아크형 직선 펄스전동기의 특성 해석

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CHARACTERISTIC ANALYSIS OF AN ARC TYPE LINEAR PULSE MOTOR

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ABSTRACT

In this paper, the characteristics of an arc-type linear pulse motor (ALPM) with permanent magnet are analysed using analytical and 2-D finite element method. To verify the analysing method, An ALPM which can be used as actuators of servo systems is designed and constructed.

The stator of the ALPM has a permanent magnet and 4 pole exciters in order to provide a detent and thrust force. It's rotor radius is 70 mm and average torque of 60 N·cm. The test results of the prototype ALPM have reasonably good agreement with those of analytic solutions.

1. INTRODUCTION

The proposed motor is an arc type hybrid linear pulse motor (ALPM) which can be used as an arc-linear motion like a window brush or point-to-point rotating carrier system.

The stator of the ALPM has a permanent magnet and 4-pole exciters in order to provide a detent and thrust force. An ALPM, whose radius is 70 mm and average torque of 60 N·cm, is constructed. A rare earth and pure iron is used for the permanent magnet and core, respectively.

To estimate flux density distribution in the air gap and thrust force as a function of exciting current, the characteristic of ALPM is analysed using an equivalent magnetic circuit and 2-D finite element method. The outline configuration of the ALPM is evaluated using the analytical method, and its parameters such as dimensions of pole and slot are decided using the results of finite element method analysis as to satisfy the given specifications.

2. BASIC CHARACTERISTIC EQUATIONS

ELECTROMAGNETIC EQUIVANENT CIRCUIT

The configuration of the arc type linear pulse motor is shown in Fig.1. The actuator consists of 4 pole/2 phase stator and a rotary type mover. The stator cores are assembled with two magnets in series which are energized with a dc source. As shown in Fig.1, each of the two phases has 2 poles, each pole has 3 teeth, to the 2ndary slot by half of the slot pitch.

The poles of the phase 2 are displaced by a quarter of tooth pitch, $\tau_s/4$, which is a step size, with respect to the poles of the phase 1. The coils of phase A and B which are alternately excited by a proper sequence of pulse signal of voltage source. The mover is composed of the iron poles arranged in the same stator pole pitch. To estimate the outline geometry of ALPM, an equation of the electromagnetic circuit is assumed as follows.

1) The relation between the flux linkage with the magnetic circuit and the exciting current is linear and there is no hysteresis phenomena.

2) The magnetic reluctance of core is ignored and the electromagnetic energy exists in the air gap.

3) The permeance variation in the air gap varies in sinusoidally.

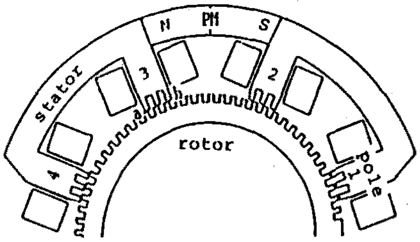


Fig.1 A fundamental structure of the arc type LPM

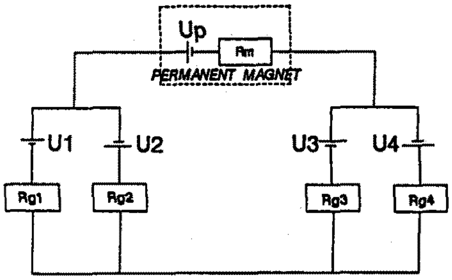


Fig.2 An equivalent magnetic circuit of ALPM

Fig. 2 shows an equivalent magnetic circuit of the ALPM, where R_{g1}, R_{g2}, R_{g3} and R_{g4} represent the magnetic reluctance in the air gap and R_m is the magnetic reluctance of permanent magnet.

When the coil is energized with current, I(A), to move the mover, the magnetic flux $\Phi_1(\theta)$ and $\Phi_2(\theta)$ in the magnetic pole are produced according to the displacement x(m) as the follows.

$$\Phi_1(\theta) = \Phi_{1m}(\theta) + \Phi_{1i}(\theta)$$
$$= \Phi_m + \triangle\Phi_m \cos(2\pi/\tau)\theta + \Phi_i + \triangle\Phi_i \cos(4\pi/\tau)\theta \qquad (1)$$

$$\Phi_2(\theta) = \Phi_{2m}(\theta) + \Phi_{2i}(\theta)$$
$$= -\Phi_m + \triangle\Phi_m \cos(2\pi/\tau)\theta + \Phi_i - \triangle\Phi_i \cos(4\pi/\tau)\theta \qquad (2)$$

,where the subscript 1 and 2 represent the magnetic pole, m and i show the magnetic flux produced by the permanent magnet and the exciting current, respectively.
The static force produced by one phase exciting current can be obtained from the virtual displacement principle.

$$F_1 = \frac{1}{2} nNI \frac{d\Phi_1(\theta)}{d\theta} + \frac{1}{2} n NI \frac{d\Phi_2(\theta)}{d\theta}$$
$$= -\frac{2nS}{\tau} NI \triangle B_m \sin(2\pi/\tau)\theta + \frac{4nS}{\tau} NI \triangle B_i \sin(2\pi/\tau)\theta \quad (3)$$

,where n is number of teeth per pole, S (mm^2) is the cross section area of a tooth on the mover, $\triangle B_m$ is $\triangle\Phi_m/S$ and $\triangle B_i$ is $\triangle\Phi_i/S$. The first term of Eq.(3) is the force produced by the interaction between the fields of permanent magnet and the phase current. The secondary term of Eq.(3) is the force produced by the magnetic flux of the exciting current.

In the case of 2-phase excitation, the static force, F_2, can be described in terms of $\theta \pm \tau/8$ because the stable point of 2-phase excitation is apart $\theta=\tau/8$ from the stable point($\theta=0$) of single-phase excitation.

$$F_2 = F_1(\theta + \tau/8) + F_1(\theta - \tau/8)$$
$$= -\frac{4\ n\pi S}{\tau} NI \ \triangle B_m \sin(2\pi/\tau)\theta \qquad (4)$$

FINITE ELEMENT ANALYSIS

To analyse characteristics of the arc type LPM, 2-D finite element method is used. Electromagnetic system of LPM can be described from Maxwell's equation combined with the magnetic vector potential **A** and magnetizing current $J_r = \nabla \times M$ as follows :

$$\nu_o \nabla \times \nabla \times \mathbf{A} = J_o + \nu_o \nabla \times M \qquad (5)$$

,where ν_o is reluctivity of the medium, J_o is input current vector and M is a magnetization vector. For a 2-D finite element formulation, the usual Galerkin's weighted residual method is applied to Equation (5).

$$F = \iint \{ \nu_o \nabla^2 A + J_o + \nu_o \nabla \times M \} \cdot W \, d\Omega = 0 \quad (6)$$

,where Ω represents the whole domain and W is an arbitrary weighting function. After discretizing Eq.(6), a system matrix equation is obtained and solved for A.

Also, the torque of ALPM can be obtained from the virtual work method as follows :

$$T(\theta) = -\frac{\partial W(\theta)}{\partial\theta} = -\frac{\partial}{\partial\theta}\iint_B H \cdot dB \, d\Omega \quad (7)$$

,where $W(\theta)$ is the stored energy in the air gap and $T(\theta)$ is the produced torque.

3. CHARACTERISTIC EXAMINATION

The developing ALPM requires an oscillating motion of 120 degrees along the arc direction and the torque more than 1400 g·cm. To design an ALPM, specifications are given as the following Table 1.

Table 1. Specifications of ALPM

Average Torque	60 N·Cm
Speed	70 mm/sec
Load	1.5 Kg
Detent force	200 g
Outer radius of rotor	70 mm
Stroke of 1 step	1.5 mm
Total stroke	300 mm
Input current	DC 1 A

If the ALPM of Fig.1 is energized by the proper sequence of excitation (1 or 2-phase) the rotor moves by $\tau/4$ of the pole pitch each time. The pole pitch of the rotor can be calculated in terms of the given 1 step size(τ_{ss} = 1.212°). When the radius of the arc LPM is 70 mm, the pole pitch, τ, will be about 6.0 mm. The diameter and the length of coil can be calculated from electrical specifications of the rated voltage and current in order to produce the required tangential force of Eq.(4). The dimension of permanent magnet can be determined from the demagnetizing B-H curve

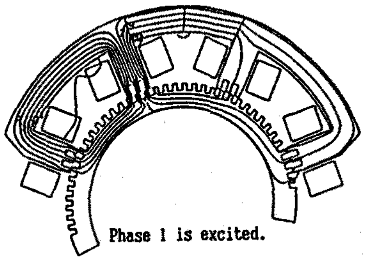


Fig.3 Equi-vector potential lines of the ALPM.

Fig.3 shows equi-vector potential lines when the phase 1 is excited. Fig.4 shows the flux density in the air gap along the arc line between pole 3 ·4 and rotor. The average flux density in the air gap is 0.63, 1.0 and 1.3 [Wb/m^2] respectively. As shown in Fig.5, the optimal exciting current is found around J = 1.0 A/mm^2.

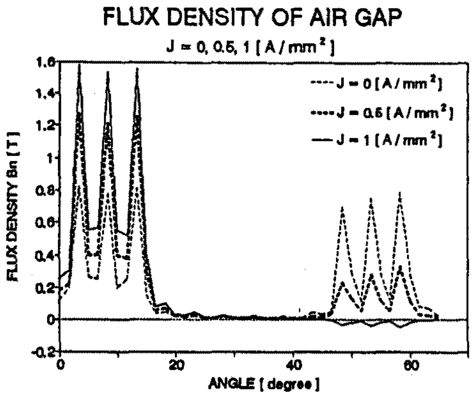


Fig. 4 Distribution of air gap flux density.

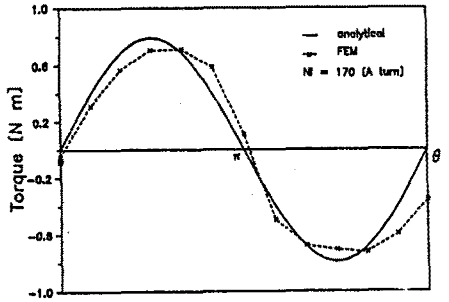


Fig. 5 Torque characteristics of ALPM.

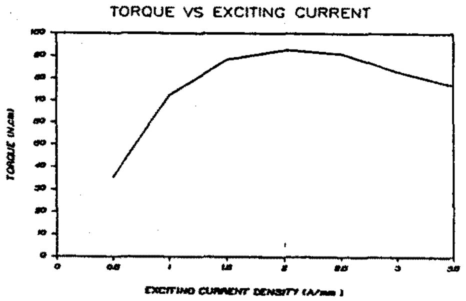
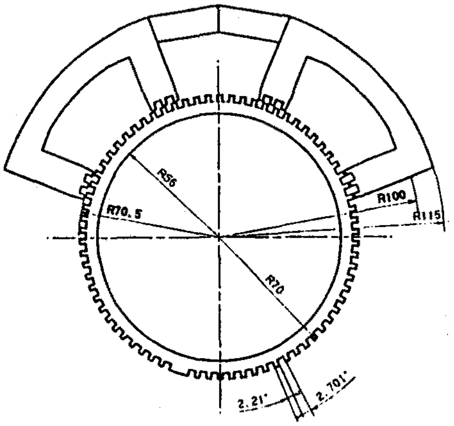


Fig.6 Static torque vs. exciting current.



Design drawing of the ALPM.

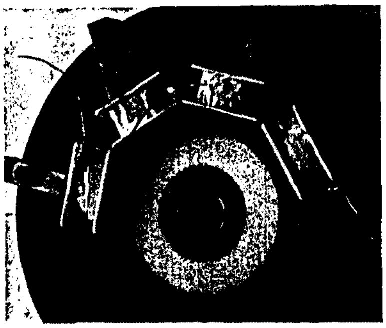


Fig. 7 The constructed arc type hybrid LPM.

Torque of the ALPM appears in Fig.5. The solid line is the result of analytical solution and dot-line is those of FE calculation. Two values have a little difference due to numerical error or established assumptions. Fig. 6 shows a torque characteristics of the ALPM as a function of exciting current. When the current is 2 A/mm^2, the torque is maximum. However, optimal operating current is 1 - 1.2 A/mm^2 as shown in Fig. 4. After constructed the ALPM, its performance test will be made and the results is to be verified with the calculated. Fig.7 shows the constructed prototype hybrid LPM which is on the plastic base for testing.

4. CONCLUSIONS

An ALPM is designed and analysed using analytical and finite element method. The stator of the ALPM is composed of a permanent magnet and 2-phase/4-pole excitors in order to provide a detent and thrust force. To investigate the characterstics of the ALPM, a motor whose radius is 70 mm is constructed and tested as functions of input power and displacement. The experimental results are compared with those of the simulated by the analytical and FEM. There is a little difference between two values due to the established assumptions and numerical error.

The analytical and numerical methods will be improved or expanded for more accurate and optimal design of the motor using optimization. If a practical model of ALPM were compactly developed with high accuracy, it will be used for an actuator of servo systems or element of automation mechanism of arc-linear motion.

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