The Thrust Control Characteristics of Single-Sided Linear Induction Motor

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ABSTRACT

The thrust control characteristics of single-sided linear induction motor (SLIM) is achieved using PI controller in this paper. The trembling of air gap length between the primary winding and the secondary structure of the SLIM must be minimized in order to get quick response results. Also, the input voltage of SLIM is involved with the time harmonics because most SLIM is driven by inverter.

According to the feedback linear control system, this paper describes with applying the non-linear control, speed and estimated flux algorithm. At the result of this experiment, we reached to the improvement of thrust characteristics with PI controller.

1. Introduction

In difference with the rotary type electrical machinery, a Linear Induction Motor that generates the direct thrust directly, is widely used for the operation system of electrified railroad, elevation system, convayer system, and so on.

The operational principle of SLIM is constructively same with the general rotary induction motor. But the air gap is relatively wide and the operational principle of SLIM has the end effect, so the distortion of thrust and low power effect occur

There are the electrical magnetic analyzing methode and equivalent circuit analyzing one - in concerned with the methode of SLIM characteristics analyzing.

The electical magnetic analyzing methode has available advantages to consider the physical condition. The equivalent circuit analyzing methode has the elementary methode in the control system of vector control and over shoot situation.

To use SLIM for servo system, the exact account of thrust about the initial speed is needed, but analyzing by equivalent circuit analyzing methode such as rotary induction motor, the error occurs because of the end effect.

On the other hand, there is the vector control system that is applied for the conventional PI controller.

The vector control system using PI controller converts stop position element into synchronous position one by using magnetic flux angle. In order to extinguish the mutual interrupt, it generally has the compensational circuit in the output.

Also, to keep consistently the magnetic flux, it controls the reference value of magnetic flux current located to the forth part of magnetic flux elementary current controller. To compensate the flux sartuation of the low flux field, the function generator-consisted of velocity and flux value- located to the forth of the flux controller is added.

In this paper, we use the dynamic charateristics analyzing methode that can calculate efficiently the initial thrust by using finite element methode in the operating SLIM system and examine the thrust characteristics of PWM inverter-fed SLIM that applies PI controller operated sinusodial voltage source.

2. Modeling of SIIM

The experiment to calculate circuit parameter consists of the braking test and equivalent no-load test. The braking test is the same way with the rotary induction motor. The equivalent no-load test is the different methode with the rotary induction motor that moves rotor in synchronous velocity.

The no-load test should be done under the following condition-the rotor rotates in synchronous velocity, and the primary core should move in the synchronous velocity.

In concern with the equivalent circuit, s=0, $r_2 / S = \infty$, so secondary current is zero. In the equivalent no-load test, the secondary resistant is ∞ by removing the secondary conductor AL.

$$X_1 = (X_1 + X_m)\frac{X_1'}{(X_1' + X_m')} \quad (1)$$

$$X_m = (X_1 + X_m)\frac{X_m'}{(X_1' + X_m')} \quad (2)$$

It is estimated R_1, Rc, X_1, Xm by resulting from the resistant test, the equivalent no-load test R_2 and X_2 by resulting from the equivalent circuit test and breaking test.

The structure of SLIM is shown in fig.1.

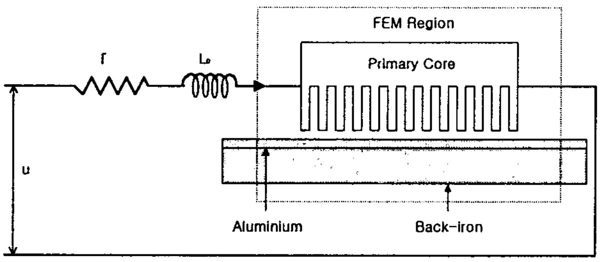

Fig.1 Analysis model of SLIM

The primary consists of laminated core made from Si steel plate, slot and winding. The secondary consists of Al plate and Back Iron.

The thrust occurs by the moving flux put in the primary core and the secondary current induced electromotive force generated by the primary flux.

In the difference with rotary induction motor, SLIM needs the induced current because of the relatively wide air gap. The end effect occurs in the direction of moving flux in the both ends.

To calculate the magnetic flux density of air gap, express with equ.3- vectorpotential equation and max-well equation.

$$\frac{\partial^2 A_z}{\partial x^2} + \frac{\partial^2 A_z}{\partial y^2} = \mu\sigma[\frac{\partial A_z}{\partial t} + (1-s)\, V_s \frac{\partial A_z}{\partial t}] \quad (3)$$

Where, the vectorpotential is the following - equ, 4

$$A_z = A_z(y)\, e^{j(wt-kx)} \quad (4)$$

Put equ,. 4 into equ. 3, then equ. 5

$$\frac{d^2 A_z(y)}{dy^2} = (k\lambda)^2 \quad (5)$$

Where, $\lambda = \sqrt{1 + j\sigma\mu s Vsk'}$

The solution of equ. 5 is the following - equ.6

$$A_z(y) = B_1\, e^{k\lambda y} + B_2\, e^{-k\lambda y} \quad (6)$$

Through two equations can estimate the magnetic flux density. Also induced electromotive force per z vector is the following - equ. 7

$$E_{z1} = \partial \frac{A_z^{\text{III}}}{\partial t}$$

$$= V_s - j\,\mu_0\, V_s\, J_1 U\, e^{j(wt-kx)} \quad (7)$$

The induced voltage effect value of primary winding is equ. 8.

$$E_1 = 4m\frac{K_w\, N_{ph}^2}{p}\frac{h}{\tau}\, V_s\, \mu_0 jU \quad (8)$$

So the impedance of a phase Z_{2e} is euq. 9.

$$Z_{2e} = \frac{E_1}{I_1} = j4m\frac{K_w\, N_{ph}^2}{p}\frac{h}{\tau}\, V_s\, \mu_0 u \quad (9)$$

To express the primary leakage reactance X_1' is euq. 10.

$$X'_1 = 8mfh\frac{(K_w N_{ph})^2}{p} \times 10^{-7}$$

$$\times[\frac{K_1}{K_w^2}\frac{20}{mq}(\frac{d_{2s}}{W_s} + \frac{d_{1s}}{3W_s}) + \frac{4}{h}(2\, l_{e2} + l_{e1})] \quad (10)$$

Where, $K_1 = \frac{1}{4}(3\beta + 1)$

3. Vector controller modeling of SLIM

The vector control system of SLIM has been studied in different type control method, but PI control system is widely used in terms of strength.

The vector controller SLIM system using PI controller compensates non-linear characteristics, so models the SLIM modeling. We should estimate the moving flux and speed equation from the modeling. The d-axis and q-axis current is equ. 11, 12

$$i_{ds}^e = \frac{V_{ds}^e}{R + p\sigma L_s} \quad (11)$$

$$i_{qs}^e = \frac{V_{qs}^e}{R + p\sigma L_s} \quad (12)$$

Constructing the closed loop with the applied PI controller, d-axis and q-axis current of motor are shown in fig. 2.

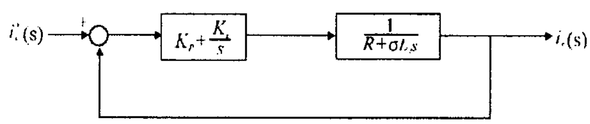

Fig. 2 PI controller for current control of LIM.

External loop control system of SLIM consists of mutual independent rotary flux control loop and speed control loop.

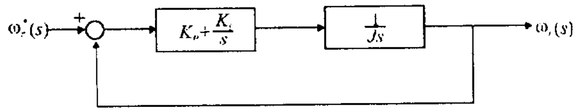

Fig. 3 PI controller for speed control of LIM.

The rotary flux is equ. 13 and 14.

$$p\lambda_{dr}^{e} = -\frac{R_r}{L_r}\lambda_{dr}^{e} + R_r\frac{L_m}{L_r}i_{ds}^{e} \quad (13)$$

$$\lambda_{dr}^{e} = \left(R_r\frac{L_m}{L_r}\right)/\left(p + \frac{R_r}{L_r}\right)i_{ds}^{e} \quad (14)$$

PI controller for rotor flux control of SLIM is shown in fig.4

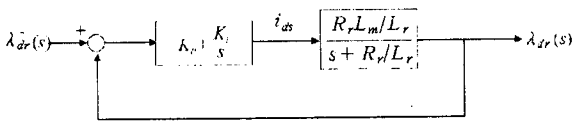

Fig. 4 PI controller for rotor flux control of LIM.

The schematics of vector control of SLIM with the PI controllers is shown in fig.5.

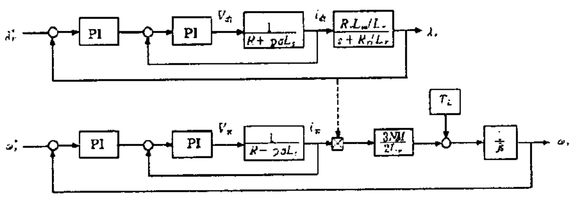

Fig. 5 Vector Control of LIM with the PI controllers.

4. Experimental and results

Table 1 shows the parameter of single-sided linear induction motor.

Table1. Parameter of linear induction motor

parmeter	Estimated value
R1	2.30
X1	1.13
Xg	3.25

Fig. 7 shows the thrust characteristics, and Fig.8 shows normal thrust characteristics in the initial velocity.

The current of the PWM inverter-fed that is controlled by PI controller is shown in fig.8. Fig.9 shows the thrust characteristics of SLIM system.

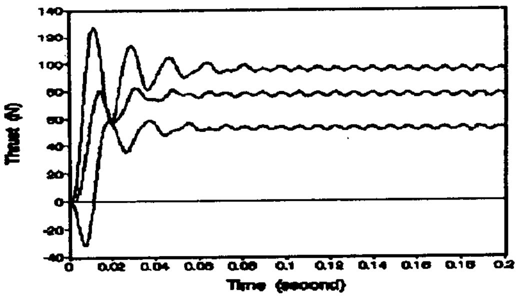

Fig. 6 Thrust characteristics of SLIM

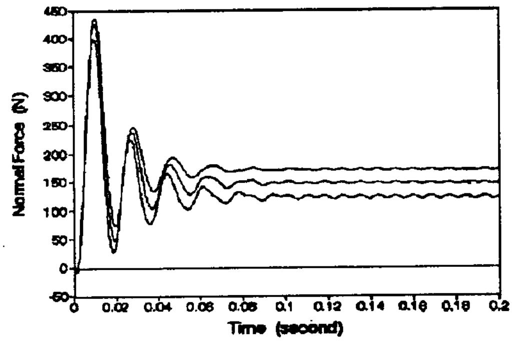

Fig. 7 Normal force characteristics of SLIM

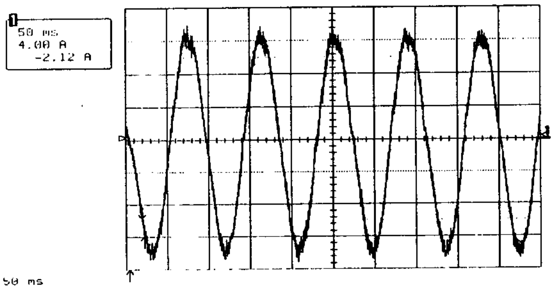

Fig. 8 The current of the PWM inverter-fed that is controlled by PI controller

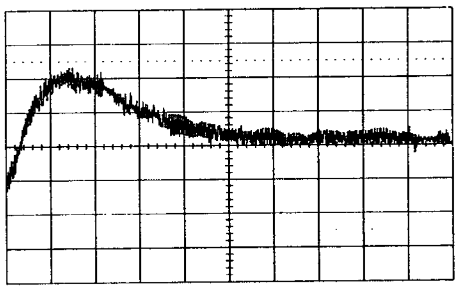

Fig. 9 The thrust characteristics of SLIM system

5. Conclusion

In this paper, we estimated exactly the parameter to consider leakage flux, iron loss and induced current because of the relatively wide air gap in comparison to general rotary induction motor.

And applied the dynamic charateristics analyzing methode that can calculate efficiently the initial thrust using finite element methode in operating SLIM.
Also examined the theory and result applying to the vector controller by PWM inverter-fed using the way to interpret dynamic characteristics effectively.

According to the feedback linear control system, we experimented with applying the non-linear control, speed and estimated flux algorithm. At the result of this experiment, we reached to the improvement of thrust characteristics with PI controller.

Reference

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