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Bulletin of University of Osaka Prefecture
Vol. 41, No. 2, 1993, pp. 13–21.

Performance Improvement of Micro-step Drive on Cylindrical Linear Pulse Motor

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(Received Oct. 31, 1992)

A linear pulse motor(LPM) can operate in an open-loop control mode similarly to a rotary stepper motor, and can therefore serve as an effective positioning actuator when used in conjunction with digital electronic control circuits. A micro-step drive in the LPM is generally used for the high resolution positioning application. As the thrust distribution of practical LPM, however, includes high thrust distortion and imbalance, the positioning error in the micro-step drive mode is not so small. In this paper, influences of the thrust distortion and imbalance on the positioning accuracy are examined. Effects of a exciting current control and improvement of positioning accuracy in a new cylindrical LPM configuration are also examined.

I. Introduction

A linear pulse motor(LPM) can operate in an open-loop control mode similarly to a rotary stepper motor, and can therefore serve as an effective positioning actuator when used in conjunction with digital electronic control circuits. The linear motion without any mechanical linkage in the LPM result in several advantages for precise positioning actuators[1]-[5]. A micro-step drive in the LPM is generally used for the high resolution positioning application. The micro-step drive generally requires that the thrust distribution of the LPM is sinusoidal. As the thrust distribution of practical LPM, however, includes high thrust distortion and imbalance[6]-[8], the positioning error in the micro-step drive mode is not so small.

In this paper, thrust characteristics of a conventional and a new cylindrical LPM (CLPM) configurations are examined, and the scheme of the micro-step drive and influences of the thrust distortion and imbalance on the positioning accuracy are also explained. Effects of the exciting current control is also discussed.

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II. Basic Construction

The basic construction of a conventional CLPM (CLPM-A) is shown in Fig.1. The advantages of the CLPM-A, which has permanent ring magnet between the A- and B-phase stators, are a simple magnet shape and small motor diameter. And the disadvantages are the thrust imbalance resulting from the magnetic flux pass of the outer poles being longer than that of the inner poles.

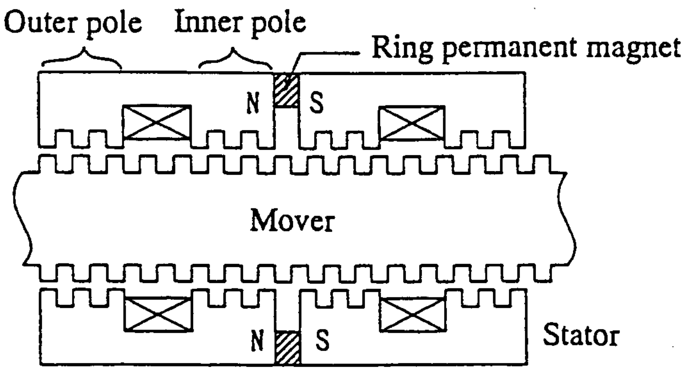

Fig. 1 Basic construction of the conventional CLPM.

The basic construction of the new CLPM with an interior permanent magnet mover (CLPM-B) is shown in Fig.2. There is a half-pitch difference between the mover teeth on the north and south pole sides. The A-phase stator piece has 1/4 pitch offset from the position of the B-phase stator piece. This motor therefore has the same 1/4 pitch step length in the full-step drive as the CLPM-A.

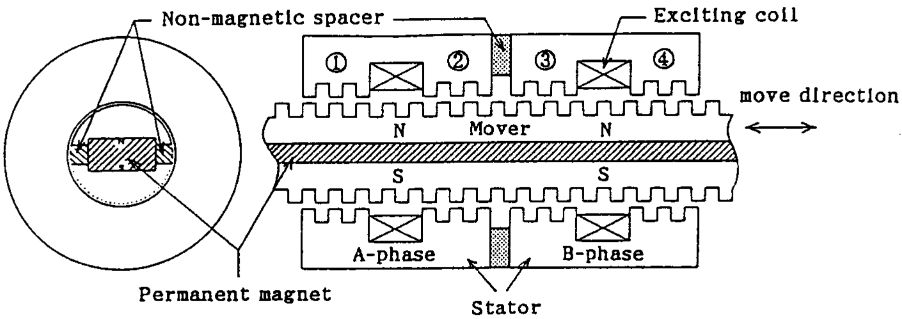

Fig. 2 Basic construction of the CLPM with interior permanent magnet mover.

The magnetic flux pass of a CLPM-A is shown in Fig.3. As the flux pass of the outer pole is much longer than that of the inner pole, the permanent magnet flux of the outer pole is less than that of the inner pole. It follows that the produced thrusts are not equal on the outer and inner poles, and the thrust imbalance occurs. Moreover, as the thrust distributions of both poles has the high distortion, it causes very large position error in the micro-step drive mode. It seems that the thrusts of the non-exciting poles affect to the thrust distribution due to the magnetic flux imbalance of the permanent magnet. This is considered to be the same as the end effect of a linear induction motor.

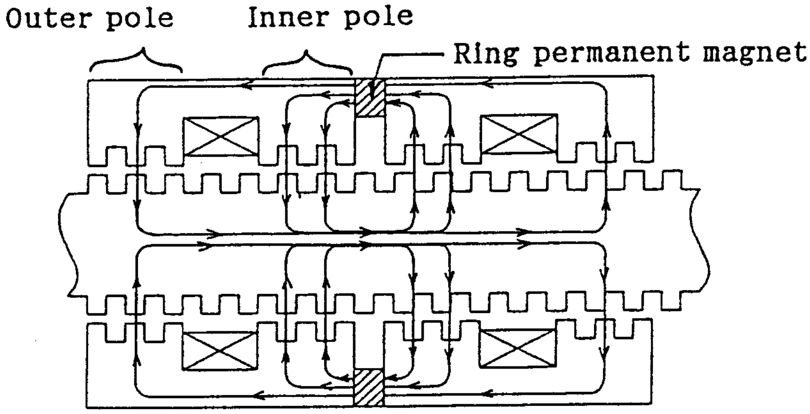

Fig. 3 Scheme of the magnetic flux of the CLPM-A.

The magnetic flux pass of the CLPM-B is shown in Fig.4. In this CLPM the flux of the permanent magnet flows around the circumference rather than the axial direction. Both poles are fixed at the same distance from the permanent magnet, and the end effect described above does not occur. The magnetic reluctance of both poles from permanent magnet becomes equal, and the thrust imbalance is therefore does not occur.

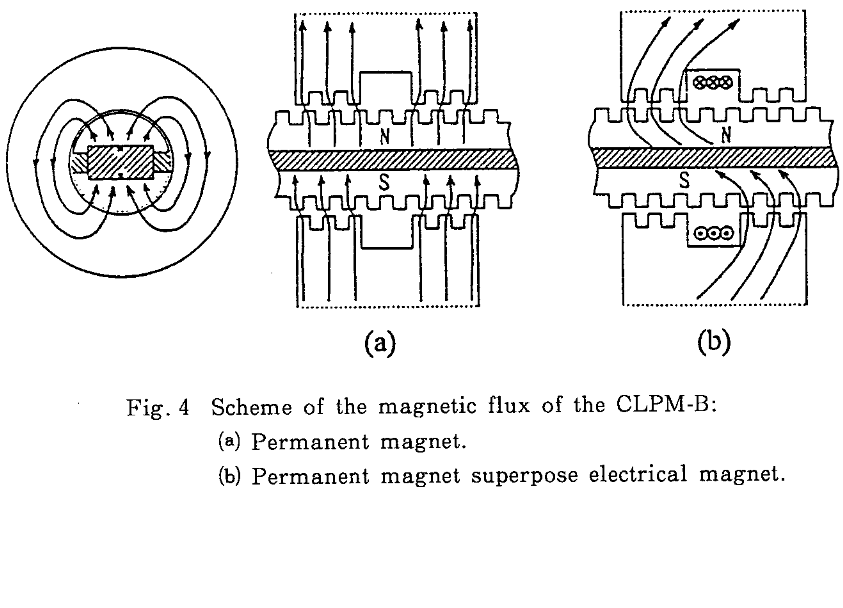

Fig. 4 Scheme of the magnetic flux of the CLPM-B:
(a) Permanent magnet.
(b) Permanent magnet superpose electrical magnet.

As the thickness of the ring permanent magnet in the CLPM-A is affected the distance between the teeth on the A-phase stator and that on the B-phase stator, it is required very high accuracy. In the CLPM-B, the process error of the permanent magnet does not directly affect the positioning accuracy. Moreover, as the sectional area of the permanent magnet is designed wide, the CLPM-B does not require a strong and expensive permanent magnet.

Ⅲ. Scheme of The Micro-step Drive

It requires very small teeth and slots geometry that the LPM apply to the high resolution positioning actuator. Besides the mechanical subdividing, an electrical method can subdivide the step length into very small steps, it is called micro-step drive. The scheme of the micro-step drive is shown in Fig. 5. As shown in Fig.5, high resolution step length is realized and transient vibration is disappeared by the micro-step drive. In this section, the scheme of the micro-step drive is described.

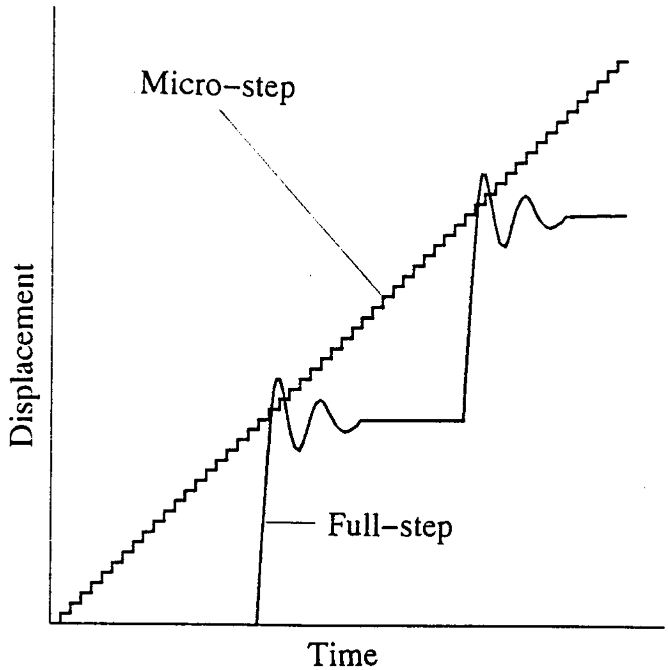

Fig. 5 Schene of the micro-step drive.

The thrust of the LPM is given as follows, if the thrust distribution of the LPM is sinusoidal,

$F_A = -ki_A \sin\theta$ (1)

$F_B = +ki_B \cos\theta$ (2)

where

F_A, F_B : thrust of A and B phase

i_A, i_B : exciting current of A and B phase

k :thrust constant

θ :mover position(in electrical degrees).

Therefore, the total thrust is given as follows, if both phases are excited simultaneously.

$$F = k(-i_A \sin\theta + i_B \cos\theta) \quad (3)$$

If the exciting currents i_A and i_B control sinusoidally, stable positions on the LPM are not depend the tooth pitch but the phase of the exciting currents. The mover position of the LPM can be controlled just as our likes by the phase of the exciting currents.

The exciting currents are controlled such that

$i_A = I_R \cos\mu$ (4)

$i_B = I_R \sin\mu$ (5)

where

I_R : rated exciting current

μ :phase of exciting current.

Therefore, from Eqs.(3), (4) and (5),

$$F = kI_R(-\cos\mu \sin\theta + \sin\mu \cos\theta) = kI_R \sin(\theta - \mu) \quad (6)$$

As shown in Fig.6, the no-load stable position is the point at F=0, which oc-

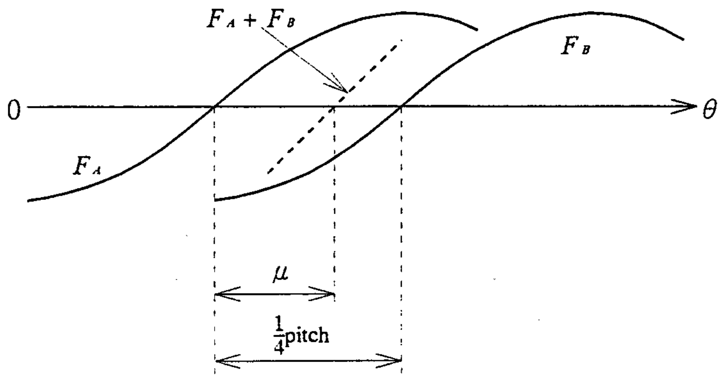

Fig. 6 Phase of current and stable position for the micro-step drive.

curs at $\theta=\mu$ in Eq.(6) with the exciting currents, i_A and i_B given by Eqs.(4),(5). Therefore, by controlling the exciting currents sinusoidally, the LPM acts in the micro-step drive mode.

Ⅳ. Effects of Thrust Distortion and Thrust Imbalance

In the previous section, the scheme of the micro-step drive is discussed assuming the thrust distribution of the LPM is sinusoidal. The thrust distribution of the practical LPM, however, includes large harmonic distortion and thrust imbalance. Therefore, the mover position of the LPM don't move linearly even if the phases of the exciting currents are controlled linearly.

The thrust in the practical LPM is generally given as follows

$$F_A=-i_A(k_1\sin\theta+k_2\sin2\theta+k_3\sin3\theta+\cdots) \tag{7}$$

$$F_B=+i_B(k_1\cos\theta-k_2\sin2\theta+k_3\cos3\theta+\cdots) \tag{8}$$

Therefore, from Eqs.(4),(5),(7) and (8),

$$F=I_R\{k_1\sin(\theta-\mu)+2\sqrt{2}k_2\sin2\theta\sin(\mu+\frac{\pi}{4})+k_3\sin(3\theta-\mu)+\cdots) \tag{9}$$

As the no-load stable position is the point at F=0, which occurs no longer at $\theta=\mu$ in Eq.(9) even if the exciting currents i_A and i_B are given by Eqs.(4),(5). Therefore, in spite of the exciting currents are controlled sinusoidally in the micro-step drive mode, the mover don't move linearly.

The thrust distribution included large harmonic distortions is shown in Fig.7. The mover position trajectory of the CLPM-A, which has the thrust distribution

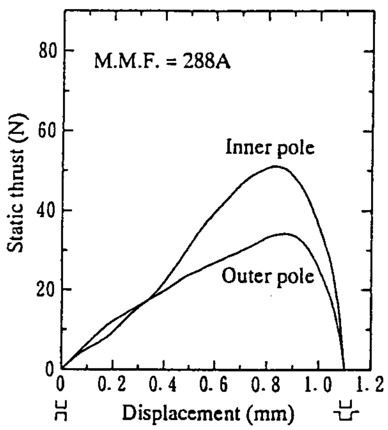

Fig. 7 Thrust distribution of the CLPM-A.

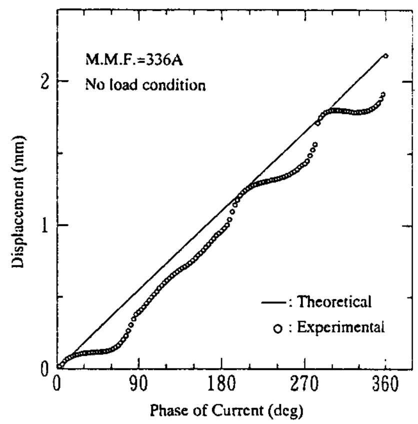

Fig. 8 Mover position trajectory of the CLPM-A.

as Fig.7, in the micro-step drive mode is shown in Fig.8. As shown in Fig.8, the mover position isn't in proportion to the phase of the exciting current, and it includes some undulation.

V. Improvement of Position Accuracy

A. Compensation with exciting current control

The influences of the thrust distortion and imbalance can be compensated by the excitation current control. The positioning linearity of the CLPM-A included harmonic distortion is about 13% at no-load as shown in Fig.8. The positioning linearity becomes worth as the load increases and the maximum positioning error becomes about 18% at 20 N load condition. If the exciting currents i_A and i_B controlled as follows, the positioning error reduces theoretically from 11% to 0.2% in comparison with no current control.

$$i_A = I_R(k_1\cos\theta - k_2\sin2\theta + k_3\cos3\theta + \cdots) \quad (10)$$

$$i_B = I_R(k_1\sin\theta + k_2\sin2\theta + k_3\sin3\theta + \cdots) \quad (11)$$

The mover position trajectory of the CLPM-A, which has the thrust characteristics as shown in Fig.7, in the micro-step drive mode with current control is shown in Fig.9. As shown in Fig.9, the positioning linearity of the CLPM-A included harmonic distortion with current control is about 5% at no-load. The effects of thrust distortion and imbalance in the micro-step drive can be effectively compensated by the current control.

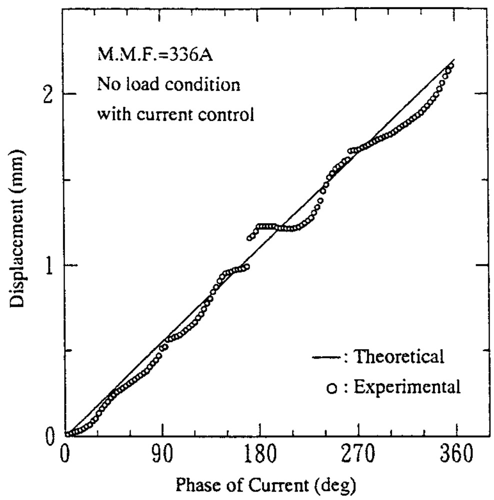

Fig. 9 Effect of the exciting current control on the CLPM-A.

B. Micro-step drive on Cylindrical LPM with interior permanent magnet mover

The thrust distribution of the CLPM-B is shown in Fig.10. As the thrust distributions of the CLPM-B are similar to the sinusoidal wave, it is favorable in the micro-step drive mode.

The mover position trajectory of the CLPM-B, which has the thrust characteristics as Fig.10, in the micro-step drive mode is shown in Fig.11. As shown in Fig.11, the positioning linearity of the CLPM-B is about 2% at no-load. It is observed that the influences of the thrust distortion and imbalance are greatly improved with the CLPM-B with interior permanent magnet.

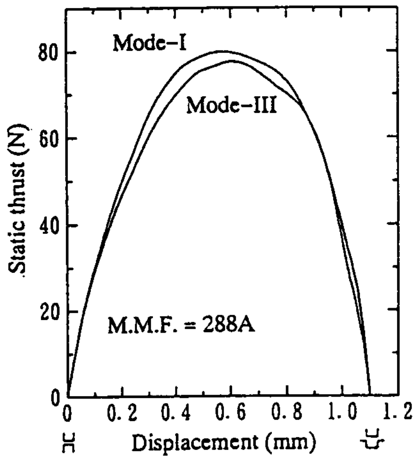

Fig. 10 Thrust distribution of the CLPM-B.

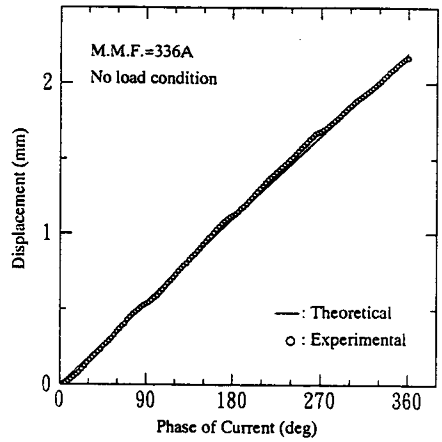

Fig. 11 Mover position trajectory of the CLPM-B.

Ⅵ. Conclusions

In this paper,the influences of the thrust distortion and imbalance in the micro-step drive in the CLPM are examined. Some important characteristics were also examined and the improvement of the positioning accuracy was discussed. From the analysis and the experimental results, the following conclusions are obtained.

(1) From the analysis and the experimental results, it is cleared that the thrust distortion and imbalance affect to the positioning accuracy in the micro-step drive.

(2) The positioning error in the conventional CLPM can be compensated by the exciting current control.

(3) The thrust distortion and imbalance are greatly improved with the new CLPM configuration.

(4) The positioning accuracy in the micro-step drive in the new CLPM configuration becomes excellent.

This new C-LPM with proposed configuration is useful for the small actuator for the high resolution and precise positioning applications.

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