(12) UK Patent Application (19) GB (11) 2 157 089 A

(43) Application published 16 Oct 1985

(21) Application No **8407818**

(22) Date of filing **26 Mar 1984**

(71) Applicant
Ching Chuen Chan,
Dept of Electrical Engineering, University of Hong Kong,
Pokfulam Road, Hong Kong

(72) Inventor
Ching Chuen Chan

(74) Agent and/or Address for Service
Dr C C Chan,
c/o D S Rowat, 130 Cromwell Road, London SW7

(51) INT CL^4
H02K 37/00

(52) Domestic classification
H2A RV

(56) Documents cited

GB A 2115231	GB 0989172
GB 1476120	GB 0944046
GB 1269812	GB 0389158
GB 1204444	GB 0358709

(58) Field of search
H2A

(54) Single-phase reluctance motor

(57) A single-phase, variable speed reluctance motor comprises a stator and a rotor each with an equal number of poles. The poles are made of solid mild steel and can be fabricated by die casting process for mass production. An annular coil is wound on the stator and is supplied with single-phase switched pulses so that the stator poles can be excited simultaneously to attract the rotor poles.

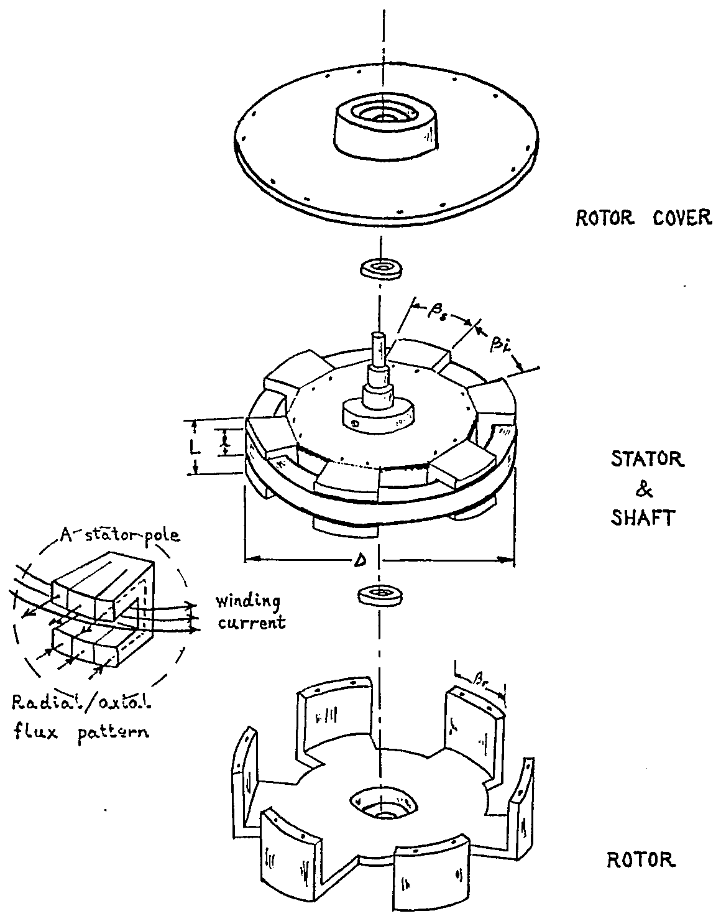

Fig. 1 Basic construction (Type 1)

GB 2 157 089 A

2157089

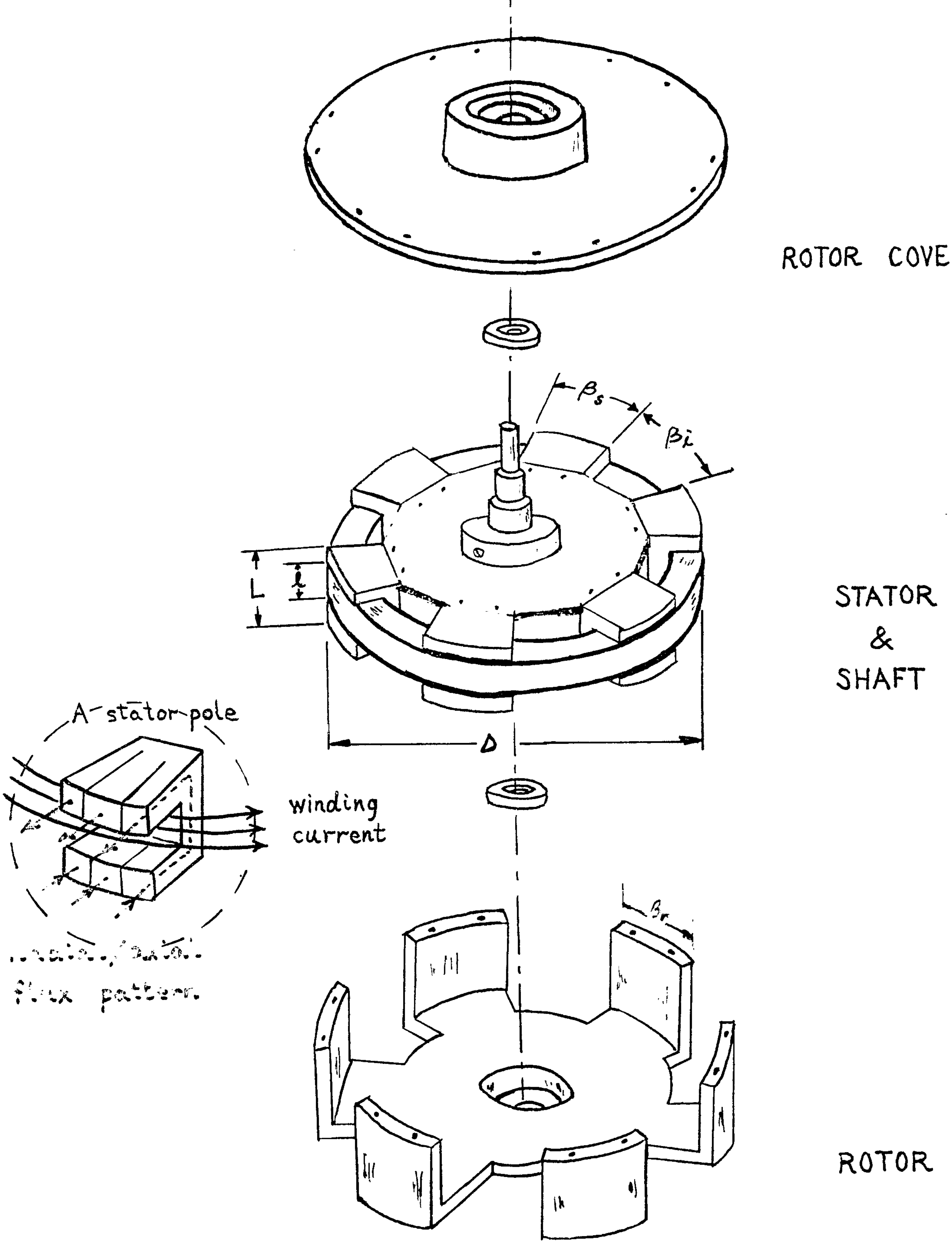

Fig. 1 Basic construction (Type 1)

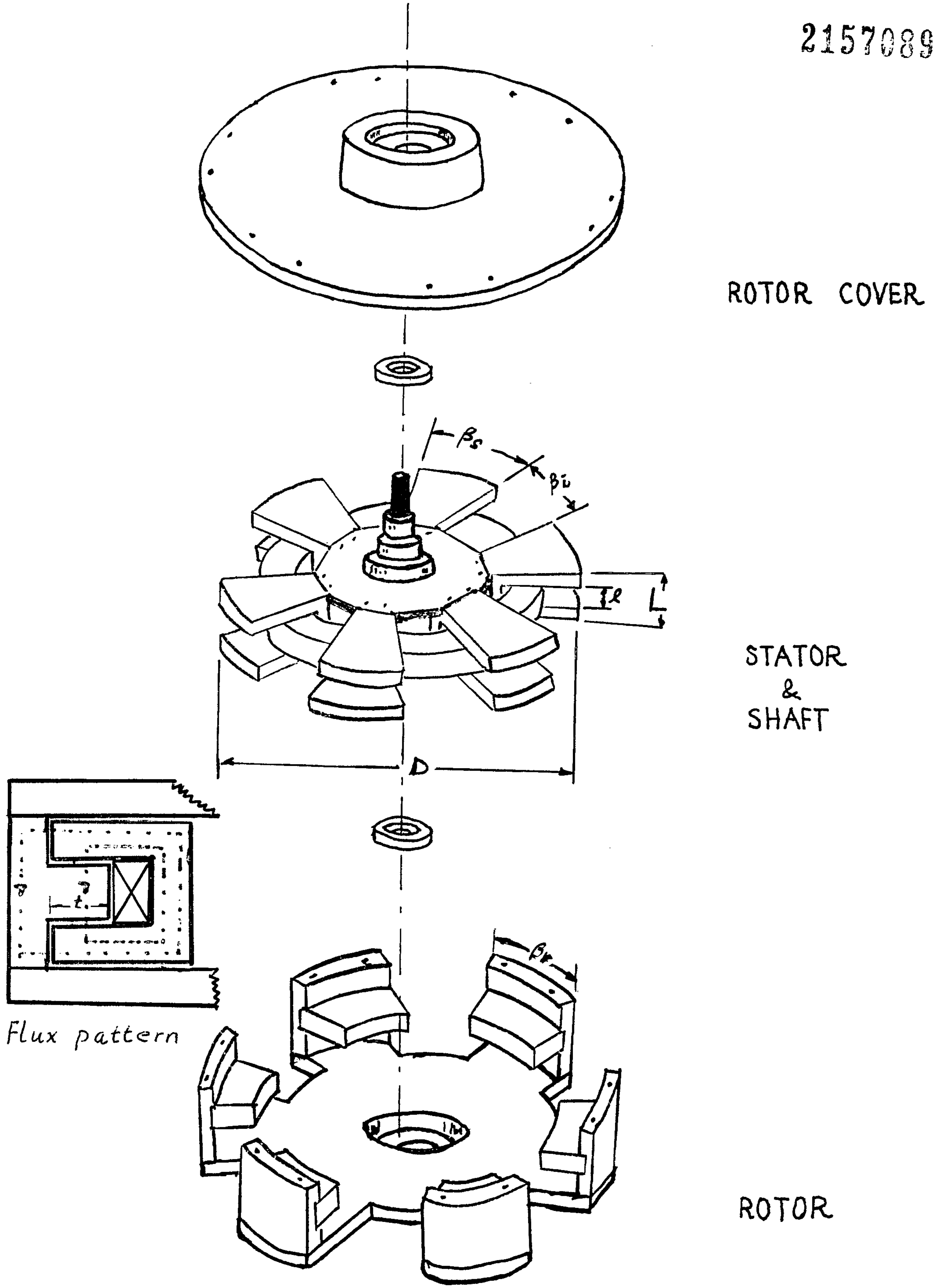

Fig. 2 Basic construction (Type 2)

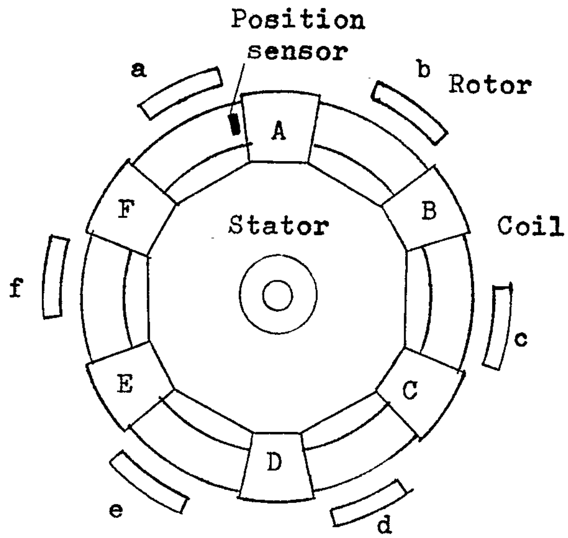

Fig. 3 Reluctance motor
top view

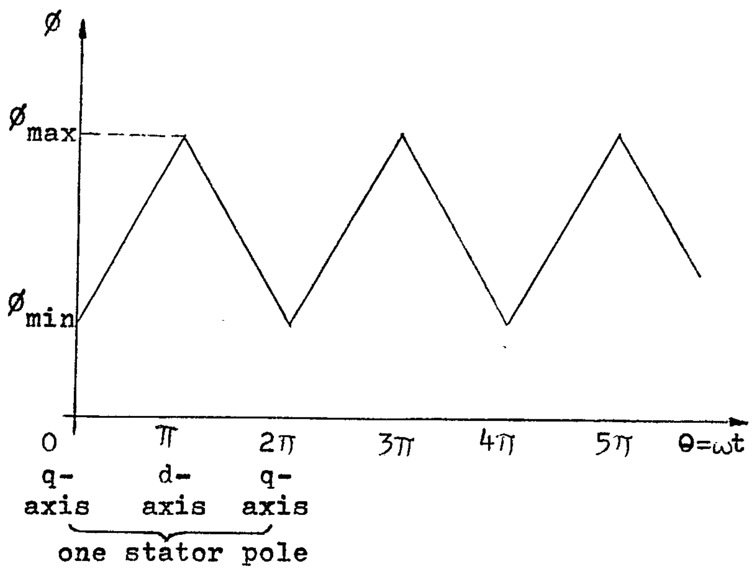

Fig. 4 Motor flux variation

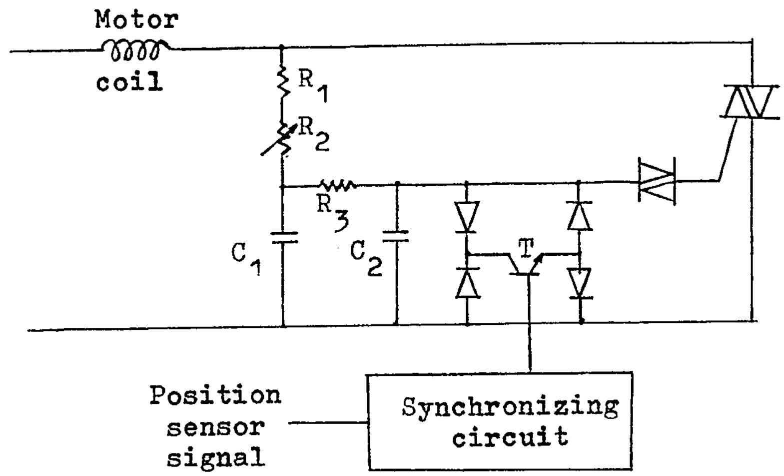

Fig. 5 Triac circuit

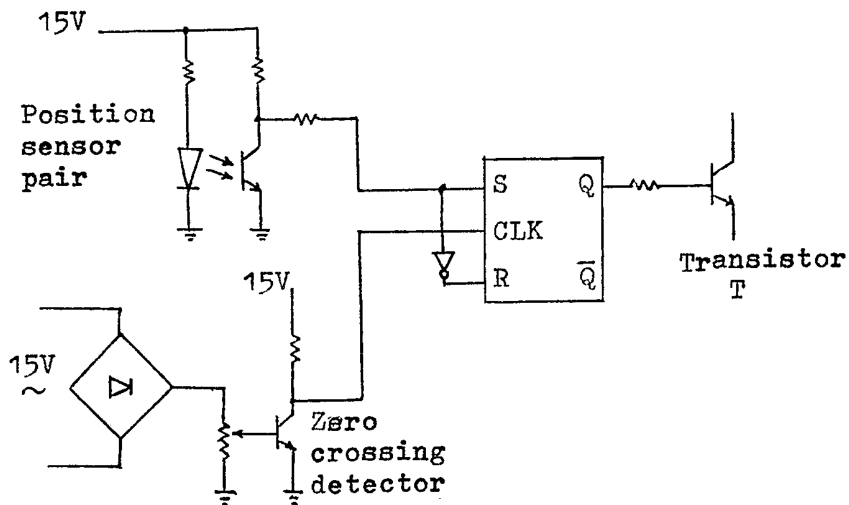

Fig. 6 Synchronizing circuit

SPECIFICATION

Single-phase reluctance motor

This invention relates to a new design and method of construction for low-cost, single-phase, variable speed reluctance motor. It differs from the conventional single-phase reluctance motor or single-stack reluctance stepping motor in that: (i) both the stator iron core and rotor iron core are made of solid mild steel, (ii) the number of stator poles and rotor poles are equal, and (iii) the magnetic flux path per pole is in radial/axial loop. The main advantages of the invented motor lie in simple and robust construction, very low production cost, and reasonable efficiency and performances.

1. Basic construction

Figure 1 and Figure 2 show the basic construction of the invented motor. The motor mainly consists of stator poles, rotor poles and stator winding. The stator poles and rotor poles are made of solid mild steel and can be fabricated by die casting process for mass production. The stator core consists of several independent pole pieces, which are fixed together by two aluminium or non magnetic plates. There is a simple circular type winding in the stator core. The rotor consists of pole face, lower endplate and upper cover-plate. The cover-plate may be made of aluminium or plastic. The number of rotor poles are equal to that of the stator, and there is no winding in the rotor. The magnetic flux path per pole is radial/axial as shown in Figure 1 and Figure 2. It is noted that the configuration of the rotor pole in Figure 2 is different with that in Figure 1. In Figure 2 each rotor pole has a pole shoe, which improves the utilization of the airgap flux. Therefore, a higher power density is achieved.

2. Principle of operation

The stator winding is supplied by a single-phase switched pulses and all the stator poles are excited simultaneously. The rotor poles are then attracted by stator poles and a rotating torque is produced. For example, if the initial relative position of the rotor and stator is as shown in Figure 3 (where rotor pole "a" is closer to stator pole "A" than to pole "F"), and then the stator winding is switched on, the stator poles will attract the rotor poles to rotate clockwisely. The stator current must be switched off before the rotor poles align with the next stator poles. The rotor then will continue to rotate by in its inertia while the next stator current is switched off. The stator current is switched on again when the rotor poles are closer to the next stator poles. Thus by repeated switching action of stator current, the rotor will rotate continuously.

A position sensor is incorporated to sense the relative position between the rotor and the stator, so as to provide relevant switching control accordingly.

A parking magnet is adopted to ensure that the rotor is stopped at the proper position when the main supply is switched off. Thus the rotor can be started up at the same direction when the main supply is switched on again.

3. Motor design principles

(1) Flux linkage

The useful flux, which links the stator poles and rotor poles, is depended on the input current and the position of the rotor pole. For a given speed and current, the linkage flux will vary from a maximum $\varnothing_{max}$ when the rotor poles are facing the stator poles, to a minimum $\varnothing_{min}$ when the rotor poles are at the midway between two stator poles. Neglecting magnetic nonlinearity, the flux variation can be approximated by a triangular waveform as shown in Figure 4. This waveform can be expressed by a Fourier expansion:

$$\varnothing = \varnothing_o + \sum_{n=1}^{\infty} \varnothing_n \cos \omega t$$

where: $\varnothing_o = \frac{1}{2}(\varnothing_{max} + \varnothing_{min})$

$$\varnothing_n = \frac{2[(-1)^n - 1]}{\pi^2 n^2} (\varnothing_{max} - \varnothing_{min})$$

$n = 1, 3, 5, 7, \ldots\ldots\ldots\ldots$

If only the fundamental component is considered.

$$\varnothing = \varnothing_o + \varnothing_1 \cos \omega t \quad \ldots\ldots\ldots (1)$$

(2) Induced e.m.f.

$$e = -N \frac{d\phi}{dt} = N \phi_1 \omega \sin \omega t$$

$$E = k N \phi_o \omega/\sqrt{2} \quad \ldots\ldots\ldots (2)$$

where $k = \phi_1/\phi_o$

e, E	instantaneous and r.m.s. value of the induced e.m.f.
N	number of turns of stator winding
ϕ_o	average value of flux
ϕ_1	fundamental component of flux

(3) Output equation

The main dimensions of the motor can be expressed in term of the power of the motor, which is known as output equation.

$$P_g = E I \cos \psi = k N \phi_o \omega I \cos \psi/\sqrt{2} \quad \ldots\ldots\ldots (3)$$

Considering that:

Angular velocity $\omega = 2\pi pn/60$ [elect.rad/sec]

specific electric loading $A = NI/\ell$ [AT/m]

specific magnetic loading for motor of Fig. 1,

$$B = p \phi_o/\pi D(\frac{L - \ell}{2}) \quad [Wb/m^2]$$

specific magnetic loading for motor of Fig. 2,

$$B = p \phi_o/\pi D(\frac{L - \ell}{2}) + \pi k(D - t) \quad [Wb/m^2]$$

Substituting the above equations into eqn. (1), and an approximation is taken into account due to D >> t, the output equation of the invented motor can be written as follows:

For motor of Fig. 1:

$$D\ell[L - \ell] = \frac{C P}{B A \eta n \cos \psi} \quad \ldots\ldots\ldots (4)$$

For motor of Fig. 2

$$[D(L - \ell) + 2tD] \ell = \frac{C P}{B A \eta n \cos \psi} \quad \ldots\ldots\ldots (5)$$

where $C = 120/4.44k\pi$

η	efficiency
n	speed r.p.m.
$\cos \psi$	power factor
P, P_g	output power and airgap power [W]

p – number of poles
D – stator outer diameter (m)
L – stator pole height (m)
B – stator slot height (M)
t – penetration depth of rotor pole shoe (m)
I – r.m.s. value of stator current (A)

It can be seen from equation (4) and (5) that the main dimensions and volume of the motor of Figure 2 are smaller than that of the motor of Figure 1. This is because the effective airgap are for the linkage flux is larger due to the use of rotor pole shoe in Figure 2. On the other hand, the average diameter of the stator winding coil of motor of Figure 2 is smaller as compared with that of motor of Figure 1, thus resulting in significant saving of copper used.

(4) Pole arcs

The ratios of the stator and rotor pole arcs to stator interpole arc are the key parameters in the motor design. These ratios can be estimated empirically. The stator pole arc β_s should be nearly equal to rotor poole arc β_r in order to maximize the torque. On the other hand, the stator interpole arc β_i should not be less than the stator pole arc β_s. This ensures that when the stator poles are attracting the approaching rotor poles, the opposing forces due to the previously passed stator poles are insignficant. Based on these criteria, the ratios can be taken around $\beta_i/\beta_s = 1.3$ and $\beta_i/\beta_r = 1.4$.

4. Drive circuit

Several configurations of simple and low cost drive circuit using triac or transistor are possible. For example, Figure 5 is one of the possible drive circuit which has been tested with quite satisfactory result. The drive circuit consists of a triac, a phase controller, a bridge and a synchronizing circuit. The firing of the triac is controlled by the phase controller which comprises a R-C circuit and a diac. By adjusting the reheostat R_2, the charging time for the voltage across C_2 up to the breakdown voltage of the diac can be varied, so is the conduction period of the triac. Hence, the motor speed can be controlled by R_2.

The triac must be switched off before the rotor poles align with the next stator poles, as discussed earlier. To accomplish this, the voltage across C_2 is prohibited to build up by shorting it with the bridge and transistor T, which is in turn controlled by the position sensor via the synchronizing circuit. The R-C charging circuit resumes its normal function when T is off.

The synchronising circuit is as shown in Figure 6. The synchronizing action is done by a R-S flip-flop which senses the input and changes state only if a clockpulse is received. Such clockpulses are generated by the zero crossing detector, and hence the switching of transistor T is synchronized with the zero crossing points of the a.c. mains.

Several motor prototypes in the range of 100-200 Watts have been built and tested with the drive circuit. The test results show that the performance of the motor is satisfactory, the full-load efficiency reached around 0.2-0.25, which is comparable with those of conventional single-phase inductions motors or conventional reluctance motors at the same power rating. Moreover, the construction of the invented motor is much simpler and the production cost is much lower as compared with that of conventional motor.

CLAIM

1. A single-phase switched reluctance motor with equal number of stator poles and rotor poles made of solid mild steel as described above, and with the construction like in Figure 1 or Figure 2, which lead to have simple, robust construction and lower production cost.

Printed in the UK for HMSO, D8818935, 8/85, 7102.
Published by The Patent Office, 25 Southampton Buildings, London, WC2A 1AY, from which copies may be obtained.