

SPECIFICATION

Electro-magnetic stepping motor

This invention concerns an electro-magnetic stepping motor, and although the invention is not so restricted, it is more particularly concerned with an electro-magnetic stepping motor for use in an analogue type quartz electronic timepiece such as a wrist watch.

The present invention has the object of providing an electro-magnetic stepping motor which is of superior performance to previously known motors and which does not necessitate the use of shield plates or the like to protect the motor from the effect of external magnetic fields.

According to the present invention, there is provided an electro-magnetic stepping motor comprising a magnetically permeable core having a coil wound thereabout, and a one-piece stator of magnetically permeable material which is magnetically coupled to the core and which has an aperture therein within which is rotatably mounted a rotor having magnetic poles, the wall defining the aperture having recesses therein, which control the operation of the rotor, the core being made of a material having a saturation flux density of at least 11,000 Gauss, the stator being made of a material having a saturation flux density in the range of 7000 to 8000 Gauss, and the cross-sectional area of the core being less than 1.0 mm^2 , the arrangement being such that the motor is able to operate in an external magnetic field of up to 20 Gauss without the use of a shielding plate.

Preferably the stator has recesses in its external surfaces, which recesses are disposed adjacent to the said aperture so that the thinnest portions of the stator are disposed adjacent to the rotor.

The saturation flux density of the core may be at least 12,000 Gauss and the saturation flux density of the stator may be in the range 7,000 to 7,200 Gauss.

The cross-sectional area of the core is preferably between 0.6 and 0.7 mm^2 . Thus the core may be square in cross-section, each of the sides of the cross-section being substantially 0.8 mm in length.

The invention also comprises an electronic timepiece provided with a stepping motor as set forth above.

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

Figure 1 is a plan view of a conventional stepping motor;

Figure 2 shows a conventional drive voltage waveform employed to drive the stepping motor of Figure 1;

Figure 3 is a plan view of a stepping motor of the type with which the present invention is concerned;

Figure 4 is a view similar to Figure 3 but illustrating diagrammatically the distribution of the magnetic flux in the stepping motor;

Figure 5 illustrates the flux distribution which occurs in an ellipsoidal core when the latter is placed in an uniform magnetic field, and

Figure 6 is a graph whose ordinate represents the ratio between the flux density in the magnetic material of the ellipsoidal core of Figure 5 and the flux density externally thereof, and whose abscissa represents the ratio between the short axis and the long axis of the ellipsoidal core.

In Figure 1 there is shown a conventional electro-magnetic stepping motor for an electronic timepiece which comprises two magnetically permeable stator members $1a$, $1b$ each of which is magnetically coupled to a magnetically permeable core 2 having a coil $2a$ wound thereabout. The stator members $1a$, $1b$ have curved surfaces $1c$, $1d$ respectively which face each other and between which there is a cylindrical space in which is rotatably mounted a permanently magnetised rotor 3 having diametrically oppositely disposed peripherally located poles N, S. The relative positions of the stator members $1a$, $1b$ can be adjusted so as to ensure that the rotor 3 rotates in one predetermined angular sense only. Rotation of the rotor in this sense is achieved by supplying the coil $2a$ with a drive voltage whose waveform is shown in Figure 2. As will be seen from Figure 2, the waveform comprises pulses of opposite polarity separated by one second intervals.

In Figure 3 there is shown an electro-magnetic stepping motor for an electronic timepiece of the type with which the present invention is concerned. The motor of Figure 3 comprises a magnetically permeable core 5 having a coil $5a$ wound thereabout. An one-piece stator 4 of magnetically permeable material having a high saturation flux density is magnetically coupled to the core 5 and has an aperture $4a$ therein within which is rotatably mounted a permanently magnetised rotor 6 having diametrically oppositely disposed peripherally located magnetic poles N, S. The wall of the aperture $4a$ has a pair of diametrically oppositely disposed recesses $8a$, $8b$ therein which determine the stopping positions of the rotor and ensure that the rotor 6 always rotates in one predetermined angular sense. Thus the provision of the recesses $8a$, $8b$ simplifies the construction of the stepping motor since it enables the stator 4 to be of one-piece construction instead of the two-piece construction of the stator $1a$, $1b$ of Figure 1.

The stator 4 has recesses $4b$, $4c$ in its external surfaces, the recesses $4b$, $4c$ being disposed adjacent to the aperture $4a$ so that the thinnest portions $4d$, $4e$ of the stator 4 are disposed adjacent the rotor 6. This arrangement ensures that the stator 4 is, in operation, provided with poles $7a$, $7b$ located in the portions $4d$, $4e$ respectively.

In a conventional stepping motor of the type shown in Figure 3, it would be usual to make both the core 5 and the stator 4 of the material sold under the Trade Mark 78—Permalloy. If such

78—Permalloy material is used, however, it is necessary for the core 5 to have relatively large cross-sectional dimensions in order to ensure that, in operation, sufficient flux is produced to saturate the portions 4d and 4e of the stator 4. An increase in the cross-sectional dimensions of the core 5 reduces the resistance and therefore increases the winding efficiency thereof, but reduces the efficiency of the stepping motor as a whole.

In accordance with the present invention, therefore, the core 5 is made of a material having a higher saturation flux density than that of the stator 4. Thus the saturation flux density of the core 5 may be at least 11,000 Gauss, and preferably at least 12,000 Gauss, while the saturation flux density of the stator 4 may be in the range 7,000 to 8,000 Gauss and preferably in the range 7,000 to 7,200 Gauss.

Figure 4 is a view of a stepping motor of the type with which the present invention is concerned which is similar to Figure 3 but on which the magnetic flux distribution is schematically represented. In Figure 4, Φ_1 is a magnetic flux which is produced by the permanently magnetised rotor 6, Φ_{4d} and Φ_{4e} are the portions of the magnetic flux generated by the rotor 6 which are necessary for respectively effecting saturation of the portions 4d, 4e of the stator 4, and Φ_3 is the magnetic flux which is induced in the core member 5 by an external magnetic field. Further magnetic flux, Φ_5 , does of course exist for driving the rotor 6, after the portions 4d, 4e of the stator 4 have been saturated, but this flux Φ_5 is not shown in Figure 4 since it is very small in comparison with the other magnetic flux.

A known stepping motor of the type shown in Figure 3 may have the following dimensions:—

Outer diameter of the rotor 6: 1.3 mm

20 Thickness (i.e. axial length) of the rotor 6: 0.6 mm

Inner diameter of the aperture 4a of the stator 4: 2.0 mm

Thickness of the stator 4: 0.7 mm

Cross-sectional dimensions of the core 5: 1 mm x 1 mm

Length of the core 5: 10 mm

25 Material of the rotor 6: SmCo₅

Material of the stator 4: 78 "Permalloy"

Material of the core 5: 78 "Permalloy"

In the rotor referred to in the preceding paragraph:—

$\Phi_1 = 40$ Maxwell

30 $\Phi_4 = \Phi_{4d} + \Phi_{4e}$
 $= 2 \times 0.01 \times 0.07 \times 7,200$
 $= 10.08$ Maxwell

(Since the width of each of the portions 4d, 4e is 0.1 mm, the thickness is 0.7 mm, and the saturation flux density is 7,200 Gauss); and

35 $\Phi_0 = \Phi_1 + \Phi_4$
 $\div 50$ Maxwell.

The magnetic flux capacity of the core 5, i.e.

$\Phi_c = 7,200 \times 0.1 \times 0.1$
 $= 72$ Maxwell, and therefore

40 $\Phi_c - \Phi_0 \div 22$ Maxwell

so that the difference between the flux through the stator 4 and that through the core 5 is of the order of 20 Maxwell. Thus, the stepping motor is designed to be able to operate even when in an external magnetic field of up to 20 Maxwell.

When an external magnetic field is applied to the stepping motor having a long, thin core, it is concentrated. As shown in Figure 5, if the core 5 is represented as an ellipsoid of revolution disposed in a uniform magnetic field, then, according to the shape, i.e. to the relation between the length and width of the core, there may be 100 times as much magnetic flux density in the core than there is external flux density. As will be seen from Figure 5, the flux density is concentrated in the ellipsoid and the magnetic flux density extends in the direction of the long axis thereof. With the stepping motor described above, the magnetic flux density induced in the core 5 by the external field will thus be about 20 Maxwell if the

external magnetic field is 20 Gauss, and the core 5 will then be saturated. If the core 5 is saturated, however, driving power is not applied to the rotor 6 which therefore does not rotate.

In order to ensure that the stepping motor has an anti-magnetic level of 20 Gauss, it has been necessary in the past to provide a shielding plate in the neighbourhood of the stepping motor to shield the motor from external magnetic fields.

As indicated above, the conventional dimensions for the stepping motor have been to provide the core 5 with cross-sectional dimensions of 1 mm x 1 mm. However, such dimensions do not make for efficiency, since it is more efficient to have a core 5 of reduced cross-sectional size.

In an embodiment of the present invention, therefore, instead of making the core 5 from the conventional 78 Permalloy, the core 5 is made of the material sold under the Trade Name 45 Permalloy having a saturation flux density of 12,000 Gauss. Thus, by continuing to use 78 Permalloy for the stator 4, it is arranged that the core 5 is made of a material having a higher saturation flux density than that of the stator 4.

In order to obtain the same magnetic flux capacity as in the conventional 78 Permalloy core of 1 mm x 1 mm, it is desirable in the case of the present invention that the cross-sectional area of the core (SC) should be as follows:—

$$SC = (7,200/12,000) \times 1 \text{ mm}^2 \\ = 0.6 \text{ mm}^2.$$

Consequently, if, for example, the core is of square cross-section then each of the sides of the core will need to be substantially 0.8 mm in length. Such an arrangement improves the efficiency of the stepping motor.

In the Table below, there are shown the characteristics of cores whose sides are 0.8 mm x 0.8 mm and of cores whose sides are 1 mm x 1 mm, the coils having the same diameter in each case and being wound so that the outer diameter of the wound coils is the same in each case.

TABLE

Cross Sectional Dimensions of Core	Characteristics		
	Resistance	No of Turns of Coil	Magnetomotive Force (N x I)
0.8mm x 0.8mm	2.5 kΩ	9,300	5.84
1.0mm x 1.0mm	2.3 kΩ	8,200	5.50

Coil: 51 Ω/m

Outer diameter of wound coil: 2.5 mm

Actual length of wound coil: 8.2 mm

The ratio of the magnetomotive force of the two cores referred to in the Table is 5.84/5.50 = 1.06. Consequently the efficiency of a stepping motor having the 0.8 mm x 0.8 mm core is about 6% greater than that of the one having the 1.0 mm x 1.0 mm core.

Thus there is a significant improvement in efficiency by arranging that the core 5 is made of a material, namely 45 Permalloy, having high magnetic permeability and high saturation magnetic flux density.

In the graph shown in Figure 6, the abscissa represents the ratio of the short axis to the long axis of the ellipsoid shown in Figure 5, and the ordinate represents the ratio of the flux density in the magnetic material of the ellipsoid to the external flux density. As the graph shows, the amount of external magnetic flux which can be concentrated in the core 5 is affected by the length and width, i.e. the cross-sectional dimensions, of the core 5. Thus the external magnetic field which is concentrated in the core 5 becomes smaller as the core 5 is shortened. It is possible in the case of the present invention to omit a shield plate by reason of the fact that the amount of external magnetic flux concentrated in the core 5 is arranged to be less than 20 Maxwell.

As may be deduced from Figure 6, the ratio of the average thickness of the wound portion of the core 5 to the length of the core 5 is preferably greater than 1:10. If this ratio is greater than 1:10, the ratio of the flux density of the core 5 to the external flux density is, as shown by Figure 6, less than 100. That is to say, if the core is rectangular in cross-section, then the said average thickness will be given by the average

$$\frac{l + w}{2}$$

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where l and w are the lengths of the sides of the rectangle. If the core is circular form, then the average thickness is constituted by its average diameter.

The invention thus not only provides a stepping motor of improved efficiency, but also enables the stepping motor to be used in a small analogue quartz wrist watch, because the fact that an outer shield plate does not need to be used enables the size of the stepping motor to be reduced.

CLAIMS

1. An electro-magnetic stepping motor comprising a magnetically permeable core having a coil wound thereabout, and a one-piece stator of magnetically permeable material which is magnetically coupled to the core and which has an aperture therein within which is rotatably mounted a rotor having magnetic poles, the wall defining the aperture having recesses therein, which control the operation of the rotor, the core being made of a material having a saturation flux density of at least 11,000 Gauss, the stator being made of a material having a saturation flux density in the range of 7000 to 8000 Gauss and the cross-sectional area of the core being less than 1.0 mm², the arrangement being such that the motor is able to operate in an external magnetic field of up to 20 Gauss without the use of a shielding plate.
2. A motor as claimed in claim 1 in which the stator has recesses in its external surfaces, which recesses are disposed adjacent to the said aperture so that the thinnest portions of the stator are disposed adjacent the rotor.
3. A motor as claimed in claim 1 or 2 in which the saturation flux density of the core is at least 12,000 Gauss, and the saturation flux density of the stator is in the range 7,000 to 7,200 Gauss.
4. A motor as claimed in any preceding claim in which the cross-sectional area of the core is between 0.6 and 0.7 mm².
5. A motor as claimed in claim 4 in which the core is square in cross-section, each of the sides of the cross-section being substantially 0.8 mm in length.
6. An electro-magnetic stepping motor as claimed in claim 1 and substantially as hereinbefore described with reference to and as shown in Figures 3 and 4 of the accompanying drawings.
7. An electronic timepiece provided with a stepping motor as claimed in any preceding claim.



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