VERY SLOW SPEED AXIAL MOTION RELUCTANCE MOTOR

by
L. A. Agu
Electrical Engineering Department
University of Nigeria, Nsukka.

ABSTRACT

This paper presents the scheme for a very slow speed linear machine which uses conventional laminations and with which speeds of the same low order as that of the screw-thread motor can be obtained.

LIST OF SYMBOLS:

α = Displacement of the centre of arbitrarily chosen rotor thread from the z = 0 plane.
β = flux density distribution
λ = displacement of the mmf axis from the $\theta = 0$, a position in the z = 0
g(z) = function expressing grooving of rotor along the z direction
L = unit axial length of machine
L(Z) = function expressing distribution of inductance as a function of z.
M = mmf
θ = position in the circumferential direction.
Δ = an expression representing permeance distribution

1. DESCRIPTION OF MACHINE

An axial cross sectional view of the machine is shown in Fig. 1. The windings, which are polyphase, are located on the stator. The laminations have identical shallow channels arranged symmetrically around the inner bore of the stator to form a 2p pole salient pole structure_ A special feature of the machine is that the laminations are grouped in stacks, each stack is separated from its neighbours by an insulating medium. The axes of the stack is advanced progressively by an angle π/n, where n is the number of stacks in unit length of machine. The rotor is also arranged in stacks, however the number of rotor stacks per unit length of machine is one more or one less than the number of stator stacks. The relationship between the stator and rotor stack is therefore that of a venire.

Assume the rotor stack to have the same width as the stator stack; and let the space between the stator stacks also have the same width. When a rotor stack is in alignment with a stator stack, that is, completely laps it, then because of the vernier arrangement the extent of overlap between rotor and stator stacks will diminish progressively on either side of the aligned stacks, and the n/2th stator stack will have no rotor stack overlapping it. The pattern is repeated for each unit length of machine.

2. ACTION OF THE MACHINE:

When the machine is excited with polyphase currents the inductance of the system will be a maximum if a rotor stack is fully aligned with that stator stack where the mmf axis coincides with the stator d-axis. If the axis of the mmf is shifted, a force will be developed tending to move the rotor axially. Motion will cease or the force is again zero when the rotor and stator stacks

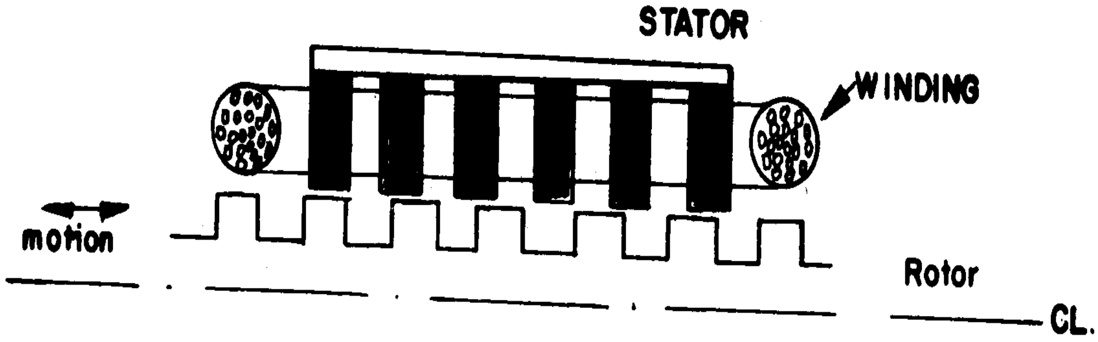

Fig.1. longitudinal cross-section through machine

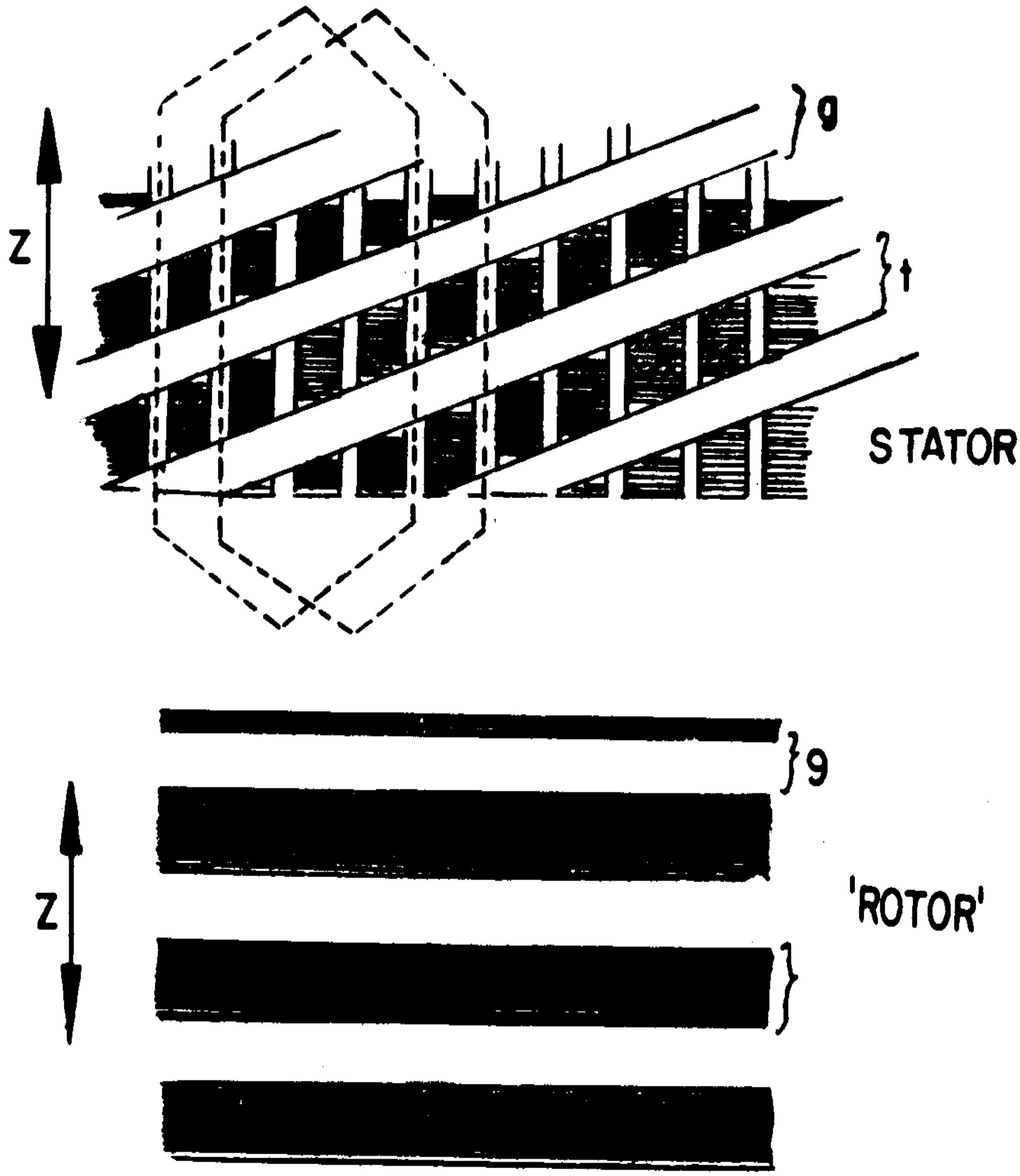

Fig 2. Stator and rotor of screw -thread motor

are aligned on the new stack where the mmf axis and d-axis coincide.

3. ANALYSIS.

All insight into the working of the machine may be gained by considering an opened-out version of the well known screw-thread motor, which is shown in plan in Fig. 2. The uniformly distributed winding is mounted on the stator but could also have been placed on the rotor. The basic screw-thread motor is a belical screw arrangement in which a cylindrical stator has a two-start thread of square cross section cut on the inner surface of the stator bore. The armature or rotor is in the form of a cylinder with annular grooves cut in the surface.

For the purpose of deterring the airgap flux density of the screw- thread motor the following assumptions are made:

(a) That the material of rotor has infinite permeability

(b) That the flux lines enter the rotor radially in the cylindrical machine or perpendicular to the surface in the opened-out version

(c) It follows from (b) that there would be no fringing

Consider in the first instance · a motor with a smooth rotor without grooves. The air-gap permeance distribution for a cylindrical 2-pole machine may be written

$$\Delta_n = a_s \cos 2_{s\left(\theta - \frac{\pi z}{1}\right)} \qquad (1)$$

If harmonics are neglected the permeance distribution becomes

$$\Delta = a_{o+a_1 \cos 2\left(\theta - \frac{\pi z}{1}\right)} \qquad (1a)$$

If harmonics are neglected the permeance distribution becomes

This is an expression for a wave whose axis shifts clockwise as progress is made along the z axis. The condition at z = 0 is, the same as that at z = 1

The airgap flux density distribution is the product of the mmf distribution. $M = m\cos(\theta - \lambda)$ and the permeance distribution . Thus the flux density distribution: $B = M\Delta = a_o\hat{m}\cos(\theta - \lambda)$

$$+ \frac{a_1\hat{m}}{2}\cos\left(\theta - \frac{2\pi z}{1} + \lambda\right)$$

$$+ \frac{a_1 m}{2}\cos\left(3\theta - \frac{2\pi z}{1} - \lambda\right) \ldots\ldots\ldots\ldots\ldots. (2)$$

The contribution Δ L made to the inductance by conductors occupying a short Δz length of machine is given by

$$\Delta L = K\Delta_{z\int m}^{\left(\lambda + \frac{\pi z}{1} + \pi/2\right)}_{\left(\lambda + \frac{\pi z}{1} - \pi/2\right)} d\theta$$

$$= kf(z)\,\Delta z$$

$$= L(z)\ \Delta z \ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots (3)$$

The function kf(z) is the distribution of the inductance expressed as a function of z and may be expanded as

$$L(z) = Kf(z) = L_O + L_1\cos 2\left(\frac{\pi z}{1} - \lambda\right) \quad (4)$$

The total inductance of winding is obtained by integrating Kf(z) with respect to z between the limits o and 1

4. EFFECT OF ROTOR GROOVES:

The rotor grooves will modify the distribution of inductance along the z direction. The modified distribution is obtained by multiplying (4) by a rectangular wave function which makes the inductance distribution negligible over the grooves but unchanged over the threads from the previous (ungrooved rotor) value. Such a function may be represented by a Fourier series, thus:

$$g(z) = A_0 + \sum A_m \cos\frac{2m\pi}{1}(z - \alpha) \qquad (5)$$

The product of (4) and (5) will give the new inductance distribution

$$L_{new}(z) = g(Z).l(z)$$

$$= A_o L_o + A_o L_1 \cos 2\left(\frac{\pi z}{1} - \lambda\right)$$

$$+\sum_m A_m L_o + A_o L_1 \cos\frac{2\pi m}{1}(z-\propto)$$
$$+\sum_m A_m L_1 \cos\frac{2\pi m}{1}(z-\propto)\cos 2\left(\frac{\pi z}{1}-\lambda\right) \quad (6)$$

The total inductance is obtained by integrating (6) with respect to z between the imits 0 → l. The 2nd and 3rd terms of the RHS of (6) make zero contribution to the integral; and the 4th term makes a non-zero contribution only for the case m = 1. It follows that it would be valid to consider only the fundamental component of the variable portion of the rotor airgap permeance.

Suppose each I-unit length of the screw-thread motor is divided into n axial packets (stacks) equal width and each packet rearranged so that the axes of each component lamination is aligned with the axes of the middle lamination. The principal element of the distribution of inducantace along the length of the machine will not be altered to any appreciable extent. Suppose now that each I-unit length of rotor is comprised of n packets of equal diameter but unequal axial width the outer packets having the ' greatest width and the packet-width diminishing symmetrically and progressively towards the centre. The permeance distribution in this case will be similar to the permeance distribution of the previous case. Whereas the changes in distribution is obtained in the first case by the change in airgap length, it is achieved in the second case by modulation of the airgap widths.

The practical method of achieving this effect is to adopt the well-known vernier configuration, which principle is familiar in stepping motors. The n stator have equal non- magnetic spacers separating adjacent stacks, and there are n ± 1 rotor stacks in the same equivalent unit length of machine.

5 . SIMPLE COMPARISON ON SCREW THREAD MOTOR AND VERNIER MOTOR.

Consider the varnier linear machine which has six stator stacks and five rotor stacks per effective unit length, 1 of machine. Let the separation between adjacent stator stacks be of the same width as the stacks. Let the rotor stacks also have the same width. The winding inductance will go through one complete cycle of variation for a(1/5 x 6)1 movement of the rotor. A screw-thread motor of length 1 will require a rotor movement of only 1/6 x 1 for the inductance to go through one complete cycle. This means that the vernier step is 1/5 of the screw-thread step. The overall length of the vernier machine would however be at least 21 i.e. double that of the screw-thread motor. On the other hand the force developed by the vernier machine will be five times as large. One of the experiment· al motor described by Gerrad[1] has a pitch of 2.5mm. A six-stack vernier motor deriving directly from this machine would have stacks of O.42mm each. Thin laminations of that size could be sufficiently rigid to con-stitute a stack without buckling. There may however be problems arising from fringing.

The linear advance or step of the screw-thread rotor for unit angular change in the mmf axis is determined by the pitch of the thread. There is a practical lower limit to this imposed by the physical process of machining the threads. The vernier arrangement offers the possibility for a smaller step and at the same time gives a machine easier to fabricate and mas-produce. Small bore machines would be as easy to manufacture as large bore machines.

In order to obtain steps of the same size as that of the screw-thread motor, the nernier stacks would be five times as wide, each would be approximately 2.10mm. Although the simple vernier machine will be at least two times as long as a screw-thread motor which develops as much force, it however has certain advantages. In the screw-thread motor the windings may be located on the member with the two-start thread (the stator) or on the grooved member (the rotor). For the first the screw is cut in after the stator stack has been assembled. It is a better practical proposition from a manufacturing view point to have the windings on the grooved member (grooves in a laminated machine consist of lamination of different didffi8ter from the' laminations in the active areas), the other member could be a solid iron on which the thread is machine dorin the flat opened-out machine the laminations are placed at an angle to the direction of travel. This arrangement however leads to lateral forces which would be part of the total developed force, and consequently, the available axial forces reduced. Furthermore in order to prevent motion in the lateral direction some restraint is necessary, and this in turn gives rise to frictional forces which subtracts from the useful force of 'the machine. In the vernier machine it is as convenient to locate the windings on one member as it is to locate it on the other.

6. CONCLUSION

The machine described in this paper, and also the screw-thread motor, are special cases of a general class of machines in which motion of the rotor is axial even though the windings, the stator and rotor structures are of the type used in conventional rotary machines or their opened- out linear equivalents. This class of machines is described as Trans-verse-motion (TRVM) machines. They are not to be confused with Transverse flux machines to which they are closely related. The distribution be twee n the two would be apparent if the flux patterns of the opened-out screw-thread motor is compared with those of an E- core polyphase single-sided transverse· flux linear induction motor. An elementary general transverse machine would consist of two rows of alternate
and S poles placed side by side so that a N-pole of one row is opposite a S-pole on the other row. In the transverse-flux regime the main direction of flux is across from one row to the other and the motion of the rotor is parallel to the rows. In the transverse-motion regime the direction of flux and the direction of motion are interchanged. Whereas transverse-flux machines are really adaptation of conventional machines, transverse- motion machines, on the other hand, are a distinct class by themselves.

REFERENCES

1. J. Gerrad and R.J.A. Paual. "Rectilinear Screw-thread reluctance motor". Proc. I.E.E. Vol. 118, p. 1575 - 1584. November 1971.