Optimum LIM Interval Selections of 3D Conveyor System for Control Algorithm Developments

Jung Ho Lee, Hun Young Lim, Soon Myung Jang, Member, IEEE

Department of Electrical Engineering, Hanbat National University, Daejeon, 305-719, Korea

limotor@hanbat.ac.kr, 13579young@naver.com, smjtown@naver.com

ABSTRACT: This paper deals with the dynamic characteristic analysis & the intervals selection for constant speed control of primary stacks in the secondary moving (aluminum plate) type 3D conveyer system using Linear Induction Motor (LIM). The dynamic characteristic analysis method of the vector controlled LIM using coupled FEM and control algorithm taking into account the movement is proposed. The focus of this paper is the analysis relative to selecting primary stack intervals in order to constant speed control in horizon and vertical driving conditions of the 3D conveyer system using LIM.

1 INTRODUCTION

Linear Induction Motor (LIM) has been developed for use in the industry, transportations, OA, FA, because of the merits of direct drive and simple structure.

Especially in case of applying LIM to auto conveyor system, there is no limitation of acceleration and deceleration by slip in which was a problem in the conventional system using chain or belt.

Since there is no moving part and contact part except roller, it is possible to transport objects noiselessly with high speed (Maximum velocity: 5 m/sec) and control position exactly.

And the repair of maintenance of it is almost not necessary and the extension or change of the line is very simple.

This paper deals with the three dimensional conveyor systems for light objects out of the auto conveyor systems.

This system is an auto-conveyor system that moves carrier which loads devices, drugs, and documents on three dimensional circulating rail composed of horizontal, vertical and curve part, and that make a relative motion by driving force generated between the secondary stuck to running carrier and the primary (single sided linear motor) installed on the ground as shown in Fig. 1.

In this system, since LIM is turn on only when carrier is over it, it can be saved much energy and obtained many merits of high speed, automation (acceleration and deceleration control, the control of precision position), and removed the power supply cable or lead wire.

As the principle of vector control operation, linear motor of starting point is to accelerate the carrier in a wanted direction and, since carrier runs with inertia after it is propelled by interaction with the primary stuck to the ground and its speed is reduced by friction between rail and running roller, therefore, there is next linear motor to reaccelerate it.

For the constant speed control of secondary aluminum plate mover using single vector control inverter system, it is important that primary stack is located in appropriated intervals.

There are two earlier approaches for the vector controlled linear induction motor.

The first approach is the d-q equivalent circuits considering each poles asymmetry by the pole-by-pole d-q modeling [1].

The second approach is the construction of the asymmetrical d-q equivalent circuits by the lock test and the test under an equivalent no-loaded state [2].

However, the physical properties of inner LIM cannot accurately be predicted by these equivalent methods and the types are moving primary those.

The finite element approach has been gaining progressively greater importance than the equivalent circuit method in solution of non-linearity, anisotropy characteristic and motion analysis, etc.

These approaches, which are coupled with control algorithm and numerical analysis method, have an interest for researchers now [3]-[5].

This paper deals with the dynamic characteristic analysis method & optimum intervals selection of primary stacks in the secondary moving (aluminum plate) type 3D conveyer system using LIM.

The focus of this paper is the analysis relative to selecting primary stack intervals in order to constant speed control horizon and vertical driving conditions of in the 3D conveyer system using LIM.

2 ANALYSIS MODEL

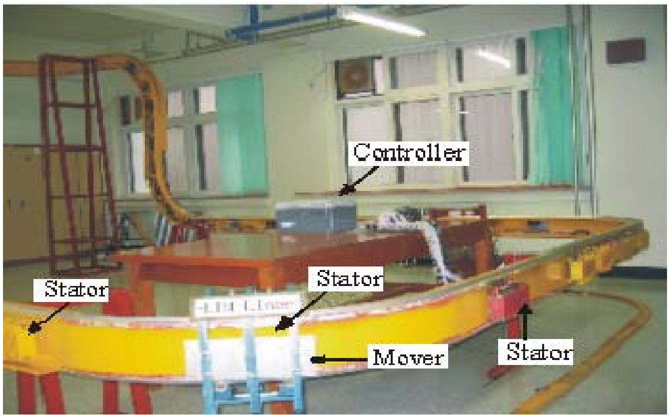


Figure 1. Prototype of 3D conveyer system

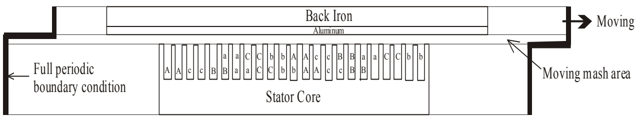


Figure 2. Analysis model of LIM

TABLE I
SPECIFICATION OF ANALYSIS MODEL

Part of motor	Specification
Number of phase	3
Number of poles	3
Length of primary stack	198.5 (mm)
Width of primary stack	80.0 (mm)
Height of primary stack	49.0 (mm)
Thickness of aluminum	4.0 (mm)
Thickness of back-iron	6.0 (mm)
Air gap length	3.0 (mm)

The two dimensional model of LIM is shown in Fig.2, and the specifications are as follows in TABLE I.

The primary stack intervals increasing (2m, 1.6m, 1.2m, 0.8m, 0.6m, 0.4m) are considered by enlarging full periodic boundary condition of both sides to x direction.

The mesh should be changed according to the movement of the mover in moving mesh area.

A moving line is introduced to save computing time and to perform the process efficiently in FE analysis.

3 CONCLUSIONS

3.1 Finite Element Formulation With Motion

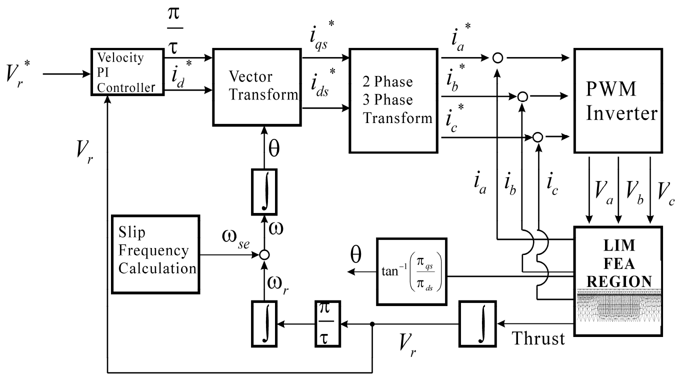


Figure 1. Prototype of 3D conveyer system

The governing equation describes the magnetic vector potential of LIM, adopting the moving coordinate system [6].

It is given by (1).

$$rot\frac{1}{\mu}rot\,\vec{A} = \vec{J}_0 - \sigma\frac{\partial \vec{A}}{\partial t} \qquad (1)$$

Where, σ is an equivalent conductivity of secondary material taking into account the influence of transverse edge effect by the Russell and Norsworthy factor [7].

The circuit equation coupled with the field equation can be written as

$$[U] = [R][I] + [L_0]\frac{d}{dt}[I] + [E] \qquad (2)$$

Where,

$[E]$: e.m.f. vector in the windings

$[U]$: supplying voltage vector

$[L_0]$: leakage inductance

$[R]$: stator resistance

$[I]$: output current

To solve (1), we use the Galerkin finite element method. For the time differentiation in (1) and (2), a time stepping method is used with the backward difference formula. Coupling (1) and (2), the governing equation is given as follows.

$$\begin{bmatrix} [S] + \frac{[D]}{\Delta t} & -[N] \\ [N]^T & \frac{[L] + \Delta t[R]}{h_{eff}} \end{bmatrix} \begin{bmatrix} [A] \\ [I] \end{bmatrix} = \qquad (3)$$

$$\begin{bmatrix} \dfrac{[D]}{\Delta t} & [0] \\ -[N]^T & \dfrac{-[L_0]}{h_{eff}} \end{bmatrix} \begin{bmatrix} [A] \\ [I] \end{bmatrix}_t + \begin{bmatrix} [0] \\ -\dfrac{\Delta t}{h_{eff}}[U] \end{bmatrix}_{t+\Delta t}$$

Where, [A] : magnetic vector potential, [D] : coefficient matrix related to eddy current, h_{eff} : efficient lamination width of stator.

3.2 Thrust and Flux Calculation

The thrust F_x acting on LIM at each time is calculated by the surface integral of the Maxwell stress tensor on the surface.

$$F_x = \int_l \frac{w}{2\mu_0}\{(B_x{}^2 - B_y{}^2)n_x + 2n_y B_x B_y\}dl \qquad (4)$$

Where, n_x and n_y are the unit normal direction vectors, w is the primary stack width. In FE region, the linkage flux of each phase per pole is calculated as follows.

$$\lambda = N\int \vec{B}\cdot d\vec{S} = N(A_1 - A_2)w \qquad (5)$$

Where w is the primary stack width, N is number of coil turns in the slot and A_1, A_2 are the mean value of vector potential in the slot.

Fig. 3 shows the block diagram of system.

Angular velocity w calculator is applied to the control logic for the vector control.

The proposed analysis method is applied to the step velocity commend (2.0 m/sec) in the vector control logic part using 10(μsec) sampling time.

The thrust current reference is i_q^* and magnetizing current reference is i_d^*, where maximum i_q^* is 7A and i_d^* is 4A for staring force at rated watt.

In motion analysis, the speed of LIM is calculated by the equation as follows:

$$\begin{aligned} V_r &= \int (F_x - F_l)/m \cdot dt \\ \omega_r &= (\pi/\tau)\cdot V_r \\ \theta &= \int (\omega_r + \omega_{sl})\cdot dt \end{aligned} \qquad (6)$$

Where, V_r , ω_r , ω_{sl} are the velocity, angular velocity and slip angular velocity of mover, F_x , F_l are the thrust and load thrust, τ is pole pitch.

Flux angle, which is calculated in the FE region, is as follows:

$$\theta = \tan^{-1}(\lambda_{qs}/\lambda_{ds}) \qquad (7)$$

4 SIMULATION RESULT & DISCUSSION

TABLE II
VELOCITY RIPPLE IN HORIZON AND VERTICAL POSITIONS OF MOVER

Motor interval (m)	Horizon	Vertical
2 (m)	1.18207	35.0674
1.6 (m)	0.91502	23.9488
1.2 (m)	0.79453	14.242
0.8 (m)	1.21243	7.0515
0.6 (m)	0.86080	3.8741
0.4 (m)	0.44554	0.8114

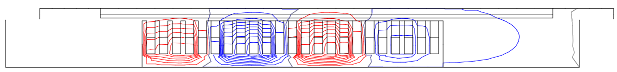
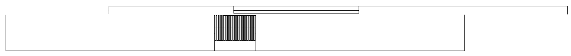
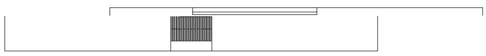


Figure 4. Flux plot example of analysis model considering movement

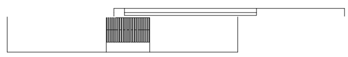


(a) Primary stack interval (2 m)

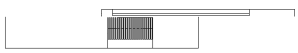


(b) Primary stack interval (1.6 m)

(c) Primary stack interval (1.2 m)



(d) Primary stack interval (0.8 m)



(e) Primary stack interval (0.4 m)

Figure 5. Primary stack intervals considering periodic boundary condition

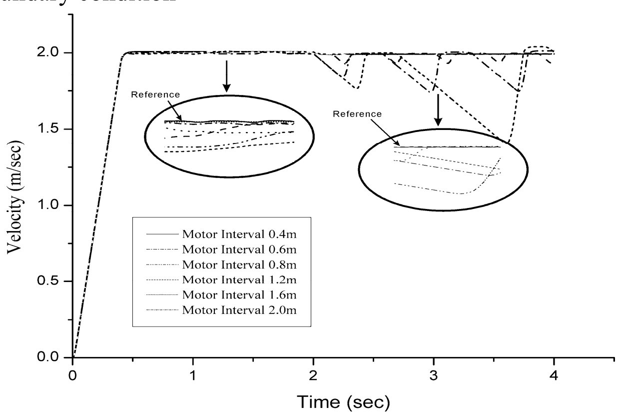


Figure 6. Velocity responses for constant velocity commend

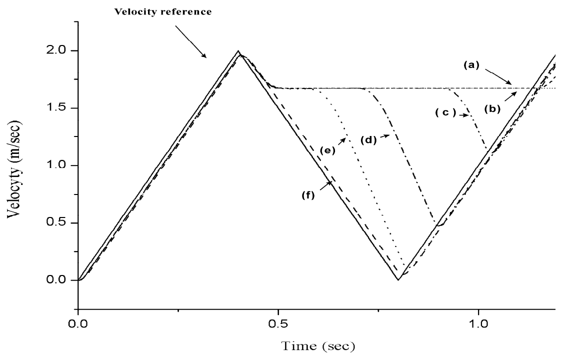
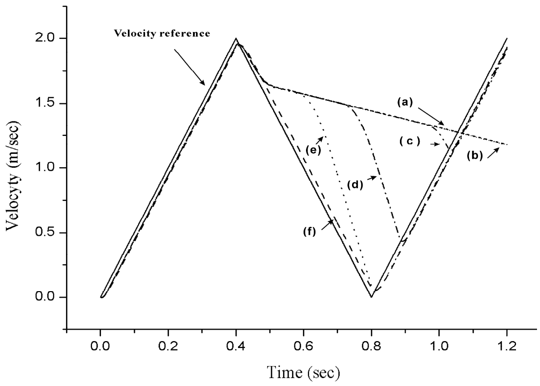


Figure 7. Forward-reverse velocity responses in horizon position of mover



(a) Motor interval = 2m (b) Motor interval = 1.6m
(c) Motor interval = 1.2m (d) Motor interval = 0.8m
(e) Motor interval = 0.6m (f) Motor interval = 0.4m

Fig. 8. Forward-reverse velocity responses in vertical position of mover

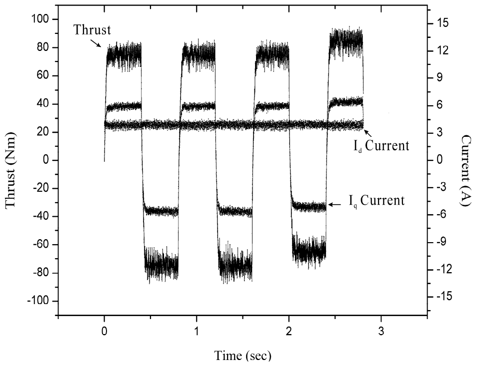


Fig. 9. Thrust/magnetizing current and thrust responses in forward-reverse velocity commend (Motor interval = 0.4m)

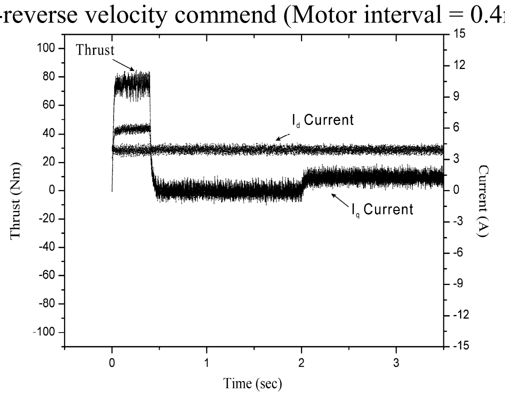


Fig.10 Thrust/magnetizing current and thrust responses in constant velocity commend (2m/sec, Motor interval = 0.4m)

5 CONCLUSION

In the system of moving secondary plate and primary motor on the ground, since motor is turn on only when carrier is over it, it can be saved much energy and obtained many merits of high speed, and removing the power supply cable or lead wire difficulties due to the long stroke.

However it is difficult, especially in moving secondary plate system, for the accurate speed control of LIM by the state-of-the-art of rotating machine theory because of absence of sensing source.

In order to improve the control algorithm, the dynamic characteristic analysis method of the controlled LIM sets of 3D conveyer system using coupled FEM and control algorithm taking into account the movement is proposed and it has been selected a appropriated interval of primary motors in order to constant speed control.

The proposed method is useful in the configurations and control algorithms development of MAGLEV, conveyor system, elevator, transportations system and etc. using LIM and other machines.

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