# Sensorless Vector Control for LSLSM Using PI Tracking Method

No. 100
Qiongxuan Ge，Fei Wang and Yaohua Li
*Research Center of Maglev and Linear Motor Drive, Institute of Electrical Engineering, Chinese Academy of Sciences, 100190, Beijing, China, gqx@mail.iee.ac.cn, wangfei@mail.iee.ac.cn, yhli@mail.iee.ac.cn*

Chongjian Li
*Automation Research and Design Institute of Metallurgical Industry, 100071, Beijing, China, chjli@ariml.om*

ABSTRACT: This paper presents a simple and effective mover speed and position estimation method for long stator linear synchronous motor (LSLSM). The proposed method is based on the regulation of estimated *d*-axis current. The rotor position estimation error is included in the difference between the *d*-axis estimated current and reference current. After extraction of the position error, the proposed approach utilizes a PI regulator to estimate the speed. With the regulation, the position error could converge to zero. Then, the mover position can be calculated by integration of the speed. The sensorless scheme is simple to realize and robust to the parameter variations. A VME-bus based drive system is set up to verify the method and the results are given.

## 1 INTRODUCTION

In the applications of factory automation, building transportation and high speed Maglev system, the linear synchronous motors are of special interest because of their high accuracy, no rotative-to-linear conversion and high efficiency. To achieve high dynamic response and accuracy positioning, the motor controller needs to know the speed and position of the mover. In the long-stator linear synchronous motor application, the speed and position sensors, which extend along the guide way, will largely increase the system cost and complexity. Therefore, a sensorless controller which could estimate the speed and position can be a cost-effective alternate.

In literatures, many estimation algorithms have been developed for the speed and position sensorless control of rotative synchronous motor. In these sensorless techniques, back-EMF based estimation is widely studied and implemented, mainly because the computation is simple and a good performance at middle and high speed. But it is apt to be affected by system noise and parameter variation, and it has a low performance in the low speed region. Some other methods use the rotor saliency for position calculation, but this is limited to those with high saliency ratio and is difficult to implement. Some more complex methods such like Kalman filter or observer based estimation can be considered as close-loop estimation methods, thus they can provide a better estimation under disturbances. But these techniques require heavy computation and careful selection of parameters.

This paper presents a simple and effective mover velocity and position estimation method for LSLSM. This method is based on the regulation of estimated d-axis current. The rotor position error information is included in the difference between the d-axis estimated and reference current. After extraction of the position error, the proposed approach utilizes a PI regulator to estimate the velocity. By the regulation, the position error could converge to zero. Then, the mover position can be calculated by integration of the speed. Without the involvement of motor models, this proposed sensorless scheme is simple to realize and robust to the parameter variations.

## 2 LINEAR SYNCHRONOUS MOTOR MODEL

To implement the proposed vector control scheme, a mathematic model of long stator LSM should be constructed. For simplify of analysis, some assumptions are proposed in modeling of the motor:

1. The stator windings are symmetrical three phases, and only fundamental frequency is taking into consideration.
2. Magnetic saturation is neglected.
3. Mover flux linkage is constant.
4. The end effect is neglected.

With these assumptions, the LSLSM can be approximately modeled as a rotated synchronous motor. The dynamic equations of the linear synchronous motors in the synchronously rotating reference frame (*d*-*q* reference frame) are given as:

$$u_d = R_s i_d + pL_d i_d - \frac{\pi}{\tau} v_m L_q i_q$$
$$u_q = R_s i_q + pL_q i_q + \frac{\pi}{\tau} v_m (L_d i_d + \psi_m) \quad (1)$$

Where:

$R_s$ - stator winding resistance

$L_d$ , $L_q$ - stator inductance of *d*-axis and *q*-axis respectively

$\psi_m$ - mover magnetic linkage

$v_m$ - mover speed

$\tau$ - stator pole pitch

$p$ - differential operator.

The electromagnetic thrust force is:

$$F_e = (L_d - L_q) i_d i_q + K_f i_q \quad (2)$$

Where, $K_f$ is the force constant.

## 3 SENSORLESS VECTOR CONTROL SCHEME

Vector control is widely used in high performance motor drive control. In order to get the decoupling of thrust and flux, a rotator field oriented vector control strategy is chosen.

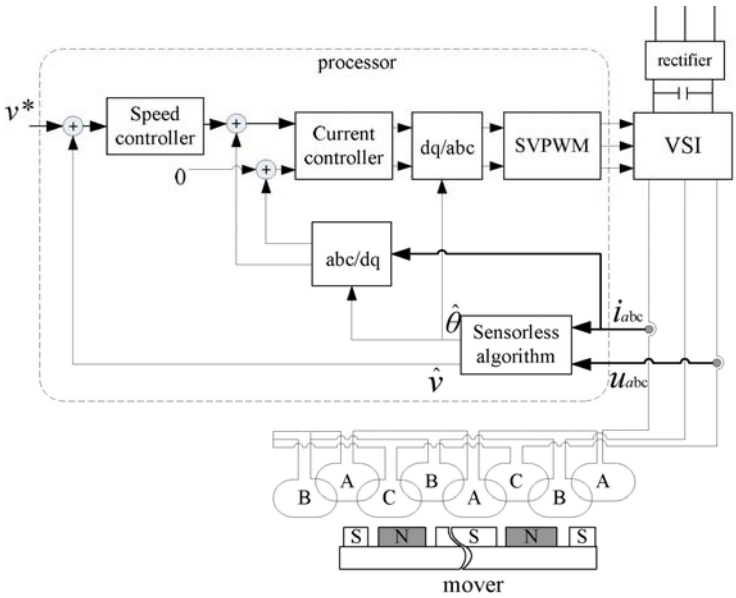
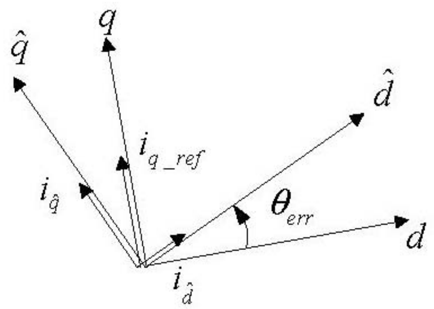



Figure 1. Sensorless vector control of LSLSM.

Fig.1 shows the proposed linear synchronous motor drive system utilizing sensorless vector control. In the vector control scheme, the synchronous rotation axis is aligned in phase to phasor of rotor flux. Thrust linearization can be achieved by controlling stator current vector under constant rotor flux. If the stator current vector is kept orthogonal to rotor flux, the stator current is decoupled to rotor flux. The stator current vector could be decomposed as two components. The q-axis current controls the output torque, and its reference value is commanded by the speed controller. The d-axis current reference is set to zero to achieve the max torque-per-current ratio. In the d-q reference frame which is fixed on the rotor, the current reference vector is actually the q-axis current reference. This is shown in Fig.2.




F Figure 2. The estimated and real *d*-*q* reference frames.

Without the position and speed sensor feedback, the real mover position information is unknown. Instead, an estimated position is used in the coordination transformation. Suppose the estimated mover position tracks the real position to a small error $\theta_{err} = \theta_{esti} - \theta_{real}$ . In the estimated $\hat{d} - \hat{q}$ frame, the $i_{q\_ref}$ is projected on the *d*-axes as

$$i_{\hat{d}} = i_{q\_ref} \sin(\theta_{err})$$
$$i_{\hat{q}} = i_{q\_ref} \cos(\theta_{err}) \quad (3)$$

In the above equation, the position error $i_{q\_ref}$ can be calculated from the difference between the *d*-axis and $\hat{d}$ -axis current $\Delta i_d$ .

$$\begin{aligned}\Delta i_d &= i_{d\_ref} - i_{\hat{d}} \\ &= 0 - i_{q\_ref} \sin(\theta_{err}) \\ &\approx -i_{q\_ref}\theta_{err}\end{aligned}$$

Thus, the position error can be calculated as

$$\theta_{err} \approx -\frac{i_{\hat{d}}}{i_{q\_ref}} \quad (4)$$

The position error $\theta_{err}$ is then controlled to zero by a PI tracking regulator. The output of the PI regulator is the estimated mover speed in electrical angle. The position estimation in electrical angle is derived by integration of the speed. The entire sensorless scheme is shown in Fig.3.

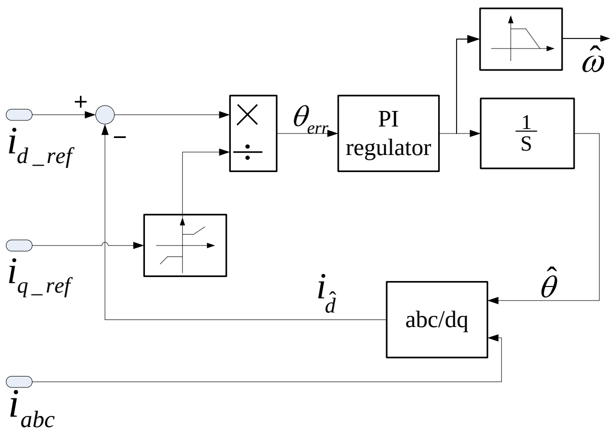


Figure 3. Sensorless scheme diagram.

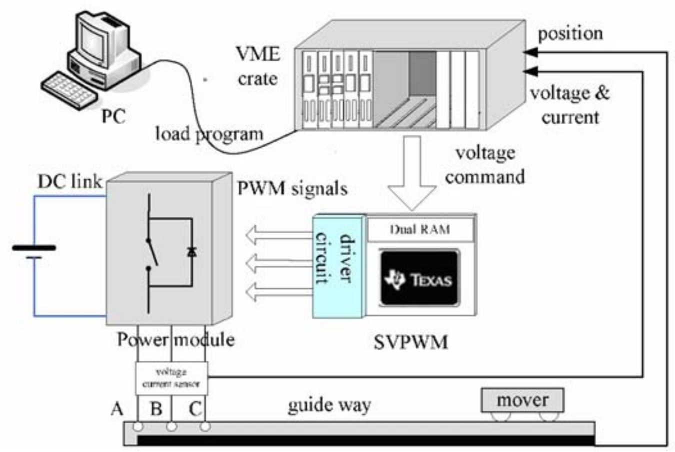
In the above equation, a small or zero value of $i_{q\_ref}$ could magnify the $\theta_{err}$ to an extent that the noise could degrade the estimation. To avoid this, a low threshold $K_l$ for the absolute value of $i_{q\_ref}$ is introduced. If the absolute value of $q$-axis current reference is lower than the threshold, the threshold is used; Otherwise, the $i_{q\_ref}$ is divided. So, the estimation of $\theta_{err}$ is given as

$$\hat{\theta}_{err}=\begin{cases}-\dfrac{i_{\hat{d}}}{i_{q\_ref}} & abs(i_{q\_ref})>K_l\\[2ex] -\dfrac{i_{\hat{d}}}{\mathrm{sgn}(i_{q\_ref})K_l} & abs(i_{q\_ref})\le K_l\end{cases} \tag{5}$$

## 4 EXPERIMENT

### *4.1 Hardware setup*

In order to investigate the proposed strategy of speed and position estimation, a control system platform based VME bus is constructed. Fig.4 shows the complete hardware setup for the sensorless vector control of long-stator linear synchronous motor. The heart of the control system is the VME crate, which contains a VME processor board 7750 from VMIC. There is also an A/D board is equipped on the VME bus for data acquisition and conditioning. The PC is for cross-platform program development. The DSP board utilizes a TI TMS320F2812 32-bit floating-point controller to generate PWM signals, the communication path between the VME processor and the DSP chip is a dual-port RAM. The power module is a 3-phase voltage source inverter, the DC voltage source is actually a diode rectifier. On the guide way, a linear optical encoder is equipped to detect the real mover position to be compared with the estimated position.



F Figure 4. Hardware setup.

The motor parameters of the long stator LSM is given in table 1.

Table 1. LSLSM parameters table.

| | |
|---|---|
| Stator resistance | 0.149 Ω |
| Stator inductance | 1.06mH |
| Rotor flux linkage | 48mH |
| Pole pitch | 254mm |

The control scheme for the whole drive system is rotor (mover) field orient control, as shown in Fig.1. The speed and current PI regulators are programmed in the VME processor, the output $d$-axis and $q$-axis voltage commands are transformed into the stationary $\alpha-\beta$ axes with the estimated angle. In the coordination transform, the sensorless algorithm provides the angle information. Then, the $\alpha-\beta$ voltage commands, along with the DC link voltage are written into the dual-port RAM in a preset location. The SVPWM generation program which is loaded in the DSP controller reads this location in a frequency of 20 kHz, and transforms the voltage command into a PWM pattern to drive the inverter switches.

### *4.2 Experimental results*

The proposed speed and position estimation strategy is verified by using the above constructed system. We control the LSLSM running in different speed and direction and compare the estimated speed and position with the measured speed and position. The experimental results are presented in figure 5 and 6. Fig.5 shows the actual and estimated mover speed when the motor first accelerates to 1.55 m/s and then decelerates to -1.55 m/s. The actual speed is calculated by the optical encoder at a fixed frequency and then interpolated. The estimation error falls into the range of -0.2m/s to 0.2m/s in steady state. While, at around zero speed the estimation error is relative large and in this region, the control scheme is switched from sensorless scheme to the feedback encoder.

Fig.6 shows the actual and estimated mover position in electrical angle degrees. In the time span, the mover is moving forward at a constant speed of 1.55 m/s. According to the experimental result, the estimated position shows good correspondence to the actual mover position with an average error less than 5° of electrical angle.

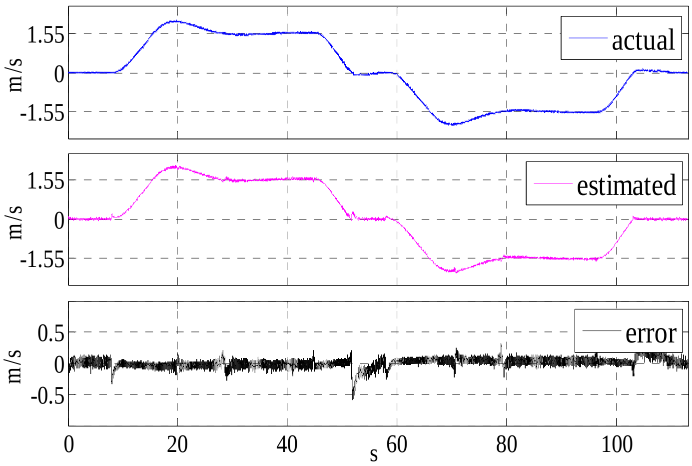



Figure 5. Mover speed estimation. (a) actual speed; (b)estimated speed; (c) estimation error.

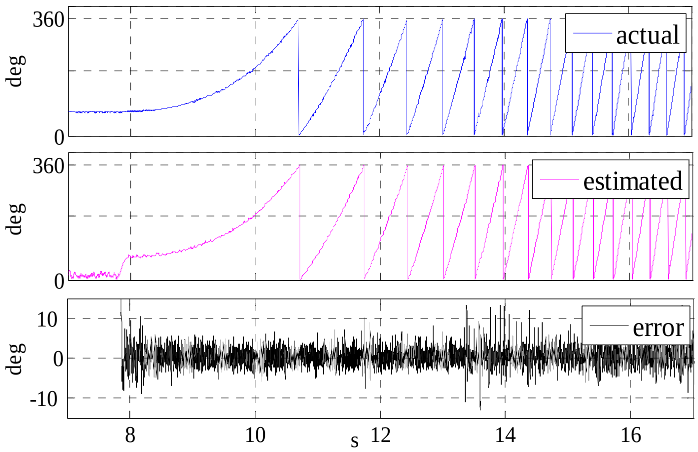



Figure 6. Mover position estimation. (a) actual position; (b)estimated position; (c) estimation error.

## 5 CONCLUSION

In this paper, a simple and effective velocity estimation method for vector control of long stator LSM is proposed. The principle of this method is to extract the error value between the estimated and real mover position by the regulation of d-axis current. Then, a PI regulator is utilized to estimate the speed and position. Because this method doesn't involve any motor parameters, it's insensitive to parameter variations. To verify the method, a VME-bus based drive system is set up and the details are given. Observed experimental results indicate the effectiveness of the proposed sensorless method.

## 6 REFERENCES


Jong-Kun Lee and Sang-Gyu Bae and Jul-Ki Seok and Dong-Choon Lee and Heung-Geun Kim, “Sensorless control of nonsalient permanent magnet synchronous motor drives using rotor position tracking PI controller”, Electrical Machines and Systems, 2003. ICEMS 2003. Sixth International Conference on, vol. 2, pp. 522-525, 9-11 Nov. 2003.

Bugeza M., Fiser R., “Simulation model of controlled PM linear synchronous motor,” Power Electronics Congress, 2004. CIEP 2004. 9th IEEE International, pp. 109-113, 17-22 Oct. 2004.

Buja G.S. and Kazmierkowski M.P., “Direct torque control of PWM inverter-fed AC motors - a survey,” Industrial Electronics, IEEE Transactions on, 51, 4, pp744-757, Aug, 2004.

Bolognani, S. and Oboe, R. and Zigliotto, M., “Sensorless full-digital PMSM drive with EKF estimation of speed and rotor position,” Industrial Electronics, IEEE Transactions on, 46, 1, pp. 184-191, Feb 1999.