[54] STEP MOTOR MECHANISM FOR ELECTRONIC TIMEPIECE
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ABSTRACT
A step motor driving mechanism for use in an electronic timepiece and especially suitable for reducing the current consumption thereof is provided. Means are provided for detecting the rotational position of a step motor and controlling the current applied thereto during a loaded and unloaded condition. The detecting means is coupled to the driving and control circuit to reduce the pulse width or peak value of the current applied to the step motor during the unloaded condition thereof to thereby reduce the current necessary to drive same.

12 Claims, 13 Drawing Figures
FIG. 3
PRIOR ART

OSCILLATOR → DIVIDING CIRCUIT → DRIVING CIRCUIT → STEP MOTOR → GEAR TRAIN INDICATION

FIG. 4

OSCILLATOR → DIVIDING CIRCUIT → [DRIVING CIRCUIT] → STEP MOTOR → GEAR TRAIN INDICATION

LOAD DETECTION MECHANISM

FIG. 5

OSCILLATOR → DIVIDING CIRCUIT → [CONTROLLING DRIVING CIRCUIT] → GEAR TRAIN INDICATION → STEP MOTOR
FIG. 10

FIG. 11
STEP MOTOR MECHANISM FOR ELECTRONIC TIMEPIECE

BACKGROUND OF THE INVENTION

This invention relates generally to a step motor driving mechanism in an electronic timepiece and especially to a step motor driving circuit for reducing the current required to drive same. As electronic timepieces have become popular, the demand for small sized and thin electronic wristwatches has increased. The use of quartz crystal oscillators in such electronic wristwatches to produce a time base has helped reduce the size of such watches.

It has been recognized that by utilizing a small battery the size of the wristwatch can be further reduced. However it is further appreciated that reduction in the size of the battery effects a corresponding drop in the life of and energy supplied by such battery. Thus, it is desired to provide an electronic timepiece wherein the current consumption of the step motor is substantially reduced.

SUMMARY OF THE INVENTION

Generally speaking, in accordance with the invention, an electronic timepiece having a step motor for driving the gear train is provided including pulse generator means for generating a high frequency time standard signal, divider means formed from a plurality of series connected divider stages producing low frequency timing signals in response to said high frequency time standard signal and representative of present time, and a driving control circuit for driving the step motor and reducing the electric current consumed in driving the step motor. A detection circuit is provided for detecting whether the step motor is in a loaded or unloaded condition and upon detecting an unloaded condition, causing the driving control circuit to limit the amount of current used to drive the step motor. Accordingly, it is an object of this invention to provide an improved small-sized electronic timepiece wherein the current required to drive the step motor is minimized.

Still another object of this invention is to provide a step motor drive mechanism for use in an electronic timepiece which is capable of considerably decreasing the current consumption thereof.

Still another object of this invention is to provide an improved small-sized electronic timepiece wherein the size of the battery required to drive same can be reduced considerably.

Still other objects and advantages of the invention will in part be obvious and will in part be apparent from the specification.

The invention accordingly comprises the features of construction, combination of elements, and arrangements of parts which will be exemplified in the construction hereinafter set forth, and the scope of the invention will be indicated in the claims.

BRIEF DESCRIPTION OF THE DRAWINGS

For a fuller understanding of the invention, reference is had to the following description taken in connection with the accompanying drawings, in which:

FIG. 1 is a plan view and circuit diagram of a step motor and the current signals for driving same which are known in the prior art;

FIG. 2 is a graphical representation of two curves corresponding to the current utilized by a step motor of the type depicted in FIG. 1 in an unloaded and loaded condition;

FIG. 3 is a circuit diagram of an electronic timepiece circuit constructed in accordance with the prior art;

FIG. 4 is a circuit diagram of an electronic timepiece including step motor driving and control circuit and is constructed in accordance with the instant invention;

FIG. 5 is a circuit diagram of still another electronic timepiece including a step motor driving and control circuit and constructed in accordance with an alternative embodiment of the instant invention;

FIG. 6 is a plan view of a step motor constructed in accordance with the circuit depicted in FIG. 4;

FIG. 7 is a circuit diagram of the driving control circuit depicted in FIG. 4;

FIGS. 8a, 8b and 8c are wave diagrams corresponding to circuit of FIG. 7;

FIG. 9 is a wave diagram of the timing signals corresponding to the circuit of FIG. 7;

FIG. 10 is a plan view of a step motor mechanism in accordance with the embodiment of the invention depicted in FIG. 5;

FIG. 11 is a circuit diagram of the control and driving circuit depicted in FIG. 5;

FIG. 12 is a plan view of a mechanical gear train constructed in accordance with still another alternative embodiment of the instant invention; and

FIG. 13 is a circuit diagram of the circuit and driving control circuit used in combination with the gear train mechanism illustrated in FIG. 12.

DESCRIPTION OF THE PREFERRED EMBODIMENT

Referring to FIG. 1, a step motor used in an electronic timepiece and comprising a permanent magnet rotor 1, and high permeability stators 2 and 3 being driven by a driving coil 4 is depicted. The step motor is rotated in a single direction by applying the alternating current pulses 5 to the driving coil 4.

Reference is now made to FIG. 2 wherein the current utilized by a step motor's drive coil in a non-loaded and loaded condition are graphically illustrated. A non-loaded condition is the condition in an electronic timepiece where the load of the step motor is merely a gear train of the timepiece and the load is substantially equal to zero. The loaded condition occurs in an electronic timepiece when the step motor is under a load such as when a calendar indicator is advanced. It is appreciated from a comparison of curves a and b, in FIG. 2 that the driving current (driving current = peak current \(i_p\) \(\times\) pulse width \(\tau\)) differs according to the presence or absence of a load on the step motor. In conventional timepieces, the step motor is driven at a definite peak current \(i_p\) and at a specific pulse width \(\tau\) resulting in a very inefficient use of current. In particular, when the step motor is in a load condition as depicted in FIG. 2, a pulse width \(\tau_0\) is needed to drive same. However, when the step motor is not under a load condition the rotor is rotated at a time \(\tau_0\) which is considerably earlier than \(\tau_0\). Thus, the current during \(\tau_0\) = \(\tau_1\) (which is slightly greater than half of the current used between zero and \(\tau_0\)) has been wasted when the step motor is in a non-loaded condition. Such a waste of current in driving a non-loaded step motor is significant in view of the
fact that a step motor utilized to advance a calendar mechanism in an electronic timepiece remains loaded somewhere between 2 to 4 hours, during a 24 hour timekeeping period and is unloaded during the remaining 20 to 22 hours that the calendar advance mechanism is inoperative. Thus the driving current applied to a step motor in prior art electronic timepieces, with the exception of the 2 to 4 hours when the step motor is loaded, is a waste of more than half the current applied thereto and hence reduces the life of the battery in an electronic timepiece.

Accordingly, in accordance with the instant invention, a driving and current control circuit is provided to control the pulse width or peak value of the driving current in response to the presence or absence of a load on a step motor so that the driving current of the stepper motor is minimized during no load conditions and is maximized when the motor is loaded. Reference is made to FIG. 4 wherein an electronic timepiece circuit which is adapted to control the current of the step motor drive signals is illustrated. As in the conventional electronic timepiece circuit depicted in FIG. 3, an oscillator provides a high frequency signal to a dividing circuit comprising of multi-stage counters which supply a low frequency signal to a driving circuit. The driving circuit applies an alternating drive signal to the step motor which is actuated and drives the gear train of the electronic timepiece. A comparison of the circuit depicted in FIG. 4 with the prior art circuit depicted in FIG. 3 shows that applicant has provided a load detection mechanism and a driving and control circuit which will, as hereinafter be pointed out, control current applied to the step motor in response to a loaded or unloaded condition. As illustrated in FIG. 2, the time in which the rotor is rotated is different depending on whether the step motor is loaded or unloaded. Thus, if the step motor reaches a specific position or stated another way, rotates through a certain angle, it will be detected by the detection circuit and the pulse width of the signal applied to the step motor in response to the detection signal, the pulse width of the current signal applied to the step motor will correspond to the loaded or unloaded condition of the step motor.

A preferred embodiment of the circuit of FIG. 4 is illustrated in FIGS. 6 and 7 wherein a step motor and a drive and control circuit corresponding to the circuit depicted in FIG. 4 are respectively illustrated, like reference numerals denoting like elements. Thus, the step motor includes a detection coil 6 which is adapted to detect the rotational angle of the rotor. The detection coil 6 is coupled through a two-directional wave rectifier circuit 7 in order to insures that the detection signals are unidirectional. A differentiation and inverter circuit 8 receives the unidirectional signals and provides a signal which is usually of a low voltage state and is at a high voltage state at the time the rotor rotates to the angular position which is detected. The signal at the output of the inverter of circuit 8 shaped by applying same to a one-shot single state multivibrator which applies the shaped signal to the inverter 10 so that the output thereof is usually at a high voltage. The pulse width of the driving current is controlled by the NAND gate circuit 11 which is adapted to control the time standard signals IN 1 and IN 2 provided from the divider circuit at terminals 13 and 14. The time carrying signals IN 1 and IN 2, which are gated by each of the NAND gates and are inverted by supplying same to the inverters of circuit 12, are in turn applied to the drive coil 4 of the motor as an alternating pulse driving signal. It is appreciated that all the elements of the circuit depicted in FIG. 7 could be constructed from complementary field effect transistors, and therefore monolithically integrated on a single circuit chip.

Reference is made to FIGS. 8 and 9 to illustrate the operation of the embodiment depicted in FIGS. 6 and 7. When the timing signal IN 1 applied to NAND gate circuit 11 is of a high voltage, the driving current is supplied to the step motor to drive same. When the rotor is rotated through a certain angle, a detection signal as is illustrated in FIG. 8b is induced in the detection coil and is applied to the gate of the inverter and differential circuit 8 the signal at the inverter being illustrated in FIG. 8b. As the rotor is rotated through a predetermined angle, the voltage in the detection coil decreases. Since the gate voltage of the inverter of circuit 8 is lowered to the threshold voltage Vth by the differential circuit, and the signal at the output of the inverter of circuit 8 becomes a high voltage signal. Accordingly, the output S of the inverter circuit 10 is inverted to a low voltage signal and consequently, both NAND gate outputs of the NAND gate circuit 11 become high voltage signals to thereby interrupt the driving current. Accordingly, in accordance with this embodiment, the current consumed is remarkably decreased, because the driving current in the driving coil 4 is applied in response to a time signal and the time signal is interrupted when the rotor rotates through a specific angle of rotation. Thus, the pulse width of the signals applied to the drive coil are changed in a manner which is highly sensitive to and responsive to the load condition of the step motor, to thereby utilize the minimum driving current necessary for driving the step motor.

In the prior art driving circuit depicted in FIG. 3, the consumed current at no load conditions was of the order of 6.05 μamps. When a drive signal having a fixed pulse width and a definite peak current were applied thereto, whereas a circuit constructed in accordance with the present embodiment reduces current consumption to less than half or 2.45 μamps., without any appreciable difference in the motor's operation at maximum torque levels. Furthermore, since the control circuit current in a C-MOS construction is only 0.5 μamps., the total current consumed for both the oscillator and divider circuitry is reduced to about 6 μamps or two-thirds of the current (9 μamps) consumed in prior art devices operating at the same levels, thus making use of a smaller sized battery possible or increasing the working life of the batteries utilized therein.

Reference is now made to FIG. 5 wherein a control and driving circuit receives a signal from a load detection mechanism which is adapted to detect the mechanical position of a fourth wheel in the watch mechanism to provide a detection signal for reducing the pulse width of the step motor drive signals. The detection mechanism senses signals from the gear train and apply the signals to the control and driving circuit to modify the signals applied to the step motor.

Reference is made to FIGS. 10 and 11 wherein a mechanical structure and circuit for practicing the invention illustrated in FIG. 5 is depicted. A fourth wheel 15 is engaged with a rotor pinion in a conventional man-
A second jumper 16 for regulating the fluctuation of the second hand is coupled to a barium titanate decoder 17 which admits of an electrostriction effect to provide detecting signals. The second jumper 16 is engaged with the fourth wheel and vibrates in accordance with the rotation of the rotor to detect the rotating angle of the rotor by detecting the voltage produced by the barium titanate decoder. Accordingly, when the rotor rotates through a definite angle, the drive current applied to the detection coil is interrupted. Thus, according to this embodiment of the instant invention, the detection coil 6 depicted in FIG. 6 is replaced by the barium titanate decoder coupled to the second jumper. However, the method of controlling signals supplied to the drive coil is in every other respect the same as that of the embodiment illustrated by FIG. 4.

As is illustrated in FIG. 11, the control and driving circuit includes the barium titanate decoder 17 coupled to an amplifier circuit 18 for amplifying the detection voltage produced by the decoder, the remainder of the circuit operating in the same manner as the circuit depicted in FIG. 7, like reference numerals denoting like elements. It is further possible to include a delay signal by designing the resistor 9b and the capacitor 9c to have a specific time constant when necessary or desired. It is noted that current consumption is reduced by more than 50 percent while the step motor continues to operate at maximum torque when practicing the instant invention according to this embodiment.

Reference is now made to FIGS. 12 and 13 wherein a system for controlling the driving current of the step motor by detecting a time zone disposed on a calendar advance wheel by providing a switching mechanism responsive to the gear train is depicted, it being noted that such embodiment is still another way of carrying out the circuit of FIG. 5. A calendar wheel 20 is advanced by a calendar advancing wheel 19 which is made of a conductive material and is connected to a conductive plate. A ratchet member 21 is adapted to rotate the calendar wheel 20. An insulator 22 is disposed on the calendar advancing wheel 19 and defines a non-loaded time zone. A slider 23 is disposed in contact with the date advancing wheel. The calendar advancing wheel 19, the insulator 22 disposed thereon, and the slider 23 form a switch mechanism for detecting the loaded time zone. In the control and driving circuit depicted in FIG. 13, the switch mechanism 28 is the equivalent of the switching mechanism comprised of the calendar advancing wheel 19, the insulator 22 and the slider 23. An inverter circuit 24 has a bias resistor 27 coupled to a first side thereof. The other side of the inverter 24 is coupled to a P-channel MOS field effect transistor which in turn is coupled to resistor 26 which controls the driving current, both the transistor 25 and the resistor 26 being coupled to the driving circuit 12 which is comprised of inverter stages. It is noted that the inverters are all of C-MOS construction and the input terminals IN 1 and IN 2 of the inverter 12 receive the time signals from the dividing circuit which signals are of a definite period and pulse width.

In operation, when the slider 23 and the calendar advancing wheel 19 are in non-conductive contact with the time zone caused by the insulator 22, the equivalent switch mechanism 28 is shown as an open circuit and represents a no load condition. For such a no load condition, the output of the inverter 24 is a high voltage and in view thereof, the P-MOS transistor 25 is turned off. Since the driving control current resistor 26 is coupled in series with the driving coil 4, only driving currents having a small peak value are applied to the driving coil. On the other hand, when the time zone of the calendar is advanced by the rotation of the calendar advancing wheel, the slider 23 and the calendar advancing wheel 19 contact each other and render the equivalent switch closed or in an ON position. In such case, the output of the inverter 24 is at a low voltage, the P-MOS transistor 25 is turned on to thereby short circuit the driving current resistor 26, thereby supplying a driving current having a large peak value through the driving coil 4 during the loaded condition. Accordingly, the pulse width of the applied signals remain fixed whether the step motor remains loaded or non-loaded and the peak value is adjusted. Thus, it is possible to control the peak value of the driving current by means of simple circuits which would result in a considerable reduction in the current consumed during no-load conditions.

It is noted, that in practicing the instant invention, the step motor need not be of the electromagnetic type but instead could be of the dynamo-electric type or any other which is utilized in an electronic timepiece. It is further noted, that in all of the embodiments of the instant invention, the driving current of the step motor is controlled by providing a load detection mechanism, but that an amplifier of sufficiently high sensitivity and which could operate on small amounts of current could be provided to detect the rotating angle of the rotor by converting the driving current into a voltage and amplifying the voltage. It would then be possible to control the driving current without providing a load detection mechanism. Finally, it is noted that although the instant invention effects a considerable reduction in the current consumed by the step motor, there is no sacrifice in the torque of the motor to thereby effect an improved quartz crystal electronic wristwatch.

It will thus be seen that the objects set forth above, among those made apparent from the preceding description, are efficiently attained and since certain changes may be made in the above construction without departing from the spirit and scope of the invention, it is intended that all matter contained in the above description or shown in the accompanying drawings shall be interpreted as illustrative and not in a limiting sense.

It is also to be understood that the following claims are intended to cover all of the generic and specific features of the invention herein described, and all statements of the scope of the invention which, as a matter of language, might be said to fall therebetween.

What is claimed is:

1. An electronic timepiece having a step motor and comprising a quartz crystal vibrator producing a high frequency time standard signal, driving circuit means for purposely low frequency time signals in response to said high frequency time standard signal, a gear train driven by said step motor and adapted to place the step motor in one of a loaded and unloaded conditions; load detection means for detecting the condition of the step motor and supplying a signal corresponding thereto; and driving and control means intermediate the driving circuit and the step motor for receiving the low frequency signals from the dividing circuit and applying same to the step motor for driving same, the signals ap-
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applied to the step motor being controlled by application of the load detection signal to the driving and control circuit means.

2. An electronic timepiece as depicted in claim 1, wherein the time signals applied to the step motor are controlled by reducing the pulse width of the drive signals upon detection of an unloaded condition.

3. An electronic timepiece as claimed in claim 2, wherein the load detection means is adapted to detect the angle of rotation of the rotor and apply signals corresponding to the angular position of the rotor to the driving and control means.

4. An electronic timepiece as claimed in claim 3, wherein said step motor includes a rotor and said load detection means includes a detecting coil for detecting the angular rotation of the rotor.

5. An electronic timepiece as claimed in claim 4, wherein said driving and control means includes circuit means for receiving the signal detected by the detection coil and using same to gate the low frequency time signals supplied by the divider to thereby reduce the pulse width thereof when the unloaded condition is detected.

6. An electronic timepiece as claimed in claim 2, wherein the gear train includes a wheel gear, and said load detecting means includes a decoder means for mechanically sensing the condition of the step motor and supplying signals to the control and driving means representative of such condition.

7. An electronic timepiece as claimed in claim 6, wherein the wheel gear is a fourth wheel, and said decoder includes a second jumper sensing the fluctuation in the fourth wheel, and the decoder is made of barium titanate so that when the jumper engages the fourth wheel, the second jumper is vibrated to supply the load detection signal to the driving and control circuit.

8. An electronic timepiece as claimed in claim 1, wherein the drive signals applied to said step motor have a uniform pulse width and are controlled by reducing the peak value thereof during an unloaded condition.

9. An electronic timepiece as claimed in claim 1, wherein said gear train includes a calendar advancing wheel and said load detection means includes means for sensing the orientation of said date advancing wheel, when said wheel is in a calendar date advancing position.

10. An electronic timepiece as claimed in claim 9, wherein the driving and control means includes an electronic switching element and said orientation sensing means providing a switching signal to the electronic switching element for controlling the peak value of the drive signal applied to the step motor.

11. An electronic timepiece as claimed in claim 10, wherein said orientation sensing means includes a rotating conductive calendar advancing wheel, a sensing element adapted to provide said switching signal when said sensing element is in contact with said calendar advancing wheel, and insulator means disposed on part of said advancing wheel between said sensing element and said conductive wheel, the absence of the insulator on the calendar advancing wheel defining a loaded condition of the step motor.

12. An electronic timepiece having a step motor and comprising a quartz crystal vibrator producing a high frequency time standard signal; divider circuit means for producing low frequency time signals in response to said high frequency time standard signals; a gear train driven by said step motor and adapted to place a load on the step motor; load detection means for detecting the load condition of the step motor and supplying a signal corresponding thereto; and driving and control means intermediate the dividing circuit and the step motor for receiving the low frequency signals from the dividing circuit and applying same to the step motor for driving same, the signals applied to the step motor being controlled by application of the load condition signal to the driving and control means.

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