

1 539 989

PATENT SPECIFICATION

(11) 1 539 989

- (21) Application No. 1235/76 (22) Filed 13 Jan. 1976
- (31) Convention Application No. 50/114897
- (32) Filed 25 Sept. 1975 in
- (33) Japan (JP)
- (44) Complete Specification published 7 Feb. 1979
- (51) INT CL² H02K 21/14 1/06 H02P 8/00//G04C 9/00
- (52) Index at acceptance
 - H2A 1101 1902 1C7P
 - G3T 101 401 AAB KC
 - H2J SM



(54) STEPPING MOTOR

(71) We, CITIZEN WATCH COMPANY LIMITED, a corporation organized under the laws of Japan, of No. 9-18, 1-chome, Nishishinjuku, Shinjuku-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 in general to stepping motors and, more particularly, to a reversible stepping motor, e.g. for use in an electronic timepiece.

As is well known, stepping motors, also called pulse motors, are becoming increasingly employed in industrial applications due to the introduction of digital pulse techniques. For example, electronic timepieces have electro-mechanical timekeeping movements which are driven by the stepping motors. Such motors are unidirectional and typically rotate 180° per input pulse. The stepping motor usually comprises a rotor and a stator provided with a driving coil. The stator has two pole pieces which are displaced or offset from each other with respect to a central axis between the pole pieces. With this arrangement, it is difficult to assemble the stator pole pieces so as to provide a stable operation of the rotor. In another expedient, the stator pole pieces are integrally formed with one another and shaped by stamping. This requires the provision of a complicated die for the specific stator pole pieces. In addition, the stepping motor of this type can not be driven in the reverse direction due to its inherent construction.

It has heretofore been proposed to provide various types of reversible stepping motors for use in the electronic timepieces. Each of these stepping motors usually comprises more than three stator pole pieces and two driving coils which provide a larger construction, and is not suited for the electronic timepieces in which a

minimum spacing for the stepping motor is required. Since, further, the stepping motor of this type is driven by four-phase pulses, a driver circuit is necessarily complicated in construction. 50

According to the present invention, there is provided a reversible stepping motor comprising: 55

a permanent magnet rotor having a North pole and a South pole spaced apart around the circumference of the rotor; 60

a stator including a driving coil and two stator pole pieces diametrically opposite one another relative to the rotational axis of said rotor with the rotor between said stator pole pieces, with air gaps being defined between said stator pole pieces on a central line passing through the axis of rotation of said rotor and perpendicular thereto, each of said stator pole pieces having an inwardly rounded periphery, and a higher flux reluctance providing portion on an axis at an angle of 60—90 degrees with respect to said central line to provide an axis of static equilibrium of the rotor at an angle of 0—30 degrees with respect to said central line, each of said axes passing through the axis of rotation of said rotor and being perpendicular thereto, said stator pole pieces being magnetically connected to one another by a magnetically conductive member on which said driving coil is wound; and 70 75 80 85

a driver circuit connected to said driving coil and including gate means connected to a source of clock pulses to alternately apply two-phase pulses to said driving coil to alternately energize said stator pole pieces in North and South polarities for thereby causing said rotor to rotate in a normal direction, and circuit means connected to switch means and responsive to a switching signal delivered therefrom to 90 95

cause said gate means to change the order of supply of said two-phase pulses being applied to said driving coil within a predetermined time interval for thereby causing rotation of said rotor in an opposite direction.

Arrangements embodying the invention will now be described by way of example, with reference to the accompanying drawings, in which:

Fig. 1 is a schematic view of a conventional stepping motor used in an electronic timepiece;

Fig. 2 is a schematic view of another conventional stepping motor used in an electronic timepiece;

Fig. 3 is a schematic view of a preferred embodiment of a stepping motor according to the present invention;

Figs. 4A to 4C are views illustrating a mode of operation of the stepping motor shown in Fig. 3;

Figs. 5A to 5C are views similar to Figs. 4A to 4C but show another mode of operation of the stepping motor shown in Figure 3;

Fig. 6 is a block diagram of an electric circuit for an electronic timepiece having a driver circuit for the stepping motor shown in Fig. 3;

Fig. 7 is a detail circuit diagram of an example of the driver circuit shown in Fig. 6;

Figs. 8 and 9 are wave diagrams of various pulses produced in the driver circuit shown in Fig. 7;

Fig. 10A is a graphical representation of the electric current utilized by the stepping motor shown in Fig. 3 during normal rotation of the rotor;

Fig. 10B is a graphical representation of variations in a rotational angle of the rotor rotated by the electric current shown in the graph of Fig. 10A;

Fig. 11A is a view similar to Fig. 10A but shows a graph of the electric current utilized by the stepping motor shown in Fig. 3 during reverse rotation of the rotor;

Fig. 11B is a view similar to Fig. 10B but shows the variations in the rotational angle of the rotor rotated by the electric current shown in the graph of Fig. 11A;

Fig. 12 is a torque diagram illustrating the operation of the stepping motor shown in Fig. 3 during normal rotation;

Fig. 13 is a view similar to Fig. 12 but shows a torque diagram in a reverse rotation of the rotor;

Fig. 14 is a schematic view of a modified form of the stepping motor shown in Fig. 3; and

Fig. 15 is a schematic view of another modified form of the stepping motor shown in Fig. 3.

Referring now to Fig. 1, there is

schematically shown an example of a conventional stepping motor used in an electronic timepiece. As shown, the stepping motor comprises a permanent magnet rotor 10, and a stator 12 including stator pole pieces 14 and 16 which are driven by a driving coil 18. The stator pole pieces 14 and 16 are arranged such that the centers of radius of curvature are offset from each other by a distance Δt and, thus, the rotor 10 may be stable on an axis A—A' of static equilibrium. Consequently, the rotor 10 is rotated in a single direction by applying alternating current pulses to the driving coil 18 and cannot rotate in the reverse direction. Another drawback is encountered with this prior art motor in that it is difficult to accurately assemble the stator pole pieces.

Fig. 2 shows an example of a conventional reversible stepping motor. As shown, the reversible stepping motor comprises a rotor 20 and a stator 22. The stator 22 comprises four stator pole pieces 30 and 32, which are partly overlapped with each other and magnetically connected to each other by screws 34. Each pole piece is driven by a driving coil 36 wound around a portion of the pole piece. With this construction, the rotor 20 can be rotated in a normal or reverse direction by applying four-phase pulses to the driving coils 36. However, a drawback is encountered with this construction in that the stepping motor is large due to its inherent construction. Thus, the stepping motor of this type is not suited for use in an electronic timepiece such as wrist watch in which a narrow spacing is required for mounting the stepping motor.

The present invention contemplates the provision of an improved stepping motor which is simple in construction and easy to manufacture. A preferred embodiment of a stepping motor to achieve the above concept is illustrated in Fig. 3. In this illustrated embodiment, the stepping motor comprises a permanent magnet rotor 40 which is rotatably mounted in an air gap 42 provided by a stator 44. The stator 44 comprises stator pole pieces 46 and 48, which are magnetically connected to each other by a magnetically conductive elongated member 49. A driving coil 50 is wound around the magnetically conductive elongated member 49 and energized in a manner as will be described in detail hereinafter. The stator pole pieces 46 and 48 have inwardly rounded peripheries 46a and 48a, respectively, which are symmetrical with respect to the center line Y—Y' of air gaps 52 and 52' between the stator pole pieces 46 and 48. The stator pole pieces have portions providing higher flux reluctance of an axis at an angle from 60 to

of
in an
n, the
manent
cluding
70
ich are
or pole
that the
offset
d, thus,
75
s A—A'
ly, the
tion by
to the
in the
80
back is
otor in
ble the

of a
85
otor. As
motor
22. The
pieces
ed with
90
ected to
piece is
round a
th this
tated in
95
pplying
oils 36.
ed with
g motor
uction.
100
e is not
nepiece
narrow
ng the

105
ites the
motor
easy to
ent of a
above
110
In this
epping
et rotor
air gap
ator 44
115
nd 48,
to each
luctive
il 50 is
ductive
120
ed in a
detail
46 and
ies 46a
h are
125
ter line
en the
or pole
er flux
n 60 to
130

90 degrees with respect to the center line
Y—Y' of the air gaps 52 and 52' between
the stator pole pieces whereby an axis of
static equilibrium for the rotor is at an angle
with respect to the center line Y—Y' of
5 from 0 to 30 degrees. More specifically, the
stator pole pieces 46 and 48 have indented
portions 46b and 48b, respectively, on an
axis V—V' at a predetermined angle β , from
10 about 60 to 90 degrees with respect to the
center line Y—Y'. With this arrangement,
the rotor 40 is stable on an axis Z—Z' of
static equilibrium at an angle α , from about
15 0 to 30 degrees with respect to the center
line Y—Y'. The axis Z—Z' coincides with
static equilibrium points 54 and 54' on the
stator pole pieces 46 and 48, respectively.
Fig. 6 illustrates a block diagram of an
electronic timepiece of the quartz crystal
oscillator type incorporating the stepping
motor of Fig. 3. The electronic timepiece
comprises a frequency standard 60 having a
quartz crystal (not shown), a frequency
divisor 62, a wave shaping circuit 64 and a
20 driver circuit 66 connected to a control
switch 68 and the driving coil 50 of the
stepping motor. As shown in Fig. 7, the
driver circuit 66 comprises first and second
NAND gates 70 and 72. The first NAND
25 gate 70 receives at its one input a clock
pulse ϕ_1 passed through by the wave
shaping circuit 64, which also passes a clock
pulse ϕ_2 which is applied to one input of the
second NAND gate 72. The output f of the
30 NAND gate 70 is applied to a reset input of
a first flip-flop 74 and to a set input of a
second flip-flop 76 through an OR gate 78.
The output g of the second NAND gate 72
is applied to a set input of the first flip-flop
40 74 and to the set input of the second flip-
flop 76 through the OR gate 78. A reset
input of the second flip-flop 76 is connected
to the control switch 68. The control switch
68 has a stationary contact 80 connected to
45 the positive power supply terminal 82, a
stationary contact 84 connected to the
grounded side of the power supply, and a
movable contact arm 86 engageable with
either one of the stationary contacts 80 and
50 84. The output b of the "F" side of the first
flip-flop 74 is applied to one input of a third
NAND gate 88. The output a of the "F"
side of the second flip-flop 76 is applied to
another input of the third NAND gate 88
55 and one input of a fourth NAND gate 90.
The output c of "F" side of the first flip-flop
74 is applied to another input of fourth
NAND gate 90. The output d of the third
NAND gate 88 is applied to another input
60 of the first NAND gate 70. The output e of
the fourth NAND gate 90 is applied to
another input of the second NAND gate 72.
The output f of the first NAND gate 70 is
also applied to an inverting amplifier 92
65 connected to the driving coil 50 of the

stepping motor, to which the output g of the
second NAND gate 72 is also applied
through an inverting amplifier 94.
With this arrangement, the movable
contact arm 86 of the control switch 68 is
70 normally held in contact with the stationary
contact 80 connected to the positive power
supply terminal 82. Under this
circumstance, the output a of the second
flip-flop 76 is low, and the outputs d and
75 e of the third and fourth NAND gates
88 and 90 are high. In this instance, the
outputs f and g of the first and second
NAND gates 70 and 72 are alternately
applied to the driving coil 50 of the stepping
80 motor which is consequently rotated in its
normal direction in a manner as will be
described in detail hereinafter.
In contrast, when the contact arm 86 is
brought into momentary contact with the
stationary contact 84 connected to the
85 grounded side of the power supply at the
time instant t_1 , the output a of the second
flip-flop 76 becomes high as shown in Fig.
8. Since, in this instance, the output b of the
first flip-flop 74 is high in response to the
90 input pulse ϕ_1 applied prior to the time
instant t_1 , the output d of the third NAND
gate 88 becomes low whereby the first
NAND gate 70 is inhibited. Since, on the
other hand, the output c of the first flip-
flop 74 is low, the output e of the NAND
95 gate 90 is high. Thus, the clock pulse ϕ_2 is
gated through the second NAND gate 72
and inverted thereby. The second flip-flop
76 is reset in response to the inverted pulse
 ϕ_2 and the output a of the second flip-flop
100 76 becomes low. Therefore, the output d of
the third NAND gate 88 becomes high so
that the clock pulse ϕ_1 is gated through the
first NAND gate 70. Thus, when the control
switch is connected to the grounded side of
the power supply at the time instant t_1 , the
105 driving pulse ϕ_2 is consecutively applied to
the driving coil 50 of the stepping motor
within a predetermined time interval in a
manner as shown by the wave diagram g in
Fig. 8. Subsequently, the driving pulses ϕ_1
and ϕ_2 are alternately applied to the driving
110 coil 50 by which the rotor is rotated in the
reverse direction in a manner as will be
described in detail hereinafter.
If during reverse rotation the contact arm
86 of the control switch 68 is brought into
115 momentary contact with the stationary
contact 84 connected to the grounded side
of the power supply at a time instant t_2 , as
shown in Fig. 9, the output a of the second
flip-flop 76 becomes high. Since at the same
120 time, the output c of the first flip-flop 74 is
high in response to the output f of the first
NAND gate 70 applied to the first flip-flop
74 prior to the time instant t_2 , the output e
of the fourth NAND gate 90 is low and the
125 second NAND gate 72 is inhibited as shown
130

by the wave form g in Fig. 9. Since, on the other hand, the output b of the first flip-flop 74 is low, the output d of the third NAND gate 88 is high so that the clock pulse ϕ_1 is gated through the first NAND gate 70. The output of the first NAND gate 70 is represented by the waveform f in Fig. 9. The second flip-flop 76 is reset in response to the output f of the first NAND gate 70 and the output a is low whereby the clock pulse ϕ_2 is gated through the second NAND gate. Thus, the driving pulse ϕ_1 is consecutively applied to the driving coil 50 of the stepping motor within a predetermined time interval in a manner as shown by the wave diagram f in Fig. 9. Thereafter, the driving pulses ϕ_1 and ϕ_2 are alternately applied to the driving coil 50 whereby the rotor which had been rotated in the reverse direction is allowed to rotate in the normal direction in a manner as will be described in detail.

Fig. 10A illustrates a graphical representation of the electric current utilized by the stepping motor during its normal rotation. Fig. 10B illustrates a curve indicating a rotational angle of the rotor of the stepping motor when the electric current is applied thereto in a manner shown in Fig. 10A.

Fig. 11A illustrates a graphical representation of the electric current utilized by the stepping motor during its reverse rotation. Fig. 11B illustrates a rotational angle of the rotor of the stepping motor when the electric current is applied thereto in a manner as shown in Fig. 11A.

Fig. 12 shows a torque diagram which is plotted in terms of rotational angle of the rotor of the stepping motor during its normal rotation. In Fig. 12, a curve P_1 indicates a driving torque, and a curve T_1 indicates an attraction force applied to the rotor of the stepping motor.

Fig. 13 shows a torque curve which is plotted in terms of the rotational angle of the rotor of the stepping motor during its reverse rotation. In Fig. 13, a curve P_2 represents a driving torque, and a curve T_2 represents an attraction force applied to the rotor of the stepping motor.

Usually, the equation of motion of a reversible stepping motor using a permanent magnet rotor is expressed as follows:

$$J \frac{d^2\theta}{dt^2} + \mu \frac{d\theta}{dt} = A(\theta)i(t) - T(2\theta \pm \alpha) - \rho(\theta) \quad (1)$$

$$L \frac{di(t)}{dt} + A(\theta) \frac{d\theta}{dt} + \rho i(t) = E \quad (2)$$

where

J =moment of inertia of the rotor

μ =coefficient of fluid resistance

A =torque coefficient or coefficient of electromechanical connection which varies as a factor of θ

T =attraction force between the stator and the rotor which varies as a factor of 2θ

θ =rotational angle of the rotor

$i(t)$ =driving current

L =inductance of the driving coil of the stepping motor

E =biasing current

α =phase angle of the attraction force T with respect to the center line of the gaps of the stator pole pieces

ρ =load torque.

The coefficient of the electromechanical connection and the attraction force of the stepping motor used in the electronic timepiece are usually expressed in terms of the center line of the air gaps between the stator pole pieces as follows:

$$A(\theta) = A_0 \sin\left(\theta + \frac{\pi}{2}\right) \quad (3)$$

$$T(2\theta \pm \alpha) = T_0 \sin(2\theta \pm \alpha) \quad (4)$$

$$P = A(\theta)i(t) = A_0 \sin\left(\theta + \frac{\pi}{2}\right) \cdot i(t) \quad (5)$$

Where P =driving torque.

The curves T and P are illustrated in Figs. 12 and 13 as already stated hereinabove. During the normal rotation of the rotor, the difference θ_0 in phases between the attraction force T and the driving torque P is expressed by

$$\theta_0 = \frac{\pi}{2} - \alpha.$$

During reverse rotation of the rotor, the difference θ_0' in phases between the attraction force T and the driving torque P is expressed by

$$\theta_0' = \frac{\pi}{2} + \alpha$$

Since the rotor is stable when $T=0$, the symbol " α " represents an angle of static equilibrium relative to the center line of the air gaps between the stator pole pieces. It is to be noted that the sum of θ_0 and θ_0' is equal to a value π .

The operation of the stepping motor shown in Fig. 3 will now be described in detail as follows:

In case of normal rotation of the rotor, the rotor 40 is initially stationary under a condition in which the north and south poles of the rotor 40 are aligned with the

4
cient
ection
 θ
e stator
a factor
60
65
l of the
70
force T
e of the
ss
75
chanical
e of the
ectronic
erms of
een the
80
(3)
(4)
(5)
85
in Figs.
above.
tor, the
attrac-
P is ex-
90
or, the
attrac-
P is ex-
95
ie sym-
static
s of the
es. It is
l θ_0 ' is
100
motor
bed in
105
rotor,
nder a
saurth
ith the
110

5
1,539,989
5
axis Z—Z' of static equilibrium crossing the
static equilibrium points 54 and 54'. The
static equilibrium point 54 corresponds to a
point A in Fig. 12, and the static equilibrium
point 54' corresponds to a point E in Fig.
12. Under this condition, the pulse ϕ_1 is
applied to the driving coil 50 of the stepping
motor so that the stator pole piece 46 is
energized to a north polarity while the
stator pole piece 48 is energized to a south
polarity. In this instance, the north pole of
the rotor 40 is repulsed by the north
polarity of the stator pole piece 46 and
attracted by the south polarity of the stator
pole piece 48. At the same time, the south
pole of the rotor 40 is repulsed by the south
polarity of the stator pole piece 48 and
attracted by the north polarity of the stator
pole piece 46. Consequently, the rotor 40 is
rotated in a normal direction, i.e.,
clockwise as shown in Fig. 4B. The torque
applied to the rotor 40 becomes positive
after the rotor 40 has been rotated to a posi-
tion in which the north pole of the rotor is
aligned with the axis W—W' crossing the
point 58' corresponding to a point B in Fig.
12 in which $T_1=0$. Accordingly, the rotor 40
is further rotated to a position in which the
north pole of the rotor is aligned with the
axis Z—Z' of static equilibrium crossing the
point 54' corresponding to the point E in
Fig. 12. It is to be noted in this instance that
even when the supply of pulse ϕ_1 to the driv-
ing coil 50 is interrupted before the north
pole of the rotor 40 reaches the point B in
Fig. 12, the rotor 40 is rotatable to this posi-
tion due to its kinetic energy if the pulse
width is sufficiently large.
While the lower limit in the pulse width is
such that the kinetic energy of the rotor is
zero at the point B in Fig. 12, it is desired
that the pulse width be slightly larger than
the lower limit mentioned above the
overcome the load torque. While the upper
limit in the pulse width is not restricted
because the attraction force T_1 is in a
positive range and the rotor tends to rotate
in the normal direction at the point D in
which the sum of the driving torque P_1 and
the attraction force T_1 is zero, it is desired
that the pulse width be set in the order of,
for instance 16 milliseconds for the sake of
minimizing power consumption.
Fig. 4C shows that the rotor 40 is rotated
at 180 degrees to a position in which the
north pole of the rotor 40 is stable at the
static equilibrium point 54' corresponding
to the point E in Fig. 12. The waveform of
the electric current applied to the driving
coil 50 is illustrated in Fig. 10A. In Fig.
10A, a symbol "r" indicates a pulse width,
and broken line represents the waveform of
the electric current when the rotor 40 is
stopped. Fig. 10B shows the mode of
rotation of the rotor. In case of the
electronic timepiece employing the
stepping motor, the coefficient μ of fluid
resistance is relatively small and, therefore,
the rotor is stopped after damped
vibrations. While it is possible to brake the
stepping motor by increasing the value of
the coefficient μ of the fluid resistance, the
power consumption will increase.
As the pulse ϕ_2 is applied to the driving
coil 50 when the rotor 40 remains stable in a
position shown in Fig. 4C, the polarities of
the stator pole pieces 46 and 48 are
reversed so that the north pole of the rotor
40 is repulsed by the north polarity of the
stator pole piece 48 and attracted by the
south polarity of the stator pole piece 46
while the south pole of the rotor 40 is
repulsed by the south polarity of the stator
pole piece 46 and attracted by the north
polarity of the stator pole piece 48. Thus,
the rotor 40 is rotated in the normal
direction through 180 degrees to a position
shown in Fig. 4A. In this manner, the rotor
40 is rotated in the normal direction by the
two-phase pulses alternatively applied to
the driving coil 50.
The mode of reverse rotation of the rotor
will be described with reference to Figs. 5A
to 5C. Fig. 5A shows the state of the rotor
similar to that shown in Fig. 4A. As already
mentioned hereinabove, as the pulse ϕ_2 is
applied to the driving coil 50 when the rotor
40 is stable at a position shown in Fig. 4C,
the rotor 40 is rotated through 180 degrees
to a position shown in Fig. 4A which
corresponds to Fig. 5A. Under these
conditions, if the pulse ϕ_2 is applied again to
the driving coil 50 in a manner as shown by
waveform g in Fig. 8, the stator pole piece
46 is energized to a south polarity while the
stator pole piece 48 is energized to a north
polarity. In this instance, the rotor 40 is
caused to rotate in the reverse direction,
i.e. counterclockwise as shown in Fig. 5B
by the attraction forces applied to the rotor
40. The driving torque P_2 for the rotor is
zero at the point 56 corresponding to the
point C' in Fig. 13. Since, however, the
kinetic energy of the rotor is greater than
the negative attraction torque T_2 , the rotor
40 is rotated to a position shown in Fig. 5N
corresponding to the point B' in Fig. 13 in
which $T=0$. In this situation, the rotor 40 is
further rotated by the positive attraction
force T_2 to a position shown in Fig. 5C, i.e.
a position in which the north pole of the
rotor 40 reaches the static equilibrium point
54' corresponding to the point E' in Fig. 13.
The width of the pulse ϕ_2 is determined in a
manner as already described hereinabove.
Since the attraction force T_2 has a value
within a negative range as shown in Fig. 13
when the sum of the driving power P_2 and
the attraction force T_2 is zero, the rotor 40
is caused to return to the point D' in Fig. 13

if the width of the pulse ϕ_2 is too large and, when the supply of the pulse ϕ_2 to the driving coil 50 is stopped, the rotor 40 tends to rotate to the point A' in Fig. 13 corresponding to the static equilibrium point 54. Therefore, it is desired that the width of the pulse ϕ_2 be determined to be small and preferably in the order of 16 milliseconds.

As previously described, the rotor 40 is rotated through 180 degrees in the reverse direction in response to the pulse ϕ_2 and becomes stable at the point E' corresponding to the static equilibrium point 54' after the damped vibrations for about 30 milliseconds. The wave form of the electric current supplied to the driving coil 50 is illustrated in Fig. 11A. In Fig. 11A, a symbol " τ " indicates a width of the pulse ϕ_2 . Fig. 11B illustrates the mode of rotation of the rotor 40 when the electric current is applied to the driving coil 50 in a manner shown in Fig. 11A. The rotor is subjected to damped vibrations when the supply of the pulse ϕ_2 is stopped. However, the damped vibrations will cease earlier than in the normal rotation because the rotational speed of the rotor during reverse rotation is lower than during normal rotation of the rotor.

As the pulse ϕ_1 is applied to the driving coil 50 when the rotor 40 is stable at the position shown in Fig. 5C, the stator pole piece 46 is energized to a north polarity while the stator pole piece 48 is energized to a south polarity. In this condition, the north pole of the rotor 40 is repulsed by the north polarity of the stator pole piece 46 and attracted by the south polarity of the stator pole piece 48 while the south pole of the rotor 40 is repulsed by the south polarity of the stator pole piece 48 and attracted by the north polarity of the stator pole piece 46. Thus, the rotor 40 is caused to rotate through 180 degrees in the reverse direction to a position shown in Fig. 5A. In this manner, the rotor 40 is continuously rotated in the reverse direction in response to the two-phase pulses alternately applied to the driving coil 50.

In an electronic timepiece equipped with a calendar advance mechanism, it is required that the output torque of the stepping motor be larger than the load of the calendar mechanism during normal rotation of the stepping motor. Since the stepping motor is rotated in the reverse direction only during second zeroing and the load is small, it is preferable to determine the phase difference θ_0 between the driving torque and the attraction force such that the stepping motor provides a maximum efficiency during its normal rotation. In this case, the angle α of static equilibrium ranges from 0 to 30 degrees. In

a case where it is desired to obtain the same operating characteristics for the normal and reverse rotations of the rotor, the phase difference θ_0 between the driving torque and the attraction force is determined to have a value of 90 degrees. In this case, the static equilibrium angle is zero and the operating characteristics of the stepping motor will be slightly lowered during normal rotation of the rotor.

If the phase difference between the driving torque and the attraction force for the reverse rotation of the rotor is set to a value greater than 120 degrees such that the driving torque becomes zero before the attraction force reaches its maximum value, the rotor cannot be rotated to the point B' in Fig. 13 so that the rotor cannot be rotated in the reverse direction and, thus, the rotor is rotatable only in the normal direction.

Fig. 14 illustrates a modified form of the stepping motor of the present invention. In this illustrated modification, the stator pole pieces 46 and 48 have oval-shaped inner peripheries 46'a and 48'a of which apices 96 and 98 lie on the axis V—V' at an angle β with respect to the center line Y—Y' of the air gaps 52 and 52' between the stator pole pieces 46 and 48. With this arrangement, the static equilibrium points 54 and 54' lie on the axis Z—Z' at an angle α with respect to the center line Y—Y'. The stepping motor shown in Fig. 14 will operate in a manner similar to that of Fig. 3 and, therefore, a detailed description of the same is herein omitted. Each of the oval-shaped inner peripheries of the stator pole pieces may be formed by two arcs having different centers of curvature if desired.

Fig. 15 shows a further modified form of the stepping motor of the present invention. In this illustrated modification, the indented portions 46b and 48b are replaced by hollow portions 100 and 102 which are formed in the stator pole pieces 46 and 48. The centers 100a and 102a of the hollow portions 100 and 102 lie on the axis V—V' at an angle β with respect to the center line Y—Y' so that the static equilibrium points 54 and 54' lie on the axis Z—Z' at an angle α . The stepping motor shown in Fig. 15 will operate in a manner similar to that shown in Fig. 3 and, therefore, a detailed description of the same is omitted.

In both of the examples shown in Figs. 14 and 15 the angles α and β are again in the ranges 0 to 30 degrees and 60 to 90 degrees respectively.

It will now be understood from the foregoing description that in accordance with the present invention a stepping motor can be simplified in construction with the use of minimum number of components and is particularly suited for use in an

electronic timepiece such as a wrist watch in which spacing for each component is limited.

It will also be noted that the illustrated stepping motors of the present invention can be rotated either in normal or reverse direction by merely changing the order of supply of alternating current pulses into a single driving coil. The stepping motor comprises two stator pole pieces in addition to the single driving coil and, therefore, the stepping motor can be miniaturized.

It will further be appreciated that in a case in which a stepping motor of the present invention is applied to a wrist watch it is possible to achieve time correction within the shortest period of time by quickly advancing or retarding the hours hand, minutes hand or seconds hand by applying a time correction pulse train of a pulse repetition frequency higher than that normally applied to the driving coil of the stepping motor. The control switch for producing the time correction pulse train may be associated with an external control element such as a push button. In addition, a memory circuit may be provided to store the angular position of the hours hand, minutes hand and seconds hand for thereby producing a number of time correction pulses corresponding in number to the numerical value stored in the memory circuit during time correction, which pulses are applied to the driving coil of the stepping motor whereby quick time correction can be achieved.

While the present invention has been shown and described with reference to particular embodiments, it should be noted that various changes and modifications may be made without departing from the scope of the present invention as defined by the appended claims.

WHAT WE CLAIM IS:—

1. A reversible stepping motor comprising:

a permanent magnet rotor having a North pole and a South pole spaced apart around the circumference of the rotor;

a stator including a driving coil and two stator pole pieces diametrically opposite one another relative to the rotational axis of said rotor with the rotor between said stator pole pieces, with air gaps being defined between said stator pole pieces on a central line passing through the axis of rotation of said rotor and perpendicular thereto, each of said stator pole pieces having an inwardly rounded periphery, and a higher flux reluctance providing portion on an axis at an angle of 60—90 degrees with respect to said central

line to provide an axis of static equilibrium of the rotor at an angle of 0—30 degrees with respect to said central line, each of said axes passing through the axis of rotation of said rotor and being perpendicular thereto, said stator pole pieces being magnetically connected to one another by a magnetically conductive member on which said driving coil is wound; and

a driver circuit connected to said driving coil and including gate means connected to a source of clock pulses to alternately apply two-phase pulses to said driving coil to alternately energize said stator pole pieces in North and South polarities for thereby causing said rotor to rotate in a normal direction, and circuit means connected to switch means and responsive to a switching signal delivered therefrom to cause said gate means to change the order of supply of said two-phase pulses being applied to said driving coil within a predetermined time interval for thereby causing rotation of said rotor in an opposite direction.

2. A reversible stepping motor according to Claim 1, in which said gate means comprises first and second gates each having an input connected to said source of clock pulses, and third and fourth gates connected between other inputs of said first and second gates and an output of said circuit means for controlling said first and second gates in response to said switching signal.

3. A reversible stepping motor according to Claim 2, in which said circuit means comprises first and second flip-flop circuits connected to inputs of said third and fourth gates, said first flip-flop circuit being normally responsive to outputs from said second and first gates to cause said first and second gates to alternately apply said two-phase pulses to said driving coil, and said second flip-flop circuit being responsive to said switching signal to inhibit one of said first and second gates within said predetermined time interval.

4. A reversible stepping motor according to Claim 1, 2 or 3, in which each said higher magnetic flux reluctance providing portion is in the form of an indented portion formed at the inner periphery of the respective stator pole piece.

5. A reversible stepping motor according to Claim 1, 2 or 3, in which said stator pole pieces have oval-shaped inner peripheries by which said higher magnetic flux reluctance providing portions are provided.

6. A reversible stepping motor according to Claim 1, 2 or 3, in which said stator pole pieces each have a hollow formed therein

20

the same
normal
the phase
torque
ained to 70
case, the
and the
stepping
during 75
een the
orce for
set to a
that the
fore the 80
m value,
point B'
not be
d, thus,
normal 85
m of the
ation. In
tor pole
ed inner 90
pieces 96
angle β
Y' of the
tor pole
gement, 95
d 54' lie
respect
stepping
ate in a
3 and, 100
of the
he oval-
tor pole
s having
sired. 105
form of
vention.
on, the
replaced
hich are 110
and 48.
hollow
V—V' at
ter line
n points 115
an angle
15 will
hown in
ription 120
Figs. 14
n in the
degrees
om the 125
ordance
g motor
with the
ponents
in an 130

electronic timepiece such as a wrist watch in which spacing for each component is limited.
It will also be noted that the illustrated stepping motors of the present invention can be rotated either in normal or reverse direction by merely changing the order of supply of alternating current pulses into a single driving coil. The stepping motor comprises two stator pole pieces in addition to the single driving coil and, therefore, the stepping motor can be miniaturized.
It will further be appreciated that in a case in which a stepping motor of the present invention is applied to a wrist watch it is possible to achieve time correction within the shortest period of time by quickly advancing or retarding the hours hand, minutes hand or seconds hand by applying a time correction pulse train of a pulse repetition frequency higher than that normally applied to the driving coil of the stepping motor. The control switch for producing the time correction pulse train may be associated with an external control element such as a push button. In addition, a memory circuit may be provided to store the angular position of the hours hand, minutes hand and seconds hand for thereby producing a number of time correction pulses corresponding in number to the numerical value stored in the memory circuit during time correction, which pulses are applied to the driving coil of the stepping motor whereby quick time correction can be achieved.
While the present invention has been shown and described with reference to particular embodiments, it should be noted that various changes and modifications may be made without departing from the scope of the present invention as defined by the appended claims.
WHAT WE CLAIM IS:—
1. A reversible stepping motor comprising:
a permanent magnet rotor having a North pole and a South pole spaced apart around the circumference of the rotor;
a stator including a driving coil and two stator pole pieces diametrically opposite one another relative to the rotational axis of said rotor with the rotor between said stator pole pieces, with air gaps being defined between said stator pole pieces on a central line passing through the axis of rotation of said rotor and perpendicular thereto, each of said stator pole pieces having an inwardly rounded periphery, and a higher flux reluctance providing portion on an axis at an angle of 60—90 degrees with respect to said central

line to provide an axis of static equilibrium of the rotor at an angle of 0—30 degrees with respect to said central line, each of said axes passing through the axis of rotation of said rotor and being perpendicular thereto, said stator pole pieces being magnetically connected to one another by a magnetically conductive member on which said driving coil is wound; and
a driver circuit connected to said driving coil and including gate means connected to a source of clock pulses to alternately apply two-phase pulses to said driving coil to alternately energize said stator pole pieces in North and South polarities for thereby causing said rotor to rotate in a normal direction, and circuit means connected to switch means and responsive to a switching signal delivered therefrom to cause said gate means to change the order of supply of said two-phase pulses being applied to said driving coil within a predetermined time interval for thereby causing rotation of said rotor in an opposite direction.
2. A reversible stepping motor according to Claim 1, in which said gate means comprises first and second gates each having an input connected to said source of clock pulses, and third and fourth gates connected between other inputs of said first and second gates and an output of said circuit means for controlling said first and second gates in response to said switching signal.
3. A reversible stepping motor according to Claim 2, in which said circuit means comprises first and second flip-flop circuits connected to inputs of said third and fourth gates, said first flip-flop circuit being normally responsive to outputs from said second and first gates to cause said first and second gates to alternately apply said two-phase pulses to said driving coil, and said second flip-flop circuit being responsive to said switching signal to inhibit one of said first and second gates within said predetermined time interval.
4. A reversible stepping motor according to Claim 1, 2 or 3, in which each said higher magnetic flux reluctance providing portion is in the form of an indented portion formed at the inner periphery of the respective stator pole piece.
5. A reversible stepping motor according to Claim 1, 2 or 3, in which said stator pole pieces have oval-shaped inner peripheries by which said higher magnetic flux reluctance providing portions are provided.
6. A reversible stepping motor according to Claim 1, 2 or 3, in which said stator pole pieces each have a hollow formed therein



to form said higher magnetic flux reluctance providing portion.

- 5 7. A reversible stepping motor according to any preceding claim wherein the higher flux reluctance providing portions are situated on an axis at an angle of about 60 degrees with respect to said central line, and said axis of static equilibrium is at an angle of about 30 degrees with respect to said central line.
- 10 8. A reversible stepping motor

substantially as shown and described with reference to Figures 3 to 13, or Figures 3 to 13 as modified by Figure 14 or Figure 15, of the accompanying drawings.

15

R. G. C. JENKINS & CO.,
Chartered Patent Agents,
Chancery House,
53/64 Chancery Lane,
London WC2A 1QU.
Agents for the Applicants.

Printed for Her Majesty's Stationery Office, by the Courier Press, Leamington Spa, 1979
Published by The Patent Office, 25 Southampton Buildings, London, WC2A 1AY, from which copies may be obtained.



* C L M S *