15 When this system is used as a detecting device of an external alternating magnetic field, it is able to easily detect a magnetic field because of a large amplification factor.

Generally, the frequencies of external alternating magnetic fields to which electronic timepieces are subject are 50 Hz or 60 HZ which are the commercial frequencies whose periods are 20 msec. or 16.7 msec.

- Figure 16(B) illustrates the case where the high resistance loop time is 0.5 msec. and the low resistance loop time is 1.5 msec. to detect an external alternating magnetic field of 50 Hz. A detecting signal amplification factor in this case is about 15 times theoretically.

- In Figure 16(C) a straight line 55 is a voltage generated in the coil of the stepping motor in the case where there is no switching and line 56 is the voltage in the coil when the low resistance loop time is 0.5 msec. and the high resistance loop time is 0.5 msec. giving an amplification factor of about 5. Line 57 represents the increased amplification of the voltage induced in the drive coil when the low resistance loop time is longer than the high resistance loop time.

- As noted above, an analogue amplifier, which is difficult to make in C-MOS IC for watches, is unnecessary because amplification of the detection signal is executed by switching between the high resistance loop and the low resistance loop both of which includes the coil of the stepping motor in which voltage is induced by the external alternating magnetic field and the results of this switching are compared by a comparator. As an amplification factor of greater than ten times is obtained, a comparator using the threshold voltage of a C-MOS inverter is possible and this is superior from the viewpoint of power consumption, the construction of the circuit and the area of the resulting integrated circuit. Though a resistance is used as a detecting element in the embodiment of Figure 7 a capacitive or inductive element may be used instead. Moreover, since the detecting element is preferably contained in a C-MOS IC, the characteristic of a non-saturated portion of a buffer transistor, which is an active element, may be used. Ideally, it has been found advantageous to use the ON-resistance of a buffer transistor in the low resistance loop, an IC diffused resistor in the high resistance loop and a C-MOS inverter or comparator as a voltage detecting element.

- In the embodiment described in relation to Figure 7, a high resistance element is connected in the high resistance loop; this high resistance element can be an infinite resistance so that the loop is preferably an open loop. Although in this case, since there is parasitic capacity, the detecting voltage cannot be amplified infinitely.

- Generally, in the case where a detecting resistance is higher than five times the coil resistance of the coil of the stepping motor the amplification factor becomes greater than 1.

- At the time of design, as a detection system of rotation and non-rotation conditions of the rotor, an important factor is the setting of the resistance value of the detecting resistor 16 and a detecting voltage of the voltage detector. Further, as this driving/detecting circuit is used for detecting the magnetic field commonly, there is no significant factor which causes complication of the composition of the circuit if it is used in a stepping motor which is driven by a correction driving system. The detecting resistor 16 for detecting rotation conditions of the rotor and a detector 17 are set at optimum values taking into consideration the inductance of the stepping motor, direct current resistance and magnetic circuits etc. Two detection voltages may be set and it is possible to select a lower detection voltage in the case of magnetic field detection and a higher voltage in the case of rotation detection. The setting and switching of two detection elements with different values is thus conceivable. Thus in the case of the magnetic field detection sensitivity is higher because the value of the detection element is higher. Therefore, the establishment of two detection elements of different values is easier if one is an infinite resistance i.e. it is an open loop which includes the coil.

- Further, as discussed above the amplification can be controlled also by the ratio of the high impedance loop relative to the low impedance loop and sensitivity of the magnetic detection can be increased by making the low impedance loop time longer than that of the high impedance loop. In this case, a single detection element and detection voltage are used for both magnetic field detection and rotation detection. Further, a sensitivity of magnetic field detection which is as high as possible is required, and this may be achieved by a combination of the above features.

- In the case where an alternating magnetic field is detected, detection of the rotation of the rotor

thereafter becomes unnecessary because a driving pulse of increased width is in any case necessary. In this case, if the rotation detection circuit operates, the voltage induced by oscillation of the rotor is confused by the external alternating magnetic field. There is the possibility, therefore, that the rotor is judged in the non-rotation condition when it actually is in the rotation condition and so it may be better that the rotation detection is prevented after detection of an external magnetic field from the viewpoint of stability of circuitry and current consumption.

Figure 17 is a graph showing the relationship of a driving pulse width and torque of a stepping motor of this embodiment. With a fixed pulse drive, the pulse width is set at a point a to ensure the maximum torque $T_{q\max}$ of the stepping motor. In the correction drive as noted in the previous embodiment, a normal driving pulse width is set to a_2 or a_3 if a torque T_{qc} is that necessary for driving a calendar display. Because a correction pulse is added when the rotor does not rotate with the normal driving pulse there are many correction pulses which can be impressed current consumption is a function of the addition of these two pulses. When the stepper motor is under no or substantially no load the rotor may be rotated with a pulse width a_0 in practice so a further reduction of power consumption appears possible. This is the purpose of the present embodiment and the operation thereof is illustrated in Figure 18.

Normally, the rotor is driven by a pulse width a_0 . When the rotor does not rotate with the pulse width a_0 owing to calendar load for example a detecting circuit judges that the rotor does not rotate, and the rotor is immediately driven by a correction driving pulse. A pulse width of the correction driving pulse is shown as a in Figure 17. The next driving pulse width a_1 , after one second, which is slightly longer than a_0 is set automatically as the normal driving pulse and is applied to the stepping motor.

However, according to Figure 17, calendar torque T_{qc} is not achieved even with pulse width a_1 and so the rotor again will not rotate and a correction pulse a is again applied. Then the normal driving pulse after one second automatically becomes a_2 which creates an output torque which is greater than the torque T_{qc} so the stepping motor is driven with the pulse width a_2 .

However, the pulse width a_2 will continue even after the calendar load disappears and this is a disadvantage when it comes to reduction of power consumption. Thus by adding a circuit which shortens the driving pulse every N seconds the pulse width is returned to a_1 after N pulses with a pulse width a_2 have been produced and further becomes a_0 after N pulses with a pulse width a_1 .

By driving a stepping motor in this manner power consumption can be reduced further. As shown in Figure 5 as pulse width is reduced so alternating current anti-magnetic characteristics become worse. However, in the above embodiments of the present invention a magnetic field detecting circuit is operated before the application of a normal driving pulse and if the condition detected is such that an external alternating magnetic field is detected the correction driving circuit is inhibited, the normal driving pulse width is set at a peak point in the region 8 or the region 9 of Figure 5, that is at a point to maximise anti-magnetic characteristics.

Therefore, a stepping motor is produced which is little influenced by external alternating magnetic fields and whose electric power consumption is reduced, miniaturisation is possible and thickness may be reduced because there is no increase in the number of parts and further, from the viewpoint of cost, it is advantageous because a specific anti-magnetic structure does not have to be provided.

The influence of external alternating magnetic fields is discussed above. In the case of an external direct current magnetic field, misoperation of the detection of the rotation and non-rotation conditions of the rotor does not occur because though whilst a voltage is induced in the coil of the stepping motor by an external alternating magnetic field, a voltage is not generated in the coil in the case of an external direct current magnetic field.

The present invention has been discussed above in connection with a stepping motor with a one piece stator but a similar effect can also be achieved using any conventional stepping motor and in particular one whose stator is a multi-part stator and even a mono-phase driving stepping motor.

Figure 19(A) shows an example of a watch according to the present invention having a base plate 70, a coil 71 and a stator 72, a supporting member 73 for a rotor and gear train of the stepping motor, a battery 74, a quartz crystal oscillator 75 and a circuit block 76 on which an IC is mounted and which is moulded of resin. The three embodiments described above merely differ in the form of the IC.

Figure 19(B) is a block diagram of the whole of an electronic timepiece according to the present invention comprising an oscillator circuit 90 including a quartz crystal oscillator producing a 32,768 Hz signal as conventional, a frequency divider circuit 91 having 15 dividing stages and producing an output signal of 1 Hz, a waveform combining circuit 95 for producing pulses of different width which are necessary for detecting and driving etc., a control circuit 92 and a driving/detection circuit 93 for applying different driving pulses (according to the existence or non-existence of a detection signal) to a stepping motor 94 with a pulse width which suits each condition.

Figure 20(A) and Figure 20(B) show an example of a driving/detecting circuit of the electronic timepiece of Figure 19(B). The driving/detecting circuit comprises P gates 21, 22 and N gates 23, 24 which constitute CMOS inverters producing outputs a , b applied to opposite terminals of a coil 20 of the stepping motor and one side of a respective detecting resistor 28, 29. The other sides of the detecting resistors 28, 29 are connected to source inputs of N gates 25, 26 respectively. Each positive input terminal of a voltage comparator 30, 31 is connected to respective outputs a , b and each negative terminal is connected to a dividing point of a base voltage resistor 34 and both outputs of the comparators 30, 31 are connected to an

OR gate 32.

One terminal of the resistor 34 is grounded *via* an N gate 27. Two input terminals of an AND gate 33 are connected to an output of the OR gate 32 and the gate terminal of the N gate 27. Gate terminals 101, 102, 103, 104, 105, 106, 107 of the P gates and the N gates 21, 22, 23, 24, 25, 26, 27 and an output terminal 110 of the AND gate 33 are connected to the control circuit 92 (Figure 19(B)). Terminals having the same reference numerals in Figures 20(A) and (B) are connected to each other.

In Figure 20 (B) a flip-flop 74 is of the negative edge trigger type and is connected from a phase control terminal 122 to a clock input CL *via* an inverter or NOT gate 73. An output Q of the flip-flop 74 is applied to an AND gate 75 and an AND gate 76. An output $\bar{Q}$ of the flip-flop 74 is applied to an AND gate 77 and an AND gate 78. A driving terminal 121 is applied to the AND gate 75 and the AND gate 77. A detection signal input terminal 124 is connected to the AND gate 76 and the AND gate 78. An output of the AND gate 75 is connected to a terminal 109 *via* a NOT gate 79 and is connected to a NOR gate 81. The output of the AND gate 76 is connected to the terminal 105 and the NOR gate 81. An output of the AND gate 77 is connected to a NOR gate 82 and the terminal 102 *via* a NOT gate 80. An output of the AND gate 78 is connected to the NOR gate 82 and the terminal 106. The output of the NOR gate 81 is connected to the terminal 103, and output of the NOR gate 82 is connected to the terminal 104 and a detection signal input terminal 124 is connected to the terminal 107.

Referring now to the operation of the circuit of Figure 20(B), an input signal is applied to the terminal 122 to invert the sense of current flowing in the stepping motor 94; the direction of driving and detecting pulses for the stepping motor are inverted with a pulse of positive edge because of the NOT gate 73. Therefore, in the case of a timepiece with a one second stepping action, one second pulses are applied to the terminal 122.

The relation between the inputs and outputs of the circuit of Figure 20(B) in the cases where the output Q of the flip-flop 74 is H (high level voltage) and Q is L (low level voltage) is as follows:

Table 2

		input terminal			output terminal						
30	flip-flop 74	121	124	101	102	103	104	105	106	107	30
		L	L	H	H	H	H	L	L	L	
35	Q=H	H	L	L	H	L	H	L	L	L	35
		L	H	H	H	L	H	H	L	H	
40		L	L	H	H	H	H	L	L	L	40
	Q=L	H	L	H	L	H	L	L	L	L	
		L	H	H	H	H	L	L	H	H	
45											45

When an output signal as shown in Table 2 is applied to the circuit of Figure 20(A) N gates 23, 24 become ON when Q is H, the terminal 121 is L and the terminal 124 is L whereby a low impedance loop is made.

When Q is H and the terminal 121 is H and the terminal 124 is L the P gate 21 and N gate 24 become ON and current flows in the coil 20 and the stepping motor 94 is operated.

When Q is H, the terminal 121 is L, and the terminal 124 is H, the N gate 25 and N gate 24 become ON and the detecting resistor 28 is inserted in the loop to form a high impedance loop. Further, the N gate 27 becomes ON and then a base voltage is impressed on the negative inputs of the voltage comparators 30, 31 and a signal representative of the rotation or non-rotation condition of the rotor or a signal representative of the presence of an external alternating magnetic field is produced at the terminal 110.

Figure 21(B) shows an example of the control circuit 92 of the first embodiment of the present invention shown in Figure 4 and the second embodiment of the present invention shown in Figures 7 to 9. A third embodiment of the present invention is shown in Figures 17 and 18. Figure 21(A) shows a waveform which is produced from the combining circuit 95 and is applied in the control circuit 92 its wave combination being constituted in general by gate circuitry. In this Figure PD₁ is a normal driving pulse of 3.9 msec; PD₂ is a correction driving pulse of 7.8 msec. for correction driving in the case that the load on the stepping motor is larger than the limit load determined by a normal pulse of 3.9 msec. i.e. the rotor is in the non-rotation condition; PD₃ is a pulse width which is chosen to maximise antimagnetic characteristics when the timepiece is detected as being in an external alternating magnetic field; enforcing drive is then performed with a 15.6 msec. pulse PS₁ but this is not necessary in the first embodiment of the present

invention discussed above and is a pulse used in the second embodiment; and PS_2 is a signal for designating a period in which rotation and non-rotation conditions of the rotor is detected. Each pulse of Figure 21(A) is applied to a corresponding input terminal of Figure 21(B). PD_3 is applied to a terminal 140, PS_2 is applied to a terminal 142, PD_1 is applied to a terminal 143, PD_2 is applied to a terminal 144 and PS_1 is applied to a terminal 145, and an output signal from a detecting circuit is fed to a terminal 141. The terminal 141 is connected to S-input of a SR FF 150 via an AND gate 156 and is connected to one input of an AND gate 152. The terminal 142 is connected to the other input of the AND gate 156 via a NOT gate 157 and to the other input of the AND gate 152, and the output of the AND gate 152 is applied to an S-input of a SR FF 151. The terminal 143 is connected to an R input of the SR FF 151 and to one input of an OR gate 154. An output $\bar{Q}$ of the SR FF 151 is connected to one input of an AND gate 153 the output of which is applied to the other input of the OR gate 154 and an output of the latter is applied to an AND-OR gate arrangement 155. The outputs Q, $\bar{Q}$, of the SR FF 150 are connected to the AND-OR gate arrangement 155 and the output of the AND-OR gate arrangement 155 is connected to a driving pulse output terminal 146.

The $\bar{Q}$ output of the SR FF 150 is also applied to an AND gate 157. PS_1 at the terminal 145 appears at a terminal 147 via the AND gate 157 and if an external alternating magnetic field is detected the SR FF 150 is set immediately and all detections are inhibited.

In normal operation, when there is no exterior alternating magnetic field, there is no output from the magnetic field detecting circuit and the SR FFs 150, 151 are not set. Therefore, $PD_1 = 3.9$ msec. appears at the terminal 146 via the OR gate 154 and the AND-OR gate arrangement 155. Hence, if the rotation signal of the rotor is applied to the terminal 141, the SR FF 151 is set and $\bar{Q}$ output becomes L and $PD_2 = 7.8$ msec is not generated at the terminal 146. However, in the case where the rotor does not rotate then the signal applied to the terminal 141 is such that the SR FF 151 is not set and the $\bar{Q}$ output is H. For that condition, $PD_2 = 7.8$ msec is generated at the terminal 146 via the AND gate 153, the OR gate 154 and AND-OR gate arrangement 155.

When the watch or timepiece encounters an external alternating magnetic field, a detection signal is applied to the terminal 141, the SR FF 150 is set and, as the Q output becomes H, a signal of 15.6 msec from the terminal 140 appears at the terminal 146 via the AND-OR gate 155.

The terminal 146 is connected to the terminal 121 of the driving circuit of Figure 20(B) and the terminal 147 is applied to the terminal 124 and the stepping motor is driven by a pulse whose width is 15.6 msec.

Referring now to the arrangement shown in Figures 22(A) and 22(B). Figure 22(B) is an example of the control circuit 92 designed on the basis of the arrangement shown in Figure 17. Waveforms whose timing chart is as shown in Figure 22 (A) are generated from the combining circuit 95 shown in Figure 19. The combining circuit 95 is composed of an appropriate combination of gate circuits whose inputs are signals which are generated from the divider circuit 91.

Referring now to the timing chart shown in Figure 22(A) $Pa_0 = 2.4$ msec, $Pa_1 = 2.9$ msec, $Pa_2 = 3.4$ msec, $Pa_3 = 3.9$ msec and these are normal driving pulses and one of these pulses is chosen automatically according to the load on the stepping motor and becomes a normal driving pulse PD_1 . PD_2 is a correction pulse in the case where the rotor is in a non-rotation condition after the normal driving pulse PD_1 and maximum torque is assured with a width of 7.8 msec.

The width of PD_3 is applied when the watch or timepiece is judged to be in an external alternating magnetic field and is 15.6 msec.

PS_1 is an input pulse for detection. An L = 0.5 msec, H = 1.5 msec and mark-space ratio 1:3 is provided in the case of external alternating magnetic field detection. In the case of rotation detection, the pulse width is 0.5 msec. and has a mark-space ratio of 1:1. PS_2 is a pulse to determine a period of the rotation detection, detection being begun 9.8 msec after the normal driving pulse PD_1 is terminated and being effected during 11.7 msec.

Outputs of the combining circuit 95 as above are connected to terminals of Figure 22 (B). Pa_0 is connected to a terminal 174, Pa_1 to a terminal 175, Pa_2 to a terminal 176, Pa_3 to a terminal 177, PD_2 to a terminal 173, PD_3 to a terminal 170, PS_1 to a terminal 168, PS_2 to a terminal 172 respectively and a detecting output from a detecting circuit is applied at a terminal 171 and a terminal 178 is connected to the terminal 121 of Figure 20(B) and a terminal 169 is connected to a terminal 124 of Figure 20(B).

Since the operation of signals at terminals 170, 171, 172, 173, an AND gate 183, a NOT gate 184, an AND gate 185, an SR FF 180, an SR FF 181, an AND-OR gate arrangement 182, an AND gate 200 and an AND gate 201 are the same as the corresponding terminals and components in Figure 21(B), description thereof is omitted.

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An OR gate 204, an AND gate 205, an AND gate 206, an FF 202, an FF 203, constitute an up-down counter: an input from the AND gate 200 is for the up-counting mode and an input from the AND gate 186 is for the down-counting mode, outputs of the counter are taken from the FF 202 and the FF 203 and are Q_0 , Q_1 . The outputs of the counter are connected to a decoder 189 and the output PD_1 of the decoder is as follows:

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Table 3

	Q_1	Q_0	PD_1	
10	0	0	Pa_0	10
	0	1	Pa_1	
15	1	0	Pa_2	15
	1	1	Pa_3	

20 A normal drive pulse which is generated from the decoder 189 is equal to the normal driving pulse described in Figure 21(B) and is applied to the OR gate 201 and the RS FF 181. 20

Since the output of a detecting signal is inhibited during driving by the normal pulse PD_1 which is applied to an AND gate 209 via a NOT gate 208, an output PS_1 does not appear at a terminal 169 when the normal driving pulse is applied. Since the output of the AND gate 209 appears at the terminal 169 if an

25 external alternating magnetic field is detected, other detections are inhibited. 25

Pa_0 and the normal driving pulse PD_1 are applied to an exclusive NOR gate 188: input of Pa_0 to an N-counter 187 is inhibited when PD_1 equals Pa_0 and is applied every second to the N counter 187 when PD_1 does not equal Pa_0 . When the N counter finishes counting N, an output thereof becomes H and, as a signal synchronised with PD_1 is applied to the OR gate 204, the up-down counter is counted down.

30 Since an electronic timepiece according to the present invention may have low power consumption, battery capacity can be reduced for equivalent battery life and miniaturisation of the battery can be achieved. Further, since it is difficult to stop the rotor by the application of an external alternating magnetic field, anti-magnetic characteristics are improved and specific anti-magnetic elements do not have to be provided. Consequently the present invention may have the advantages of miniaturisation, reduction of

35 thickness, reduction of cost and a high quality electronic timepiece may be produced. 35

CLAIMS

1. An electronic timepiece including: a stepping motor consisting of a stator, a drive coil and a rotor; 40 drive means for applying a pulsiform driving signal to the stepping motor; detecting means for detecting when the load on the stepping motor is such that the driving signal is incapable of causing the rotor to rotate stepwise and for detecting when the stepping motor is subjected to the influence of an external alternating magnetic field; and varying means for increasing the pulse width of the pulses of the driving signal in response to detection that either the driving signal is incapable of causing the rotor to rotate or 45 the stepping motor is subjected to the influence of an external alternating magnetic field, one or more additional driving pulses being generated to cause the rotor to rotate. 45

2. An electronic timepiece as claimed in claim 1 in which the detecting means includes a rotation detecting means for detecting that the driving signal is incapable of causing the rotor to rotate stepwise by detecting the voltage induced in the coil by oscillations of the rotor after each driving pulse has terminated.

3. An electronic timepiece as claimed in claim 1 in which the detecting means includes a magnetic field detecting means for detecting the presence of an external alternating magnetic field by detecting the voltage induced thereby in the coil. 50

4. An electronic timepiece as claimed in claim 3 in which the magnetic field detecting means includes switching means for alternately connecting a relatively low impedance element and a relatively high impedance element across the coil. 55

5. An electronic timepiece as claimed in claim 4 including comparator means for comparing the voltage produced across the relatively high impedance element with a reference voltage to produce an indication of the strength of the external magnetic field.

6. An electronic timepiece as claimed in any preceding claim in which the varying means are such that pulses with larger and larger pulse widths are applied to the rotor when the driving signal is incapable of causing the rotor to rotate until a pulse width is reached which causes the rotor to rotate. 60

7. An electronic timepiece as claimed in claim 6 including counter means which causes the varying means to produce a predetermined number of pulses of said pulse width which causes the rotor to rotate, the varying means then reducing said pulse width.

8. An electronic timepiece as claimed in any preceding claim in which the detecting means is arranged 65

43



An OR gate 204, an AND gate 205, an AND gate 206, an FF 202, an FF 203, constitute an up-down counter: an input from the AND gate 200 is for the up-counting mode and an input from the AND gate 186 is for the down-counting mode, outputs of the counter are taken from the FF 202 and the FF 203 and are Q_0 , Q_1 . The outputs of the counter are connected to a decoder 189 and the output PD_1 of the decoder is as follows:

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Since the output of a detecting signal is inhibited during driving by the normal pulse PD_1 which is applied to an AND gate 209 via a NOT gate 208, an output PS_1 does not appear at a terminal 169 when the normal driving pulse is applied. Since the output of the AND gate 209 appears at the terminal 169 if an external alternating magnetic field is detected, other detections are inhibited. 25

Pa_0 and the normal driving pulse PD_1 are applied to an exclusive NOR gate 188: input of Pa_0 to an N-counter 187 is inhibited when PD_1 equals Pa_0 and is applied every second to the N counter 187 when PD_1 does not equal Pa_0 . When the N counter finishes counting N, an output thereof becomes H and, as a signal synchronised with PD_1 is applied to the OR gate 204, the up-down counter is counted down. 30

Since an electronic timepiece according to the present invention may have low power consumption, battery capacity can be reduced for equivalent battery life and miniaturisation of the battery can be achieved. Further, since it is difficult to stop the rotor by the application of an external alternating magnetic field, anti-magnetic characteristics are improved and specific anti-magnetic elements do not have to be provided. Consequently the present invention may have the advantages of miniaturisation, reduction of thickness, reduction of cost and a high quality electronic timepiece may be produced. 35

CLAIMS

1. An electronic timepiece including: a stepping motor consisting of a stator, a drive coil and a rotor; drive means for applying a pulsiform driving signal to the stepping motor; detecting means for detecting when the load on the stepping motor is such that the driving signal is incapable of causing the rotor to rotate stepwise and for detecting when the stepping motor is subjected to the influence of an external alternating magnetic field; and varying means for increasing the pulse width of the pulses of the driving signal in response to detection that either the driving signal is incapable of causing the rotor to rotate or the stepping motor is subjected to the influence of an external alternating magnetic field, one or more additional driving pulses being generated to cause the rotor to rotate. 40 45

2. An electronic timepiece as claimed in claim 1 in which the detecting means includes a rotation detecting means for detecting that the driving signal is incapable of causing the rotor to rotate stepwise by detecting the voltage induced in the coil by oscillations of the rotor after each driving pulse has terminated. 50

3. An electronic timepiece as claimed in claim 1 in which the detecting means includes a magnetic field detecting means for detecting the presence of an external alternating magnetic field by detecting the voltage induced thereby in the coil. 55

4. An electronic timepiece as claimed in claim 3 in which the magnetic field detecting means includes switching means for alternately connecting a relatively low impedance element and a relatively high impedance element across the coil. 60

5. An electronic timepiece as claimed in claim 4 including comparator means for comparing the voltage produced across the relatively high impedance element with a reference voltage to produce an indication of the strength of the external magnetic field. 65

6. An electronic timepiece as claimed in any preceding claim in which the varying means are such that pulses with larger and larger pulse widths are applied to the rotor when the driving signal is incapable of causing the rotor to rotate until a pulse width is reached which causes the rotor to rotate. 70

7. An electronic timepiece as claimed in claim 6 including counter means which causes the varying means to produce a predetermined number of pulses of said pulse width which causes the rotor to rotate, the varying means then reducing said pulse width. 75

8. An electronic timepiece as claimed in any preceding claim in which the detecting means is arranged 80



44

to inhibit detection that the load on the stepping motor is such that the driving signal is incapable of causing the rotor to rotate stepwise when it is detected that the stepping motor is subject to the influence of an external alternating magnetic field.

9. An electronic timepiece substantially as herein described with reference to and as shown in the 5 accompanying drawings.

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