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Modelling of Linear Synchronous Motor in Nonlinear Applications

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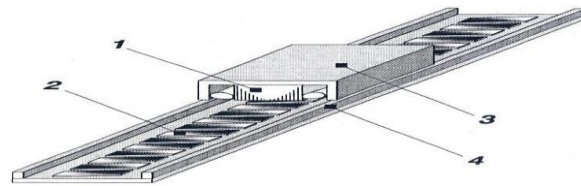
ABSTRACT: This paper presents a nonlinear model of the Permanent Magnet Linear Synchronous Motor and an comparison between the rotary motor and the linear motor. Manufacturing details of various sub-models for the permanent magnet linear synchronous motor are provided ,as well as their SIMULINK implementation. The system nonlinearity is Neutralized using a novel PMSM control. Along with , to improve the dynamic response, a linear state feedback control law based on pole placement approach to reach the zero steady state error with respect to reference current condition is taken into consideration. MATLAB SIMULINK is used to perform the substantial simulation.

KEYWORDS: Dynamic Modelling; Permanent magnet linear synchronous motor

I.INTRODUCTION

In these days industries growing need for faster development times and more accurate manufacturing is placing new demands on the technology used in machine auto machine, tools and the systems used in machine handling. Linear motors can provide linear motion to machine tools without the use of indirect coupling mechanisms like gear boxes, chains and screws. Permanent magnet direct drive motors are becoming increasingly used in machine automation. Permanent magnet motor drives provide several advantages, including a gearless structure, outstanding control Characteristics such as high speed , acceleration and most importantly, great motion precision and efficiency. PMLSMs are utilized in lifts, paper machines, ship propulsion units windmills and other applications.

The moving part (mover) of PMLSM is made up of a slotted armature and three-phase windings, with the surface permanent magnets (SPMs) installed along the entire path (stator).



1 -armature, 2 - PMs 3 -carrier, 4 - guiderail

Fig.1 : permanent magnet linear synchronous motor

LSMs works on the travelling magnetic field concept, where the moving part speed v is equal to the synchronous speed v_s of the travelling magnetic field and the input frequency f and pole pitch τ are the only variables. It is independent of the number of poles $2p$.

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

This paper is arranged as follow: Section I gives the overview of the Permanent Magnet Linear Synchronous Motor. Section II focuses on understand the comparison between permanent magnet linear synchronous motor and rotary motor. Section III gives a brief explanation of the System dynamic modelling of motors. Section IV projects the performance ability of open loop motor and Section V briefs about closed loop system and Section VI show the performance of closed loop motor and at the end section finalizes the paper and references as follows

II. ANALOGY BETWEEN THE PERMANENT MAGNET ROTARY SYNCHRONOUS MOTOR AND THE PMLSM

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

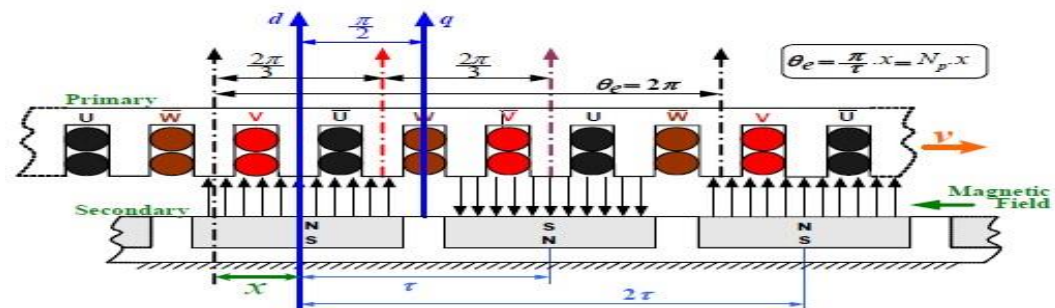


Fig 2 : Electrical model of the PMLSM

By this comparison, the stator of armature windings of a PMLSM shift one by one by a distance of $2\tau/3$ and each winding rotates a distance of τ in the linear reference frame.



The 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 I. 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 change in development of computer hardware and software, new simulation packages which are faster and with more user friendly interfaces are now available and these are increasing day by day. This paper confesses the need of such product, the SIMULINK software of MATLAB, in the dynamic modelling of the PMLSM is discussed in this work. The fundamental benefits of SIMULINK over other programming applications is that the simulation model is built up methodically using simple function blocks rather than compiling computer code. The function blocks may be readily generated, connected and updated using menu commands, the keyboard and an appropriate pointing device like mouse, to a user friendly graphical user interface (GUI). Interconnection of suitable function blocks, each of which performs a separate function, may therefore be used to describe a set of machine differential equations. Programming efforts are less and to make the debugging of errors is not so difficult. Because SIMULINK is a model to expand the simulation model by adding additional sub-models to handle different control functions. The PMLSM might be used as a submodel in a full electric motor drive system.

III. DYNAMIC MODEL OF PMLSM USING SIMULINK

A nonexclusive dynamic model of the PERMANENT MAGNET LINEAR SYNCHRONOUS MOTOR includes an electrical sub-model for performing the three-phase to two-axis (3/2) transformation of stator voltage and current calculation, a thrust submodel to calculate the evolved electromagnetic thrust, and a mechanical sub-model for measuring the rotor or mover velocity.

III.1. ELECTRICAL SUB-MODEL OF THE PMLSM

In synchronously rotating reference frame, the voltage equations for a permanent magnet synchronous motor are

$$V_{qs} = R_s i_{qs} + P \lambda_{qs} + \omega_e \lambda_{ds} \tag{1}$$

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

Where,

$$\lambda_{qs} = L_{qs} i_{qs} \tag{3}$$

$$\lambda_{ds} = L_{ds} i_{ds} + \lambda_{PM} \tag{4}$$

By substituting eq no's (3) & (4) in equations (1) & (2) respectively, we get $V_{qs} = R_s i_{qs} + L_{qs} P i_{qs} + \omega_e L_{ds} i_{ds} + \omega_e \lambda_{PM}$ (5)

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

By rearranging equations (5) & (6), then



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

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

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

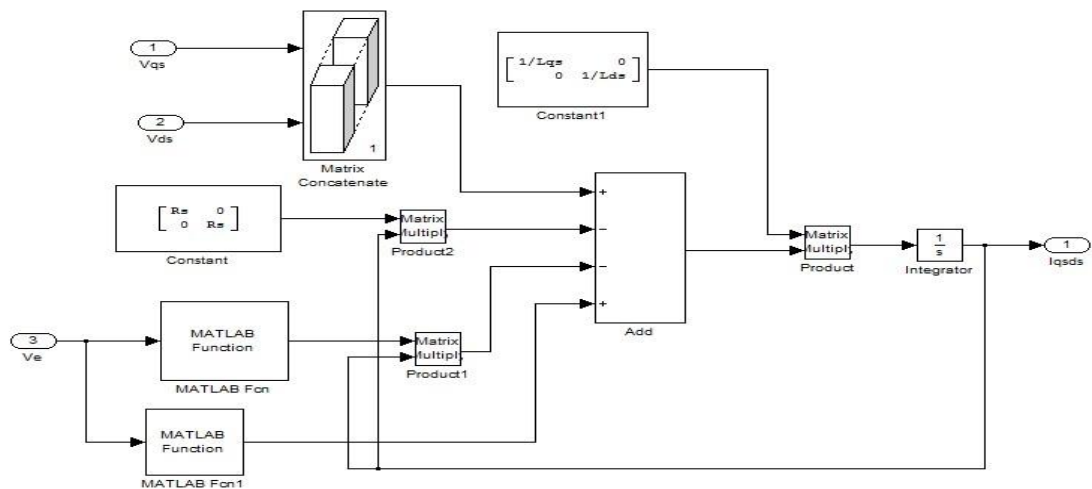


Fig-3 : Electrical Sub Model of PMLSM

III.2. THRUST SUB-MODEL OF PMLSM

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

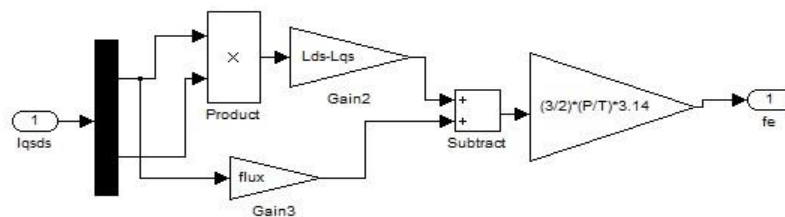


Fig-4 : Electromagnetic Thrust sub model

Where flux = λ_{PM}

III.3. MECHANICAL SUB-MODEL OF PMLSM

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

Applying the laplace transform for the above equation we get

$$F_e - F_l = M s V_e + B V_e$$



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

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

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

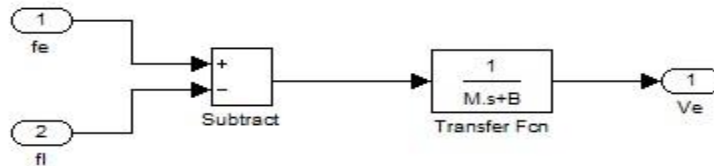


Fig-.5: Mechanical Sub Model of PMLSM

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

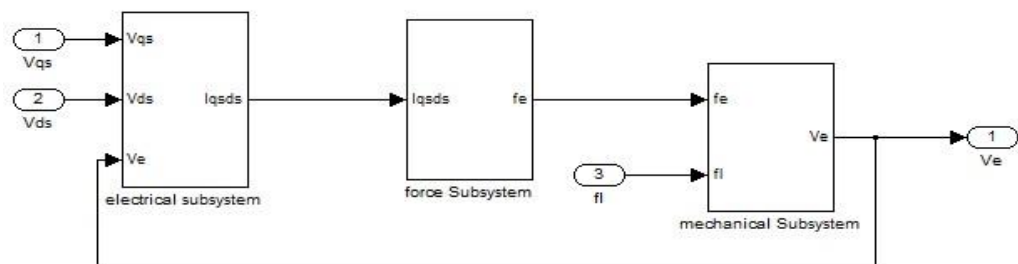


Fig.6: PMLSM overall Model in SIMULINK

IV.OPEN LOOP RESULTS

Open loop results of simulation 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.

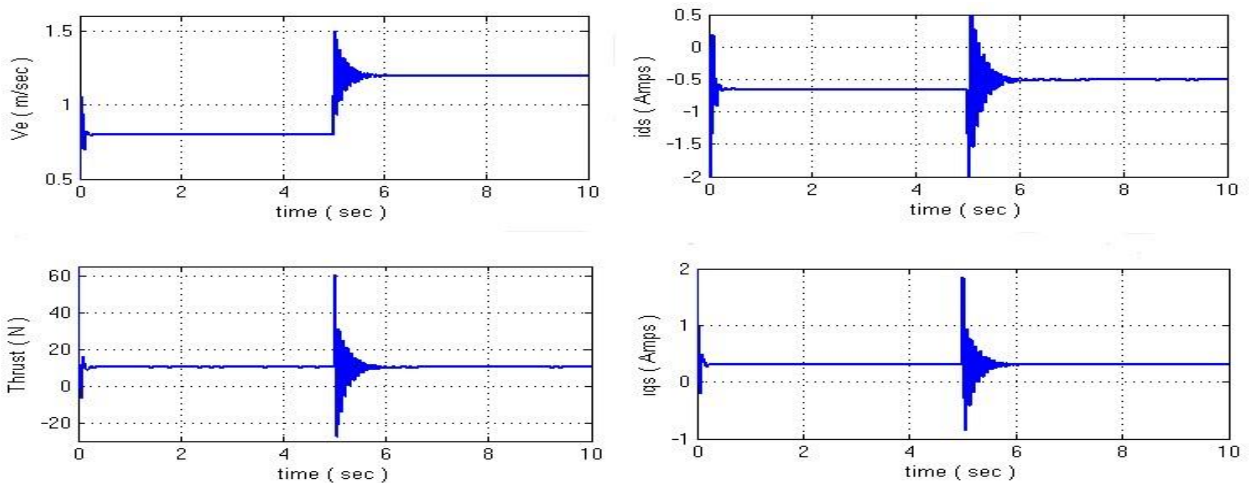


Fig-7. The results of simulation of PMLSM for step change in speed from 0.8 m/s to 1.2 m/s at 5th sec at constant thrust of 10N

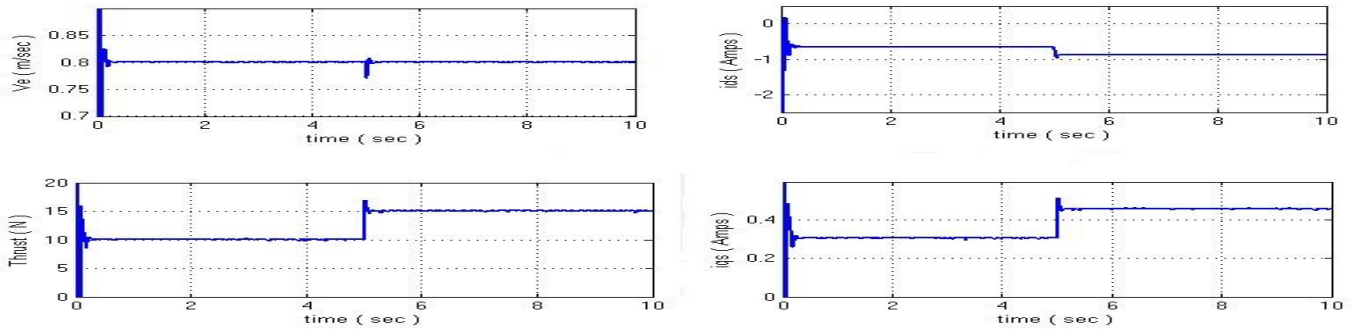


Fig.8 :The results of simulation of PMLSM for step change in thrust from 10N to 15 N at 5th sec at constant Speed of 0.8m/s.

V.CLOSED LOOP CONTROL SYSTEM

The proposed controller for the motor drive is depicted in this paper as a traditional two-loop structure is shown in Fig.9. The speed controller, whose output is the reference value of the thrust F_e^* .As the outer loop is the speed controller.The q-axis current component control method. As a result, while i_d^* is zero the reference value of the current i_q^* is computed from reference thrust.

The present controller is the inner loop , which consists of a nonlinear controller that uses accurate feedback linearization to cancel the systems nonlinearity. In order to obtain the desired dynamic performance ,the eigen values of the resulting linear systems are shifted to appropriate position via state feedback because the current controllers primary function is to achieve the desire dynamic performance. The current controller’s principal responsibility is to follow reference thrust established by the outer speed loop. The state feedback architecture is enhanced with an integral of output errors for this purposes.

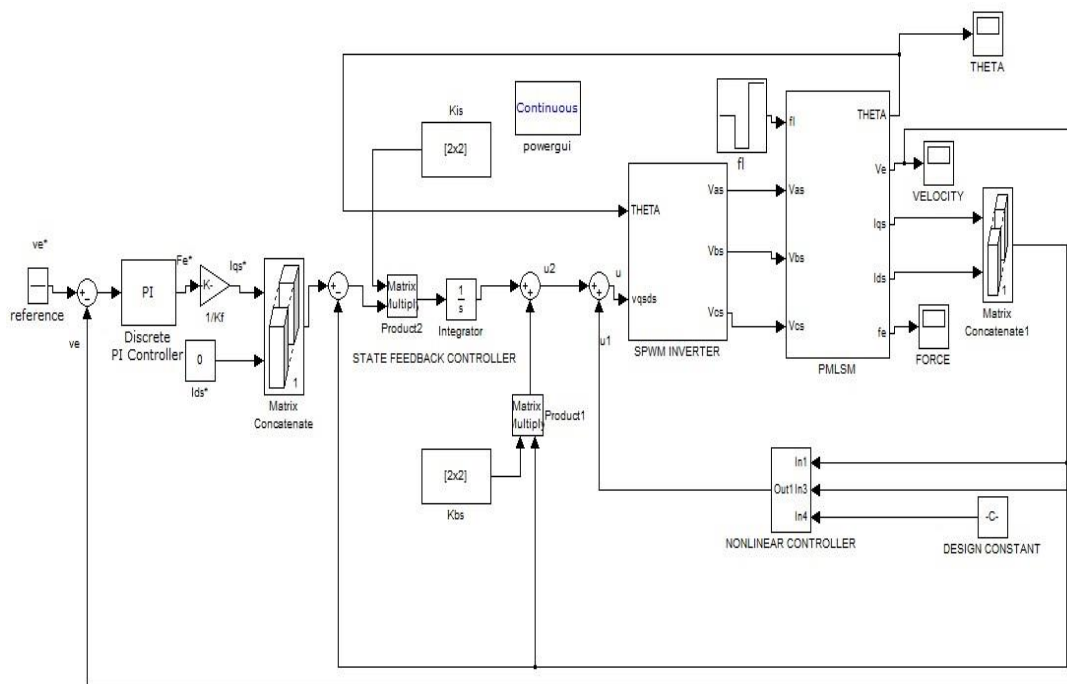


Fig.9 : Closed loop Simulink Diagram



VI.CLOSEDLOOPCONTROLRESULTS

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

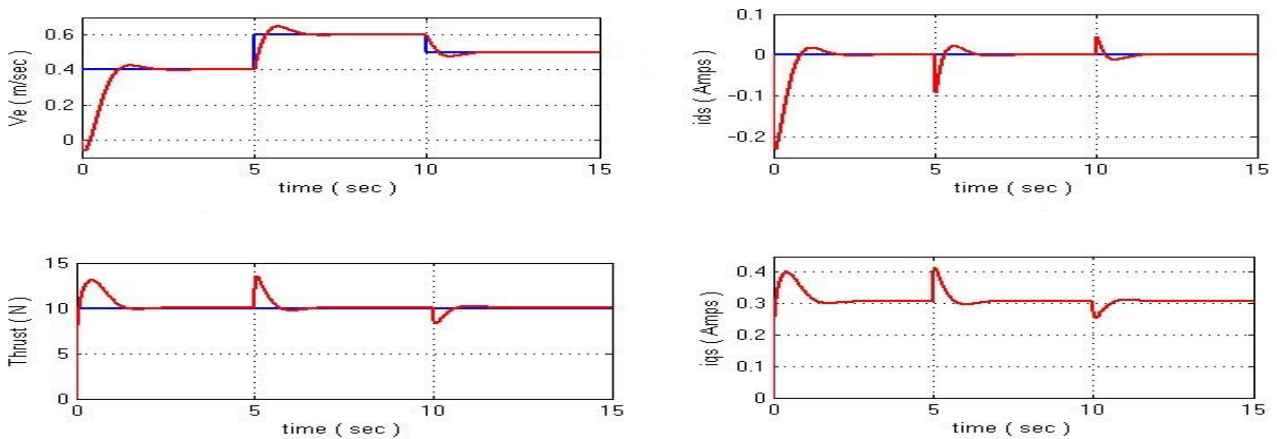


Fig.10 Simulation results of PMLSM for step change in Speed from 0.4 to 0.6 at 5th sec and from 0.6 to 0.5 at 10th sec at constant thrust of 10N

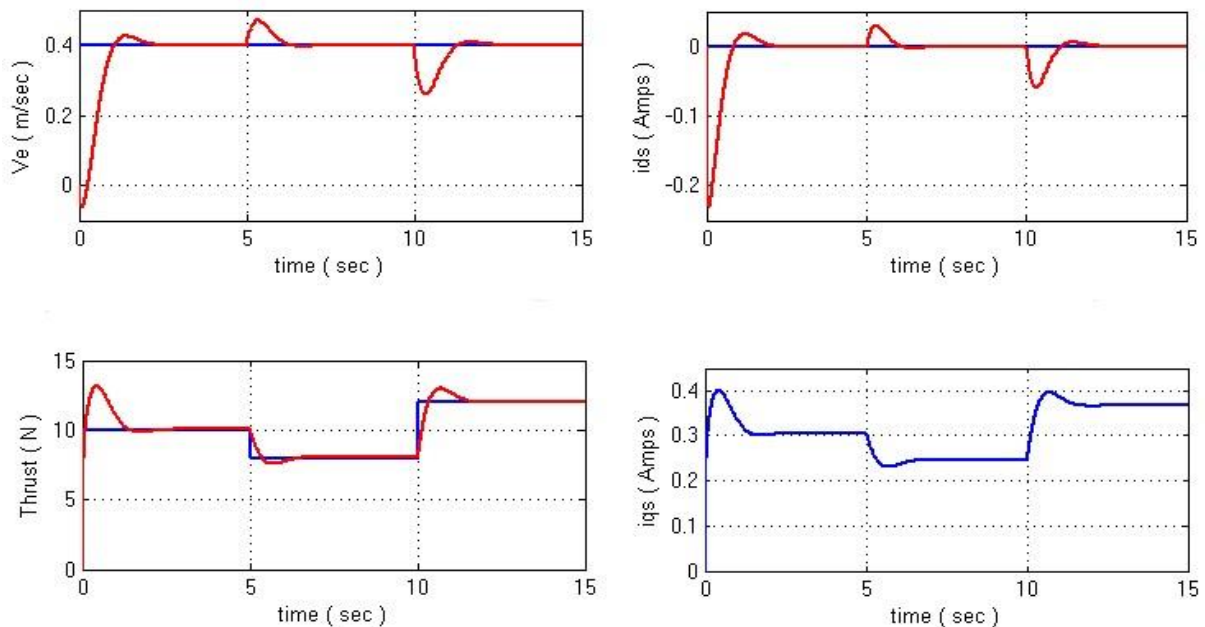


Fig.11 The results of simulation of PMLSM for Step change in thrust from 10 to 8 at 5th sec and from 8 N to 12N at 10thsec at constant speed of 0.4m/sec



VII. CONCLUSION

In this research, we used the MATLAB SIMULINK software to test the dynamic model of PMLSM in both open loop & closed loop control. A generalized technique to design the Linear synchronous Motor speed has been presented by which cancels system nonlinearity. A nonlinear controller has been designed and simulated using exact feedback linearization. The pole placement technique has also been adopted in which the dynamics of the system can be controlled directly by specifying the closed loop locations. The anticipated current step responses were in good agreement with the measurements and less were fewer overshoots.

SIMULATION PARAMETERS

The permanent magnet linear synchronous motor chosen for the simulation studies has the following parameters:

L_{ds} (Stator direct-axis inductance)	=	0.0131 mH
L_{qs} (Stator quadrature-axis inductance)	=	0.0131 mH
R_s (Stator winding resistance)	=	2.1 OhmS
λ_{PM} Permanent magnet flux linkage	=	0.1391 webers
τ = pole pitch	=	20 mm
M (mass of the mover)	=	4.5 kgs

VIII. NOTATIONS USED

V_{ds}, V_{qs} d & q AXIS STATOR VOLTAGES RESPECTIVELY

i_{ds}, i_{qs} d & q AXIS STATOR CURRENTS RESPECTIVELY

$\lambda_{ds}, \lambda_{qs}$ d & q AXIS STATOR MAGNETIC FLUXES RESPECTIVELY

λ_{PM} PERMANENT MAGNET FLUX LINKAGE

L_{ds}, L_{qs} d & q AXIS STATOR INDUCTANCES RESPECTIVELY

R_s STATOR RESISTANCE

M TOTAL MASS OF THE MOVING ELEMENT SYSTEM

F_e, F_L ELECTROMAGNETIC, EXTERNAL DISTURBANCE (OR) THRUSTS RESPECTIVELY

f_e ELECTRIC FREQUENCY

τ POLE PITCH

V LINEAR VELOCITY OF THE MOVER

v_e, v_e^* ELECTRIC, REFERENCE ELECTRIC LINEAR VELOCITIES RESPECTIVELY

V_m MECHANICAL LINEAR VELOCITY

B VISCOUS FRICTION AND IRON-LOSS COEFFICIENT

P NUMBER OF POLE PAIRS

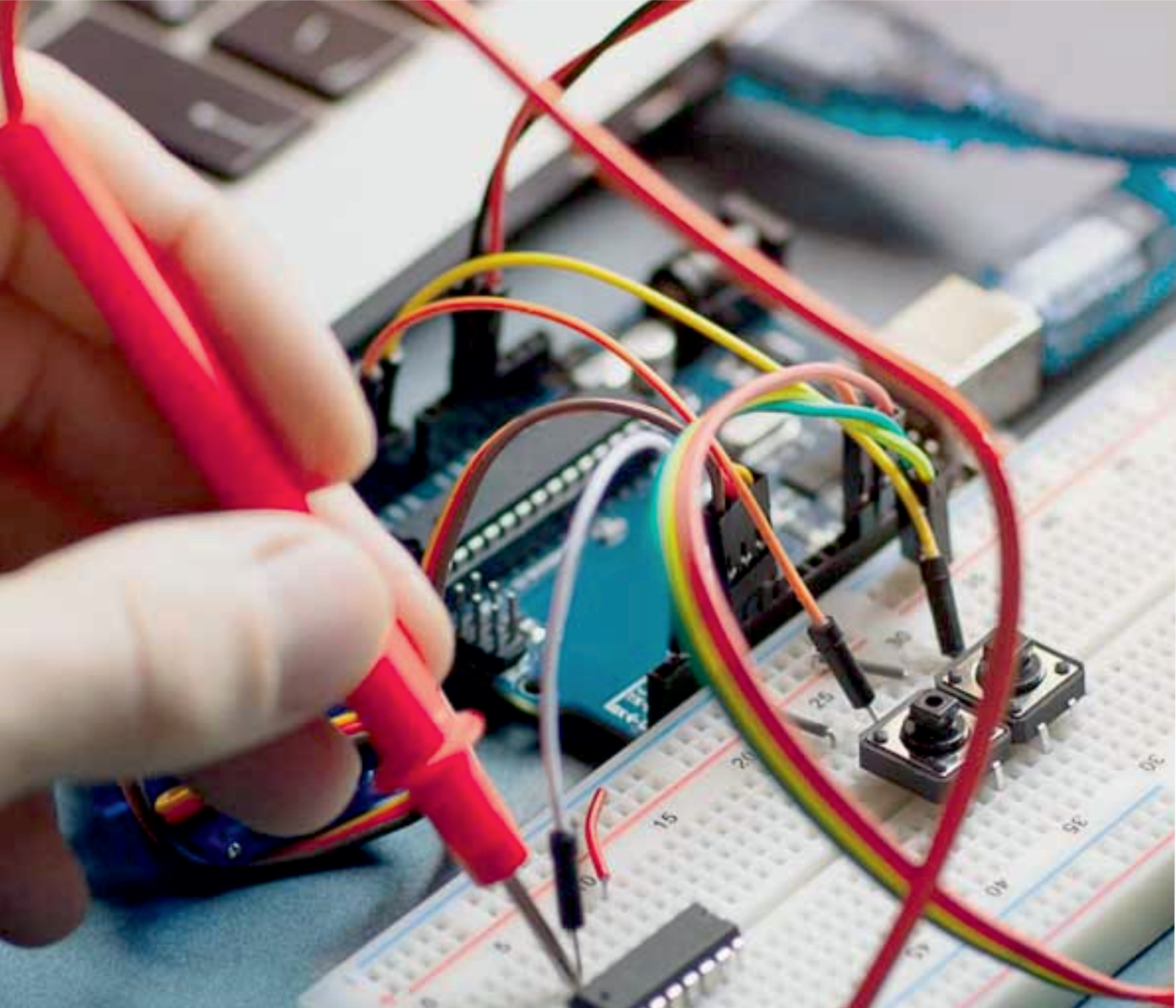


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