

CLOSED LOOP CONTROLLING OF PERMANENT MAGNET LINEAR SYNCHRONOUS MOTOR WITH STATE FEEDBACK CONTROLLER

M.PADMA^{1*}, J.PRAKASHKUMAR², L.PHANIKUMAR³, MUDAVATH RAVINDAR⁴

^{1,2,3,4}Assistant Professor, Department of Electrical and Electronics Engineering, Narsimha Reddy Engineering College, Telangana, India

*Corresponding author E-Mail ID: padmamaridieeee@gmail.com

ABSTRACT

This paper describes modelling of the Permanent Magnet Linear Synchronous Motor and an analogy between the rotary motor and the linear motor. Constructional details of various sub-models for the permanent magnet linear synchronous motor are given and their implementation in SIMULINK is outlined. A novel control of PMLSM is designed by which the system nonlinearity is cancelled. In addition, a linear state feedback control law based on pole placement technique to achieve zero steady state error with respect to reference current specification is employed to improve the dynamic response. The extensive simulation is performed through MATLAB/SIMULINK.

Keywords: Nonlinear Model; Permanent magnet linear synchronous motor

1. INTRODUCTION

In today's competitive industrial environment, a tremendous amount of resources are dedicated to simple, optimal, and efficient solutions for the process automation, machine tool and material handling systems. Linear motors can give machine tools linear motion directly without indirect coupling mechanisms such as gear boxes, chains and screws. In particular, permanent magnet direct drive motors are becoming more and more popular in machine automation nowadays. The advantages of permanent magnet motor drives are their gearless structure, excellent control Characteristics like high speed, high acceleration and the most importantly, high motion precision and better efficiency. PMLSMs are used in lifts, paper machines, propulsion units of ships, windmills etc. In

PMLSM, the moving part (mover) of which consists of a slotted armature and three-phase windings, while the surface permanent magnets (SPMs) are mounted along the whole length of the path (stator).

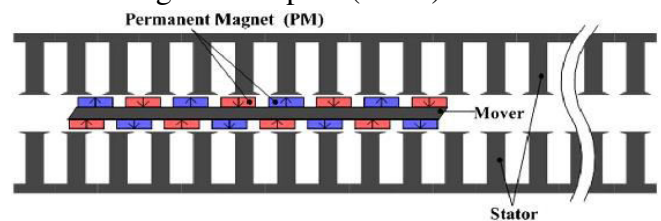


Fig.1 : permanent magnet linear synchronous motor

LSMs operating on the principle of the travelling magnetic field, the speed v of the moving part is equal to the synchronous speed v_s of the travelling magnetic field depends only on the input frequency f (angular input frequency $\omega=2\pi f$) and pole pitch τ . It does not depend on the number of poles $2p$.

$$v = v_s = 2f\tau = \frac{\omega}{\pi}\tau$$

This paper is organized as follow: Section I gives the Introduction of the Permanent Magnet Linear Synchronous Motor. Section II is helpful to understand the analogy between permanent magnet linear synchronous motor and rotary motor . Section III explains the System dynamic modeling of motor. Section IV show the performance of open loop motor and Section V describes closed loop system and Section VI show the performance of closed loop motor the last section concludes the paper and followed by the references

2. EXPERIMENTAL SETUP OF VCR ENGINE

The electrical model of the PMLSM can be obtained by analogy to a permanent magnet rotary synchronous motor, as shown in Fig. 2. For a rotary motor, the three armature windings shift one another by an electrical angle of $2\pi/3$, and each winding covers an electrical angle of π in the stationary reference.

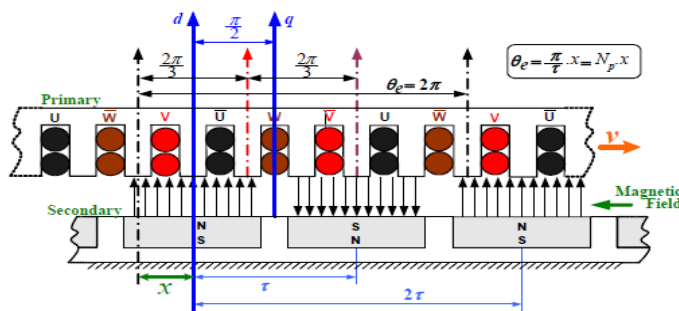


Fig 2 : Electrical model of the PMLSM

By analogy, the stator armature windings of a PMLSM shift one another by a distance of $2\tau/3$ (τ : pole pitch \rightarrow step between two consecutive magnetic poles of

secondary) and each winding covers a distance of τ in the linear reference frame.

The electrical angle along which the primary of the PMLSM moves in the linear reference frame can be expressed by

$$\theta_e = N_p x; N_p = \frac{\pi}{\tau}$$

Here, N_p is the electrical position constant of the PMLSM.

Table 1. Equivalences of Electrical Angle and Electrical Angular Speed

	Rotary motor	PMLSM
Electrical angle (θ_e)	$\theta_e = N_p \theta$	$\theta_e = N_p x$
Electrical angular speed (ω)	$\omega = N_p \Omega$	$\omega = N_p v$

With the rapid development in computer hardware and software, new simulation packages which are faster and more user friendly are now available. This paper discusses the use of one such product, the SIMULINK software of MATLAB, in the dynamic modeling of the PMLSM. The main advantage of SIMULINK over other programming software is that, instead of compilation of program code, the simulation model is built up systematically by means of basic function blocks. Through a convenient graphical user interface (GUI), the function blocks can be created, linked and edited easily using menu commands, the keyboard and an appropriate pointing device (such as the mouse). A set of machine differential equations can thus be modeled by interconnection of appropriate function blocks, each of which performing a specific mathematical operation. Programming efforts are drastically reduced and the debugging of errors is easy. Since SIMULINK is a model operation programmer, the simulation model can be

easily developed by addition of new sub-models to cater for various control functions. As a sub-model the PMLSM could be incorporated in a complete electric motor drive system.

3. NONLINEAR MODEL OF PMLSM USING SIMULINK

A generalized dynamic model of the permanent magnet linear synchronous motor consists of an electrical sub-model to implement the three-phase to two-axis (3/2) transformation of stator voltage and current calculation, a thrust sub-model to calculate the developed electromagnetic thrust, and a mechanical sub-model to yield the rotor or mover velocity.

3.1 ELECTRICAL SUB-MODEL OF THE PMLSM

The voltage equations for the permanent magnet synchronous motor in synchronously rotating reference frame are

$$V_{qs} = R_s i_{qs} + P \lambda_{qs} + \omega_e \lambda_{ds} \quad (1)$$

$$V_{ds} = R_s i_{ds} + P \lambda_{ds} - \omega_e \lambda_{qs} \quad (2)$$

Where,

$$\lambda_{qs} = L_{qs} i_{qs} \quad (3)$$

$$\lambda_{ds} = L_{ds} i_{ds} + \lambda_{PM} \quad (4)$$

By substituting eq no's (3) & (4) in equations (1) & (2) respectively, we get

$$V_{qs} = R_s i_{qs} + L_{qs} P i_{qs} + \omega_e L_{ds} i_{ds} + \omega_e \lambda_{PM} \quad (5)$$

$$V_{ds} = R_s i_{ds} + L_{ds} P i_{ds} - \omega_e L_{qs} i_{qs} \quad (6)$$

By rearranging equations (5) & (6)

,then

$$P i_{qs} = \frac{V_{qs}}{L_{qs}} - \frac{R_s}{L_{qs}} i_{qs} - \omega_e \frac{L_{ds}}{L_{qs}} i_{ds} - \omega_e \frac{\lambda_{PM}}{L_{qs}}$$

$$P i_{ds} = \frac{V_{ds}}{L_{ds}} - \frac{R_s}{L_{ds}} i_{ds} + \omega_e \frac{L_{qs}}{L_{ds}} i_{qs}$$

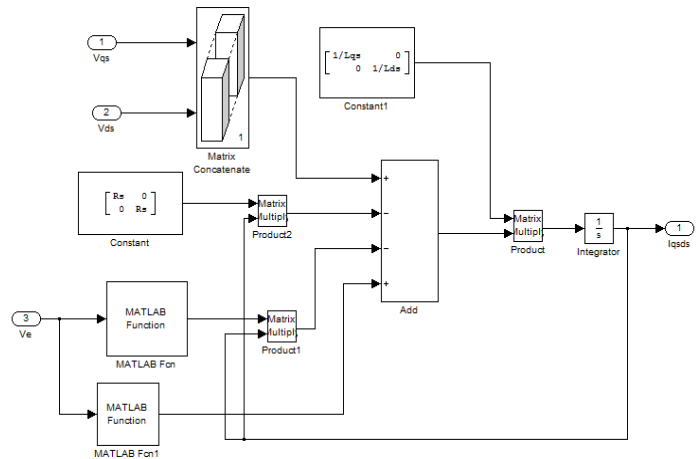


Fig-3 : Electrical Sub Model of PMLSM

$$\begin{bmatrix} i_{qs} \\ i_{ds} \end{bmatrix} = \begin{bmatrix} \frac{1}{L_{qs}} & 0 \\ 0 & \frac{1}{L_{ds}} \end{bmatrix} \left[\begin{bmatrix} V_{qs} \\ V_{ds} \end{bmatrix} - \begin{bmatrix} R_s & 0 \\ 0 & R_s \end{bmatrix} \begin{bmatrix} i_{qs} \\ i_{ds} \end{bmatrix} - \begin{bmatrix} 0 & \omega_e L_{ds} \\ -\omega_e L_{qs} & 0 \end{bmatrix} \begin{bmatrix} i_{qs} \\ i_{ds} \end{bmatrix} + \begin{bmatrix} -\omega_e \lambda_{PM} \\ 0 \end{bmatrix} \right]$$

3.2 THRUST SUB-MODEL OF PMLSM

$$F_e = \frac{3\pi}{2\tau} P [\lambda_{PM} i_{qs} + (L_{ds} - L_{qs}) i_{ds} i_{qs}]$$

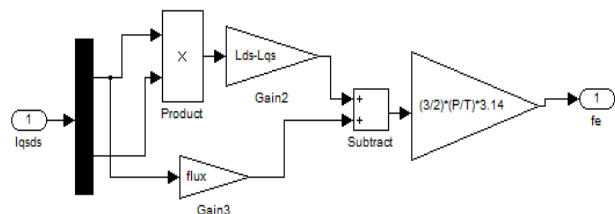


Fig-4 : Electromagnetic Thrust sub model

Where flux = λ_{PM}

3.3 MECHANICAL SUB-MODEL OF PMLSM

$$F_e - F_l = M \dot{V}_e + B V_e$$

By taking laplace transform of above equation we obtain

$$F_e - F_l = MSV_e + BV_e$$

$$F_e - F_l = (MS + B)V_e$$

From which the ratio, $\frac{V_e}{F_e - F_l}$ is obtained as

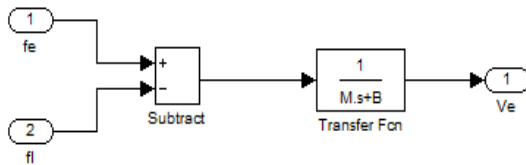
$$\frac{V_e}{F_e - F_l} = \frac{1}{MS + B}$$


Fig-5: Mechanical Sub Model of PMLSM

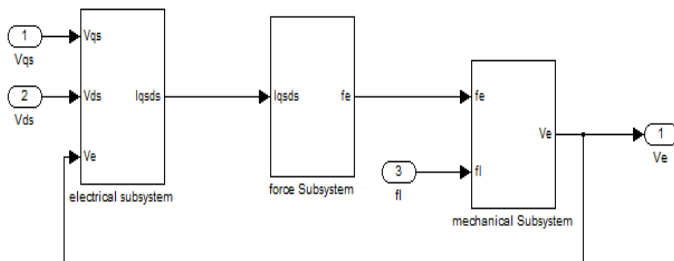


Fig.6: PMLSM overall Model in SIMULINK

The electrical sub-model in Fig-3, the thrust sub-model in Fig-4, the mechanical sub-model in Fig-5, are grouped together to form the PMLSM model as shown in Fig-6.

4. OPEN LOOP RESULTS

Open loop simulation results for step change in speed at constant Load Thrust shown in fig-7 and for step change in Load Thrust at constant speed is shown in fig-8.

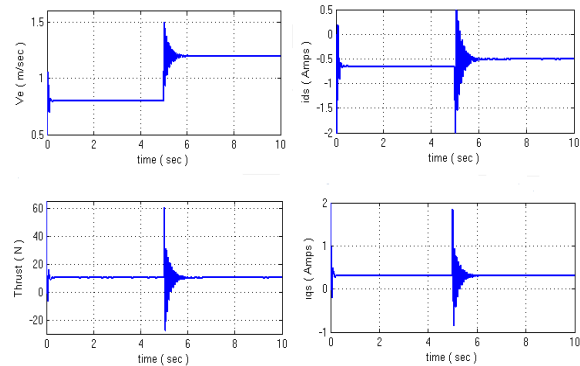


Fig-7. Simulation results of PMLSM for step change in speed from 0.8 m/s to 1.2 m/s at 5th sec at constant thrust of 10N

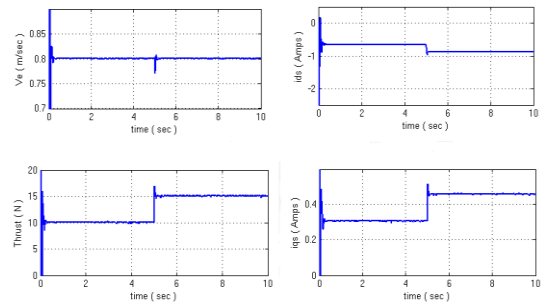


Fig.8 : Simulation results of PMLSM for step change in thrust from 10N to 15 N at 5th sec at constant Speed of 0.8m/s.

5. RESULTCLOSED LOOP CONTROL RESULTS

Closed loop simulation results for step change in speed at constant thrust of 10N shown in Fig-10. Simulation results for step change in thrust at constant speed are shown in Fig-11.

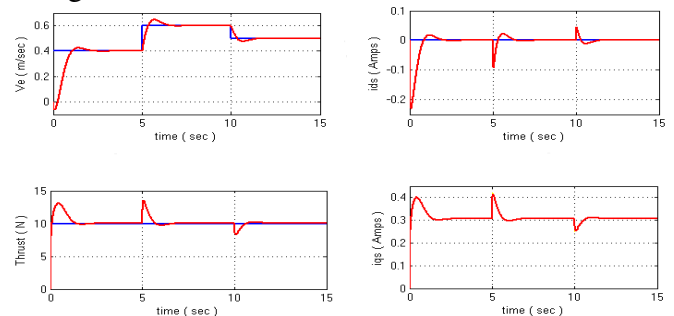


Fig.10 Simulation results of PMLSM for step change in Speed from 0.4 to 0.6 at 5th sec and from 0.6 to 0.5 at 10th sec at constant thrust of 10N



2581-4575

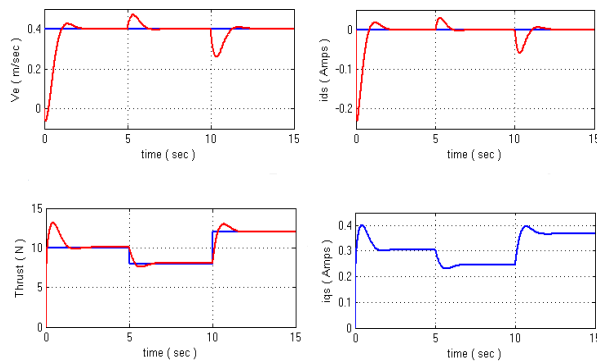
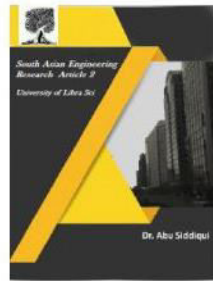


Fig.11 Simulation results of PMLSM for Step change in thrust from 10 to 8 at 5th sec and from 8 N to 12N at 10th sec at constant speed of 0.4m/sec

4. CONCLUSION

In this paper we have used SIMULINK software of MATLAB to test the dynamic model of PMLSM at open loop & closed loop control. A generalized approach to the design of the speed control of Linear synchronous Motor has been presented by which the system nonlinearity is cancelled. In addition, a linear state feedback control law based on pole placement technique to achieve zero steady state error with respect to reference current specification is employed to improve the dynamic response. The closed loop control simulation shows good results. The predicted current step responses agreed well with the measurements and less overshoots were observed.

REFERENCES

1. J. Yang, G. He, and J. Cui, "Analysis of PMLSM direct thrust control system based on sliding mode variable structure," in Proc. IPEMC'06, pp. 1-5, 2006.
2. Oskar Wallmark, "Modelling of Permanent-Magnet Synchronous Motors Machines with Non-Sinusoidal Flux Linkage", Chalmers University of Technology, Sweden.

3. Maloney, L. D., "Linear Motors Hit Their Stride", Design News (Reed Business), 2005,
4. W. Leonard, Control of Electrical Drives, Springer-Verlag, Berlin, 1996.
5. Alice Mary, K., „Nonlinear Modeling, Control System Design and Implementation for an Inverter-fed Synchronous Motor Drive“, Ph.D. Thesis, Department of Electrical Engineering, I.I.T. Kharagpur, 1998.
6. John Wiley & Sons, Parker, R.J., "Advances in Permanent Magnetism", 1990.
7. Jacek F. Gieras, Zbigniew J. Piech, Bronislaw Tomczak "Linear Synchronous Motors: Transportation and Automation Systems (Electric Power Engineering Series)]", 2000 CRC press.
8. Muthukumar P., Lekshmi Kanthan P.S., Baldwin Immanuel T., Eswaramoorthy K. (2018) FPGA Performance Optimization Plan for High Power Conversion. In: Zelinka I., Senkerik R., Panda G., Lekshmi Kanthan P. (eds) Soft Computing Systems. ICSCS 2018. Communications in Computer and Information Science, vol 837. Springer, Singapore
9. Eswaramoorthy, K., & Shunmughanaathan, V. K. (2016). A Simple And Geometry Based Fast Space-Vector Pwm Technique For 15 Level Cascaded Multilevel Inverter With Reduction Of Switches. Asian Journal of Research in Social Sciences and Humanities, 6(10), 2305-2320.



International Journal For Recent Developments in Science & Technology



A Peer Reviewed Research Journal

