

PATENT SPECIFICATION

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(54) ELECTRIC MOTOR

(71) We, KABUSHIKI KAISHA SUWA SEIKOSHA, a Japanese company of 3-4, 4-chome, Ginza, 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 concerns an electric motor and, although the invention is not so restricted, it is more particularly concerned with an electric motor adapted for use as a stepping motor of a timepiece, e.g. of a wrist watch having a quartz crystal oscillator.

An electric motor is known having a pair of stators and a six pole-rotor. In the case of this type of motor, however, only two of the six magnetic poles produce effective torque, the remaining magnetic poles serving no useful function. Such a motor, therefore, is inefficient, and although the rotor should turn through an angle of 60° at each current pulse, in fact there is a possibility of the rotor turning through an angle of 120°, i.e. through an angle corresponding to two current pulses, due to excessive rotation caused by inertia. Furthermore, a special magnetisation technique is required to provide the rotor with these six poles, while it is extremely difficult to arrange that there is equal magnetisation of each of the six poles.

Another known motor has a rotor which is provided with a permanent magnet, and which is disposed directly within a solenoid. In the case of this particular kind of motor, however, the magnetic field generated within the solenoid is used directly, and consequently the concentration of the magnetic flux cannot be increased, whereby the efficiency of this motor is low.

According to the present invention, there is provided an electric motor having a rotor comprising a permanent magnet which is magnetised to have two poles, at least a portion of the peripheral surface of the rotor being cylindrical, the rotor being disposed between a pair of stator pole pieces, each of which has a cylindrical surface facing the rotor, and at least one coil magnetically connected to the stator pole pieces, the relationship between the

radius R_r of the cylindrical portion of the peripheral surface of the rotor and the radius S_r of the cylindrical surface of each of the stator pole pieces being given by the formula

$$0.6 \leq R_r/S_r \leq 0.9.$$

The stator pole pieces are preferably spaced from each other by a distance of δ_1 on one side of the rotor and by a distance of δ_2 on the diametrically opposite side of the rotor, the relative positions of the rotor and stator pole pieces being such, or being adjustable to be such that

$$1.2 \leq (\delta_1 + \delta_2)/(S_r - R_r) \leq 2.4.$$

Preferably the said relative positions are, or are adjustable to be, such that

$$1.3 \leq (\delta_1 + \delta_2)/(S_r - R_r) \leq 2.2$$

Preferably also the ratio $R_r/S_r \leq 0.8$.

The value of the radius S_r preferably does not exceed 1.5 mm.

Means are preferably provided for adjusting each of the stator pole pieces individually so that the cylindrical surfaces of the stator pole pieces may be disposed at a desired amount of eccentricity both with respect to each other and with respect to the cylindrical portion of the peripheral surface of the rotor.

The whole of the peripheral surface of the rotor may be cylindrical.

The motor is preferably a stepping motor adapted for use in a timepiece.

The invention also comprises a timepiece, e.g. a wrist watch having a quartz crystal oscillator, provided with an electric motor as set forth above.

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

Figure 1 is a diagrammatic view of an electric motor according to the present invention.

Figure 2 illustrates the waveform of pulses applied to a coil of the motor shown in Figure 1.

Figure 3 is a graph showing the relationship between the output torque (in g-cm) measured

at a minute hand of the said timepiece, and the ratio R_r/S_r ,

Figure 4 is a graph showing the relationship between the eccentricity x (in units of 0.1 mm) of the stator pole pieces of the timepiece and the ratio R_r/S_r corresponding to an output torque, measured at the minute hand, of 4 g-cm or more,

Figure 5 is a graph showing the relationship between the factor $(\delta_1 + \delta_2)/(S_r - R_r)$ and the output torque measured at the minute hand, and

Figure 6 illustrates a modified rotor which may be used in an electric motor according to the present invention.

In Figure 1 there is shown an electric stepping motor adapted for use in a wrist watch having a quartz crystal oscillator. The electric motor has a rotor 1 which comprises a permanent magnet which is magnetised to have two poles, namely the N and S poles shown. The rotor 1, the whole of whose peripheral surface 1a is cylindrical, is disposed between and spaced by an air gap from a pair of stator pole pieces 2, 3. The stator pole pieces 2, 3 which almost completely surround the peripheral surface 1a, respectively have cylindrical surfaces 2a, 3a each of which faces the rotor 1. A coil 4, which is magnetically connected to the stator pole pieces 2, 3 is wound about a yoke 5, the yoke 5 being secured to the stator pole pieces 2, 3, by means of screws 6.

The stator pole pieces 2, 3, are respectively provided with elongated slots 2b, 3b in which are slidably mounted end portions of pins 7 whose opposite end portions are mounted in a base plate (not shown) and are eccentric to the first-mentioned end portions. Thus when the screws 6 are slackened off and the pins 7 are rotated, the cylindrical surfaces 2a, 3a of the stator pole pieces 2, 3 may be disposed at a desired amount of eccentricity x with respect to each other and may also be eccentric with respect to the cylindrical peripheral surface 1a of the rotor 1.

As will be seen from Figure 1, the stator pole pieces 2, 3 are spaced from each other by a distance of δ_1 on one side of the rotor 1, and by a distance δ_2 on the opposite side of the rotor 1. The eccentricity x is adjusted to a value which ensures that the rotor 1 will rotate in one direction only, and that the rotor 1, at each of the successive positions to which it is stepped, is so disposed that the magnetic poles N and S are substantially aligned with the narrowest radial widths of the air gap.

The coil 4 is supplied with a current whose voltage waveform is indicated in Figure 2, the said waveform being provided with so-called inversion pulses. For example, positive pulses and negative pulses may be applied alternately every 1 second to cause the rotor 1 to rotate stepwise in one direction only. At each said pulse, N and S poles are generated in the

stator pole pieces 2, 3 in positions with respect to those of the rotor 1 such that the rotor rotates through an angle of 180° .

In Figure 3 there is shown a graph illustrating the relationship between the output torque (measured in g-cm) at the minute hand of the watch when the stator pole pieces 2, 3 are adjusted to generate the maximum output torque, and the ratio R_r/S_r where R_r is the radius of the cylindrical peripheral surface 1a of the rotor 1, and S_r is the radius of the cylindrical surfaces 2a, 3a. In order to drive the watch effectively it is necessary that the output torque should not be less than 4 g-cm, and therefore, as will be seen from Figure 3, the ratio R_r/S_r should be 0.6 or more. Thus, as shown in Figure 3, if the ratio R_r/S_r is too small, the necessary output torque will not be obtained since insufficient magnetic flux will be generated to drive the rotor.

In Figure 4 there is shown a graph which illustrates the relationship between the eccentricity x of the stator pole pieces 2, 3 and the ratio R_r/S_r when the output torque, as measured at the minute hand, is 4 g-cm, x being measured in units of 0.1 mm. If R_r/S_r is 0.9 or less, the stator pole pieces can be adjusted comparatively easily to obtain the output torque of 4 g-cm or more, since x will have a value of 2.5 or more. However, if R_r/S_r exceeds 0.9, and especially as it approaches 1.0, the output torque is considerably affected by the positions of the stator pole pieces and consequently it is quite difficult to adjust the stator pole pieces to the desired position. In fact the ratio R_r/S_r of a conventional stepping motor is 0.92 to 0.97, and although it is possible to obtain the desired output torque from a conventional motor this is difficult to achieve.

As will be seen from Figure 4, if the value of x is 2 or more, the value of the ratio R_r/S_r will not exceed 0.9.

Accordingly, as is illustrated by Figures 3 to 4, the value of the ratio R_r/S_r should be in the range 0.6 to 0.9.

In Figure 5 there is shown a graph which illustrates the relationship between the output torque (in g-cm measured at the minute hand of the watch), and the factor $(\delta_1 + \delta_2)/(S_r - R_r)$, i.e. the ratio of the sum of the gaps δ_1 and δ_2 between the stator pole pieces 2, 3, and the difference between the radii S_r , R_r of the stator pole pieces 2, 3 and the rotor 1 respectively. Since, as indicated above, the output torque should not be less than 4 g-cm, it can be seen from Figure 5 that the factor $(\delta_1 + \delta_2)/(S_r - R_r)$ should be in the range 1.1 to 2.6 and preferably in the range of 1.2 to 2.4.

Thus if $(\delta_1 + \delta_2)/(S_r - R_r)$ is too small, the magnetic flux generated by the coil 4 passes mostly through the gaps δ_1 and δ_2 and does not act adequately on the rotor 1. Moreover, if $(\delta_1 + \delta_2)/(S_r - R_r)$ is too large, the efficiency

of the whole magnetic circuit is decreased. In both cases the desired output torque cannot be obtained.

5 The value of S_r should not be more than 1.5 mm when the motor is used in a wrist watch since space is limited therein. Moreover, if the value of $S_r - R_r$ is 0.1 mm or less, the air gap may be affected by dust or fluff, or by the degree of accuracy to which the cylindrical surfaces of the rotor and stator have been finished, or by the presence of a burr or some other imperfection on the surfaces 2a, 3a. Thus it is difficult to use a difference of $(S_r - R_r)$ of less than 0.1 mm. However, the motor illustrated in the drawings is particularly effective when the magnetic flux of the rotor in its open state is 600G or more.

10 Thus in the case of the electrical stepping motor discussed above, if the radius S_r is arranged to be 1.5 mm or less, the stator pole pieces require either no adjustment or extremely simple adjustment. Moreover, if the hands of the watch are advanced every second, for example, it is possible to restrict power consumption of the stepping motor to a value as little as 4 μ W or less, and it is also possible to drive the timepiece for about two years or more by the use of a single button-type battery. In this case, the output torque of the motor measured at the minute hand is 4 g-cm or more, which is more than five times as large as the necessary torque for the whole gear train of the wrist watch.

15 Thus the arrangement described above enables high power to be generated with low current consumption and at low voltage, while permitting adjustment of the stator pole pieces to be eliminated or very much simplified.

20 Figure 6 illustrates diagrammatically a rotor 1b which may be used in substitution for the rotor 1 of Figure 1. In the case of the rotor 1b, the peripheral surface of the rotor has diametrically oppositely disposed cylindrical portions 1c whose radius is R_r , and diametrically oppositely disposed planar portions 1d. Thus the rotor of the electric motor of the present invention may have any shape provided that at least a portion of the peripheral surface of the rotor is cylindrical, in which case the said R_r will be the radius of this cylindrical portion.

WHAT WE CLAIM IS:—

- 25 1. An electric motor having a rotor comprising a permanent magnet which is magnetised to have two poles, at least a portion of the peripheral surface of the rotor being cylindrical, the rotor being disposed between a pair of stator pole pieces each of which has a cylindrical surface facing the rotor, and at

least one coil magnetically connected to the stator pole pieces, the relationship between the radius R_r of the cylindrical portion of the peripheral surface of the rotor and the radius S_r of the cylindrical surface of each of the stator pole pieces being given by the formula

$$0.6 \leq R_r/S_r \leq 0.9.$$

2. An electric motor as claimed in claim 1 in which the stator pole pieces are spaced from each other by a distance of δ_1 on one side of the rotor and by a distance of δ_2 on the diametrically opposite side of the rotor, the relative positions of the rotor and stator pole pieces being such, or being adjustable to be such, that

$$1.2 \leq (\delta_1 + \delta_2)/(S_r - R_r) \leq 2.4.$$

3. An electric motor as claimed in claim 2 in which the said relative positions are, or are adjustable to be, such that

$$1.3 \leq (\delta_1 + \delta_2)/(S_r - R_r) \leq 2.2$$

4. An electric motor as claimed in any preceding claim in which the ratio $R_r/S_r \leq 0.8$.

5. An electric motor as claimed in any preceding claim in which the value of the radius S_r does not exceed 1.5 mm.

6. An electric motor as claimed in any preceding claim in which means are provided for adjusting each of the stator pole pieces individually so that the cylindrical surfaces of the stator pole pieces may be disposed at a desired amount of eccentricity both with respect to each other and with respect to the cylindrical portion of the peripheral surface of the rotor.

7. An electric motor as claimed in any preceding claim in which the whole of the peripheral surface of the rotor is cylindrical.

8. An electric motor as claimed in any preceding claim in which the motor is a stepping motor adapted for use in a timepiece.

9. An electric motor substantially as hereinbefore described with reference to and as shown in the accompanying drawings.

10. A timepiece provided with an electric motor as claimed in any preceding claim.

11. A timepiece as claimed in claim 10 in which the timepiece is a wrist watch having a quartz crystal oscillator.

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The value of S_r should not be more than 1.5 mm when the motor is used in a wrist watch since space is limited therein. Moreover, if the value of $S_r - R_r$ is 0.1 mm or less, the air gap may be affected by dust or fluff, or by the degree of accuracy to which the cylindrical surfaces of the rotor and stator have been finished, or by the presence of a burr or some other imperfection on the surfaces 2a, 3a. Thus it is difficult to use a difference of $(S_r - R_r)$ of less than 0.1 mm. However, the motor illustrated in the drawings is particularly effective when the magnetic flux of the rotor in its open state is 600G or more.

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Thus the arrangement described above enables high power to be generated with low current consumption and at low voltage, while permitting adjustment of the stator pole pieces to be eliminated or very much simplified.

Figure 6 illustrates diagrammatically a rotor 1b which may be used in substitution for the rotor 1 of Figure 1. In the case of the rotor 1b, the peripheral surface of the rotor has diametrically oppositely disposed cylindrical portions 1c whose radius is R_r , and diametrically oppositely disposed planar portions 1d. Thus the rotor of the electric motor of the present invention may have any shape provided that at least a portion of the peripheral surface of the rotor is cylindrical, in which case the said R_r will be the radius of this cylindrical portion.

WHAT WE CLAIM IS:—

1. An electric motor having a rotor comprising a permanent magnet which is magnetised to have two poles, at least a portion of the peripheral surface of the rotor being cylindrical, the rotor being disposed between a pair of stator pole pieces each of which has a cylindrical surface facing the rotor, and at

least one coil magnetically connected to the stator pole pieces, the relationship between the radius R_r of the cylindrical portion of the peripheral surface of the rotor and the radius S_r of the cylindrical surface of each of the stator pole pieces being given by the formula

$$0.6 \leq R_r/S_r \leq 0.9.$$

2. An electric motor as claimed in claim 1 in which the stator pole pieces are spaced from each other by a distance of δ_1 on one side of the rotor and by a distance of δ_2 on the diametrically opposite side of the rotor, the relative positions of the rotor and stator pole pieces being such, or being adjustable to be such, that

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