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PERMANENT MAGNET STEPPING MOTOR

The present invention relates to a permanent magnet stepping motor which is driven by DC current and makes stepwise rotation, and it is particularly designed to reduce or minimize the leak of magnetic flux to the outside of the motor, so as to be used, for example, as a motor to drive the magnetic head of a magnetic disc used as a peripheral instrument of an electronic computer.

If the magnetic flux leaking outside from the stepping motor which drives a magnetic head is large, it gives rise to the problem of erasing information memorized on the magnetic disc. To avoid this trouble, it is required to reduce the leaking magnetic flux generated from the motor as much as possible. In order to cope with this, conventionally the periphery of the motor is encircled by magnetic shield plates, or a magnetic plate is placed between the magnetic disc and the motor and the motor is installed on the side of the magnetic plate opposite the magnetic disc. With these conventional arrangements, however, there are problems due to insufficient reduction of leaking magnetic flux, a

requirement for additional space and they are also uneconomical.

The present invention seeks to overcome the problem of insufficient flux. It has been found that this can be achieved by providing a permanent magnet stepping motor comprising:

a magnetized rotor on a shaft, the rotor comprising a circular-plate permanent magnet sandwiched between two circular rotor yokes of ferro-magnetic material, the outer diameter of the yokes being D_o and the thickness of the yokes along the shaft being L ;

a stator adjacent the rotor, the stator having coils adapted to carry current to magnetize the stator thereby to cause stepwise rotation of the rotor, the stator and the rotor having opposing surfaces spaced by a distance G_1 ; and

a casing of a ferro-magnetic material mutually supporting the rotor and stator and entrapping magnetic flux around them, the casing having cylindrical flanges extending axially of the shaft towards the rotor, the outer diameter of the flanges being D_1 and the inner diameter being D_2 , each rotor yoke having a surface opposing the free end surface of a corresponding flange, the distance between the opposing surfaces of the yoke and corresponding flange being D_1 ,

wherein the dimensions of the motor satisfy the relationship

$$D_1/G_1 > n \cdot (D_1^2 - D_2^2)/(4D_o \cdot L)$$

thereby to reduce the magnetic flux leakage from the motor to $1/n$ of the effective magnetic flux, n being any natural number.

The ferro-magnetic casing entraps magnetic flux around the stator and rotor, thereby reducing magnetic flux leakage. Also, because the entrapping material is a

structural element of the rotor, the size of a rotor according to the present invention may be smaller than in conventional arrangements.

5 The casing may comprise two parts, one on each side of the stator and secured thereto by fastenings, e.g. nuts and bolts of a magnetic material.

An embodiment of the present invention will now be described in detail, by way of example, with reference to the accompanying drawings, in which:

10 Fig. 1 is a sectional drawing of a motor being one embodiment of the present invention.

Fig. 2 is a drawing showing the outer appearance of the motor exhibited in Fig. 1.

15 Fig. 3 is a sectional drawing of the motor of Fig. 1 along a plane perpendicular to the plane of Fig. 1.

Fig. 4 shows a development of Fig. 3 along the direction of the air gap.

Fig. 5 indicates the dimensional relationship of various parts of the motor.

20 Fig. 6 is a sectional drawing for demonstrating the effect of the present invention in comparison with a conventional motor.

Fig. 7 is a chart showing one example of measured data of the magnetic flux leaking outside of the motor
25 related to the present invention.

Referring first to Figs. 1 and 2, the rotor 1 of the motor comprises rotor shaft 2, permanent magnet 3 and rotor yokes 4 and 4'. The permanent magnet 3 is in the shape of a circular plate which is magnetized in poles, one surface
30 being a positive (N) pole and another being a negative (S) pole, seen from the direction perpendicular to the plate surface, namely along the shaft direction. The permanent magnet is sandwiched between the rotor yokes 4 and 4' respectively which are

made of magnetic plates, and this component is mounted on rotor shaft 2, the rotor shaft 2 extending through an axial bore on the rotor 1. The rotor 1 and the rotor shaft therefore rotate as a single unit. The casing of the motor is in two parts, a front cover 5 and a rear cover 9. The front cover 5 consists of an outer cylindrical surface 6, an annular side 7 and a flange 8 extending axially towards the rotor from the inner edge of the side 7. The front cover 5 thus forms a unitary part of magnetic material. Similarly, the rear cover 9 of the motor, consists of an outer cylindrical surface 10, an annular side 11 and a cylindrical flange 12. Ball bearings 13 and 14 hold the shaft 2 of rotor 1 at two points along its length at its front end and rear end (the side where the rotor shaft is protruding outside being the front). The bearings 13 and 14 are mounted on the inner surface of the cylindrical flanges 8 and 12. The shaft 2 and the rotor 1 are thus free to rotate within the casing. Retaining rings 15 and 16 prevent axial movement of the ball bearings 13 and 14. A stator 17, which is made of layers of stamped out magnetic iron plates, is firmly fixed to the outer cylindrical surface 6 of front cover 5 and outer cylindrical surface 10 of rear cover 9 respectively to form a single unit. The inner surface of the stator 17 opposes the outer periphery of rotor yokes 4 and 4' across a small air gap. The stator coils 18 are wound round the stator 17, and are connected to a power supply via lead wires 19. The stator 17 is secured to the front cover 5 and the rear cover 9 by nuts and bolts 20 made of a ferro-magnetic material. The nuts and bolts 20 also serve to secure the motor in place.

As shown in Fig. 3, teeth are provided on the outer periphery of the rotor yokes 4 and 4' which oppose the inner surface of the stator. The teeth are spaced apart by the same pitch to provide the variations of permeance (equivalent to the reciprocal number of the magnetic resistance, called permeance). Furthermore, teeth are provided on the inner surface of the stator opposing the aforesaid outer periphery of the rotor, the teeth on the stator 17 having a different pitch from those on the rotor 5. As shown in Fig. 3, stator coils 18 have a terminal A at the start thereof and a terminal C at the end thereof. Another stator coil 21 (not shown in Fig. 1) is wound around the stator 17, starting at a terminal B and ending at a terminal D. In the developed drawing shown in Fig. 4, the number of the teeth on the stator and the rotor yokes is reduced as compared with the number in Fig. 3 in order to illustrate more clearly the operation of the motor.

The rotating motion of the stepping electric motor of the aforesaid structure will now be described with reference to Figs. 3 and 4. First, if stator 17 is magnetically excited as shown by S(1) in Fig. 4 by letting a current flow from terminal A of stator 18 toward terminal C, rotor 1 is stabilized at the position R(1) in Fig. 4. In Fig. 4 all the poles on the rotor 1 are shown as positive (N) poles. This is because the development chart is a section along a plane, including rotor yoke 4 at the left side in Fig. 1. In a development chart sectioned at the plane involving rotor yoke 4', all the poles on the rotor 1 would be negative (S) poles. In the description to follow, it is assumed that the positive (N) poles appear as shown in Fig. 4. Next, when the

current flows through stator coil 21 from terminal B toward terminal D, the stator 17 is magnetically excited as indicated in S(2), and therefore rotor 1 becomes stabilized at position R(2). By this shift from position R(1) to position R(2), the rotor 1 has moved one step. 5 Next, when current flows from terminal C toward terminal A, the rotor is magnetically excited as shown in S(3) and the rotor 1 becomes stabilized at R(3). By this shift from position R(2) to position R(3) the rotor 1 10 has made another one-step move. In the same manner, if the current flows from terminal D toward terminal B, the rotor 1 is magnetically excited and the rotor 1 stabilizes at position R(4). By this shift from position R(3) to R(4) the rotor (1) has made another one-step 15 move. By repeating the above-mentioned motion, the rotor is driven to rotate stepwise.

The present invention uses the technical concept that the leakage of the magnetic flux outside the motor can be reduced by structuring the front cover 5 20 and rear cover 9 with magnetic material, so that the leaking magnetic flux generated inside the motor flows through the front and rear covers. Thus, as mentioned earlier, the casing formed by outer cylindrical surfaces 6 and 10, side parts 7 and 11, and cylindrical flanges 25 8 and 12 of front cover 5 and rear cover 9 respectively are made of magnetic materials and formed into a single unit. The front and rear covers can be formed by forging magnetic materials, such as iron, or by sintering magnetic powder, or by binding the magnetic powder with 30 synthetic resin. By this structure, the leaking magnetic flux that is generated when stator 17 is magnetically excited, or the leaking magnetic flux that

is generated from permanent magnet 3 when stator 17 is in a demagnetized state, flows through front cover 5 and rear cover 9, as indicated by a dotted line in Fig. 1, and the magnetic flux leaking to outside the motor is thereby reduced.

In the present invention, it is sought to minimise the magnetic flux leaking outside the motor. A detailed study of the magnetic flux flow inside the motor was made, and Fig. 5 demonstrates the flow of magnetic flux inside the motor in general. Fig. 5 is generally similar to Fig. 1 and the same reference numerals are used, with the outer diameter of rotor yokes 4 and 4' being D_o , length of rotor yokes 4 or 4' axially at the shaft being L , the outer diameter and inner diameter of the cylindrical flanges being D_1 and D_2 respectively, the distance between the free end surface of the cylindrical flanges of the front and rear covers and the opposing end surface of the rotor yokes being D_4 , and the width of the air gap between the outer periphery of rotor yokes 4 and 4' and the inner surface of stator 17 being G_4 . In Fig. 5, the magnetic flux shown by a dotted line, which flows through permanent magnet 3, stator yokes 4 and 4' and stator 17, is the effective magnetic flux, which is necessary for rotating the motor, while the magnetic flux exhibited by the one-dot chain line which flows through permanent magnet 3 to rotor yoke 4 to front cover 5 to stator 17 to rear cover 9 to rotor yoke 4' and back to permanent magnet 3 is the leakage magnetic flux. Thus most of the leakage magnetic flux flows through the front and rear covers. There is some magnetic flux which leaks out from the front and rear covers, but the amount of this is small. This magnetic flux leaking outside has



has been found to be almost proportional to the magnetic flux flowing within the magnetic path when the magnetic path of the leaking magnetic flux which includes the front and rear covers is not saturated. Therefore, in order to
 5 reduce the magnetic flux leaking outside the motor, it is important not to saturate the magnetic path through which the leaking magnetic flux flows back as exhibited by a one-dot chain line, and also to reduce the magnetic flux leakage itself.

10 To compare the amount of the effective magnetic flux which participates in the rotation of the motor with that of the leaking magnetic flux which flows back through the front and rear covers, the space permeance of the respective paths of these magnetic fluxes has to be
 15 analysed. The space permeance P of the magnetic path is equal to the amount represented by

$$P = \mu_0 \cdot A/l$$

where A is the dimension of the magnetic path along the direction perpendicular to the magnetic path, l is the
 20 length of opening and μ_0 is the magnetic permeance (which is almost equal to that of a vacuum). The gap permeance P_m of the effective magnetic flux will be

$$P_m = \mu_0 \cdot \frac{D_0 \cdot L}{G_l} \dots\dots\dots (1)$$

the gap width G_l being the effective gap width taking
 25 into account the length of teeth when teeth are provided. On the other hand, the space permeance P_l of the leakage magnetic flux will be

$$P_l = \mu_0 \cdot \frac{(D_1^2 - D_2^2)}{4 \cdot D_l} \dots\dots\dots (2)$$

Assuming that the magnetic exciting power of the magnetic flux of the respective parts is fixed, it is proportional to the permeance of the respective openings, so that in order to increase sufficiently the effective magnetic flux participating in generating the torque of the motor and also to reduce the leakage magnetic flux which may be harmful as well as useless, the ratio of P_m and P_l has to be increased. The ratio is:

$$P_m / P_l = \frac{D_t}{G_t} \cdot \frac{4D_0 \cdot L}{D_1^2 - D_2^2} \dots\dots\dots (3)$$

In this equation (3), the first term on the right hand side represents the ratio of the width of the leakage magnetic path and that of the effective magnetic path, while the second term represents the ratio between the sectional dimension of the effective magnetic path and that of the leakage magnetic path.

Study has been made of the equation (3) in the following in comparison with the result of an actual experiment. Fig. 7 is a chart which demonstrates the relationship between D_t/G_t and the magnetic flux leaking outside the motor, in the case of a compact stepping electric motor with a structure as shown in Fig. 1 and for driving a magnetic head, when $G_t = 0.03$ mm and D_t is varied within the range of 0.3 - 6 mm. In this case, $D_0 = 22$ mm, $D_1 = 22$ mm, $D_2 = 16$ mm and $L = 4$ mm, so that the value of the second term in the equation (3), namely $4D_0 \cdot L / (D_1^2 - D_2^2)$ will be about 15, while the actual measurement taken of the effective magnetic flux density was about 1,200 gauss (0.12T). In Fig. 7, the ordinate represents the density of magnetic flux, while the solid-line curve represents the density of the magnetic flux

leaking outside which was actually measured at the point G indicated in Fig. 1, and the broken-line curve exhibits the relationship between the leak magnetic flux and D_l/G_l both of which were calculated on the basis of the
 5 effective magnetic flux = 1,200 gauss (0.12T) and $4D_0 \cdot L / (D_1^2 - D_2^2) = 1.5$, provided the following equation :

$$\frac{\text{Effective Magnetic Flux}}{\text{Leading Magnetic Flux}} = \frac{D_l}{G_l} \cdot \frac{4D_0 \cdot L}{D_1^2 - D_2^2} \dots(4)$$

The difference of the magnetic flux density between the
 10 solid-line curve and the broken-line curve of Fig. 7 represents the difference between the leak magnetic flux flowing through the front and rear covers of the motor and the magnetic flux leaking outside of the motor. As can be seen from Fig. 7, the magnetic flux leaking
 15 outside the motor and the leaking magnetic flux flowing through the front and rear covers are almost proportional. From this fact, it is evident that a reduction in the magnetic flux leaking outside the motor can be attained by reducing the leakage magnetic flux flowing through
 20 the front and rear covers, and this can be accomplished, as is evident from equation (4), by increasing the value of $(D_l/G_l) \cdot (4D_0 \cdot L / (D_1^2 - D_2^2))$. The effective magnetic flux is the magnetic flux necessary for the rotation of the motor and has a fixed value in a given
 25 motor.

Furthermore, if the allowable maximum value of the density of the magnetic flux leaking outside the motor be given, the allowable minimum value of the right sides of the equations (3) and (4) respectively, will be known. As
 30 mentioned above, the density of the magnetic flux leaking

outside the motor is generally smaller than the density of the leakage magnetic flux flowing through the front and rear covers, and even in the worst case, it can be considered equal to the leaking magnetic flux. Therefore

5 by setting up the relation of

$$D_L / G_L > n \cdot (D_1^2 - D_2^2) / (4D_0 \cdot L)$$

the leakage magnetic flux flowing through the motor's front and rear covers can be controlled to less than $1/n$ of the effective magnetic flux, and also the

10 magnetic flux leaking outside the motor can be controlled to less than $1/n$ of the effective magnetic flux.

Therefore, by choice of the dimensions of the motor, n can be selected to produce a suitably small leakage magnetic flux.

15 Fig. 6 is a sectional drawing of a conventional permanent magnet-type stepping motor, wherein 22 is the front cover and 23 is the rear cover. A structure, wherein the front and rear covers are composed of an outer cylindrical surface, a side and an inner
20 cylindrical flange, formed into one unit, has been known, but in the conventional cases, the one-unit structure was made of a non-magnetic material, such as die-cast aluminium, and further, as indicated by the numbers of 24 and 25 in Fig. 6, it is usual to put a
25 slant towards the ends of the inner cylindrical flanges opposing the outer periphery of rotor in order to reduce the wall thickness towards the end of the flange, to save material and for convenience at the time of manufacture. On account of this structure, a large
30 amount of magnetic flux leaks outside the motor as shown by a two-dots-chain line in Fig. 6.

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Besides above, whereas conventionally bolts and nuts made of such non-magnetic materials as brass were used to hold the stator to the front and rear covers, by changing this material to iron or any other magnetic materials the leakage magnetic flux flows directly to the front and rear covers, and the magnetic flux leaking outside is reduced. A practical example of this effect is shown in Table-1. This shows the result of measurement of the magnetic density leaking outside a conventional motor wherein the front and rear covers are made of non-magnetic material at the point G in Fig. 6 as compared with the embodiment of the present invention as shown in Fig. 1 wherein iron covers are employed with the values of the right sides of the equations (3) and (4) respectively being set at around 60, and compared with the case when iron bolts and nuts are used for holding the covers to the stator.

Table - 1

	Conventional Motor with Non-Magnetic Covers		Motor of Present Invention with Iron Covers		Motor of Present Invention with Iron Core and Iron Bolt & Nut	
Magnetic Flux Density	W.E. *	12 V, 2** P.E.	W.E.	12 V, 2 P.M.E.	W.E.	12 V, 2 P.E.
Gauss	100	100	15	15	10	10
Note:	* W.E. - Without excitation ** 12 V, 2 P.E. - 12 V. 2 phase magnetic excitation					

Thus, as described, according to the present invention, the manufacture of a motor, equipped with a structure which ensures that the magnetic flux leaking outside at the motor is less than the maximum permissible, is facilitated. This is important in view of the objectives for the use of stepping motors. Also the mass-productivity of the motor is improved by the possibility of forging or sintering the front and rear covers, and by making the binding bolts and nuts with such magnetic materials as iron to produce a stepping motor which has very limited amount of magnetic flux leaking outside.



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CLAIMS

1. A permanent magnet stepping motor comprising:
a magnetized rotor on a shaft, the rotor comprising a
5 circular-plate permanent magnet sandwiched between two
circular rotor yokes of ferro-magnetic material, the outer
diameter of the yokes being D_o and the thickness of the
yokes along the shaft being L ;
a stator adjacent the rotor, the stator having coils
10 adapted to carry current to magnetize the stator thereby to
cause stepwise rotation of the rotor, the stator and the
rotor having opposing surfaces spaced by a distance G_1 ; and
a casing of a ferro-magnetic material mutually
supporting the rotor and stator and entrapping magnetic
15 flux around them, the casing having cylindrical flanges
extending axially of the shaft towards the rotor, the outer
diameter of the flanges being D_1 and the inner diameter
being D_2 , each rotor yoke having a surface opposing the
free end surface of a corresponding flange, the distance
20 between the opposing surfaces of the yoke and corresponding
flange being D_1 ,
wherein the dimensions of the motor satisfy the
relationship

25
$$D_1/G_1 > n \cdot (D_1^2 - D_2^2)/(4D_o \cdot L)$$

thereby to reduce the magnetic flux leakage from the motor
to $1/n$ of the effective magnetic flux, n being any natural
number.

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2. A stepping motor according to claim 1, wherein the
casing comprises two cover portions, one on each side of
the stator.
35 3. A stepping motor according to claim 2, wherein the



stator is held between the two cover portions, and secured thereto by fastenings of a ferro-magnetic material.

4. A stepping motor according to any one of claims 1 to
5 3 wherein bearings support the shaft coaxially with the
flanges.
 5. A stepping motor according to any one of the preceding
claims, wherein teeth are provided in the periphery of the
10 rotor.
 6. A stepping motor according to claim 5 wherein teeth
are provided on a surface or surfaces of the stator opposing
the teeth on the rotor, the spacing of the teeth on the
15 rotor being different from the spacing of the teeth on the
stator.
 7. A permanent magnet stepping motor substantially as
herein described with reference to, and as illustrated in,
20 Figs. 1 to 5 of the accompanying drawings.
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