Analysis the Position Signal Problem In Propulsion System With Long Stator Linear Synchronous Motor

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ABSTRACT: This paper investigates the position signal problem's effect to the maglev propulsion system, presents the modeling of long stator linear synchronous motor (LSLSM), and provides an effective and robust control strategy. An efficient method based on the interpolation algorithm is proposed and validated, which achieves favourable dynamic property according to condition of the low, high velocity or even missed signal. The work of this paper provides theoretical basis and result for the optimized design of propulsion control system.

1 INTRODUCTION

The position signal of transrapid train is key to propulsion control. In recent, in MLX maglev system it lays cross-induction coil in the middle of rail, which circulates high-frequency signal. 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 it installs PRW (coming from the German word: polradwinkelverfahren) signal detection system in the head and tail of train and locating reference flag (LRF) signal detection system, from which we can achieve the absolute position of train.

This paper analyzes the TR maglev system, which bases on the PRW and LRF signal detection system. The transmission path of the position signal system is shown in the Fig.1. The detected PRW and LRF signals are transmitted to vehicle and ground communication through radio using the RS-485 communication protocol with the cycle of 20ms and the transmission rate of 512kbps. The propulsion system also receives the position signal through RS-485. However, the transmitted signal to the propulsion control system always has 3 or 5ms delay compared to the signal from PRW and LRF detection system.

However, the position signal transmitted through the RS-485 with the cycle of 20ms can't meet the need of the real-time propulsion control, and also the time delay. So, the paper aims to solve this problem.

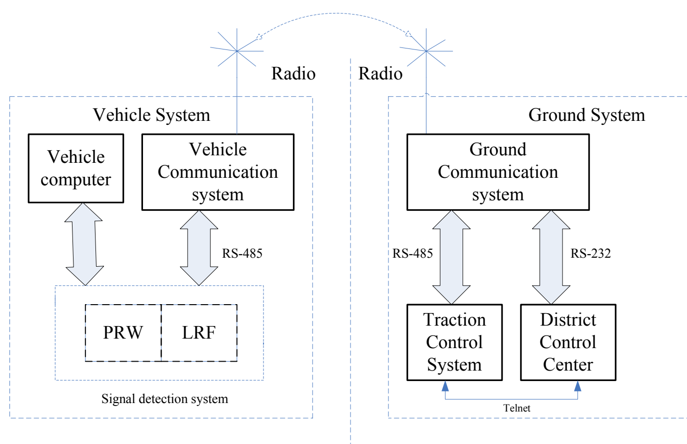

Fig.1 The transmission path for position signal

2 CONFIGURATION AND MODEL OF LSLSM

Long stator linear synchronous (LSLSM) are superior to other means of propulsion because 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 only the section where the mover should be drove. The magnetic field inducted by the stator windings which is under the magnetic poles and the magnetic field inducted by the magnetic poles constitutes the main magnetic field, so the inductance of this part of stator windings is main-inductance（Lm）. The magnetic field inducted by stator windings which have no magnetic poles forms loop with the air and constitutes the leak magnetic field, so this part of stator windings is leakage-inductance(L_σ).

Ignore the transverse and longitudinal ending effect, under the d-q-0 coordinate, the voltage equation of LSLSM can be given by：

$$u_d = r_s i_d + p\psi_d - \psi_q v \frac{\pi}{\tau_s}$$

(1)

$$u_q = r_s i_q + p\psi_q + \psi_d v \frac{\pi}{\tau_s}$$

(2)

The flux linkage expression is given by：

$$\psi_d = i_d(L_\sigma + L_{md}) + M_{sm} i_m \quad (3)$$

$$\psi_q = i_q(L_\sigma + L_{mq}) \quad (4)$$

The propelling force is:

$$F_x = \frac{3\pi}{2\tau_s} M_{sm} i_m i_q + \frac{3\pi}{2\tau_s}(L_{md} - L_{mq}) i_d i_q \quad (5)$$

Where Ld = Lmd + Lσ, Lq = Lmq + Lσ, Ld is d-axis inductance which contains Lmd and Lσ, d-axis main-inductance and d-axis linkage-inductance respectively, and Lq is q-axis inductance which contains Lmq and Lσ, q-axis main-inductance and q-axis linkage-inductance respectively. V is speed of vehicle or magnetic poles.

Generally speaking, in order not to affect the levitation force in the maglev train, rotor field orientated control is used in the current control strategy.

3 THE EFFECT OF POSITION SIGNAL DELAY

For rotor field orientated control, the synchronous rotation axis is aligned in phase to phasor of rotor flux. If the stator current vector is kept orthogonal to rotor flux, the stator current is decoupled to rotor flux. Linearization of thrust can be achieved when the excitation flux is kept constant. By only regulating armature current i then we could control the thrust of maglev vehicle easily. As LSLSM operates at this mode, the rotation synchronous M,T axis is lap over with rotor field d,q axis.

However, shown as the phasor diagram Fig.2, the control system adopts the delay dy-qy axes, but the real dr-qr axes have an advance angle of $\triangle\theta$, which leads to the couple between the stator current and rotor flux.

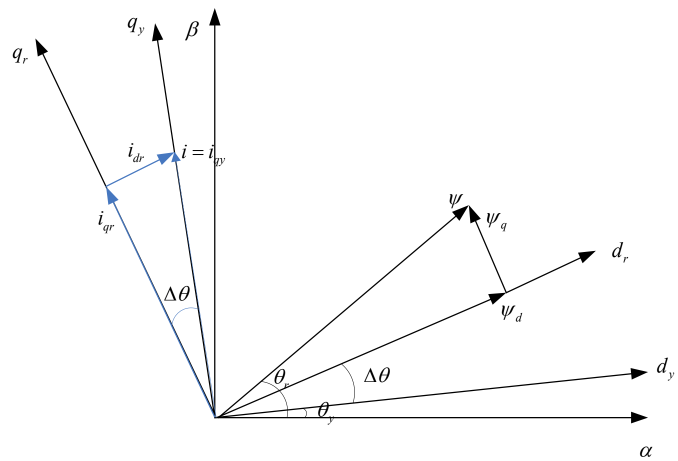

Fig.2 The real and delay d-q phasor diagram for LSLSM

From above analysis, the equation (5) can be deduced to:

$$F_x = \frac{3\pi n_p}{2\tau_s}(M_{sm} i_m i_{qr} + (L_{md} - L_{mq}) i_{dr} i_{qr}) = \quad (6)$$

$$\frac{3\pi n_p}{2\tau_s}(M_{sm} i_m i \cos\Delta\theta + (L_{md} - L_{mq}) i^2 \sin\Delta\theta \cos\Delta\theta)$$

From equation (6), we can comprehend that the delay angle $\triangle\theta$ has a detrimental effect to the propulsion system and leads to the decrease of propelling force. To get the same propelling force, we need larger current.

4 CONTROL STRATEGY

The propulsion system needs to acquire the signal of position in real time for precise phasor control, however, the position signal is transmitted from vehicle every 20ms and have a delay time about 3ms. For that, we must devise a strategy to estimate the position signal.

As shown in the Fig.3, the propulsion control system get the position signal θ_1 at the time of t_0, but between t_0 and $t_0 + T$ (T=20ms), we can't constantly use θ_1 to control the vehicle. Before we acquire the new position signal θ_2, we must estimate the real-time position signal of vehicle.

Based on the analysis above, an effective method is proposed by means of Lagrange interpolation principle to get the approximate value of position signal. As shown in the Fig.3, an analogous line represents the estimated value.

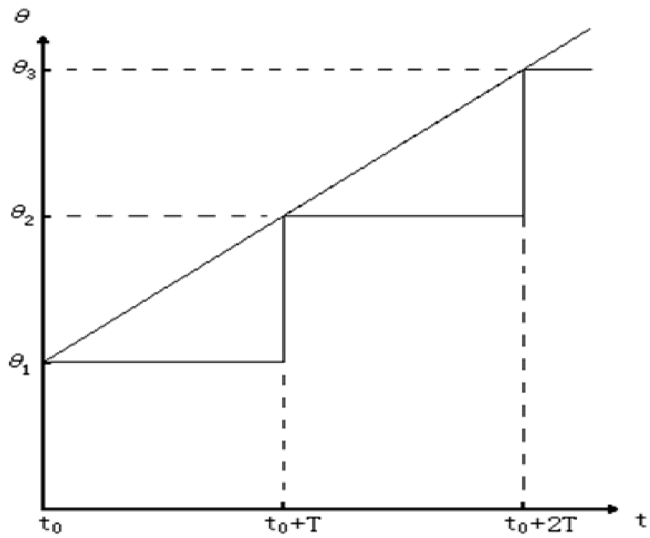

Fig.3 The interpolation principle of position signal

If ω is constant between t_0+T and t_0+2T, θ is estimated as:

$$\theta=\theta_2+\omega[t-(t_0+T)] \qquad (6)$$

If the delay time(T_d) in transmission is considered, then equation(6) can be deduced:

$$\theta=\theta_2+\omega[t-(t_0+T)]+\omega T_d \qquad (7).$$

5 EXPERIMENT RESULT

To confirm the effects of the above described control schemes, an experiment platform based on the Fig.1 is founded. Table 1 shows parameters of the experiment.

Table 1

Time	T	20ms
	f	2400Hz
	Td	3ms
	τ_s	0.516

The executed interpolation algorithm in the cup is shown as follow:

$$\begin{cases} \dfrac{\overline{V}}{f}=\Delta S \\ \dfrac{\Delta S}{\tau_s}\bullet 2\pi=\Delta\theta \\ \theta_{\_new}=\theta_{\_}+\Delta\theta+\overline{\omega}\bullet T_d \\ if \quad \theta_{\_new}\geq 2\pi,\theta_{\_new}=\theta_{\_new}-2\pi \\ if \quad \theta_{\_new}\geq 2\pi,\theta_{\_new}=\theta_{\_new}-2\pi \end{cases} \qquad (8)$$

Where, θ represents the latest transmitted angle value, $\overline{V}$ and $\overline{\omega}$ is the average of velocity and angular velocity of vehicle from the time get the latest angle value. T_d is the delay time in transmission. $\theta_{\_new}$ is the estimated value of position signal.

In the experiment platform, when the vehicle is running, we can get the transmitted position signal, and then the CPU executes the algorithm in equation (8), which generates the estimated position signal.

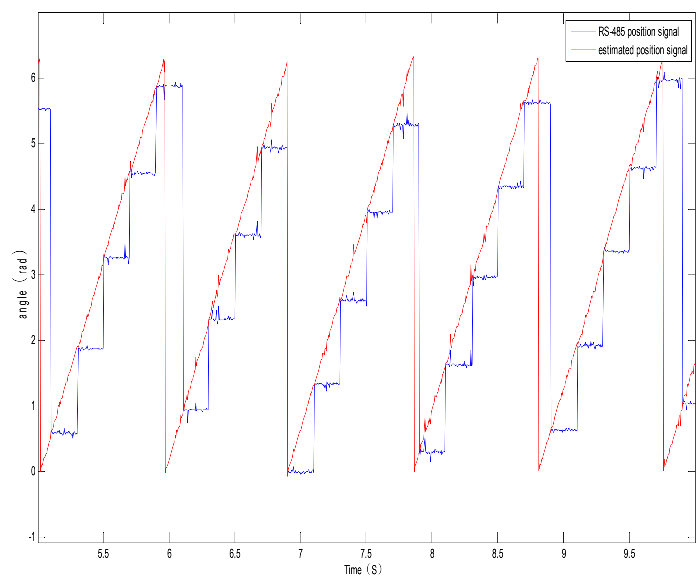

Fig.4 the estimated and transmitted position signal in low velocity

As shown in the Fig.4, a condition that the vehicle runs in low velocity is analyzed, the results show that the executed algorithm achieve an ideal effect to follow the real-time position signal.

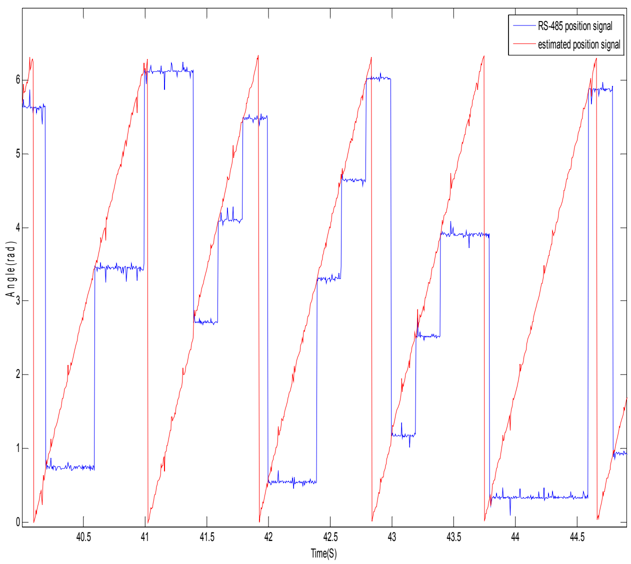

Fig.5 The estimated and transmitted position signal in high velocity

As shown in the Fig.5, a condition that the vehicle runs in high velocity and with the miss of transmitted position signal is also analyzed. Between 44s and 44.5s, the transmitted position is missed because of the fault of instrument or other reasons, but an estimated position signal is also achieved, which represents the favourable dynamic property of the control.

6 CONCLUSION

This paper analyzes the position signal problem in the propulsion system, with the cycle of signal and transmitted delay. To solve this problem, a strategy based on the Lagrange interpolation principle is proposed, and then the condition of low and high velocity is discussed. The results indicate that the novel strategy can meet the dynamic property need of propulsion control system. Although it may not be the ideal strategy, it can fit to the engineering application.

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