2상 하이브리드형 리니어 스텝핑 전동기의 미세스텝에 관한 연구

論 文
49B - 5 - 10

A Study on Micro-step of 2-phase Hybrid Type Linear Stepping Motor

吳 鴻 錫* · 金 東 熙** · 李 相 鎬***
(Hong-Seok Oh · Dong-Hee Kim · Sang-Ho Lee)

Abstract - In this paper, a voltage equations, a thrust force equations and kinetic equation are derived from the basic structure of a 2-phase hybrid type linear stepping motor(HLSM). And a new micro-stepping method in order to eliminate effectively the resonant phenomena and to increase the positional resolution of the HLSM was proposed. The proposed micro-stepping method can divide one step into the maximum 128 micro-steps under simple control system. The dynamic characteristics of proposed micro-stepping method were analyzed by the ACSL(Advanced Continuous Simulation Language) with the voltage equations, the thrust force equations and the kinetic equation, and were measured by laser experimental system. As the result, the justice of theory was confirmed, and the resonant phenomena, the positional resolution and dynamic thrust were improved by the proposed micro-stepping method.

Key Words : micro-step, HLSM, resonant phenomena, laser experimental system

1. Introduction

Nowadays, the necessity of linear position control motors have been increased in the various fields of the automatic control system. In the recently, the position control motors have disadvantaged in the efficiency and economical view since it requires a conversion equipments such as belt and gear in order to convert rotary to linear motion. On the contrary, it is known that the linear stepping motor(LSM) of linear motion digital actuator has a direct drive method that do not need mechanical conversion equipments. Therefore, the LSM is advantaged in the efficiency and economical view. Also the LSM is electromagnetic incremental motion actuator which converts a digital pulse inputs to analogue output motion. When properly controlled, the output steps are always equal to the numbers of input command pulses. Thus it can be driven to an accurate position with open loop in a simple schemes, and there is no cumulative error in their operation.[1][2]

However, the natural step displacement is too large for certain applications. Although smaller step displacement might be achieved by machining treatment, machine tolerances and magnetic saturation may result in a degradation of performance. Consequently, an attractive other method has recently studied to operate the LSM through a finite number of sub-step, stable positions in the natural step displacement. This method of operation is called micro-step or mini-step and the number of micro-step can range from 1 to about 128. Also, micro-step produces more positional resolution, less resonant phenomena, and greater stability than full steps, and extends the dynamic range of the LSM.[3]~[7]

This paper provides the simple and effective micro-stepping drive of the two-phase hybrid type LSM(HLSM), and a voltage equations, a thrust force equations and a kinetic equations are derived from the basic structure of the HLSM.[8][9]

Several dynamic characteristics of the HLSM are analyzed by the ACSL(Advanced Continuous Simulation Language) with the voltage equations, the thrust force equations and the kinetic equation, and are measured by laser experimental system.[10]

The experimental results show that the new micro-stepping method eliminates the resonant phenomena, and increases the positional resolution, and improves the motor's dynamic range.

2. Basic Construction and Equations

The basic construction of the HLSM is shown in Fig.

* 正 會 員 : 嶺南大 電氣電子工學部 博士課程
** 正 會 員 : 嶺南大 電氣電子工學部 敎授 · 工博
*** 正 會 員 : 三陟大 制御計測工學科 副敎授 · 工博
接受日字 : 1999年 12月 9日
最終完了 : 2000年 4月 3日

1. The HLSM has two basic parts ; the mover and the stator. The mover consists of two electromagnets and permanent magnets (PM) and a back-yoke. Each electromagnet has two poles, and each pole has the same number of parallel teeth. The centerline distance between two adjacent teeth is called a tooth-pitch, Tp. There is a half-tooth-pitch difference between the each mover teeth on the left and right hand sides. The A-phase mover piece is out of 1/4 tooth-pitch from the position of the B-phase mover piece. So, the HLSM has the step length of 1/4 tooth-pitch in the full-step drive mode.

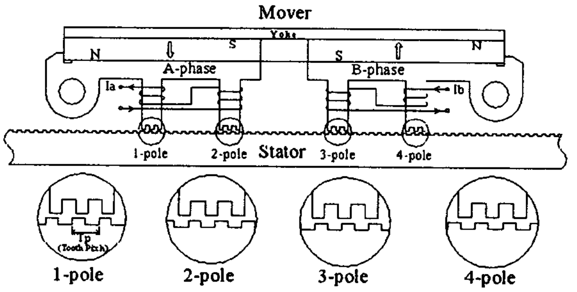


Fig. 1 Basic construction of the HLSM.

The voltage equations, the thrust force equations and the kinetic equation from the basic construction of the HLSM are given as follows[3].

(i) A-phase

$$F_A = -K_f i_A \sin\frac{2\pi}{T_p}x \tag{1}$$

$$e_A = K_1 \frac{dx}{dt}\sin\frac{2\pi}{T_p}x \tag{2}$$

$$v_A = r_A i_A + L_{1A}\frac{di_A}{dt} + M\frac{di_{cA}}{dt} + e_A \tag{3}$$

$$0 = r_{cA} i_{cA} + L_{2A}\frac{di_{cA}}{dt} + M\frac{di_A}{dt} - e_A \tag{4}$$

(ii) B-phase

$$F_B = -K_f i_B \cos\frac{2\pi}{T_p}x \tag{5}$$

$$e_B = K_1 \frac{dx}{dt}\cos\frac{2\pi}{T_p}x \tag{6}$$

$$v_B = r_B i_B + L_{1B}\frac{di_B}{dt} + M\frac{di_{cB}}{dt} + e_B \tag{7}$$

$$0 = r_{cB} i_{cB} + L_{2B}\frac{di_{cB}}{dt} + M\frac{di_B}{dt} - e_B \tag{8}$$

(iii) Kinetic equation

$$F_A + F_B = (M' + m)\frac{d^2x}{dt^2} + 2(M' + m)\zeta_n\omega_n\frac{dx}{dt} \tag{9}$$

where,

F_A, F_B : thrust forces, e_A, e_B : induced voltages, v_A, v_B : applied voltages, K_f : thrust force constant, K_1 : back EMF constant, r_A, r_B : resistances of coil, r_{cA}, r_{cB} : equivalent resistances of iron loss, i_A, i_B, i_{cA}, i_{cB} : circuit currents, T_p : tooth pitch, $L_{1A}, L_{2A}, L_{1B}, L_{2B}, M$: self- and mutual-inductance of coil, x : displacement, M' : mass of load, m : mass of mover, ζ_n : damping ratio, ω_n : natural undamped frequency

3. Implementation Principle of the New Micro-step

The block diagram of the new micro-stepping drive is shown in Fig. 2. The micro-stepping drive of the HLSM should have varied micro-step numbers because various objectives and requirements are required. In the diverse requirements, it is required that the micro-stepping drive should be able to generate various status numbers related to micro-step numbers. The micro-stepping drive is to supply various ratio currents for each phase coil under micro-step numbers.

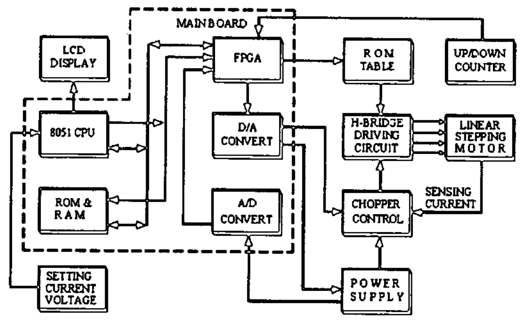


Fig. 2 The block diagram of the new micro-stepping drive.

According to this feature, we have built the exciting signal pattern corresponding to each phase current size for the HLSM to be micro-stepped. The exciting signal pattern stored into ROM table is retrieved by micro-step numbers and status numbers. In a general micro-stepping method, the digital values of each phase current must be converted into relevant analog value using continuous switching. However, the new micro-stepping method can be established only by transmitting the exciting signal stored into ROM table.

In one pitch, the status number ST_n for micro-step with the HLSM is equal to eq.(10).

$$ST_n = 4 \times M_n, \tag{10}$$

where, M_n is micro-step numbers($= 2^n$)

For example, if the micro-step number is 16, the status number is 64 in one pitch(Tp). In one pitch, the status number of current in a phase coil under M_n micro-step number is $M_n + 1$. Generally, a simple micro-step is to divide equally maximum phase current by M_n. That is to say, the phase current is changed as Fig. 3. Then the HLSM is micro-stepped with current change, accordingly the predicted step displacement of the HLSM micro-stepped by M_n is Tp/ST_n . Thus, approximate expression for the phase currents i_A, i_B of Fig. 3 is given by

$$i_A = \frac{8I}{\pi^2}\left\{ \sin\frac{2\pi}{T_p}x + \sum_{n=1}^{\infty}\frac{(-1)^n}{(2n+1)^2}\sin(2n+1)\frac{2\pi}{T_p}x \right\} \quad (11)$$

$$i_B = \frac{8I}{\pi^2}\sum_{n=1}^{\infty}\frac{1}{(2n-1)^2}\cos(2n-1)\frac{2\pi}{T_p}x \quad (12)$$

When the currents given in eq.(11) and eq.(12) are substituted by eq.(1) and eq.(5),

$$F_A = -K_f\frac{8I}{\pi^2}\left\{ \sin\frac{2\pi}{T_p}x + \sum_{n=1}^{\infty}\frac{(-1)^n}{(2n+1)^2} \times \sin(2n+1)\frac{2\pi}{T_p}x \right\} \times \sin\frac{2\pi}{T_p}x \quad (13)$$

$$F_B = -K_f\frac{8I}{\pi^2}\left\{ \sum_{n=1}^{\infty}\frac{1}{(2n-1)^2}\cos(2n-1)\frac{2\pi}{T_p}x \right\} \times \cos\frac{2\pi}{T_p}x \quad (14)$$

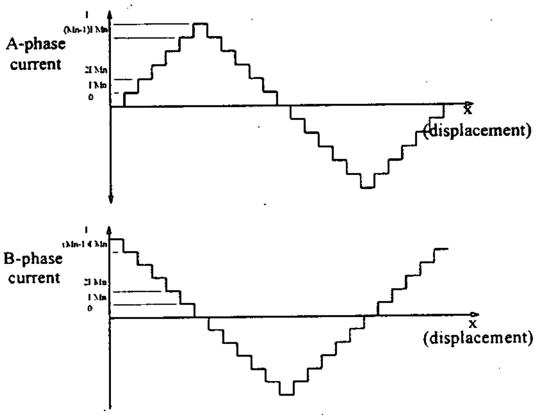


Fig. 3 Phase current patterns.

Fig. 4 shows the new micro-stepping drive to change equally phase currents. The chopper control is tried to maintain the constant current, and to enhance the characteristics of high-velocity region. In Fig. 4, the Vr is a reference voltage and the Vs a detective voltage and the Rs a detective resistor selected to maintain the constant current. And the resistor R_m have used to change equally phase currents and is equal to eq.(15).

$$R_m = R_1/2^{m-1} \ (m = 1, 2, \cdot \cdot, n) \quad (15)$$

where, m is the resistor number corresponding to M_n.

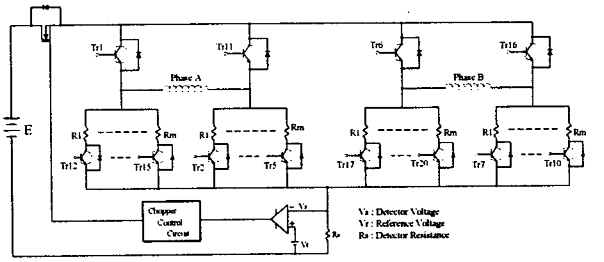


Fig. 4 New micro-stepping drive.

4. Simulation and Experimental Results

Table. 1 shows the specifications of the HLSM in order to make an experiment with the respective characteristics of it, and this is the specifications according to a typical two-phase exciting method, the full step mode.

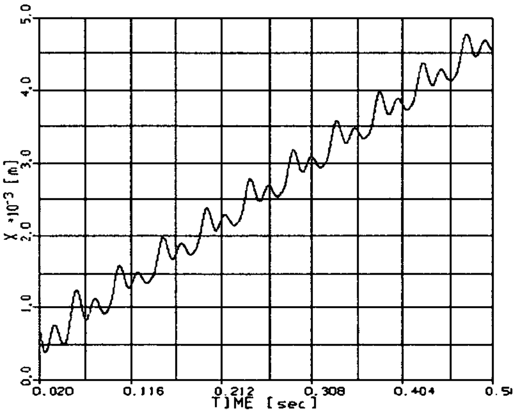
Table 1 The specifications of the HLSM

Section	Specification
driving method	bipolar chopper constant current
voltage(DC)	24 [V]
current	1 [A/phase]
displacement	0.4 [mm/pulse]
resistance	4.2 [Ω/phase]
inductance	10.7 [mH/phase]
holding force	2 [kgf]

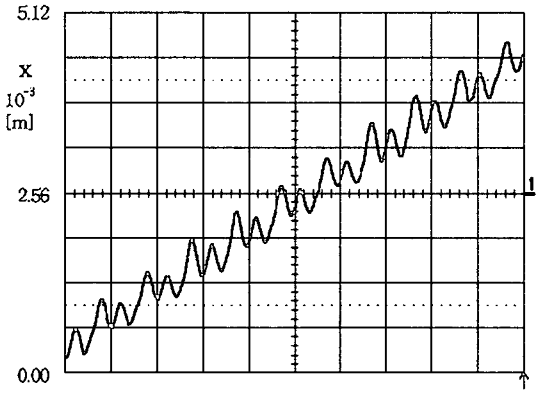
Several dynamic characteristics of the HLSM are simulated by ACSL with the voltage equations, the thrust force equations and the kinetic equation, and are measured using a laser interferometer system. And the dynamic thrusts are examined using a force gauge.

4.1 Vibration characteristics

The analysis of experimental results depends upon one basic property that the system response to the sum of two inputs is the sum of the system response to the inputs individually. Using above basic property repeatedly, the HLSM response to a number of steps is the sum, with the proper timing, of single step responses. Fig. 5(a) and Fig. 5(b) show responses for the full step mode, and Fig. 6(a) and Fig. 6(b) show responses for 128 micro-steps under same velocity. As the result of Fig. 5 and Fig. 6, the justice of theory was confirmed because the calculated and the experimental results are almost coincided with. And the 128 micro-steps is greater stability than the full step mode for the vibration characteristics.



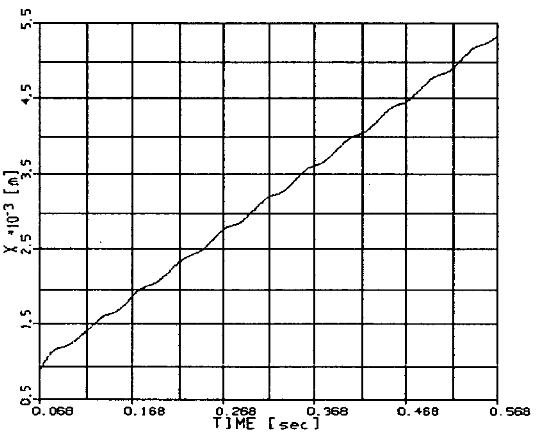
(a) Calculated result



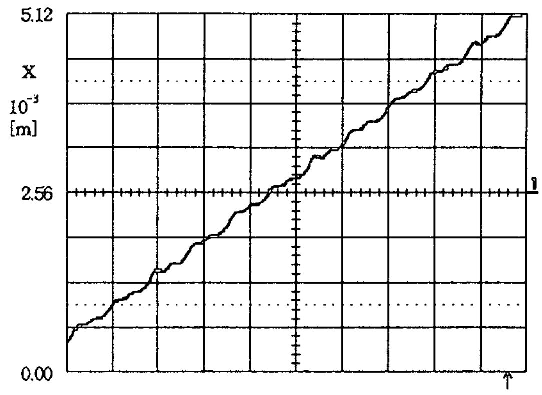
50[ms]/div, 2[V]/div, 20[pps]

(b) Experimental result($320\mu m/V$)

Fig. 5 Response for the full step mode.



(a) Calculated result



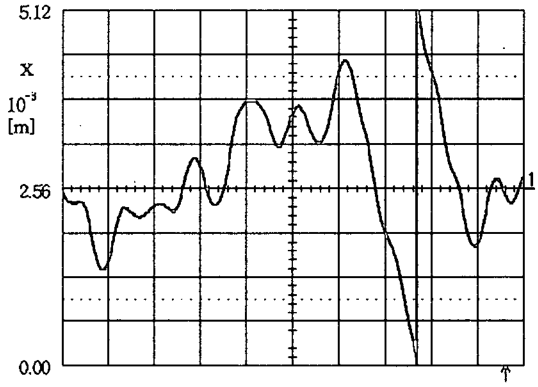
50[ms]/div, 2[V]/div, 2560[pps]

(b) Experimental result($320\mu m/V$)

Fig. 6 Response for the 128 micro-steps.

And for the full step mode, the resonances are occurred around 60[pps] as shown Fig. 7.

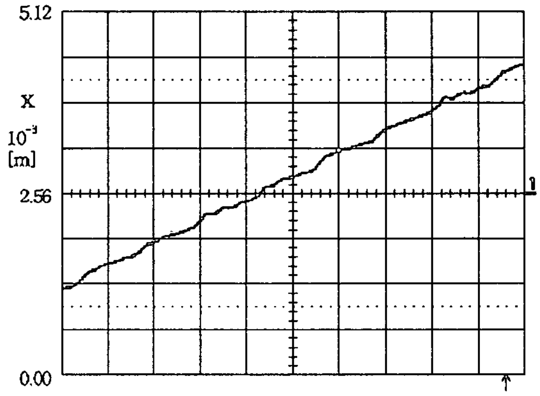
For the 128 micro-steps, however, the resonant phenomena are eliminated effectively as shown Fig. 8.



20[ms]/div, 2[V]/div, 60[pps]

Experimental result($320\mu m/V$)

Fig. 7 Response for the full step mode.



10[ms]/div, 2[V]/div, 7680[pps]

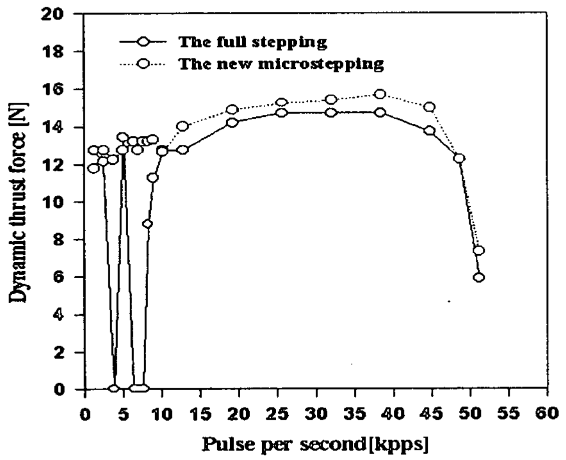
Experimental result($320\mu m/V$)

Fig. 8 Response for the 128 micro-steps.

4.2 Dynamic thrust force characteristics

After the HLSM is started by a specified drive in the specified excitation mode in the self-starting range, the frictional load thrust force is gradually increased in the constant driving frequency ; the HLSM will eventually run out of synchronism. The relation between the frictional load thrust force and the stepping rate with which the HLSM can synchronize is called as the dynamic thrust force characteristics.

Fig. 9 shows the dynamic thrust force characteristics. The dynamic thrust force characteristics clearly prove that the new micro-stepping method is remarkably superior to the typical full step mode in the dynamic thrust force characteristics(for same velocity).



(for same velocity)
Fig. 9 Dynamic thrust force characteristics.

5. Conclusion

In this paper, the voltage equations, the thrust force equations and the kinetic equation are derived from the basic structure of the HLSM.

And the new micro-stepping method in order to eliminate effectively the resonant phenomena and to increase the positional resolution of the HLSM is proposed. The proposed micro-stepping method can divide one step into the maximum 128 micro-steps under simple open loop control system. The dynamic characteristics of proposed micro-stepping method were analyzed by the ACSL with the voltage equations, the thrust force equations and the kinetic equation, and were measured by LASER experimental system. As the result, the justice of theory was confirmed because the calculated and the experimental results are almost coincided with.

The new micro-stepping method has greater stability than the full step mode for the vibration characteristics under same velocity. The resonances are occurred around 60[pps] for the full step mode, but for the new micro-step method, the resonant phenomena are eliminated effectively.

Also, the dynamic thrust force characteristics are clearly shown that the new micro-stepping method is remarkably superior to the typical full step mode in it.

Therefore, the experimental results show that the new micro-stepping method eliminates the resonant phenomena, increases the positional resolution, and improves the motor's dynamic range.

Reference

[1] J. P. Pawletko and H. D. Chai, "Linear Step Motor", IMCSD, pp.V-1~V-11, 1973.

[2] Ding Zhi-Gang, "A Novel Electromagnetic Spiral Linear Step Motor", IEEE IAS, Vol.1, pp.329~336, 1994.

[3] Kwang-Woon Lee, Won-Sik Jang, Jung-Bae Park, etc. "Development of High Performance Microstepping Driver", KIPE, Vol 2, No 3, pp.37~43. 1997.

[4] Hong-Seok Oh, Dong-Hee Kim, Sang-Ho Lee, etc. "New Micro-stepping Drive of 2-Phase Linear Stepping Motor", PEMC'98, Vol 1, pp.3-189~3-192, 1998.

[5] Eric K. Pritchard, "Mini-stepping motor drivers", IMCSD. Proc., pp. Q-1~Q-11, 1976.

[6] Paul R. Emerald et al., "CMOS step motor IC and power multi-chip module combine to integrate, multi-mode PWM operation and microstepping", PCIM, pp. 22~35, 1996.

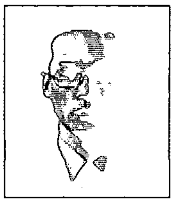
[7] Eric K. Pritchard, "Analog operation of stepping motors", IMCSD. Proc., pp. 283~294, 1976.

[8] Hong-Seok Oh, Dong-Hee Kim, Sang-Ho Lee, Long-Nam Han, "A Study on The Improvement of Characteristics in 2-phase Linesr Stepping Motor", ICEIC'98, pp.II-93~II-97, 1998.

[9] Muneaki Ishida, Shintarou Okamoto and Takamasa Hori, "Equivalent Circuit of Linear Pulse Motor", T.IEE Japan, Vol.110-D, No.12, pp. 1257~1265, 1990.

[10] Hao-Yung Lo and Jau-Ling Chen, "Microstep of digital control for step motor and its test using a laser interferometer measurement system", INT. J. ELECTRONICS, Vol. 62, No.5, pp.761~780, 1987.

저 자 소 개



오 홍 석 (吳 鴻 錫)

1969년 1월 9일생. 1992년 영남대 공대 전기공학과 졸업(학사). 1994년 동 대학원 전기공학과 졸업(석사). 1998년 동 대학원 전기공학과 박사과정수료. 현재 (주)이맥스하이테크 대표이사

Tel : 0394-535-0593, Fax : 0394-535-0594

E-mail : emacsht@chollian.net

김 동 희 (金 東 熙)

1950년 11월 20일생. 1973년 영남대 공대 전기공학과 졸업(학사). 1975년 동 대학원 전기공학과 졸업(석사). 1987년 Kobe대학 졸업(공박). 1987년~1989년 한국전기연구소 전력전자 연구부장. 현재 영남대 공대 전기전자공학부 교수

Tel : 053-810-2488

E-mail : dohkim@ynucc.yeungnam.ac.kr

이 상 호 (李 相 鎬)

1959년 7월 13일생. 1982년 영남대 전기공학과 졸업(학사). 1988년 동 대학원 전기공학과 졸업(석사). 1993년 동 대학원 전기공학과 졸업(공박). 현재 삼척대 제1공학부 제어계측과 부교수

Tel : 0397-570-6382, Fax : 0397-570-6389

E-mail : shlee@samchok.ac.kr