Study on the Servo Drive of PM-LSM to Be Used in Parallel Synchronous Drive

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Abstract: Recently, linear motors can have high speed control, high acceleration-deceleration. So linear motors are widely used in industrial applications such as precision machine tools. In our laboratory focusing on transport system, we propose parallel synchronous drive of used the PM-LSM (permanent magnet linear synchronous motor). It can pass luggage without having to stop the working. When you establish “parallel synchronous drive”, a motor follows the other motor. In our laboratory, one of the motors is called “master motor” and the other motor called “slave motor”. The master motor’s speed and position pass slave motor then establish parallel synchronous drive. Therefore, slave motor requires high-responsive and precision that follows the master motor. This paper focuses on the control of the slave motor.

Key words: PM-LSM, master-slave motor, PI control, parallel synchronous drive method.

1. Introduction

The LIM (linear induction motor) is used as the power source of long-distance conveyance system and has been extensively studied because of its simple structure [1-3]. Because of the drive principle, intermittence of the primary side is easy and the cost is decreased [1, 2].

Recently, permanent magnet type linear motors (PM-LSM) can have high speed control and high acceleration-deceleration. So linear motors are widely used in industrial applications such as precision machine tools. Our laboratory focuses on conveyance system [4]. Usually, an initial cost of PM-LSM rises to employ a full-length stator-side-on-ground design. Thus our laboratory has proposed an ISPM-LSM (intermittent stator PM-LSM) [5-9]. This system arranges the stator intermittently. The quantity of the stator decreases. And the section changing the method of the stator is proposed as this driving method [10]. Because the runway has a high degree of freedom on the bounty of non-stator area, it is possible to realize the corner part. However, in each processing area,

when the conveyance material pulls down from the mover, it is necessary to repeat “stop and go” the mover. This work leads to a reduction of transport efficiency.

Therefore, we propose parallel synchronous drive [11]. This method synchronizes the mover of the two LSMs. One assumes the main-line connecting the inter-processes and the other assumes the sub-line of each processing. Because both movers in the synchronized state have the same inertia, conveyance material may be moved without the mover stops. Main line of the motor is called “master motor” and the other motor is called “slave motor”. The master motor’s speed and position pass slave motor then establish parallel synchronous drive.

In this paper, we focus on the control of the slave motor. Control of the motor is verified by using the experimental apparatus.

2. Composition of Experimental Device

2.1 Concept of Parallel Synchronous Drive Method

The concept of the long-distance conveyance system in a factory is shown in Fig. 1. Generally, product processing in a factory differs in area for every process, and moves between each process at high speed. When

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Fig. 1 Transport system.

transferring the conveyance material to the line of each processing from the conveyor line, it is required to operate in “ride-down” on having stopped the mover. For repeating this drive, it cannot be expected efficiency of the conveyance.

Therefore, as shown in Fig. 1b, to set up a sub-line (slave) of each process in parallel with the main line (master), the mover of the two lines parallel synchronous drive, without stopping the mover can move the conveyance material. Thus, by this method, the conveyance efficiency is improved remarkably.

2.2 Construction and Specifications of Experimental Device

Parallel synchronous drive needs two linear motors, one linear motor is the master-side, and it moves in the stator intermittent placement.

The other linear motor is slave-side and it moves the stator continuous placement. When keeping freely moving the master motor, then passing the master date to the slave motor, therefore slave motor can follow to the master motor. Slave motor controlled by PI (proportional integral) control. Fig. 2 shows the configuration of the master-side experiment equipment. The outline of experimental device at master side is shown in Fig. 1. Fig. 3 is the

experimental apparatus of ISPM-LSM that assumes the main line of the transport system. The master side has a configuration which is arranged to intermittently stator. Table 1 shows the specifications used for the simulation model in. Fig. 4 shows the configuration of the slave-side experiment equipment. The outline of experimental device at slave side is shown in Fig. 5. In addition, Fig. 5 is the experimental apparatus of PM-LSM that assumes the sub line of the transport system. Slave motor is the experimental apparatus mainly used in this paper.

Fig. 2 Master motor (stator intermittent placement).

Fig. 3 An outline of experimental device of master side.

Table 1 Specification of the experimental device of master side.

Item		Value(Unit)
Stator of Master		
Number of slot	S_M	9(Slots)
Armature resistance	R_{aM}	1.55(Ω)
Inductance(overlap)	L_{aM}	53.0(mH)
Inductance(non-overlap)	L_{aM}'	39.3(mH)
Length of Stator(per unit)	l_{sM}	360(mm)
Secondary Mover of Master		
Number of Magnet	P_M'	28(Pieces)
Number of pole	P_M	12(Poles)
Pole Pitch	τ_p	30(mm)
Mass of Secondary mover	M_M	20(kg)
Length of Secondary mover		900(mm)
Thrust Constant	K_{fM}	29.6(N/A)
Induced voltage Constant	K_{eM}	9.86(V/m/s)
Non-stator Area	g'_s	420(mm)
Air-gap	g	6.0(mm)

Fig. 4 Slave motor (stator continuous placement). **Fig. 5** An outline of experimental device of slave side.

3. Results of PI Control of Slave Motor

Speed and current of the slave motor is controlled by PI control. The block diagram of the PI control is shown in Fig. 6 (Lp means the linear pulses from the magnet encoder). Internal structure of the current controller is a dq coordinate system. Command speed of the slave motor of this experiment is virtually entering the speed of the master motor. Command speed is acceleration and deceleration control of up to 0-0.5 m/s.

Table 2 Specification of the experimental device of slave side.

Item		Value (Unit)
Stator of Slave		
Number of slot	S_S	12 Slots
Armature resistance	R_{aS}	2.5 Ω
Inductance	L_{aS}	36.7 mH
Secondary Mover of Slave		
Number of Magnet	P_S'	16 Pieces
Number of pole	P_S	16 Poles
Pole Pitch	τ_p	30 mm
Mass of Secondary mover	M_S	9 kg
Length of Secondary mover		550 mm
Thrust Constant	K_{fS}	44.7 N/A
Induced voltage Constant	K_{eS}	14.9 V/m/s
Air-gap	g	6.0 mm

PI regulator of the speed feedback control of slave was set at the proportional gain $Kp_S = 3$ As/m and integration gain $Ki_S = 8.5$ A/m. Also, PI regulator of the current feedback control of slave was set at the proportional gain $Kpc_S = 9.8$ Vs/A and the integration gain $Kic_S = 100$ V/A.

Figs. 7-10 show the relationship between command values and the measured values. As a result by using PI control mechanism, it gives the speed command based on the simulated actual speed of the master motor. We noticed that the speed ripple occurs. This time we went the acceleration and deceleration control of up to 0-0.3 m/s, 0-0.5 m/s. That speed is to follow the command value from the graph. However, it can be seen from the graph is greater amplitude of the current. Slave motor uses a linear guide to the support mechanism of the movable element. That is larger and the amplitude of the current due to the influence of friction is considered.

4. Conclusions

The slave motor controlled by PI control, the speed command based on the actual speed of the master motor has confirmed that follow. Next, we will establish a speed delivery method in real-time from the master motor, we would like to clarify the usefulness of parallel synchronous drive in this way.

Fig. 6 Block diagram of the PI control of the slave motor.

Fig. 7 Speed control results (0.3 m/s).

Fig. 8 Current control result (0.3 m/s).

Fig. 9 Speed control results (0.5 m/s).

Fig. 10 Current control result (0.5 m/s).

In particular, the control system needs to be configured by adding a feed-forward control for compensating the friction.

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