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Design of Position Estimator for Propulsion Inverter Driving Long Stator LSM in High Speed Maglev

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Abstract – In the case of long-stator linear drives, unlike rotative drives for which speed or position sensors are a single unit attached to the shaft, these sensors extend along the guideway. The position signal transmitted from maglev vehicle can't meet the need of the real-time propulsion control. In this paper the position estimator for propulsion inverter driving long stator linear synchronous motor (LSLSM) in high speed maglev train is proposed. In order to get the higher resolution of the position information transmitted from vehicle, Full order state observer is proposed for position estimator.

Keywords: Long Stator Linear Synchronous Motor, Position estimator, Propulsion Control, Full Order State Observer, Maglev

1. Introduction

During past years, high speed maglev train based on Long Stator Linear Synchronous Motor (LS-LSM) is commercialized in Shanghai, China. The position signal of Transrapid train is key to drive propulsion inverter with LS-LSM. In MLX maglev system, it lays cross-induction coil in the middle of rail, which radiates high-frequency signals. When the train passes through the coil, it leads to the change of magnetic flux in the coil, from which we can obtain the accurate and precise position of train. Moreover, in TR maglev system the measuring method of the incremental vehicle location system INKREFA) provides the basic information for the location-related train control. The contactless determination of the absolute position of the vehicle on the guideway occurs redundantly, so that individual errors do not impose any operating restriction [1].

The detected position signals are transmitted to the propulsion inverter installed in ground by communication through radio using the RS-485 communication protocol with the cycle of 20ms and the transmission rate of 512kbps. However, the transmitted signal to propulsion control system can't meet the need of the real-time propulsion control [2]. In this paper, the position estimator with Full order state observer is proposed in order to get the higher resolution of the position information transmitted from vehicle. Simulation results show the proposed strategy can meet the dynamic property need of propulsion control system with long state linear synchronous motor. Full order state observer is used for the position estimator.

2. Analysis on the Digital drive control of the Transrapid

LSLSM is superior to other means of propulsion system because thrust force is applied directly to the vehicle, force does not depend on friction, force is tightly controllable, and LSLSM have no wearing parts. To save energy and get high efficiency, the stator of LSLSM is arranged by many sections and it need to detect the accurate position information of mover flux.

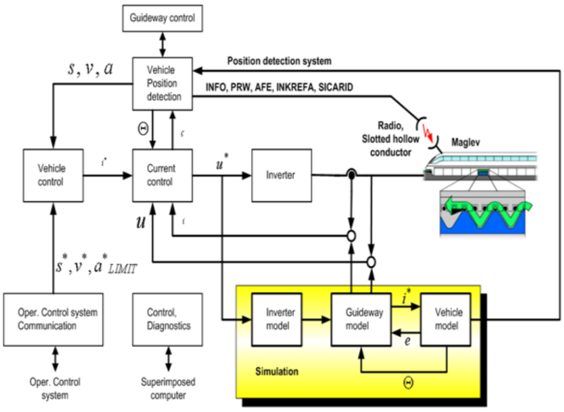

Fig. 1. Block diagram of digital drive control

For rotor field orientated control, the synchronous rotation axis is aligned in phase to phasor of rotor flux. If

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the stator current vector is kept orthogonal to mover flux, the stator current is decoupled to mover flux. Linearization of thrust can be achieved when the excitation flux is kept constant. By only regulating armature current then we could control the thrust of maglev vehicle easily [1].

The digital drive control system DDC) developed by Siemens in 1989, has proven itself at the TVE test facility in Emsland [3-5]. Figure 4 shows the block diagram of digital drive control with the position simulation for position detection. The main functions are vehicle position detection, speed control, current control, serial data communication with BLT II operations control system, target braking with reference value generation and constant distance control.

The current control system is based on the principle of field-oriented closed-loop control. To be able to break the current and voltages down as required into components that are parallel and vertical to field orientation, it is necessary to know the angle between motor excitation and the stator. Phase-angle control determines this geometrical, periodic load angle with the aid of a number of measurement methods and also establishes the actual vehicle speed.

The DDC has an enhanced test capability thanks to more accurate inverter simulation, to the inclusion of all switch section parameters, and to the creation of a digital vehicle model including all vehicle position detection and location systems.

3. Design of the position estimator for LS-LSM

For rotor field orientated control, the synchronous rotation axis is aligned in phase to phasor of rotor flux. So, it is important to detect the accurate position signals of mover flux. The propulsion inverter with the control period of 200usec needs to acquire the signal of the precise position in real time for precise phase control. However, the position signal is transmitted from vehicle every 5ms and have a delay time about 5ms. Full order state observer can estimate the real-time position signal of vehicle from propulsion torque of LS-LSM and the position signal transmitted from vehicle every 5ms.

Fig. 1 shows the propulsion drive control with position estimator for LSLSM. And full state observer for the estimation of the mover flux can be deduced to equation (2).In order to design the position observer for propulsion control system, the system model can be given by (1). where x_1 is velocity and x_2 is acceleration of the vehicle.

$$\begin{bmatrix} \dot{x}_1 \\ \dot{x}_2 \end{bmatrix} = \begin{bmatrix} 0 & 1 \\ 0 & 0 \end{bmatrix} \begin{bmatrix} x_1 \\ x_2 \end{bmatrix} + \begin{bmatrix} 0 \\ 1/M \end{bmatrix} F_{Tot} \tag{1}$$

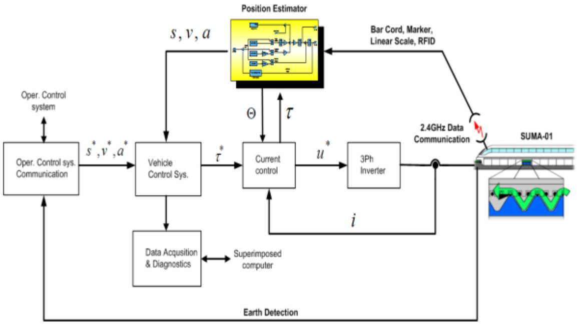

Fig. 2. Block diagram of the propulsion drive control with position estimator for LSLSM

$$\begin{bmatrix} \dot{\hat{x}}_1 \\ \dot{\hat{x}}_2 \\ \overset{*}{\hat{x}}_3 \end{bmatrix} = \begin{bmatrix} 0 & 1 & 0 \\ 0 & 0 & 1 \\ 0 & 0 & 0 \end{bmatrix} \begin{bmatrix} \hat{x}_1 \\ \hat{x}_2 \\ \hat{x}_3 \end{bmatrix} + \begin{bmatrix} 0 \\ 1/M \\ 0 \end{bmatrix} F_{Tot} + \begin{bmatrix} l_1 \\ l_2 \\ l_3 \end{bmatrix} \left(y - \hat{y} \right) \tag{2}$$

$$y = \begin{bmatrix} 1 & 0 & 0 \end{bmatrix} \begin{bmatrix} x_1 \\ x_2 \\ x_3 \end{bmatrix} \tag{3}$$

Where we obtain gains of l_1, l_2, l_3 as follows

$$\begin{aligned} \tilde{x} &= x - \hat{x} \\ \dot{\tilde{x}} &= (A - LH)\tilde{x} \end{aligned} \tag{4}$$

$$\begin{aligned} & s^3 + s^2 l_1 + s l_2 + l_3 = 0 \\ & (s + \omega_n)(s^2 + 2\xi\omega_n s + \omega_n^2) = 0 \end{aligned} \tag{5}$$

$$\begin{aligned} l_1 &= (2\xi + 1)\omega_n \\ l_1 &= (2\xi + 1)\omega_n^2 \\ l_1 &= \omega_n^3 \end{aligned} \tag{6}$$

4. Simulation results and consideration

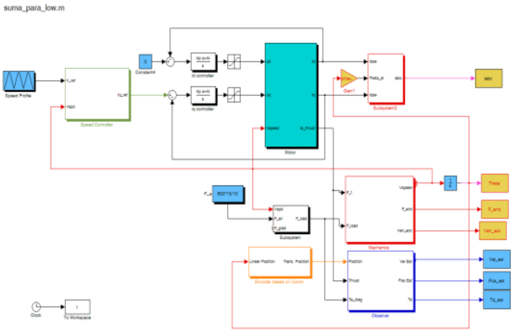

Fig. 3. LS-LSM control block diagram with the position Estimator

Simulation results show the proposed strategy can meet the dynamic property need of propulsion control system with long state linear synchronous motor. Fig. 3 shows the LSLSM control block diagram with the position estimator. The bode plots for the dynamic performance of the current controller and speed controller including system dynamics are shown in Fig. 4 ~ Fig. 5. The bandwidth of the current controller is about 1.32e4 rad/sec and the bandwidth of the speed controller is 30.8 rad/sec.

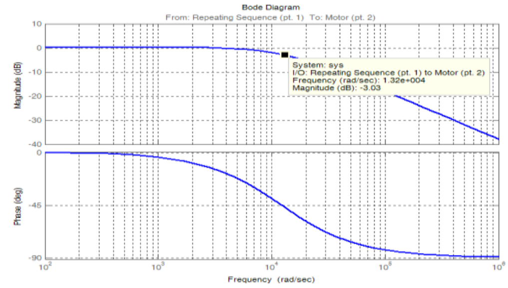

Fig. 4. The bode plot of the current controller

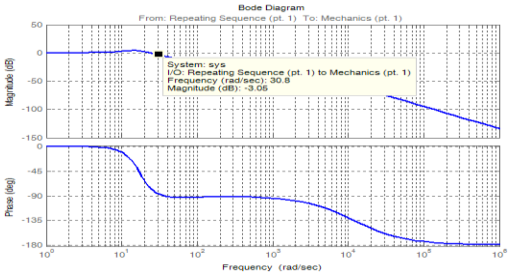

Fig. 5. The bode plot of the speed controller

As shown in Fig. 6. The simulation results show whether the goal speed of 8m/sec is achieved in the LS-LSM test track of the 150m length. During a normal testing sequence, the vehicle starts at one end of the test track and accelerates to a maximum speed up to 8m/s and then decelerates back to zero speed at the other end of the track of 150m length. The expected acceleration and maximum speed are 0.85m/s2 and 8m/s respectively. Fig. 6 shows that maximum acceleration is about 0.87m/s2 and vehicle maximum speed is about 0.87m/s.

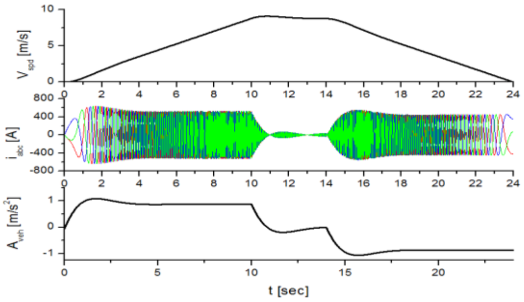

Fig. 6. Vehicle Speed, Motor current and acceleration profiles of vehicle

A speed regulator sets the “Iq” command. The speed regulator varies the thrust to maintain a desired velocity profile. Vehicle speed, the motor torque per a magnet module and vehicle position are shown in the Fig. 7.

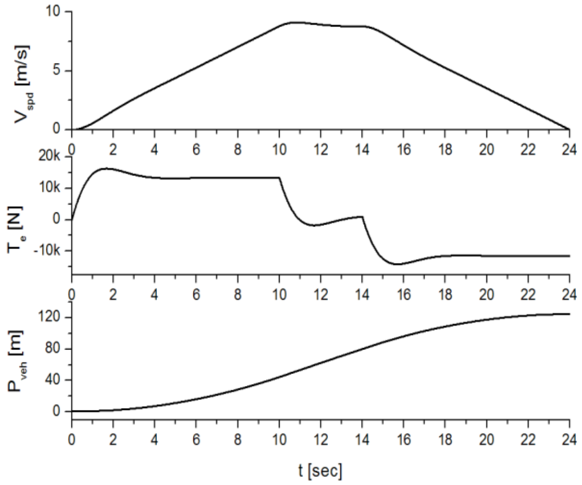

Fig. 7. Vehicle speed, the motor torque per a magnet module and vehicle position

The designed maximum motor torque per a magnet module is 1200N. The simulation results in Fig. 7 show that the maximum motor torque is about 1200N and the required track length is about 120m long when the maximum speed achieved in test track is 8m/sec.

When the vehicle is running, we can get the transmitted position signal every 5msec, and the position estimator with full order observer generates the estimated position signal. As shown in the Fig. 8. The simulation results show that the vehicle speed and estimated phase angle. Where the step line in the plot of phase angle is the real phase angle and the linear line is the estimated phase angle. From the simulation results, the proposed strategy can meet the dynamic property need of propulsion control system with long state linear synchronous motor.

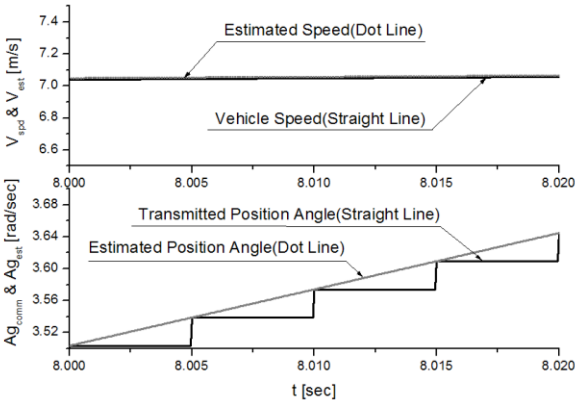

Fig. 8. Vehicle speed and estimated phase angle

5. Conclusion

This paper presents the position estimator for propulsion inverter driving LS-LSM in high speed maglev train. To save energy and get high efficiency, the stator of LS-LSM is arranged by many sections and it need to detect the accurate position information of mover flux.

In order to get the higher resolution of the position information transmitted from vehicle, Full order state observer is proposed for the vehicle position estimator. Based on these methods, simulation results indicate that the proposed strategy can meet the dynamic property need of propulsion control system with LSLSM.

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