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(54) A DRIVING ARRANGEMENT FOR A STEPPER MOTOR

(71) We, KABUSHIKI KAISHA SUWA SEIKOSHA, a Japanese Company, of 3—4, 4-Chome, Ginja, Chuo-ku, Tokyo, Japan, do hereby declare the invention for which we pray that a patent may be granted to us and the method by which it is to be performed to be particularly described in and by the following statement:—

This invention relates to driving arrangements and in particular, although not so restricted, to driving arrangements for electronic wristwatches.

An electronic wristwatch is a subminiature electronic apparatus which is driven by a very small battery. Such an electronic wristwatch must have an extremely low power consumption so that the battery has a long useful life. In fact, much effort has been made in the past to reduce the power consumption of electronic wristwatches. A stepper motor is an electromechanical converter often used in electronic wristwatches to drive time indicating hands and attempts have been made to increase its efficiency and reduce its power consumption.

Theoretically, it is sufficient to rotate time indicating hands of an electronic wristwatch in a single direction to give the time indication but not only a stepper motor capable of rotating in a single direction but also a stepper motor capable of rotating in both directions may be used. For preference, a stepper motor rotating in one direction is employed, because it has a relatively lower power consumption and so a stepper motor capable of rotating in both directions, which has a higher power consumption, has not been put into practical use as yet.

There have been proposals to use a stepper motor capable of rotating in both directions in an electronic wristwatch, but such stepper motors have proved to be of complicated construction requiring extreme high manufacturing accuracy and of relatively large power consumption. Recently, with the popularisation of electronic wristwatches, a stepper motor capable of rotating in both directions has been required for convenience, usability, extension of functions etc.

According to the present invention, there is provided a driving arrangement comprising: a stepper motor having a rotor; and a driving circuit capable of producing selectively a first driving signal for causing the rotor to rotate in one direction, and a second driving signal for causing the rotor to rotate in the opposite direction, the first driving signal consisting of pulses of a predetermined width and the second driving signal consisting of pulses which each have a first portion of the same polarity but of narrower pulse width than a corresponding pulse of the first driving signal and a second portion of opposite polarity to the corresponding pulse of the first driving signal.

The driving arrangement may include manually operable switch means for selecting the first and second driving signals.

In the preferred embodiment the rotor is mounted eccentrically with respect to a pair of spaced-apart polepieces so that the rotor has a static stable position which is off-set relative to a line joining air gaps between the polepieces.

According to a further aspect of the present invention there is provided an electronic timepiece, for example an electronic wristwatch, including a driving arrangement as recited above.

The invention is illustrated, merely by way of example, in the accompanying drawings, in which:—

Figure 1 is a schematic diagram of a conventional stepper motor and wheel train;

Figure 2 is a block diagram of an electronic wristwatch including the stepper motor of Figure 1;

Figure 3 is a circuit diagram of a driving circuit for the stepper motor of Figure 1;

Figure 4 is a block diagram of one embodiment of a driving arrangement according to the present invention;

Figure 5 is a timing chart illustrating the operation of the driving arrangement of Figure 4; and

Figure 6 illustrates the operation of the stepper motor of Figure 1 when incorporated

into the driving arrangement of Figure 4.

Figure 1 illustrates a conventional stepper motor for an electronic wristwatch having a rotor 1 of permanently magnetic material with two magnetic poles N, S and two opposed polepieces 2, 3 with air gaps therebetween. Each of the polepieces is connected to a yoke 5 around which a coil 4 is wound to form a stator. Respective arcuate portions 2*a*, 3*a* of the polepieces 2, 3 are not co-axial with the rotor 1 in order to cause the rotor to rotate in a single direction, so that the line joining the magnetic poles N, S, when the rotor 1 is in a static stable position, is at an angle to the line joining the air gaps between the polepieces. A stepper motor of this type has been put into practical use in an electronic wristwatch whose construction is illustrated in block diagram form in Figure 2.

A quartz crystal vibrator 10 controls an oscillator circuit 11 which produces a standard time signal. The standard time signal is frequency divided by a frequency divider circuit 12 and then an output signal consisting of pairs of pulses having a predetermined time interval, a predetermined pulse width and a phase difference of 180° appears at the outputs of a wave shaping circuit 13. Typically, each pulse has a pulse width of 7.8 msec and is generated every two seconds. The operation of this type of electronic wristwatch will be described hereinafter in relation to such pulses.

The output signal from the wave shaping circuit 13 is fed to driver circuits 14, 15 each comprising a C—MOS inverter and the output signals thereof are applied to terminals 4*a*, 4*b* of the coil 4.

Figure 3 illustrates the driver circuits 14, 15 and the coil 4 in greater detail. When a pulse 18 appears at the input terminal 16 of the driver circuit 14, current flows in the direction indicated by an arrow 19. When a pulse 18 appears at an input terminal 17 of the driver circuit 15, current flows in a direction indicated by an arrow 19'. That is to say, by alternately applying pulses to the input terminals 16, 17 of the driver circuits 14, 15, current flowing in the coil 4 reverses periodically. In particular, with the pulses 18, a current having a duration of 7.8 msec and reversed each second flows in the coil 4. Thus, N- and S- poles are alternatively generated in the polepieces 2, 3 so that each pulse causes the rotor to rotate through 180°. The rotation of the rotor 1 is transmitted to a fourth wheel 7 (Figure 1) through an intermediate wheel 6, the fourth wheel driving a third wheel 8 and a centre wheel 9, a cannon pinion, an hours wheel (not shown) and a calendar mechanism (not shown) so that a display mechanism, for example, comprising an hours hand, a minutes hand, a seconds hand and the calendar mechanism, is operated.

This stepper motor has, over the years, been improved by altering the eccentricity x between the polepieces 2, 3 and the rotor, and by analysis of motor operation and magnetic circuitry in an attempt to increase its efficiency and to reduce its power consumption. These improvements have been considered in relation to a stepper motor capable of rotating in one direction because the direction of rotation of this kind of stepper motor cannot normally be reversed.

The stable position of the rotor 1 changes according to the eccentricity x between the polepieces 2, 3 and the rotor, and this eccentricity also determines the direction of rotation of the rotor. That is to say, in the case of the eccentricity shown in Figure 1, the rotor 1 rotates in the direction indicated by the arrow. If the eccentricity of the polepieces 2, 3, relative to the rotor 1 were to be reversed, the rotor 1 would rotate in the opposition direction. It has been proposed to use this fact to make a rotor rotate in both directions. That is, by being able to change the eccentricity x from the exterior of an electronic wristwatch, the rotor can be caused to rotate selectively in both directions. In such a construction, in order to obtain high efficiency and low power consumption, the eccentricity x has to be about 50 microns with a permitted error of the order of 10 microns. Normally a stepper motor must be made very accurately and the stator, in particular, should be manufactured with great precision and be securely fixed to a base plate during assembly, but these criteria cannot be met in the case of a stepper motor capable of rotating in both directions upon alteration of the eccentricity x because the polepieces must be movable relative to one another and to the base plate.

Another conventional stepper motor capable of rotating in both directions, has two driving coils (i.e. a driving coil for causing rotation of the rotor in one direction and a driving coil for causing rotation of the rotor in the opposition direction). Alternatively, a stepper motor capable of rotating in both directions may have two pairs of polepieces.

However, these stepper motors cannot be put into practical use in an electronic wristwatch due to their size and especially because they employ relatively large coils. In an electronic wristwatch, the stepper motor must, of course, be of small size.

In summary, therefore, although stepper motors capable of rotating in both directions are known they are impractical and cannot be employed satisfactorily in, for example, electronic wristwatches.

Figure 4 illustrates an example of a driving arrangement according to the present invention, and Figure 5 is a time chart of the operation thereof. An oscillator circuit 20 produces a standard time signal which is fre-

quency divided by a frequency divider circuit 21. Each output of NAND gates 22, 23, 24, 25 is a pulse signal obtained by combining various output signals from the divider circuit 21. The gate 22 forms a first part of a pulse signal for causing the stepper motor to rotate in the reverse direction, the gates 23, 24 form a second part of that pulse signal, and the gate 25 forms a pulse signal for causing the stepper motor to rotate in the forward direction. Each of the pulse signals is generated with width of several milliseconds. Respective delay flip-flops 26, 27, 28, 29 produce one second signals with a delay of T_1, T_2, T_3, or T_4 seconds respectively, so that a pulse having a pulse width of T_1 is generated by a gate 30, a pulse delayed by T_2 seconds and having a pulse width of $T_3 - T_2 = T_3'$ is generated by a gate 31, and a pulse having a pulse width of T_4 is generated by a gate 32. A changeover switch 33 selectively determines forward or reverse rotation of the stepper motor. When this switch is open the rotor rotates in the forward direction and when closed the rotor rotates in the reverse direction.

In the case where the switch 33 is open, i.e. the rotor rotates in the forward direction, as the output of the switch 33 is high, a gate 36 is open and the output signal from the output C of the gate 32 can be passed therethrough. At this time gates 34, 35 are shut. The output of the gate 36 is divided by a signal having a frequency of 1/2 Hz and signals denoted by D_1 and E_1 in Figure 5 are obtained from outputs D and E of respective OR gates 39, 40. These signals D_1, E_1 are applied to driving inverters 42, 43, the outputs of which are connected to respective terminals 41*a*, 41*b* of a driving coil 41 of the stepper motor. The stepper motor is thus driven in the same manner as the stepper motor shown in Figures 2 and 3. Consequently, a voltage signal F_1 consisting of alternating pulses, each of which has a pulse width of T_4 and which appear each second, is applied to the coil 41 so that the rotor rotates in the forward direction.

In the case where the switch 33 is closed, i.e. the rotor rotates in the reverse direction, as the output of the switch 33 is low, the gates 34, 35 are open and the gate 36 is shut. Therefore, outputs A and B from the gates 30, 31 pass through the gates 34, 35, are divided by the 1/2 Hz signal and signals denoted by D_2 and E_2 are obtained at the outputs D and E of the gates 39, 40 respectively. The signals D_2, E_2 are fed to the inverters 42, 43. Thus a pulse voltage signal having a pulse width T_1 is applied to the coil 41 and current initially flows from the terminal 41*a* to the terminal 41*b* of the coil 41. Subsequently a pulse voltage signal having a pulse width of T_3' is applied to the coil 41 and current flows in the opposite direction (i.e. from the terminal 41*b* to the terminal 41*a*). After one second, a voltage pulse having a pulse width of T_1 is applied to the coil 41 and then a voltage pulse having a pulse width of T_3' is applied to the coil 41 and this sequence is repeated. The voltage signal applied to the coil 41 is denoted by F_2 in Figure 5 and this causes the rotor to rotate in the reverse direction. This will be explained in greater detail in relation to the stepper motor of Figure 1.

The pulse width T_4 in this embodiment is set to 7.8 msec. The pulse width T_1 is narrower than the pulse width T_4 and slightly narrower than the minimum pulse width required to rotate the rotor. For example, T_1 may be 3 msec. Thus a pulse having a pulse width T_1 tends to drive the rotor in the forward direction but is insufficient to cause the rotor to rotate by one step. When a pulse having a pulse width T_1 is applied, the rotor returns to the static stable position after having rotated through 40° to 50°. In Figure 1, the rotor 1 has a neutral position N.P. a little less than 90° from the static stable position already referred to. If the rotor 1, when rotating, passes over the neutral position N.P., it completes one step without any further driving force being necessary. However, if the rotor 1 cannot pass over the neutral position N.P., it returns to the original static stable position.

Figure 6 illustrates the operation of the rotor. Line (a) illustrates operation of the rotor in the case where a pulse having a pulse width T_4 of 7.8 msec. is applied and the rotor rotates in the forward direction through 180° and then comes to rest. Line (b) shows the operation of the rotor in the case where a pulse having a pulse width of T_1 (3 msec.) is applied and the rotor cannot pass over the neutral position N.P. and returns to its original static stable position. Referring back to the circuit of Figure 4, after the pulse having a pulse width of T_1 has been produced, a pulse having a pulse width of T_3', the latter being inverted with respect to the former, is produced. The pulse having a pulse width T_3' makes the rotor rotate in the reverse direction after the rotor has been rotated in the forward direction by the pulse having a pulse width of T_1. That is to say, when the magnetic poles of the rotor 1 approach the air gap between the polepieces 2, 3 the rotor is operated as shown by line (c) in Figure 6, so that it is then rotated through 180° in the opposite direction and comes to rest in a new static stable position. The pulse widths T_2 and T_3' shown in Figure 5 must have suitable values e.g. $T_2 = 4.5$ msec. and $T_3' = 4.5$ msec.

When the rotor 1 is in the static stable position, the rotor is driven in the forward direction through 180° by pulses of width T_4. On the other hand, when a driving signal for rotating the rotor in the reverse direction is applied, the rotor 1 is initially rotated in the

forward direction by pulse T_1. However, the driving torque reduces as the rotor 1 approaches the neutral position and the application of a pulse of width T_3' then causes the rotor 1 to rotate by one step in the reverse direction. The reason for this is that, as the magnetic field between the polepieces 2, 3 comprises parallel lines of magnetic flux extending between the polepieces 2, 3 in a direction normal to a line joining the air gaps therebetween, the rotor 1 obtains the largest driving torque, for a given pulse, when the magnetic poles of the rotor 1 are aligned with the air gaps between the polepieces 2, 3. The rotor 1 is therefore rotated to the vicinity of the gaps between the polepieces 2, 3, before applying a pulse for driving the rotor in the reverse direction, so that the rotor is subjected to the largest driving torque possible for that pulse.

The performance of the stepper motor, when the rotor rotates in the reverse direction, will now be explained. The pulse widths T_1, T_2, T_3' are preferably as follows:

T_1: 2 to 3.5 msec.

T_2: a minimum value of 2 to 3.5 msec and a maximum value of 6 msec.

T_3': 3.5 to 6 msec.

The output torque at the beginning of rotation of the rotor in the reverse direction is between a quarter and one half of the output torque driving the rotor in the forward direction. The range of voltage capable of rotating the rotor in the reverse direction is a little narrower compared with that for rotation in the forward direction. Thus the motor performance during reverse rotation is inferior to that during forward rotation. In the case where this type of driving arrangement is provided in an electronic wristwatch, the stepper motor is rotated in the forward direction when the wristwatch functions normally and is rotated in the reverse direction under special conditions. Thus the stepper motor must be rotated in the forward direction under all circumstances, e.g. exceedingly low temperature, high magnetic field, large external shock etc., that the wristwatch meets during use, while the stepper motor need not be capable of reverse rotation under such severe circumstances. Consequently, though sufficient performance is required when the stepper motor rotates in the forward direction, it is adequate to have somewhat inferior performance when the stepper motor rotates in the reverse direction. Thus, the driving arrangement according to the present invention as described above is most suitable for use in an electronic wristwatch.

The present invention is not limited to stepper motors of the type shown in Figure 1 and may be applied to all conventional stepper motors. However, the pulse widths T_1, T_2, T_3', T_4 etc. must be chosen to suit the particular characteristics of the stepper motor involved. Thus the present invention may be applied to a stepper motor having a rotor with 6 magnetic poles, to a stepper motor wherein a rotor is magnetically connected in the axial direction with a stator, and to a stepper motor where a rotor is magnetized by a coil. All these stepper motors are alternating pulse motors in which a driving current alternately flows in opposite directions in a coil and the rotor advances stepwise. However, in a stepper motor in which, in normal operation, a driving current always flows in the same direction, the direction of rotation of the rotor can still be reversed by applying thereto signals of the type shown in Figure 5.

A driving arrangement according to the present invention is expected to have merit in an electronic wristwatch. For example, in the case of an adjustment of the time indication where a seconds hand is to be adjusted to an exact time, the seconds hand can be rotated in the reverse direction to the exact time. In this case, the time indication can be adjusted in an instant by operating the stepper motor more rapidly than during normal timekeeping operation (i.e. one step each second). To achieve this, it is, of course, necessary only to change the driving arrangement shown in Figure 4 slightly. There are several well known ways of correcting a time indication especially seconds hands and these can be developed and improved by a driving arrangement according to the present invention.

Also, in the case of an electronic timepiece with a multitime display, remaining time display may be included, in which case a stepper motor which can rotate in goth directions is advantageous.

The present invention can be applied not only to electronic wristwatches but also to electronic apparatus in general such as measuring apparatus.

WHAT WE CLAIM IS:—

1. A driving arrangement comprising: a stepper motor having a rotor; and a driving circuit capable of producing selectively a first driving signal for causing the rotor to rotate in one direction, and a second driving signal for causing the rotor to rotate in the opposite direction, the first driving signal consisting of pulses of a predetermined width and the second driving signal consisting of pulses which each have a first portion of the same polarity but of narrower pulse width than a corresponding pulse of the first driving signal and a second portion of opposite polarity to the corresponding pulse of the first driving signal.

2. A driving arrangement as claimed in claim 1 including manually operable switch means for selecting the first and second driving signals.

forward direction by pulse T_1. However, the driving torque reduces as the rotor 1 approaches the neutral position and the application of a pulse of width T_3' then causes the rotor 1 to rotate by one step in the reverse direction. The reason for this is that, as the magnetic field between the polepieces 2, 3 comprises parallel lines of magnetic flux extending between the polepieces 2, 3 in a direction normal to a line joining the air gaps therebetween, the rotor 1 obtains the largest driving torque, for a given pulse, when the magnetic poles of the rotor 1 are aligned with the air gaps between the polepieces 2, 3. The rotor 1 is therefore rotated to the vicinity of the gaps between the polepieces 2, 3, before applying a pulse for driving the rotor in the reverse direction, so that the rotor is subjected to the largest driving torque possible for that pulse.

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The present invention can be applied not only to electronic wristwatches but also to electronic apparatus in general such as measuring apparatus.

WHAT WE CLAIM IS:—

1. A driving arrangement comprising: a stepper motor having a rotor; and a driving circuit capable of producing selectively a first driving signal for causing the rotor to rotate in one direction, and a second driving signal for causing the rotor to rotate in the opposite direction, the first driving signal consisting of pulses of a predetermined width and the second driving signal consisting of pulses which each have a first portion of the same polarity but of narrower pulse width than a corresponding pulse of the first driving signal and a second portion of opposite polarity to the corresponding pulse of the first driving signal.

2. A driving arrangement as claimed in claim 1 including manually operable switch means for selecting the first and second driving signals.

3. A driving arrangement as claimed in claim 1 or 2 in which the rotor is mounted eccentrically with respect to a pair of spaced-apart polepieces so that the rotor has a static stable position which is off-set relative to a line joining air gaps between the polepieces.

4. A driving arrangement substantially as herein described with reference to and as shown in Figures 4 to 6 of the accompanying drawings.

5. An electronic timepiece including a driving arrangement as claimed in any preceding claim.

J. MILLER & CO.,
Agents for the Applicants,
Chartered Patent Agents,
Lincoln House,
296—302 High Holborn,
London, WC1V 7JH.

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