

SPECIFICATION

Improvements in or relating to stepping motor driven analog timepieces

- 5 This invention relates to stepping motor driven analog timepieces. 5
- The invention is illustrated in and explained in connection with the accompanying drawings, in which:-
- Figure 1* is a schematic representation of a known stepping motor and a known gearing arrangement through which the hands (not shown) and the calendar (not shown) of an analog timepiece are driven;
- Figure 2* is a simplified block diagram of a typical known analog timepiece having a stepping motor driven
- 10 by drive pulses which are always of the same width; 10
- Figures 5, 6 and 7* are schematic representations of a known stepping motor and are provided to assist in an understanding of the manner in which it operates;
- Figure 9* is a diagram of a movement detection circuit for detecting movement of the rotor of a motor as represented in *Figures 5 to 7*;
- 15 *Figure 12* is a diagram of another form of movement detector which operates on a different principle from that used in the movement detector of *Figure 9*; 15
- Figure 17* is a simplified block diagram of one embodiment of the invention;
- Figures 19, 20, 22, 23 and 24* are diagrams of various different parts of an embodiment as illustrated by the block diagram of *Figure 17*;
- 20 *Figures 3, 8, 10, 11, 13, 14, 15, 16 and 21* are explanatory graphical figures; and 20
- Figures 4 and 18* are explanatory pulse wave form timing charts.
- A time display mechanism such as is commonly used at present in analog display quartz timepieces is represented schematically in *Figure 1*. It includes a stepping motor having a stator 1 on which is a driving coil 7 and a rotor 6 which drives a gear train comprising gear wheels 5, 4, 3 and 2 the output from which drives
- 25 the actual display means (not shown), such as a second hand, minute hand and an hour hand, and, in many cases, a calendar device, through additional gears (not shown). 25
- Figure 2* is a simplified block diagram representation of the circuitry of a conventional electrode timepiece having a display mechanism as represented in *Figure 1*. It comprises a quartz crystal controlled time standard oscillator 10 of relatively high frequency the output of which is fed to a frequency divider 11 which
- 30 reduces the oscillator output to a convenient lower frequency, e.g. 1Hz. The reduced frequency output from 11 is fed to a pulse combining circuit 12 which, with the aid of suitably chosen other outputs taken from points in the divider 11, produces two pulse signals of (typically) 2 secs period and 7.8ms width which are dephased with respect to one another by 1 sec and are applied through inverters 13a, 13b to the driving coil 7 of the stepping motor (not otherwise shown in *Figure 2*). The coil of the stepping motor, which is of form well
- 35 known per se and has a permanently magnetised 2-pole rotor (the poles are indicated by the letters N, S in *Figure 1*), thus receives, every second, a driving pulse of 7.8ms width, successive pulses being in opposite directions. The motor is constructed in well known manner so as to rotate through 180° in the same direction in response to each successive pulse, thus stepping forward by half a revolution every second. *Figure 3* shows the wave form of current (I) in the coil against time (T) for an applied pulse. 35
- 40 The width of the driving pulses (7.8ms in the foregoing example), and the design of the motor - resistance and number of turns in its coil, dimensions of its stator and rotor, and so on - are so chosen as to ensure that the stepping motor gives enough torque to operate in a stable and reliable manner in any circumstances to be expected in practice, that is to say, when maximum load is imposed on the motor (as occurs when the calendar is being changed - an operation which usually takes up to about 6 hours in the 24) or the timepiece
- 45 is subjected to an external magnetic field, or the internal resistance of the timepieces battery becomes abnormally high due to exposure to low temperatures. Normally, for most of the time, such conditions do not apply and the motor is not subjected to maximum load but, because the driving pulse width is made large enough to ensure stable operation when such conditions do occur, the overall power consumption is undesirably high because, for most of the time, so large a pulse width is not necessary. 45
- 50 The invention seeks to provide improved timepieces of low overall power consumption. 50
- According to this invention a stepping motor analog timepiece includes means for producing correction drive pulses of predetermined width chosen to drive the motor with the torque sufficient to drive it and expected to be required at any time in which the timepiece is in operation; means for producing a plurality of normal drive pulses of predetermined different widths less than that of the correction drive pulses; a
- 55 detection circuit for detecting the rotation or non-rotation condition of the motor; a control circuit arranged, when the non-rotation condition of the motor is detected, to supply correction pulses to the motor and, when restoration of the rotational condition is detected, to supply selected normal drive pulses to the motor to continue it in rotation, said control circuit also including means for automatically reducing the normal pulse drive width to a smaller predetermined width after a predetermined time period. 55
- 60 The timepiece may include means for producing correction drive pulses of predetermined width chosen to drive the motor with the torque sufficient to drive it and expected to be required at any time in which the timepiece is in operation; means for producing a plurality of normal drive pulses of predetermined different widths less than that of the correction drive pulses; a detection circuit for detecting the rotation or non-rotation condition of the motor, said detection circuit including means for detecting voltage induced in
- 65 the driving coil of the motor by motion of the rotor thereof during a short detection pulse supplied to the 65

motor after the termination of a normal driving pulse supplied thereto; and a control circuit arrange, when the non-rotation condition of the motor occurs, to supply correction pulses to the motor to restore the rotation condition and, when the rotation condition is restored to supply selected normal drive pulses to the motor to continue it in rotation.

5 Before giving a detailed description of an embodiment of the invention, an explanation of the manner in which it operates will first be given in conjunction with Figures 4a, 4b and 4c. 5

The driving pulses for the stepping motor used in an electronic timepiece in accordance with the present invention are of two types, namely normal driving pulses which may be of any of a plurality of selectable different predetermined widths, and correction driving pulses which are wider than the widest of the 10 selectable normal drive pulses. A correction driving pulse is supplied to the motor only when it cannot be rotated by a normal driving pulse. Because the supply of a correction driving pulse to the stepping motor results from the motor being unable to be rotated by a preceding supplied normal driving pulse, the pulse width of the next normal driving pulse after the correction pulse is made wider by a predetermined amount than the normal driving pulses which were supplied to the motor before the correction pulse, and is such 15 that it can rotate the motor. 15

In order to prevent continued supply to the motor of normal driving pulses which are unnecessarily wide, the pulse width of the normal driving pulses is made smaller by a predetermined amount when the normal driving pulses supplied to the motor are able to cause it to rotate properly through a succession of steps.

Due to the foregoing operation, the pulse width of the normal driving pulse (P_1) is made the minimum 20 width required to drive the stepping motor in the load condition which obtains at any time. As result, the overall power consumption is minimised. For example, as shown in Figure 4a, the foregoing operation may cause normal driving pulses P_1 , 3.9ms wide to be followed, after a few pulses, by shorter pulses of a width of 3.4ms. Assuming that the condition of the stepping motor is such that it can be still rotated by these narrower pulses, a repetition of the above-mentioned operation will cause the normal driving pulse width of P_1 to be 25 reduced to 2.9ms after the stepping motor has been rotated a few steps by the pulses of width 3.4ms. Assuming now that, after this, the stepping motor is not able to be rotated by the 2.9ms pulses, a non-rotation condition of the rotor is detected and a correction pulse P_2 (shown as 6.8ms wide) is quickly applied to the motor and after this the width of the normal pulse P_1 is set again at 3.4ms. If, while normal drive pulses of (for example) 3.4ms width, are being supplied to the motor, it becomes, for some reason, unrotatable by 30 these pulses, the non-rotation condition of the rotor is detected and a correction pulse P_2 is quickly applied after which wider normal driving pulses, 3.9ms wide, are supplied (see Figure 4b). After a few of these pulses have been supplied, the narrower 3.4ms pulses are supplied (see Figure 4c). Thus, to sum up, the invention operates by detecting whether the motor is able to be rotated properly by the normal driving pulses the being supplied - i.e. by detecting whether it is in the rotation condition, and, upon detection of the occurrence of 35 the non-rotation condition, quickly applying a relatively wide correction pulse and then, after this, automatically setting the normal driving pulses at the required (minimum) widths to keep the motor rotating properly. 35

As will now be appreciated an essential factor in securing the automatic adjustment of the normal driving pulse width and, when necessary, the application of a correction pulse, lies in the detection of whether the motor is in the rotation or in the non-rotation condition. Although the detection of movement 40 of the rotor could be effected by means utilising an element, such as a mechanical switch or a semiconductor device, external to the motor it is very difficult to incorporate such means in the very limited space available in a timepiece such as a wrist watch. In what follows two different methods of rotor movement detection, operating on different principles, but neither requiring the provision of switching or similar elements external to the motor and actuated thereby will be set forth. As will be seen later, both methods 45 involve the use of a detecting circuit which can be incorporated on the same integrated circuit (I.C.) chip with the time standard oscillator, frequency divider, drive and other circuits which have to be provided in the circuitry of the timepiece so that an extremely compact structure, well suited to use a wrist watch, is achievable. 45

The first method utilises the fact that the wave form of the current through the motor coil in accordance 50 with the position of the rotor if the motor employed is of a type (to be desired later) which is well known and commonly used. Referring to Figure 5, which represents such a motor, 1 is the motor stator which is integrally formed and has magnetically saturable portions 17a, 17b produced by diametrically opposite notches or recesses positioned as shown and which locally reduce the stator cross section. The motor coil 7 is on a limb of the stator. The stator also has notches or recesses 18a, 18b opposite one another on a 55 diameter at an angle to that joining the notches 17a, 17b and formed in the otherwise circular hole in which the rotor 6 is positioned. The rotor is permanently magnetised to have two poles N and S. The positions of the notches 18a, 18b determine the direction of rotation when a current pulse is applied to the coil 7. Figure 5 shows the rotor position in which current is applied to the coil 7, i.e. it shows a rest position of the rotor which is that in which the diameter joining the rotor poles is approximately at right angles to the diameter in 60 which the notches 18a, 18b lie. If, when the rotor position is as shown in Figure 5, a current pulse is applied to the coil in the direction of the arrow heads shown thereon, N and S poles are produced in the stator as indicated at N and S and the rotor 6 starts to rotate clockwise due to repulsion between like stator and rotor poles. After the current pulse through the coil 7 ceases, the rotor 6 stops at a rest position at 180° to that shown in Figure 5. If, after this, a current pulse is passed through the coil 7 in the opposite direction, the rotor 65 6 executes another half revolution clockwise. 65

In a stepping motor as illustrated in Figure 5 the current wave form through the coil exhibits an initial gradually rising portion as shown in Figure 3. This is because the magnetic resistance of the magnetic circuit as viewed from the coil 7 is very low before the saturable portions 17a, 17b of the stator saturate and as a result the time constant τ of the coil and any resistance in series therewith (this, of course, necessarily includes the ohmic resistance of the coil itself) is large. The following equation substantially applied :-

$$\tau = L/R, L \neq N^2/R_m$$

$$\tau = N^2/(R \times R_m)$$

Therefore,

where, L is the inductance of the coil; N is its number of turns; R_m is the magnetic resistance; and R is the ohmic resistance in the coil circuit. When, however, the saturable portions 17a, 17b saturate, the permeability of these portions become that of air so that the magnetic resistance R_m increases, the time constant τ becomes smaller and the current suddenly rises as shown in Figure 3. Since the saturation time also depends upon the condition of magnetisation of the motor, the saturation time becomes relatively long if the current at the time the pulse is cut off is relatively large. Therefore, because the saturation time will be long after a correction pulse has been supplied to the stepping motor, a de-magnetising pulse for cancelling the foregoing effect may be supplied to the motor.

The aforesaid first method of detection of rotor movement is dependent upon a difference in time constant produced in the coil circuit, as will now be explained.

Figure 6 shows the magnetic fluxes present at a time when current starts to flow through the coil 7, and the magnetic poles of the rotor 6 are so situated that the rotor 6 can start to rotate. Magnetic flux lines 20a, 20b represent the magnetic fluxes produced from the rotor 6. In practice, there also exists a rotor flux which crosses the coil, but this is not shown. The magnetic flux lines 20a, 20b are directed as shown by the arrow heads in Figure 6. The saturable portions 17a, 17b are in most cases well short of saturation. If, in this condition, a current pulse is applied to the coil 7 in the direction indicated so as to rotate the rotor clockwise, the stator magnetic fluxes 19a, 19b produced by the coil 7 are reinforced by the rotor fluxes 20a, 20b at the saturable portions 17a, 17b and these portions rapidly saturate. After this, a magnetic flux of sufficient strength for rotation is produced in the rotor 6, but this is not shown in Figure 6. Curve 22 of Figure 8 shows the current wave form through the coil for this case.

Figure 7 illustrates the fluxes when a current pulse has just been applied to the coil in the direction indicated in the said Figure 7 (the opposite to that in Figures 5 and 6) but the rotor is in the position shown in Figures 5, 6 and 7. This would be the case if, for some reason, the rotor had not been rotated through a half turn by the previous pulse but has returned, at the end of that pulse, to its original rest position. In these circumstances the pulse, if applied as shown in Figure 7, will not rotate the rotor clockwise through a half turn for, as will be seen, the rotor and stator poles which are adjacent one another are of opposite signs (one N and the other S) and the rotor fluxes 20a and 20b oppose the stator fluxes 21a and 21b in the saturable portions 17a, 17b so that a much longer time is required to achieve saturation. The curve 23 of Figure 8 shows the current (I) - time (T) current wave form which occurs in this case. As will be apparent the situation illustrated by Figure 7 and by curve 23 of Figure 8 will be that present whenever, for any reason, an applied pulse in a direction to rotate the rotor through a half turn - e.g. a pulse applied in the situation shown by Figures 5 and 6 - fails to do so and the next pulse arrives.

As example of a rotor position detecting arrangement operating in the manner just described will not be described with the aid of Figures 9 and 10.

Referring to Figure 9 the circuitry includes detection gates 28 and 29, a detection resistor 30, a transmission gate 31 for charging a capacitor 33 and a voltage comparator 32 which are added to an otherwise conventional driving circuit, i.e. a driving inverter composed of MOS gates 24, 25, 26 and 27. First, in a normal driving pulse operation (the motor is in the rotation condition) a current pulse is passed through the coil 7 along the path indicated at 34, the coil 7 is energised, and the rotor rotates through a half revolution. When this rotation has substantially finished, a first detecting pulse is applied to the coil 7 through the path indicated at 35 for a short time (about 0.5 to 0.1 ms) and, after that, a second detecting pulse is applied to the coil 7 through the path indicated at 36. Assuming that the motor is rotatable and the applied normal driving pulse has rotated it by one step (one half revolution) the relation between the magnetic poles of the rotor and the magnetic poles of the stator at the time when the first detecting pulse is applied to the coil will be that shown in Figure 6, i.e. that in which the rotor is in the position to be rotated through the next step by the next driving pulse. The current wave form during the pulse which has produced the half revolution is as shown by curve 22 of Figure 8. When the second detecting pulse is applied to the coil, the position of the rotor is practically the same as it was in the case of the application of the first detection pulse, for the width of a detection pulse is so short and the resistor 30 in series with the coil 7 is of sufficiently large resistance that the rotor cannot be rotated by a detection pulse. It will be seen, from the direction of the paths 35 and 36 through the coil, that the positional relation between the magnetic poles of the rotor and the magnetic poles of the stator, when the second detection pulse is applied, becomes the relation shown in Figure 7 and the rising portion of current curve through the coil exhibits a slow rising time like that of the curve 23 in Figure 8. However, since the detection resistor 30 is connected in series with the coil at the time of application of the detection pulse, the current wave form shape for the detection pulse does not coincide with the shape in Figure 8 except for the feature of the initial rising portion. Accordingly, if the motor is in the rotation

condition, the potential V_{s1} produced across resistor 30 by the first detection pulse rises to a much higher value than the potential V_{s2} produced across said resistor by the second detection pulse. This is shown by Figure 10a, which is drawn for the assumed case that the detection pulses are each 1ms wide, the second occurring 1ms after the first.

5 Now assume that an applied normal driving pulse, which is in a direction to rotate the rotor through 180°, has been for some reason (e.g. load on the motor) unable to do so and the rotor has returned, at the end of the pulse, to its original position. The positional relation between the magnetic poles of the rotor and the magnetic poles of the stator at the time of the application of the first detection pulse and the second detection pulse will be the opposite to that which would have applied had the rotor executed a half revolution. Accordingly, as shown by Figure 10b, the voltage V_{s2} developed across the detection resistor 30 by the second detection pulse will be substantially larger than the potential V_{s1} developed by the first detection pulse. 10

It is therefore possible to detect whether the rotor has performed a normal step of 180° as a result of applying a normal driving pulse by comparing the value of V_{s1} with the value of V_{s2} . In a practical case, the difference of potential between V_{s1} and V_{s2} may easily be made about 0.4V and such a difference is easily detectable. In Figure 9 such detection is effected by arranging the transmission gate 31 to be ON at the time of the first detecting pulse so that the capacitor 33 is charged substantially to V_{s1} by the potential V_{s1} , and then comparing, by means of comparator 32, the potential V_{s1} stored in the capacitor 33 with the potential V_{s2} produced across the detection resistor 30 when the second detection pulse arrives. In this way it is easy to 15 detect whether V_{s1} or V_{s2} is the larger voltage. 20

This completes the explanation of the principle of the first method of rotor movement detection.

An explanation of the principle of the second method of rotor movement detection will now be given.

Figure 11a shows the relation between the angle of rotation of the rotor and the voltage wave form produced across the coil and developed across a high value detecting resistor (such as a resistor of the order of 10K Ω) which is connected across the said coil after the application of a driving pulse thereto. θ is the angle 25 between the horizontal axis of the stator and the diameter in which the magnetic poles of the rotor lie. 25

During the time T_1 which is that in which the driving pulse is applied to the coil, the high resistance detection resistor is not connected in circuit so that no produced voltage wave form appears across it. The voltage produced across the resistor during time T_2 is the voltage which is induced in the coil during its 30 rotation and any oscillation movement of the rotor occurring after it has been driven. The actual voltage wave form produced during time T_2 will depend upon and change in accordance with the load condition and the driving condition of the motor. Accordingly it is possible to detect movement of the stepping motor by detecting such changes in the induced voltage. 30

Figure 12 shows an example of a detection arrangement operating on this principle. The gate 24, 25, 26, 27, 28 and 29, the detection resistor 30 and the coil 7 are connected in much the same way as in the arrangement of Figure 9, but the junction point of the detection resistor 30 with the elements 28 and 29 is connected to the input terminal of a voltage detector 40 having a predetermined threshold level. When a normal driving pulse is applied to the coil through the path indicated at 41, the coil is energised, thereby driving the rotor. After that, during the movement of the rotor, a switching action is intermittently accomplished between a state in which 40 both terminals of the coil are grounded through a path indicated at 42, so that the coil is short circuited on itself, and a state indicated by path 43 in which the coil is in a closed loop including also the high value detection resistor 30. The effect of the intermittent switching action will be explained later. At first, to simplify explanation, the condition that the closed loop including the detection resistor 30 is formed at a time when the rotor has just been driven will be assumed and explained. Figure 11 shows the wave form of voltage 45 produced across the detection resistor 30 in such a condition. In Figure 11 the stepping motor is in approximately the no load condition. Figure 13a shows by the curves *a* and *b* respectively the relations between angle of rotor rotation and the produced voltage wave forms under maximum load condition and over-load condition, θ being the angle between the horizontal axis of the stator and the diameter in which the rotor magnetic poles lie. Since the rotational speed of the rotor in the maximum load condition (curves *a* of Figure 13) is comparatively slow and the magnetic of the rotor oscillations after a half revolution step is small, the wave form of the produced voltage does not exhibit much irregularity, i.e. undulation. In the over-load condition *b*, however, a peak voltage is produced in the negative direction when the rotor returns back to its original position. However, the wave form of the produced voltage exhibits in general little undulation except for the above-mentioned negative direction peak voltage. 50

Clearly there are many ways in which the wave form of the produced voltage could be used to detect whether the motor is in the rotation or in the non-rotation condition, but a very simple and reliable way of achieving detection is by detecting the existence of the peak "P" (Figure 11) which occurs near the middle of the time T_2 in Figure 11. In other words, by detecting whether or not the potential across the detection resistor 30 exceeds a predetermined level within a predetermined time in which such a peak "P" should occur after the termination of the application of a driving pulse, the rotation or non-rotation state of the rotor 60 can be determined. 60

With this method, the rotor is considered to be in the non-rotatable condition despite the fact that the rotor does rotate in the condition of maximum load (as shown in Figure 13a). This however does not matter since the action in question errs on the side of safety (as will be seen later) when the principle is 65 utilised in a correction driving system as employed in carrying out the present invention. In fact, as again will 65

be seen later, the only result of such operation is to produce more correction pulses of the same polarity than are actually necessary and over-rotating operation of the rotor never occurs.

Figure 14 shows the wave forms of the produced voltage in the coil after driving by normal driving pulses P_1, P_2, P_3, P_4 having various different pulse widths. It will be seen from this figure that if the pulse width of a normal driving pulse is greater than a predetermined width, the peak value, in the produced (induced) voltage wave form becomes lower as shown by P_4 in spite of the condition being the no-load and normal rotation condition. Figure 15 serves to explain this clearly. In Figure 15 the abscissa axis represents the pulse width of the normal driving pulse and the ordinate axis represents the peak value of the produced voltage. Curve 45 is the curve for the condition that there is established a closed loop connecting the detection resistor in series with the coil and curve 46 is the curve for the condition that the detection resistor is intermittently short circuited on itself as will be described hereinafter.

The effect obtained by connecting the detection resistor in series with the coil after the application of a driving pulse will now be explained. In a conventional driving circuit as shown in Figure 2, in which the driving operation is achieved by means including two inverters, the ends of the motor coil are in effect substantially shorted together by a resistor of low value provided by the driver circuit including the inverters when the motor is in the non-operating condition. Therefore, the current caused by voltage developed or induced in the coil flows into a short circuiting path as indicated by path 42 in Figure 12. This current flow causes Joule heating in the resistance presented by the coil and driving transistors, and, as a result, there is a damping effect on rotor movement. When, however, a closed loop as indicated by the path 43 in Figure 12 is formed in order to detect the produced voltage, the detection resistor 30 of high value is in addition connected in series in the driving circuit and accordingly the current flowing through the damping circuit including resistor 30 is much smaller.

Accordingly a switching action between the two states - one when the coil is short circuited on itself and the other when the high value detection resistor is included in circuit - at a time when the rotor is being subjected to a braking action by damping will cause corresponding changes in the current in the coil circuit. However, because the inductance of the motor coil is large, the circuit cannot respond quickly to the changed in current. As a result, the circuit shows the response delay characteristics with a time constant τ depending of the value of the inductance L of the coil and the resistance $R_d (= R + R_{30})$ included in the braking or damping circuit, where R is the ohmic resistance of the coil and R_{30} is the resistance of the resistor 30. Obviously, when the coil is short circuited on itself, R_{30} in the expression $R + R_{30}$ becomes zero. The arrangement is made such that the value of the voltage produced across the detection resistor 30 during the time of intermittent switching is approximately zero volts when the braking circuit is constituted by the path 42 (Figure 12) and, at the instant of switching to the path 43, the coil 7 operates temporarily to maintain the flow of the current through the braking (damping) circuit and, in consequence, a relatively high value of voltage is developed across the detection resistor 30 at that instant. After this, the high value of voltage reduces in dependence on the time constant τ . To give a practical figure the value of R_{30} may be chosen between $3K\Omega$ and $200K\Omega$.

Figure 16 provides an example of the wave form of voltage produced across the detection resistor 30 at this time. It is a feature of the method that increase of the voltage produced by the motor at the time of braking action is possible only by changing the value of the resistor in the braking circuit of the motor, and that the maximum value of the peak voltage reaches a value beyond the voltage (about 1.5V) of the power supply to the driving circuit only when the detection resistor is intermittently connected in circuit (see curve 46 in Figure 15) whereas the maximum value of the peak voltage is only about 0.8V, at the most, when the produced voltage is continuously detected (see curve 45 of Figure 15). Consequently, it is very easy to detect such a voltage. Also, as will be seen from Figure 15, if the pulse width of the normal driving pulse is increased to some degree, the undulations of the produced voltage become less.

Detecting circuits for detecting the rotational condition of the motor and operating on two different principles having now been described, the obtaining of automatic increase and decrease of the pulse width of the normal driving pulses to suit the motor condition existing at any time will now be described with the aid of Figure 17 which is a simplified block diagram.

Referring to Figure 17, block 90 represents a time standard oscillator including a relatively high frequency quartz vibrator having a resonant frequency of (for example) 32,768Hz. The output from oscillator 90 is fed to a frequency divider 91 consisting of fifteen cascaded flip-flop stages and producing a 1Hz output timing signal.

Terminal 97 is a reset input terminal of the watch. All the frequency dividing stages in the divider 91 can be reset by the application of a suitable reset signal to terminal 97. 92 is a wave form combining circuit, by means of which desired different output pulses can be obtained by combination of selected signals taken from selected flip-flop stages in the divider 91. The combinations are achieved by NAND gates and NOR gates included in the combining circuit 92. The different wave forms obtainable at the output terminals P_0 to P_5 of the circuit 92 are shown by the lines P_0 to P_5 respectively of the timing chart shown in Figure 18. Since wave form combining logic circuits for use in the combining circuit 92 for producing the results shown in Figure 18 are well known per se and require no detailed description to those skilled in the art, no such detailed description will be given here.

Block 94 represents a driving circuit; 95 represents a detecting circuit; 93 represents a control circuit; and

96 represents a stepping motor driving the time display (not shown) of the watch. Figure 19 shows the circuitry in the driving and detecting circuits 94 and 95. The control circuit 93 has output terminals T_1 , T_2 , T_3 ; the driving circuit 94 has output terminals from which the motor is supplied and also a terminal T_0 supplying input to the detecting circuit 95. Only when the terminal T_1 is logic "High" ("H") is one input of the stepping motor 96 "H" and the other "L" (logic "Low") so that current flows into said stepping motor 96.

Referring to Figure 19, block 100 is a flip-flop (FF) to the input terminal C of which output from terminal P_0 is applied. When the terminal T_2 becomes "H", the Q and $\bar{Q}$ outputs from flip-flop 100 applied to Ex-OR gates 121 and 122 appear inverted at the outputs of these gates. By this circuit, as will be better understood later, the direction of the current flowing through the motor can be reversed.

In the watch now being described, if the motor is, for any reason, in the non-rotation condition, so that it cannot be rotated by the application of the normal driving pulse, it is driven by a wide correction pulse P_2 of 7.8ms width (see Figure 18) produced at P_2 (Figure 17) after which a pulse P_3 , 1ms wide, is fed to the motor in a direction opposite to that of the preceding pulse P_2 . If this were not done the magnetic saturation time of the saturable portions of the integrally formed stator of the motor at the time of the application of the next driving pulse would be increased when a correction driving operation is carried out by using a correction pulse P_2 and the effective pulse width would therefore be reduced. However, because the opposite pulse P_3 is applied to the coil of the stepping motor 96 when the correction driving operation is carried out by the application of a pulse P_2 , the stator is magnetised in a direction in accordance with the direction of the next driving pulse, and the time required for saturation of the saturable portions is thus reduced by the pulse P_3 .

The output T_3 of the control circuit 93 of Figure 17 is connected to the input terminal Y_3 of Figure 19 and the operation for detecting the rotational condition is carried out by using the detection pulse in accordance with the previously mentioned method in which a detection voltage produced after the rotation of the rotor is utilised.

When a pulse P_0 having a period of 1-second is applied to the FF 100 it produces an output frequency of $\frac{1}{2}$ Hz, the Q output being applied to the Ex-OR gate 121 and, the $\bar{Q}$ output being applied to the Ex-OR gate 122. The output from the control circuit terminal T_2 is applied to the remaining input terminals of the Ex-OR gates 121 and 122. The output of the Ex-OR gate 121 is applied to one input of each of two NOR gates 102 and 103, and the output of the Ex-OR gate 122 is applied to one input of each of two NOR gates 104 and 105.

The output signal of a NOT gate 101 is applied to the remaining inputs of NOR gates 103 and 104 and the output at terminal T_3 of the control circuit 93 is applied to the remaining inputs of NOR gates 103 and 104 and the output at terminal T_3 of the control circuit 93 is applied to the remaining inputs of NOR gates 102 and 105 through a NOT gate 120.

The output of the NOR gate 102 is connected to one input of a NOR gate 106 and also to the gate of a N-type MOS FET 115, while the output of the NOR gate 103 is connected to the remaining input of the NOR gate 106 and also, through a NOT gate 123, to the gate of a P-type MOS FET 113 in the drive circuit of the stepping motor (not shown in Figure 19).

The output of the NOR gate 104 is connected to one input of a NOR gate 107 and also, through a NOT gate 124, to the gate of a P-type MOS FET 118 in the drive circuit of the stepping motor, while the output of the NOR gate 105 is connected to the remaining input of the NOR gate 107 and also to the gate of an N-type MOS FET 116 in the motor drive circuit. The output of the NOR gate 106 is connected to the gate of an N-type MOS FET 114 in the motor drive circuit while the output of NOR gate 107 is connected to the gate of an N-type MOS FET 119 in said motor drive circuit.

The positive terminal V_{DD} of a power supply source (not shown) is connected to the common source electrode connection of the P-type MOS FETs 113 and 118; the common source connection of the N-type MOS FETs 114 and 119 is grounded; the drain electrodes of the MOS FETs 113 and 114 are connected together; the drain electrodes of the MOS FETs 118 and 119 are connected together; and the common source electrode connection of the MOS FETs 115 and 116 is connected to earth through a resistor 117. The coil of the motor (not shown) is connected between the common drain connection of the MOS FETs 113, 114, 115 and the common drain connections of the MOS FETs 118, 119, 116 at the terminals marked "MOTOR OUT".

The junction point T_0 of the source electrodes of the MOS FETs 115, 116 with the resistor 117 is connected to the positive input terminal of a comparator 110.

The signal appearing at the junction point T_0 will be a signal representative of the rotation state of the motor (i.e. whether the motor is rotatable or not) and the circuit comprising the resistors 108, 109, the comparator 110 and the N-type MOS FET 111 constitute the rotation detection circuit (95 of Figure 17). If the signal at the junction point T_0 is such that it can be detected by using the threshold voltage of CMOS gate circuit, a CMOS NOT gate may be used for the purpose. However, in the case illustrated, in which the comparator 110 is employed, the negative input terminal of the comparator is connected to the junction point of two resistors 108, 109. The other end of resistor 108 is connected to the supply terminal V_{DD} and the other end of resistor 109 is connected to the drain electrode of an N-type MOS FET 111 the source electrode of which is earthed and which is used as a switch for inhibiting the detecting operation when an inhibiting potential is applied from terminal T_3 to its gate. The ground terminal of the comparator 110 is also connected to the drain electrode of the N-type MOS FET 111. The output signal from the comparator 110 constitutes a signal T_4 and appears at the terminal referenced 112 and T_4 . This output signal is applied to the control circuit 93 as shown in Figure 17.

Figure 20a shows the circuitry of a preferred form for the comparator 110 which is shown again in block

diagram in Figure 20b.

Referring to Figures 20a and 20b, 164 is the "+" input terminal of the comparator, 165 is its "-" input terminal, 166 is its output terminal and T_3 is its inhibiting or enabling terminal.

The functions of the comparator are shown by Table 1 below:-

Table 1			
"+" input terminal 164	"-" input terminal 165	enable terminal T_3	output terminal 166
-	-	0	-
$V^+ > V^-$		1	"H"
$V^+ < V^-$		1	"L"

The supply source terminal V_{DD} is connected to the common source electrode connection of two P-type MOS FETs 160 and 162. The gate electrode of MOS FET 160 is connected to the drain electrode thereof and also to the gate electrode of the P-type MOS FET 162 and to the drain electrode of the P-type MOS FET 161. The gate electrode of MOS FET 161 is connected to terminal 164 source thereof if connected to the drain of MOS FET 111.

The drain electrode of the P-type MOS FET 162 is connected to the drain electrode of an N-type MOS FET 163 and also to the output terminal 166.

The gate electrode of the N-type MOS FET 163 is connected to the terminal 165 and the source electrode thereof is connected to the drain electrode of the N-type MOS FET 111 and also to the source electrode of the N-type MOS FET 161.

The source electrode of MOS FET 111 is grounded and the gate electrode is connected to the terminal T_3 .

The electrical characteristics of the N-type MOS FETs 161 and 163 are alike and the electrical characteristics of the P-type MOS FETs 160 and 162 are alike.

When the enable terminal P_3 is "L", the N-type MOS FET 111 is OFF, and the comparator cannot operate.

When the terminal T_3 is "H", the N-type MOS FET 111 goes ON, and the comparator is operable. The threshold voltage for the detection signal is determined by the values of the resistors 108 and 109 acting as a potentiometer in the circuit between V_{DD} and earth. If current always flowed through this circuit there would be unnecessary consumption of power. Therefore, as shown, the circuitry is made such that current flows only when the pulse T_3 becomes "H" and the MOS FET 111 is switched ON. In this way a material economy in power consumption is achieved.

When a certain input voltage V_1 is applied to the terminal 164, the potential and the current appearing at the junction point 168 are as shown in Figure 21a in which V_{168} is the potential at point 168, and I_{168} is the current flowing at this point, V_{GS} being the gate source voltage of 161.

Since the potential V_{168} is applied to the gate electrode of the P-type MOS FET 162, the saturation current thereof is equal to the current I_{168} .

This condition is shown by the characteristic 162 in Figure 21b.

On the other hand, assuming that the voltage applied to the terminal 165 is V_2 , the saturation current of the N-type MOS FET 163 becomes larger than I_{168} if V_2 is larger than V_1 .

Consequently, the potential V_{166} at the output terminal 166 becomes of "L" level approximately.

This condition is shown by the operational point X in Figure 21b.

However, if V_1 is larger than V_2 , the output V_{166} becomes of "H" level. This condition is shown by the point Y in Figure 21b.

The foregoing explains how achievement of the functions set out in Table 1 is obtained.

Figure 22 shows the circuitry of a preferred form for the control circuit 93 of Figure 17.

The output signal T_4 from the detecting circuit 95 is applied to the set-input terminal S of an SR-FF 140. The signal P_1 from the wave form combining circuit 92 is applied to the reset terminal R of FF 140 and also to the reset terminal R of an SR-FF 158 through a NOT gate 157 and in addition to the clock input terminal C of a binary counter 143, and to one input terminal of a three-input AND gate 156. The output signal P_2 from the wave form combining circuit 92 is applied to one input of an AND gate 141 to the other input of which the $\bar{Q}$ output of FF 140 is applied. The output P_3 from the wave form combining circuit 92 is applied to one input of an AND gate 142 to the other input of which the $\bar{Q}$ output of the FF 140 is applied. The output from gate 142 is applied to terminal T_2 of the driving circuit 94. The output P_3 from the wave form combining circuit is applied to one input of an AND gate 159 to the other input of which the $\bar{Q}$ output of the FF 140 is applied. The output from gate 159 is applied to terminal T_3 of the driving circuit 94.

In this embodiment, the binary counter 143 consists of four flip-flop stages Q_1, Q_2, Q_3, Q_4 , the output signals from which are applied each to one input of a 4-input AND gate 144 the output from which is applied to one input of an OR gate 145 the other input of which receives the output from AND gate 142. The $\bar{Q}$ output from FF 140 is applied to one input of an AND gate 146 to the other input of which the output of a NAND gate 146 is applied to the other input of which the output of a NAND gate 147 is applied. The output of the AND gate 146 is

applied to the U/D input (up/down control input) of an up/down counter 148 having three stages Q_1 , Q_2 , Q_3 and the output of the OR gate 145 is applied to the clock input C of this counter. The outputs from the stages Q_1 , Q_2 and Q_3 of counter 148 are respectively applied to the three inputs of the AND gate 147, and also to one input of each of three Ex-OR gates 150, 151 and 152 respectively. The outputs P_1 and P_4 of the wave form combining circuit 92 and the $\bar{Q}$ output of the SR-FF 158 are respectively applied to the three inputs of AND gate 156. The output of AND gate 156 is applied to the clock input C, and the $\bar{Q}$ output of the RS-FF 158 is applied to the reset input R of a binary counter 149 which consists of three flip-flop stages Q_1 , Q_2 and Q_3 , the outputs from which are respectively applied to the inputs of a three-input OR gate 154, and also to the remaining inputs of the Ex-OR gates 150, 151 and 152, respectively. The outputs of the Ex-OR gates 150, 151 and 152 are applied to the respective inputs of a three-input OR gate 153 the output from which is applied to the set input S of the SR-FF 158. The output of the AND gate 141, the output of the AND gate 142, the output of the OR gate 154 and the output P_6 of the wave form combining circuit 92 are respectively applied to the inputs of a four-input OR gate 155, the output of which is applied to the terminal T_1 of the driving circuit.

The operation is as follows.

15 The SR-FF 140 is set by the application of the detection signal T_4 , when the rotor is rotated, its $\bar{Q}$ output becomes "L" and the outputs of the AND gates 141, 142, 146 and 159 all become "L" and the outputs of the AND gates 141, 142, 146 and 159 becomes "L" at the moment the rotation is detected, and after this, the detection circuit is inhibited. The up/down counter 148 operates as an up counter when its U/D input is "H" and as a down counter when its U/D input is "L". It therefore acts as a down counter when the rotor is rotating.

20 At this time, since the output P_1 from the wave form combining circuit 92 is applied to the clock input C of the binary counter 143 every second, and this binary counter has four stages, the output of the AND gate 144 becomes "H" every sixteen seconds. This output is applied to the clock input C of the up/down counter 148 through the OR gate 145, and the count content in said up/down counter 148 is reduced by one every sixteen seconds.

25 The output P_4 of the wave form combining circuit 92 is (in the present embodiment) a signal with a frequency of 2048Hz and a period of about 0.5ms. This output is applied to the clock input C of the three stage binary counter 149 through the AND gate 156 only when the output P_1 of the wave form combining circuit 92 is "H". The Ex-OR gates 150, 151 and 152 operate to check whether output from the binary counter 149 is coincident with output from the up/down counter 148 and, when they coincide in value, all the outputs from the Ex-OR gates become "L" and the output of the NOR gate 153 becomes "H". Therefore, the SR-FF 158 is reset, its Q output becomes "H" and the binary counter 149 is reset. As a result, the output of the OR gate 154 becomes "H", the time width of its output being equal to the value of the product of the number of counts in the up/down counter 148 and time of 0.5ms.

35 On the other hand, if the output T_4 of the detecting circuit 95 does not produce an "H" signal within the time for a detection, as will be the case if the rotor could not be rotated by the application of a first normal driving pulse thereto, the Q output of the SR-FF 140 remains "H". As a result, the output P_2 from the wave form combining circuit 92 appears as it is at the output of the OR gate 155 and this output causes the motor to execute a correction drive. The output P_3 of the wave form combining circuit 92 is derived from the output of the AND gate 142 as the signal T_2 is derived from the output of the AND gate 142 as the signal T_2 applied to the driving circuit 94. At this time, since the circuit 94 controls the current direction in such a way that current flows in the motor coil in a direction opposite to the direction of current flow in the condition of the correction driving, and at the same time the signal from the output T_1 of the OR gate 155 is applied to the driving circuit 94, the result is to tend to eliminate residual magnetism effects in the stepping motor and facilitate the attainment of the required magnetic saturation of the saturable portions of the motor stator.

45 Since the $\bar{Q}$ output of the RS-FF 140 is "H", the output of the AND gate 146 becomes "H", the U/D input of the up/down counter 148 becomes "H", the said counter is set in the up counting mode, and the output P_3 if the wave form combining circuit 92 is applied to the clock input C of the up/down counter 148 through the AND gate 142 and the OR gate 145. As a result, the count content in the up/down counter 148 becomes +1, and the length of the next driving pulse produced becomes larger by 0.5ms. If all the Q_1 , Q_2 and Q_3 outputs of the flip-flops in the up/down counter 148 were "H", the contents in the counter would be "L" at the time of application of the up input. To inhibit this condition, the output of the AND gate 146 becomes "H" when all the inputs of the NAND gate 147 become "H", and the up/down counter 148 is operated as a down counter. As a result, the condition that all the contents of the counter become "L" is inhibited.

55 It is the role of the output P_6 of the wave form combining circuit to decide the minimum pulse width of a normal driving pulse. This is because considerable energy would be lost until the motor was driven by a pulse having a constant width if the pulse width were arranged to increase from 0ms. Therefore a minimum pulse width (in this embodiment 1.9ms) for the normal pulses is set.

The count contents of the up/down counter 148 are not reset even if the frequency dividing circuit 91 is reset and the pulse width of the driving pulse is started from the value of the pulse width which existed before a reset operation even if the reset condition is released.

60 When the pulse width of a normal driving pulse for the stepping motor is too short for rotating it, it is possible to rotate the stepping motor by the pulse width of that driving pulse. However, because the output signal T_4 from the detecting circuit is "L", the Q output of the SR-FF 140 becomes "H" and the output signal P_2 from the wave form combining circuit 92 is applied to the stepping motor 96 as a correction driving pulse.

34

The pulse width of the correction driving pulse is set at a value sufficient to produce a torque big enough to overcome the worst condition expected to be encountered in practice. In the embodiment the correction pulse width is set at 7.8 ms. Since the up/down counter 148 acts as an up counter when the output P_3 of the wave form combining circuit 92 is applied to its up/down control terminal the count becomes +1. Therefore, if the pulse width of the driving pulse developed after one second is 1.9ms, the pulse width of the normal driving pulse developed after two seconds becomes equal to the total pulse width of the output $T_1 = 1.9\text{ms}$ from the wave form combining circuit plus 0.5ms. In other words the driving pulse is given a width of 2.4ms. If, even then, the motor is not rotatable by a pulse of this width, its driving is assured by the application of a correction driving pulse with a width of 7.8ms.

In practice a correction pulse width of 7.8ms is adequate for ensuring driving the stepping motor in the worst practical conditions i.e. when the load imposed by the gear train it drives becomes large during a period of calendar changing, and/or if the timepiece is subjected to external magnetic fields, or the internal resistance of the timepiece battery increases because of subjection to low ambient temperatures, and/or if the battery is approaching the end of its useful life.

So far the description has set out what happens to the normal drive pulses up to the time when the count content of the up/down counter 148 becomes +1. If, after this, the count of counter 148 is set at 2 by the output T_3 of the wave form combining circuit 92, the length of the normal driving pulse developed after three seconds becomes 2.9ms. If the motor could not be rotated by the application of a pulse of this width, a sequence of operations as described above is repeated. As a result, it is ensured that driving of the motor is effected by normal driving pulses of the minimum pulse width necessary for rotating it. When the count content of the binary counter 143 becomes 16, the output of the AND gate 144 becomes "H" and the contents of the up/down counter 148 becomes -1. As a result, if (for example) the normal driving operation is being carried out by using a pulse having a width of 3.4ms, the next normal driving pulse will become a pulse having a width of 2.9ms. So long as a normal drive pulse having a width of 2.9ms remains the minimum width normal pulse for rotating the motor it continues to be rotated by the application of these pulses. If, however, for any reason, the motor becomes non-rotation by these pulses, this non-rotation condition is detected, the rotor is rotated by the application of a correction driving pulse, 1 is added to the count contents of the up/down counter 148 and the length of the normal driving becomes 3.4ms again.

In a timepiece having a calendar mechanism, the load on the motor is very substantially increased during the time - up to about six hours each day - which is taken to change the calendar display. During this time the invention will automatically adjust the width of the normal driving pulses (also, as and when necessary providing wide correction pulses) the normal drive pulses being (for example) 3.4ms, 3.9ms, 4.4ms at different times to suit the differing loads on the motor. After a normal drive pulse which has been extended in width to meet the load has been applied for 16 seconds it is shortened by 0.5ms in accordance with the above described operations and, as a result, the motor is driven by the application of normal driving pulses which are automatically adjusted to be of the minimum pulse width it is subjected at different times. In this way the great advantage of minimum power consumption in the motor is achieved.

In the particular embodiment described since the binary counter 143 consists of four stages of flip-flops, driving pulses and the correction pulses are produced at the same time every sixteen seconds. If still greater economy of power consumption is required, the rate at which normal driving pulses and correction driving pulses are at the same time produced within one second can be reduced by further increasing the number of stages of the binary counter 143.

However, if the number of stages of the counter is excessively increased, it takes a long time for the width of the driving pulse to return to the original width when the load becomes small after the pulse width of the driving pulse has been increased to meet a large load. Thus, if the number of stages in the counter is made excessively large, increase in the number of stages becomes of no advantage. To give a practical figure the number of stages in the counter may be chosen between 3 and 7 inclusive so that the number of normal drive pulses supplied continuously to the motor before a reduction of pulse width occurs will be chosen between 8 (for 3 stages) and 128 (for 7 stages). Results experimentally obtained with a watch made in accordance with the described embodiment of the present invention will now be given.

The watch experimentally tested was a man's analog wrist watch including a calendar mechanism with a data display and a day of the week display. Its driving stepping motor has a rotor of a diameter of 1.25mm and a thickness of 0.5mm. The thickness of the gap between rotor and stator was 0.325mm and the coil had an ohmic resistance of $3K\Omega$ with 10000 turns.

Table 2 shows the results obtained when the stepping motor was driven by pulses of different widths, the output torque being measured at the minute hand and the pulse generating ratio P_1 and P_2 being measured by operating the watch for a day.

When 64 pulses P_1 were continuously applied to the stepping motor, the pulse width was made shorter by one step of 0.5ms.



Table 2

		Pulse Width	Current	Torque	Pulse Generating Ratio	
5		2.4msec	0.563 μ A	0.38gcm	87.0%	5
		2.9msec	0.647 μ A	0.82gcm	10.0%	
10	P ₁	3.4msec	0.708 μ A	1.26gcm	2.8%	10
		3.9msec	0.759 μ A	1.44gcm	0.2%	
15		4.4msec	0.816 μ A	1.80gcm	0%	15
	P ₂	6.8msec	1.518 μ A	2.76gcm	0.2%	

The current average over a day is obtained by taking the total of the product of the pulse generating ratio into the current as given in Table 2. As will be seen the current average is about 0.58 μ A.

The stepping motor was designed so as to be able to take driving pulse widths up to a little more than 6.8msec, and, as will be seen from Table 2, its average current consumption when continuously so driven was 1.518 μ A. By automatically varying the pulse width in accordance with this invention, the average current consumption was brought down to about 0.58 μ A - a saving of about 62%. This is obviously a very great improvement.

Figure 23 shows a modification of Figure 19 for the driving and detecting circuits 94 and 95 of Figure 17. In Figure 23 one terminal of the stepping motor coil (not shown) is connected to the drain of the switching NMOS FET 115 via a detection resistor 117a, and its other terminal is connected to the drain of the switching NMOS FET 116 via a detection resistor 117b. The respective terminals of the stepping motor coil are also connected to the positive inputs of comparators 110a and 110b, so that a detection signal produced in the coil of the stepping motor can be directly and accurately detected.

The outputs of the comparators 110a and 110b are of a digital nature and are applied to the respective inputs of an OR gate 126 whose output provides, at terminal 112, the T₄ signal which is applied to terminal T₄ of Figure 22.

In Figures 19 and 23 the voltage applied to the negative input of the voltage comparator 110 (in the case of Figure 19) or to the negative terminals of the comparators 110a 110b (in the case of Figure 23) will change with change in the power supply voltage V_{DD}. If, however, the voltage applied to the potentiometer consisting of the resistors 108 and 109 is arranged to be constant and independent of the power supply voltage, it is possible to detect the rotation and non-rotation states of the motor under constant detection conditions so that the operation of the detection circuit is greatly stabilised.

Figure 24 shows one form of constant voltage producing circuit which can be used for this purpose. In Figure 24 the source electrode of a PMOS FET 170 is connected to the positive terminal V_{DD} of the power supply source and its gate and drain electrodes are respectively connected to the gate and drain electrodes of an NMOS FET 171, the common gate connection and the common drain connection being connected together and the source electrode of 171 being connected to the negative terminal (earth) of the power through a resistor 172. The output voltage V₀ of the circuit is obtained at the terminals shown from between the source electrodes of the MOS FETs 170 and 171.

If the threshold voltage of PMOS FET is V_{TP} the K factor thereof is K_P, the threshold voltage of NMOS FET is V_{TN}, the K factor thereof is K_N, and the value of the resistor 172 is R Ω , we may write :-

$$V_0 = V_{TN} + V_{TP} + \sqrt{V_{DD}R_{KP}} + \sqrt{V_{DD}R_{KN}}$$

Therefore, if R is larger than V_{DD}/K_P and V_{DD}/K_N , V₀ is not changed even if V_{DD} changes. In a practical experimentally tested case the resistor 172 was 500K Ω and V₀ was about 1.2V.

As will now be appreciated, the illustrated embodiment has the considerable advantage that, since the constituent elements in its circuitry can be embodied in a MOS integrated circuit (IC) construction it can be manufactured relatively cheaply and lends itself admirably to miniaturisation making it highly suitable for use in wrist watches which are usually required to be of small size and also thin. Moreover, the stepping motor used may be of conventional design there being no need to provide a specially designed motor. Of course the main advantage of the invention, which is that of consumed power economy, means that a battery of given capacity and size will have a very substantially increased useful life, or alternatively, that a smaller battery can be used than would be the case if the motor was always driven by pulses of the same constant width chosen to provide reliable working in the worst loading and other conditions to which it is

36

expected to be subjected.

Although in the embodiment described and illustrated the stepping motor has been assumed to be the well known stepping motor having an integrally formed stator, and a two-pole permanently magnetised rotor, the invention is not limited to the use of such a motor and other known stepping motors, including those having stators comprising two body parts, can be used.

Attention is directed to our Specification No. 81/32187 Ser No..., which was divided out of the present specification.

CLAIMS

1. A stepping motor analog timepiece including means for producing correction driving pulses of predetermined width chosen to drive the motor with the torque sufficient to drive it and expected to be required at any time in which the timepiece is in operation; means for producing a plurality of normal driving pulses of predetermined different widths less than that of the correction drive pulses; a detection circuit for detecting the rotation or non-rotation condition of the motor; a control circuit arranged, when the non-rotation condition of the motor is detected, to supply correction pulses to the motor and, when restoration of the rotation condition is made, to supply selected normal driving pulses to the motor to continue it in rotation, said control circuit also including means for automatically reducing the normal pulse drive width to a smaller predetermined width after a predetermined time period.
2. A stepping motor analog timepiece including means for producing correction driving pulses of predetermined width chosen to drive the motor with the torque sufficient to drive it and expected to be required at any time in which the timepiece is in operation; means for producing a plurality of normal driving pulses of predetermined different widths less than that of the correction driving pulses; a detection circuit for detecting the rotation or non-rotation condition of the motor, said detection circuit including means for detecting voltage induced in the driving coil of the motor by motion of the rotor thereof during a short detection pulse supplied to the motor after the termination of a normal driving pulse supplied thereto; and a control circuit arranged, when the non-rotation condition of the motor occurs, to supply correction pulses to the motor to restore the rotation condition and, when the rotation condition is restored, to supply selected normal driving pulses to the motor to continue it in rotation.
3. A timepiece as claimed in claim 1, or 2 wherein the normal driving pulses range in width from a predetermined smallest width to a predetermined largest width in predetermined steps of width.
4. A timepiece as claimed in claim 3 wherein the steps are steps of 0.5 ms.
5. A timepiece as claimed in claim 1 or 3, wherein the selected normal driving pulses supplied to the motor after it has been driven by a correction driving pulse in response to detection of the non-rotating condition are wider by one step than the normal driving pulses which were supplied to the motor before detection of that condition.
6. A timepiece as claimed in any of claims 1, 3, 4 or 5 wherein a memorising circuit for memorising normal driving pulse widths is included in a control circuit controlling the widths of the driving pulses supplied to the motor.
7. A timepiece as claimed in claim 1 wherein said means in the control circuit for automatically reducing the normal pulse drive width include a counter.
8. A timepiece as claimed in claim 7 wherein the counter is a binary counter.
9. A timepiece as claimed in claim 7 or 8 wherein the number of the predetermined plurality of selected normal driving pulses is between 8 and 128 inclusive.
10. A timepiece as claimed in claim 1 wherein the detection circuit includes means for detecting the difference between the time constant of the motor coil circuit when the motor is in the rotation condition and the time constant of said circuit when the motor is in the non-rotation condition.
11. A timepiece as claimed in claim 2 wherein the means for detecting the voltage induced in the driving coil includes a high impedance in a circuit to which said coil is connected and in which there is produced a voltage the value of which is dependent upon whether the motor is in the rotation or in the non-rotation condition.
12. A timepiece as claimed in claim 11 and comprising a comparator arranged to compare said produced voltages with predetermined reference voltage and to provide a control signal for controlling the control circuit.
13. A timepiece as claimed in claim 11 in which the means for detecting the voltage in the driving coil includes a high impedance and means for intermittently inserting it in a closed loop which includes said coil in series therewith.
14. A timepiece as claimed in claim 12 wherein the reference voltage is constituted by the threshold voltage of a C-MOS device circuit.
15. A timepiece as claimed in any of claims 11 to 14 wherein the value of the high impedance is between 4K Ω and 200K Ω .
16. A timepiece as claimed in claim 2 wherein the means for detecting the voltage induced in the coil include means for switching said coil alternately into a closed loop of high impedance and a closed loop of low impedance.
17. A timepiece as claimed in any of the preceding claims wherein means are provided for applying to



expected to be subjected.

Although in the embodiment described and illustrated the stepping motor has been assumed to be the well known stepping motor having an integrally formed stator, and a two-pole permanently magnetised rotor, the invention is not limited to the use of such a motor and other known stepping motors, including those having stators comprising two body parts, can be used.

Attention is directed to our Specification No. 81/32187 Ser No..., which was divided out of the present specification.

CLAIMS

1. A stepping motor analog timepiece including means for producing correction driving pulses of predetermined width chosen to drive the motor with the torque sufficient to drive it and expected to be required at any time in which the timepiece is in operation; means for producing a plurality of normal driving pulses of predetermined different widths less than that of the correction drive pulses; a detection circuit for detecting the rotation or non-rotation condition of the motor; a control circuit arranged, when the non-rotation condition of the motor is detected, to supply correction pulses to the motor and, when restoration of the rotation condition is made, to supply selected normal driving pulses to the motor to continue it in rotation, said control circuit also including means for automatically reducing the normal pulse drive width to a smaller predetermined width after a predetermined time period.
2. A stepping motor analog timepiece including means for producing correction driving pulses of predetermined width chosen to drive the motor with the torque sufficient to drive it and expected to be required at any time in which the timepiece is in operation; means for producing a plurality of normal driving pulses of predetermined different widths less than that of the correction driving pulses; a detection circuit for detecting the rotation or non-rotation condition of the motor, said detection circuit including means for detecting voltage induced in the driving coil of the motor by motion of the rotor thereof during a short detection pulse supplied to the motor after the termination of a normal driving pulse supplied thereto; and a control circuit arranged, when the non-rotation condition of the motor occurs, to supply correction pulses to the motor to restore the rotation condition and, when the rotation condition is restored, to supply selected normal driving pulses to the motor to continue it in rotation.
3. A timepiece as claimed in claim 1, or 2 wherein the normal driving pulses range in width from a predetermined smallest width to a predetermined largest width in predetermined steps of width.
4. A timepiece as claimed in claim 3 wherein the steps are steps of 0.5 ms.
5. A timepiece as claimed in claim 1 or 3, wherein the selected normal driving pulses supplied to the motor after it has been driven by a correction driving pulse in response to detection of the non-rotating condition are wider by one step than the normal driving pulses which were supplied to the motor before detection of that condition.
6. A timepiece as claimed in any of claims 1, 3, 4 or 5 wherein a memorising circuit for memorising normal driving pulse widths is included in a control circuit controlling the widths of the driving pulses supplied to the motor.
7. A timepiece as claimed in claim 1 wherein said means in the control circuit for automatically reducing the normal pulse drive width include a counter.
8. A timepiece as claimed in claim 7 wherein the counter is a binary counter.
9. A timepiece as claimed in claim 7 or 8 wherein the number of the predetermined plurality of selected normal driving pulses is between 8 and 128 inclusive.
10. A timepiece as claimed in claim 1 wherein the detection circuit includes means for detecting the difference between the time constant of the motor coil circuit when the motor is in the rotation condition and the time constant of said circuit when the motor is in the non-rotation condition.
11. A timepiece as claimed in claim 2 wherein the means for detecting the voltage induced in the driving coil includes a high impedance in a circuit to which said coil is connected and in which there is produced a voltage the value of which is dependent upon whether the motor is in the rotation or in the non-rotation condition.
12. A timepiece as claimed in claim 11 and comprising a comparator arranged to compare said produced voltages with predetermined reference voltage and to provide a control signal for controlling the control circuit.
13. A timepiece as claimed in claim 11 in which the means for detecting the voltage in the driving coil includes a high impedance and means for intermittently inserting it in a closed loop which includes said coil in series therewith.
14. A timepiece as claimed in claim 12 wherein the reference voltage is constituted by the threshold voltage of a C-MOS device circuit.
15. A timepiece as claimed in any of claims 11 to 14 wherein the value of the high impedance is between 4K Ω and 200K Ω .
16. A timepiece as claimed in claim 2 wherein the means for detecting the voltage induced in the coil include means for switching said coil alternately into a closed loop of high impedance and a closed loop of low impedance.
17. A timepiece as claimed in any of the preceding claims wherein means are provided for applying to

37



the motor coil a short pulse for de-magnetising the magnetic circuit of the motor after a correction driving pulse has been supplied thereto and before a following normal driving pulse is applied thereto.

18. A timepiece as claimed in claim 1; 2 or 3 and having driving and detection circuits substantially as herein described with reference to Figures 23 of the accompanying drawings.

5 19. A timepiece as claimed in any of the preceding claims and having a relatively high frequency time standard oscillator and a multi-stage frequency divider dividing the output thereof to a predetermined relatively low frequency wherein the various difference pulses, including correction driving pulses, normal driving pulses and short detection pulses for selective supply to the motor are derived by combination of outputs taken from different stages of the divider.

10 20. A timepiece as claimed in any of the preceding claims and substantially as herein described with reference to the accompanying drawings.