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(54) IMPROVEMENTS IN OR RELATING TO ELECTRONIC TIMEPIECES HAVING TIME DISPLAY MEANS DRIVEN BY STEPPING ELECTRIC MOTORS

(71) We, KABUSHIKI KAISHA DAINI SEIKOSHA, a Japanese company, of 31-1, 6-chome, Kameido, Koto-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 electronic timepieces (principally but not exclusively to analog type quartz wrist watches) having time display means driven by stepping electric motors and has for its object the provision of improved and simple timepieces of this nature the stepping motors of which can be reversed in their direction of rotation, when required, without involving the use of mechanical means for securing such reversal, and without requiring the motor to be other than a stepping motor of a design as normally used at present in analog type quartz timepieces. As will be seen later, the invention provides improved electronic timepieces the stepping motors of which, when reversed in their direction of rotation, will run in a reliable and stable manner, and with adequate torque and which require only relatively small voltages to be applied thereto to achieve this result.

According to this invention, there is provided an electronic timepiece including time display means driven by a stepping electric motor, means for generating a periodic pulse train and supplying it to said motor for rotating the same in one direction and means for generating a periodic train of groups of at least three sub-pulses which are of successively opposite polarities and supplying the train of groups to said motor for rotating the same in the opposite direction.

Preferably the periodic pulse train consists of simple pulses and the periodic train of groups consists of groups each of three sub-pulses which immediately follow one another and are of successively opposite polarities.

Preferably also successive pulses in the periodic pulse train are inverted with respect to one another and successive groups in the

periodic train of groups of sub-pulses are inverted with respect to one another, the motor having a single driving coil to which the periodic pulse train is supplied for rotation in one direction and the periodic train of groups of sub-pulses is supplied for rotation in the opposite direction.

The timepiece may include a crystal controlled time standard oscillator driving a frequency divider comprising a sequence of frequency dividing flip-flop stages and the periodic pulse train and the periodic train of sub-pulses may be derived by means of a pulse combining circuit fed with output pulses from selected flip-flop stages of the divider and controlled by a control circuit to produce either the periodic pulse train or the periodic train of sub-pulses for driving the motor.

The invention is illustrated in and explained in connection with the accompanying drawings in which:—

Figure 1 shows a preferred form of stepping motor for use in carrying out the invention;

Figures 2, 5, 6 and 7 are explanatory figures provided in order to explain the operation of the motor of Figure 1;

Figures 3 and 8 are explanatory graphical figures;

Figure 9 is a block diagram of one embodiment and Figure 11(a) shows some of the circuitry of the said embodiment; and

Figures 4, 10 and 11(b) are explanatory wave form diagrams.

Figures 1(a) and 1(b) are mutually perpendicular views of one form of stepping motor commonly used for driving the time indicating means (hands) of analog type electronic timepieces. The motor has a stator 1 on which is an energizing coil 3 and a motor 2 (shown with a driving gear on its shaft) which is permanently magnetised to have two diametrically opposite poles indicated by the letters N and S. The rotor is mounted concentrically in a hole in the stator and two diametrically opposite notches q_1 and q_2 are provided in the stator hole as shown. The rest position of the rotor is with the diameter

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joining its poles N, S approximately at right angles to that joining the notches q_1 and q_2 . In customary present day practice the motor is driven by pulses supplied to the coil 3 by the time keeping circuitry of the timepiece and which occur at 1-second intervals. Successive pulses are in opposite directions of current flow, a typical practical pulse width being, as indicated in Figure 3(a), 7.8 m sec. The rotor makes one step of half a revolution in response to each pulse. Figure 3(b) typifies against time T the wave of current I which flows through the coil at each pulse. As will be explained later each successive rotor step occurs in the same direction when a wave form as shown in Figure 3(a) is applied to the coil 3, despite that the successive pulses are in opposite directions, the notches q_1 and q_2 acting as magnetic index means determining the position at which the rotor stops after a pulse terminates. Some stepping motors have mechanical index means for the same purpose. With the magnetic index means shown, the direction of rotor rotation is determined by the angular relation between the diameter in which the rotor poles lie and that in which the notches q_1 and q_2 lie.

Recent developments in wrist watches require that, in order to achieve certain objects notably time correction and changing the displayed time from that used in one country to that used in another or from summer time to standard time, the motor shall be able, when required, to reverse its direction of rotation. Hitherto such reversal of direction of rotation has been obtained by methods such as changing the position of the motor index means mechanically, or detecting the position of the rotor by means of a current wave form applied thereto and using the result of such detection to change the timing of the successively reversing pulses. Such methods have, however, serious defects, mainly that the apparatus required to carry them into effect is ill-suited to mass-production and/or it is difficult to obtain reversal of the direction of rotation in a reliable manner without adversely affecting the performance of the motor when reversal takes place. The main object of the present invention is to provide for reversing the direction of rotation of the stepping motor of a timepiece in a simple and improved way which does not present the foregoing defects.

The four diagrams of Figure 2 serve to explain how the motor is rotated in the forward direction (anti-clockwise as seen in Figure 2) by a wave form as shown in Figure 3(a). Each of the four diagrams shows the rotor 2, the part of the stator 1 where the rotor is situated, and magnetic index means constituted by the notches q_1 and q_2 . Figure 2(a) shows the rotor in its rest position, with no current passed through the motor coil 3 (Figure 1). If, when the rotor is in this posi-

tion, a current is passed through the coil in such a direction as to produce North and South stator poles in the positions indicated respectively at N and S on the stator as shown in Figure 2(b), the rotor steps in the forward direction due to the mutual repulsion between adjacent like poles, two on the stator and two on the rotor. If the current pulse fed to the coil terminates when the rotor is in the position shown in Figure 2(c) the rotor will assume, before the next pulse, its other rest position shown in Figure 2(d), advanced by 180° from the position shown in Figure 2(a). When the next pulse, which is in the opposite direction to that which produced the stator poles indicated in Figure 2(b), is fed in to the coil 3, it will produce stator poles which are opposite to those shown in Figure 2(b) and the rotor will take another step in the same direction as before.

Figures 4 and 5 illustrate the principle used, in this invention, for securing reversed direction rotation of the motor, Figure 4 showing the pulsed wave form applied to the coil 3 and Figure 5 consisting of explanatory motor diagrams of the same nature as those of Figure 2. Comparing the wave form of Figure 4 with that of Figure 3 it will be seen that, instead of the successively reversed simple pulses shown in Figure 3(a) as used for forward rotation, there are successively reversed groups of sub-pulses as shown at (a) and (b) in Figure 4, each group consisting of three sub-pulses which immediately follow one another with the middle one in a direction opposite to that of the two outer ones between which it is sandwiched. The widths of the sub-pulses in a group are indicated at P_1 , P_2 and P_3 in Figure 4(a). In Figure 5 it is assumed, as in Figure 2, that the forward direction of rotation is anti-clockwise, so that the reversed direction is clockwise, as viewed in Figure 5. The direction of the sub-pulse P_1 of the group (a) of Figure 4 is such as to produce forward (anti-clockwise) rotation of the rotor from the rest position shown in Figure 5(a), the stator poles produced by this sub-pulse being as indicated in Figure 5(b). When, however, the rotor poles have almost reached positions in which they lie in the same diameter as the notches q_1 and q_2 , the sub-pulse P_2 arrives, reversing the stator poles as shown in Figure 5(c) and thus producing a force to rotate the rotor in the reversed direction (clockwise). When the rotor comes to the position shown in Figure 5(d), the third sub-pulse P_3 arrives. The groups of sub-pulses follow one another at 1-second intervals and each group occupies a total width of, for example, 15.6 m sec. Suitable widths for the individual sub-pulses P_1 , P_2 and P_3 will be given, by way of example, later. Figure 6 shows the relation between the position of the rotor 2 and the total magnetic energy which the motor has (when there is no volt-

age across the motor coil) and Figure 7 serves to define various positions of the rotor 2. In Figure 7 forward rotation of the rotor 2 is to be taken as the positive direction of the angle θ , reverse rotation of the rotor 2 is to be taken as the negative direction of the angle θ , and the assumption is made that the initial rest position of the rotor is that in which the angle θ is $\pi/4$. The rotor is forced forward, i.e. in the positive direction of θ , by the sub-pulse P_1 . When θ becomes $3\pi/4$ approximately, the rotor is forced in the negative direction of θ by the sub-pulse P_2 . Then, when θ has become approximately zero, the rotor has large kinetic energy by reason of the force due to the pulse P_2 and also the potential energy obtaining at the time when the magnetic energy is decreased. By applying the sub-pulse P_3 to produce stator poles as shown in Figure 5(d) the rotor is forced in the negative direction of θ , and, accordingly, it continues to rotate in the reverse direction. After the termination of the sub-pulse P_3 , the rotor 2 will have travelled from the position shown in Figure 5(a) by $-\pi$ and stops in the rest position shown in Figure 5(e). Thus the pulse group (a) of Figure 4 produces an overall rotor rotation step of 180° in the reverse direction. The next group (b) of sub-pulses is the inverse of group (a) and, accordingly, when this group arrives, it produces another 180° step of rotor rotation, again in the reversed direction of rotation. Figure 8 typifies the wave forms of current I against time T through the motor coil 3 during the sub-pulses P_1 , P_2 and P_3 in reversed direction of rotation.

Figure 9 is a block diagram of one form of timepiece embodying the present invention. Referring to Figure 9, block 50 is a crystal controlled time standard oscillator including a quartz crystal having a frequency of, for example, 32768 Hz. The generated oscillations of this frequency are fed to a frequency divider 51 consisting of fifteen flip-flop stages (hereinafter referred to as FFs), the last of which provides a pulsed output having a frequency of 1 Hz. 52 is a pulse combining circuit and 53 is a driving circuit the output from which consists either of the pulsed wave form required for causing the time display driving stepping motor 54 of the timepiece to rotate in the forward direction or the wave form required for driving the motor in the reverse direction. Determination of whether the forward rotation wave form or the reversed direction wave form is fed to the motor is effected by a control circuit 55.

Figure 10 shows wave forms appearing at the Q or $\bar{Q}$ outputs of the fourth to tenth and the fifteenth FF stages of the divider 51 by the lines referenced Q_4 to Q_{10} and Q_{15} respectively. The combining circuit combines

selections of these outputs to provide pulses P_1 , P_2 and ϕ_1 , ϕ_2 and ϕ_3 .

The combinations effected to produce the wave forms P_1 , P_2 , ϕ_1 , ϕ_2 and ϕ_3 are:—

$$P_1 = \bar{Q}_{10} \cdot \bar{Q}_{11} \cdot \bar{Q}_{12} \cdot \bar{Q}_{13} \cdot \bar{Q}_{14} \cdot \bar{Q}_{15}$$

$$P_2 = \bar{Q}_9 \cdot P_1$$

$$\phi_1 = \bar{Q}_4 \cdot \bar{Q}_5 \cdot \bar{Q}_6 \cdot \bar{Q}_7 \cdot \bar{Q}_8 \cdot P_n$$

$$\phi_2 = \bar{Q}_4 \cdot Q_5 \cdot \bar{Q}_6 \cdot Q_7 \cdot \bar{Q}_8 \cdot P_n$$

$$\phi_3 = Q_4 \cdot Q_5 \cdot Q_6 \cdot Q_7 \cdot Q_8 \cdot P_n$$

Figure 11(a) shows the main circuitry of combining circuit 52, the driving circuit 53, and the control circuit 55, the stepping motor 54 being represented in Figure 11(a) by its driving coil 80.

The forward-reverse rotation control circuit 55 consists of an RS flip-flop 70, the reset terminal R of which is connected to a terminal 61 to which the wave form P_n is applied and the set input terminal S of which is connected to a terminal 60 to which the wave form P_1 is applied. Also the wave forms P_1 , P_n , ϕ_1 , ϕ_2 and ϕ_3 are applied to the terminals 62, 63, 64, 65 and 66 respectively. The Q output of the RS-FF 70 is applied to one input of the first AND gate of an AND/OR gate 71 and the Q output thereof is applied to one input of the second AND gate of said AND/OR gate 71 and also to one input of a NOR gate 73. The other input of said first AND gate receives the wave form P_1 and the remaining input of said second AND gate receives the input P_n . The wave forms ϕ_2 and ϕ_3 are applied to the respective inputs of a NOR gate 72, the output of which is applied to the remaining input of the NOR gate 73. The output of NOR gate 73 is applied to one input of an OR gate 74 to the other input 64 of which the wave form ϕ_1 is applied. The output of the OR gate 74 is applied to the clock input terminal CL of an FF 75 the Q output of which is applied to one input of a NAND gate 76 and the Q output of which is applied to one input of a NAND gate 77. The output of the AND/OR gate 71 is applied to the remaining inputs of the NAND gates 76 and 77.

The output of the NAND gate 76 is connected at C to one end of the coil 80 of the stepping motor through a driving inverter 78, and the output of the NAND gate 77 is connected to the other end D of said coil 80 through a driving inverter 79.

The operation will now be explained with the aid of Figure 11(b). In the normal condition, that is to say when the motor rotates in the forward direction, terminal 61 is at HIGH ("H") level and the $\bar{Q}$ terminal of FF 70 is therefore also "H". In this condition, operation occurs in accordance with the three wave

forms shown in the upper half of Figure 11(b), the three wave forms A, B and C—D showing, respectively, the voltage pulses at the points A and B and between the points C and D in Figure 11(a).

As will be seen the output of the AND/OR gate 71 is applied to the NAND gates 76 and 77 as a forward rotation driving pulse, and the points C and D become "H" and "L" (LOW) respectively or "L" and "H" respectively in dependence on the state of the FF 75, and successively reversed current pulses flow through the coil 80. Since the signal at point B is in synchronism with the wave form P_2 , the state of the FF 75 changes every second. The motor rotates forwardly in the normal, ordinary way.

The operation for reverse rotation of the motor will now be explained. The three curves shown in the lower part of Figure 11(b) apply to reverse direction rotation of the motor. When the wave form P_1 at terminal 60 becomes "H", the Q output of FF 70 also becomes "H" and the wave form at the output of the AND/OR gate 71 is the wave form P_2 .

However, when driving in the reverse direction, the pulses ϕ_1 , ϕ_2 and ϕ_3 appear at point B and are applied to the clock terminal CL of the FF 75 so that its state is changed every time one of these pulses appears. Accordingly the wave form applied across the motor coil 80 is as shown by the bottom line of Figure 11(b). As an example the widths of the successive sub-pulses making up a group (i.e. the widths of the sub-pulses P_1 , P_2 and P_3 of Figure 4) may be 2.4 m sec, 4.9 m sec and 8.3 m sec respectively, giving a total group sub-pulse width of 15.6 m sec.

As will now be seen, additional circuitry required for securing reversed rotation of the motor purely electrically, when required, is quite small and involves very little increase in manufacturing cost to obtain this facility. Moreover, there being no mechanism required for reversing the direction of rotation and no requirement for the provision of other than a normal stepping motor, the invention is very advantageous from both the operating and manufacturing point of view. In addition, because, during reversed rotation, the inertial force of the rotor is aided by the effects of the applied sub-pulses, the driving voltage applied to the motor coil can be less than is necessary when known methods of reversal are employed but nevertheless stable operation with adequate motor torque can be obtained when reversed rotation takes place.

As a practical example, with a stepping motor as illustrated in Figure 1 and having a rotor made of Samarium-Cobalt material with an outer diameter of 1.3 mm, an inner diameter of 0.7 mm and a thickness of 0.6 mm; a stator having a hole (in which the rotor is situated) of 2 mm diameter; a driv-

ing coil of 2.25 K Ω resistance with 7300 turns; and using sub-pulse widths of 2.4 m sec, 4.9 m sec and 8.3 m sec for the sub-pulses P_1 , P_2 and P_3 respectively, it was found experimentally that very satisfactory operation was obtained when the voltage applied to the motor coil was in the range of 1.1 V to 2.0 V. Indeed experiment indicated that use of a voltage in the range of 1.3 V to 1.8 V was enough to take care of non-uniformity of motor characteristics likely to occur due to mass production of motors.

The invention is not limited in its application to the particular stepping motor herein described and illustrated in Figure 1 but can be used with a wide variety of designs of stepping motors of different shapes of rotor and stator, including motors having coreless driving coils.

WHAT WE CLAIM IS:—

1. An electronic timepiece including time display means driven by a stepping electric motor, means for generating a periodic pulse train and supplying it to said motor for rotating the same in one direction and means for generating a periodic train of groups of at least three sub-pulses which are of successively opposite polarities and supplying the train of groups to said motor for rotating the same in the opposite direction.

2. A timepiece as claimed in claim 1 wherein the periodic pulse train consists of simple pulses and the periodic train of groups consists of groups each of three sub-pulses which immediately follow one another and are of successively opposite polarities.

3. A time piece as claimed in claim 1 or 2 wherein successive pulses in the periodic pulse train are inverted with respect to one another and successive groups in the periodic train of groups of sub-pulses are inverted with respect to one another, the motor having a single driving coil to which the periodic pulse train is supplied for rotation in one direction and the periodic train of groups of sub-pulses is supplied for rotation in the opposite direction.

4. A timepiece as claimed in claim 3 wherein the period of both trains is one second, the width of each pulse in the periodic pulse train is approximately 7.8 m sec, and the width of the successive sub-pulses in each group are approximately 2.4 m sec, 4.9 m sec and 8.3 m sec respectively.

5. A timepiece as claimed in any of the preceding claims and having a crystal controlled time standard oscillator driving a frequency divider comprising a sequence of frequency dividing flip-flop stages wherein the periodic pulse train and the periodic train of sub-pulses are derived by means of a pulse combining circuit fed with output pulses from selected flip-flop stages of the divider and controlled by a control circuit to produce



forms shown in the upper half of Figure 11(b), the three wave forms A, B and C—D showing, respectively, the voltage pulses at the points A and B and between the points C and D in Figure 11(a).

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The operation for reverse rotation of the motor will now be explained. The three curves shown in the lower part of Figure 11(b) apply to reverse direction rotation of the motor. When the wave form P_r at terminal 60 becomes "H", the Q output of FF 70 also becomes "H" and the wave form at the output of the AND/OR gate 71 is the wave form P_r .

However, when driving in the reverse direction, the pulses ϕ_1 , ϕ_2 and ϕ_3 appear at point B and are applied to the clock terminal CL of the FF 75 so that its state is changed every time one of these pulses appears. Accordingly the wave form applied across the motor coil 80 is as shown by the bottom line of Figure 11(b). As an example the widths of the successive sub-pulses making up a group (i.e. the widths of the sub-pulses P_1 , P_2 and P_3 of Figure 4) may be 2.4 m sec, 4.9 m sec and 8.3 m sec respectively, giving a total group sub-pulse width of 15.6 m sec.

As will now be seen, additional circuitry required for securing reversed rotation of the motor purely electrically, when required, is quite small and involves very little increase in manufacturing cost to obtain this facility. Moreover, there being no mechanism required for reversing the direction of rotation and no requirement for the provision of other than a normal stepping motor, the invention is very advantageous from both the operating and manufacturing point of view. In addition, because, during reversed rotation, the inertial force of the rotor is aided by the effects of the applied sub-pulses, the driving voltage applied to the motor coil can be less than is necessary when known methods of reversal are employed but nevertheless stable operation with adequate motor torque can be obtained when reversed rotation takes place.

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The invention is not limited in its application to the particular stepping motor herein described and illustrated in Figure 1 but can be used with a wide variety of designs of stepping motors of different shapes of rotor and stator, including motors having coreless driving coils.

WHAT WE CLAIM IS:—

1. An electronic timepiece including time display means driven by a stepping electric motor, means for generating a periodic pulse train and supplying it to said motor for rotating the same in one direction and means for generating a periodic train of groups of at least three sub-pulses which are of successively opposite polarities and supplying the train of groups to said motor for rotating the same in the opposite direction.

2. A timepiece as claimed in claim 1 wherein the periodic pulse train consists of simple pulses and the periodic train of groups consists of groups each of three sub-pulses which immediately follow one another and are of successively opposite polarities.

3. A time piece as claimed in claim 1 or 2 wherein successive pulses in the periodic pulse train are inverted with respect to one another and successive groups in the periodic train of groups of sub-pulses are inverted with respect to one another, the motor having a single driving coil to which the periodic pulse train is supplied for rotation in one direction and the periodic train of groups of sub-pulses is supplied for rotation in the opposite direction.

4. A timepiece as claimed in claim 3 wherein the period of both trains is one second, the width of each pulse in the periodic pulse train is approximately 7.8 m sec, and the width of the successive sub-pulses in each group are approximately 2.4 m sec, 4.9 m sec and 8.3 m sec respectively.

5. A timepiece as claimed in any of the preceding claims and having a crystal controlled time standard oscillator driving a frequency divider comprising a sequence of frequency dividing flip-flop stages wherein the periodic pulse train and the periodic train of sub-pulses are derived by means of a pulse combining circuit fed with output pulses from selected flip-flop stages of the divider and controlled by a control circuit to produce



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5 either the periodic pulse train or the periodic train of sub-pulses for driving the motor.

5 6. A timepiece as claimed in any of the preceding claims wherein the motor has a rotor with a plurality of permanently magnetised poles and magnetic index means produced by the co-operation of said poles with notches provided in the wall of a stator hole in which the rotor is situated.

10 7. A timepiece as claimed in claim 6 wherein the motor is substantially as herein described with reference to Figure 1 of the accompanying drawings and operates substan-

tially as described herein with reference to Figures 2, 5, 6 and 7 of the accompanying drawings. 15

8. Electronic timepieces substantially as herein described and illustrated in the accompanying drawings.

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