2011 International Conference on Signal, Image Processing and Applications
With workshop of ICEEA 2011
IPCSIT vol.21 (2011) © (2011) IACSIT Press, Singapore

Fuzzy Position Controller for Permanent Magnet Linear Synchronous Motors based on Direct Thrust Force Control

H. Nematian, M. Abroshan, K. Torabi, J. Khodaei

Electrical Engineering Department, Shahre Rey Branch - Islamic Azad University, Tehran, Iran

Abstract. This paper presents a fuzzy position control based on direct thrust force control for permanent magnet linear synchronous motors and field weakening strategy for utilizing maximum capacity of these motors. The proposed scheme incorporates maximum thrust force per ampere and field weakening strategies to keep operate the drive within the voltage and current limits of the motor/inverter. Simulation is down for a prototype permanent magnet linear synchronous motor.

Keywords: Direct thrust force control, Field weakening, Fuzzy control, Maximum force per ampere, Permanent magnet linear synchronous motor, Position control.

1. Introduction

Increase the use of permanent magnet linear synchronous motors (PMLSM) can be observed in widespread industrial application particularly in precision machine tools, semi-conductor manufacture equipments [1], [2]. The direct drive of mechanical application based on permanent magnet linear synchronous motor benefits from simple structure, less loss, less friction, faster response and high precision resulting into a higher reliability compared to rotary motors [3]-[7].

There are some papers have recently published on the PMLSM servo drive [1]-[4]. With no exception, in all of them, implementation of force control was established using currents. However, the direct thrust force control (DTFC) strategy has a very fast response to flux and force changes and it is robust against motor parameters' variations and perturbations as well, which is a suitable candidate for the substitution of field oriented control strategy [5]. The basic principle of Direct Thrust Force Control (DTFC) is to directly select stator voltage vectors according to the differences between the references of force and stator flux linkage and their actual values [2], [5].

Because of fuzzy controller does not rely on the analysis and the synthesis of the mathematical model of the process, it have good control performance for nonlinear systems which is ill-defined or too complex, therefore, it is an effective controller for servo control drives and robotics [7]. There are many studies on using fuzzy controller for high performance servo derives, in most of them; implementation is based on vector controlled drive [7]- [9].

In this study, a fuzzy position controller for DTFC drive system is proposed, which combines the merits of the fuzzy controller and direct drive system. The MTPA strategy is utilized for achieving greater maximum force and the FW strategies one used for obtain response to position command.

2. Modelling Of PMLSM

The machine model of a PMLSM can be described in rotor reference frame as follows [3],

$$\begin{bmatrix} u_d \\ u_q \end{bmatrix} = \begin{bmatrix} R_s + L_d \frac{d}{dt} & -P\frac{\pi}{\tau}v_m L_q \\ P\frac{\pi}{\tau}v_m L_d & R_s + L_q \frac{d}{dt} \end{bmatrix} \begin{bmatrix} i_d \\ i_q \end{bmatrix} + \begin{bmatrix} 0 \\ P\frac{\pi}{\tau}v_m \psi_f \end{bmatrix} \tag{1}$$

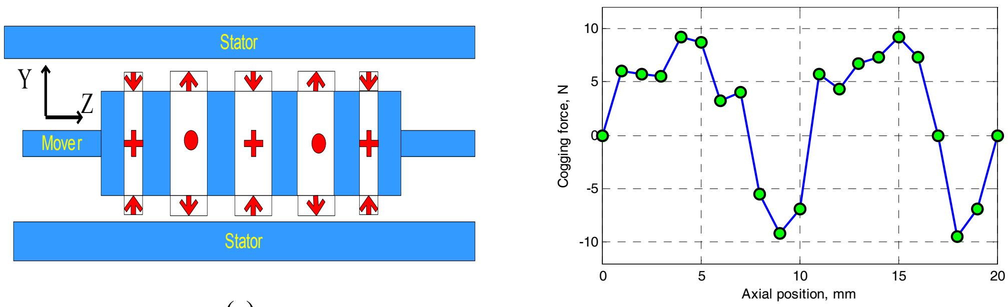
$$F_T = \frac{3}{2} P \frac{\pi}{\tau} \frac{1}{L_d L_q} |\psi_S| [2\psi_f L_q \sin\delta - |\psi_S| (L_q - L_d) \sin 2\delta] \tag{2}$$

$$F_T + F_{cogging}(d_m) = M \frac{dv_m}{dt} + Bv_m + F_L \tag{3}$$

where,

P	number of pole pairs;	τ	pole pitch;
v_m	mover velocity;	d_m	mover position;
ψ_f	permanent magnet flux linkage;	ψ_S	stator flux linkage;
R_S	phase winding resistance;	L_d, L_q	d- and q-axis inductances;
u_d, u_q	d- and q-axis voltages;	i_d, i_q	d- and q-axis currents;
δ	load angle;	M	mover mass;
B	friction factor;	F_L	load force;
F_T	electrical thrust force	$F_{cogging}$	cogging force.

The motor that used in this study is moving secondary and has surface mount permanent magnet (PM) as shown in Fig.1 (a), which is based on a real PMLSM [10]. The parameters of the PMLSM are shown in Table 1. By using finite element method (FEM) the cogging force is extracted and is shown in Fig. 1(b).



(a) (b)

Fig.1 Machine structure of the PMLSM: (a) Side View, (b) Cogging force of the PMLSM.

3. MTPA based Direct Thrust Force Control

The block diagram of the conventional DTFC for a PMLSM position servo drive is shown in Fig. 2. The basic principle of DTFC, is to directly select stator voltage vectors according to the differences between the references of force and stator flux linkage and their actual values [3], [4].

Using the maximum thrust force per ampere strategy in a direct thrust force control based drive mode of the PMLSM drives leads to achieve minimum copper losses which in turn leads to a better utilization of motor capacity. In order to achieve the MTPA for a given force demand, the line current amplitude, is minimized to achieve the maximum force within the current and voltage constraint

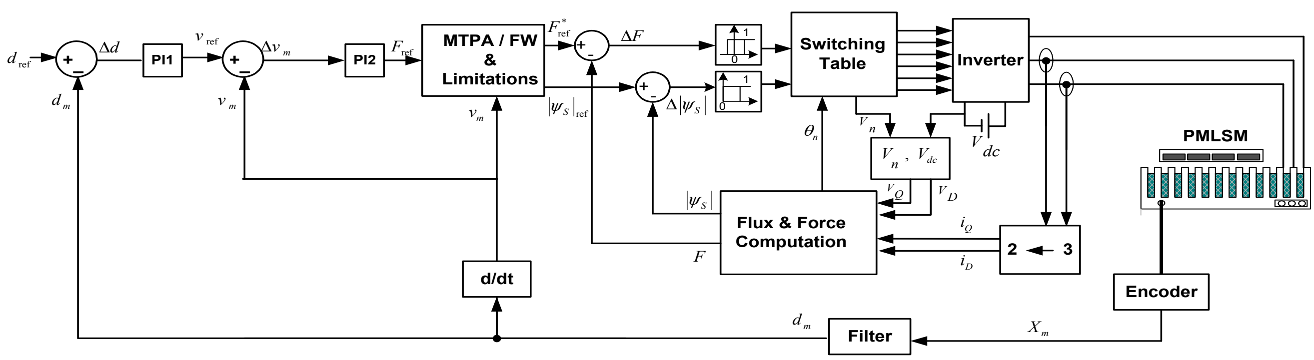


Fig. 2. Block diagram of the conventional DTFC-based drive for PMLSM.

If the magnetic saturation is neglected, the relation between the i_d and i_q currents for PMLSM becomes [11],

$$i_d = \frac{\psi_f}{2(L_q - L_d)} - \sqrt{\frac{\psi_f^2}{4(L_q - L_d)^2} + i_q^2} \tag{4}$$

When the mover velocity is increased above the base velocity, the area within the voltage limit contour, which is allowable operation area, will be decreased. As a result, the stator flux linkage for FW operation must be reduced appropriately according to (5).

$$U_{om} = p\frac{\pi}{\tau}v_m|\psi_s| = p\frac{\pi}{\tau}v_{base}|\psi_s|_{base} \tag{5}$$

Where, v_m and v_{base} are the mover velocity and base velocity, respectively, $|\psi_s|$ and $|\psi_s|_{base}$ are respectively the stator flux linkage and the rated stator flux linkage.

4. Fuzzy Position Controller

The proposed fuzzy position controlled DTFC-based drive for PMLSM is shown in Fig. 4. The fuzzy logic controller (FLC) has two inputs and one output, its inputs are the position error and mover velocity, its output is the force reference.

The membership functions for the fuzzy sets corresponding to the position error (Δd), mover velocity (v_m) and force reference (F_{ref}) are defined in Fig. 8 and the fuzzy rule-based are given in Table 2. Fuzzy output (F_{ref}) is calculated by the centre of area (COA) defuzzification method.

Because the data manipulated in the fuzzy inference mechanism is based on fuzzy set theory, the associated fuzzy sets involved in the fuzzy control rules are defined as follows:

NL: Negative Large   N: Negative   Z: Zero

P: Positive   PL: Positive Large

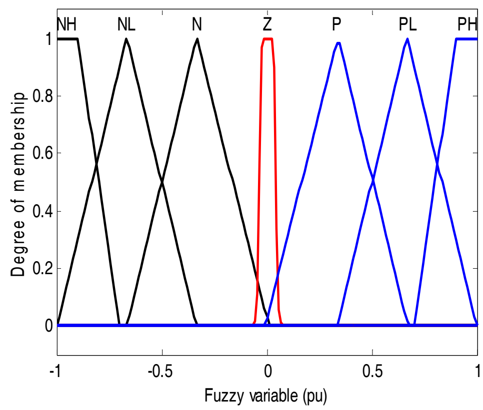


Fig.3 Term sets of membership functions

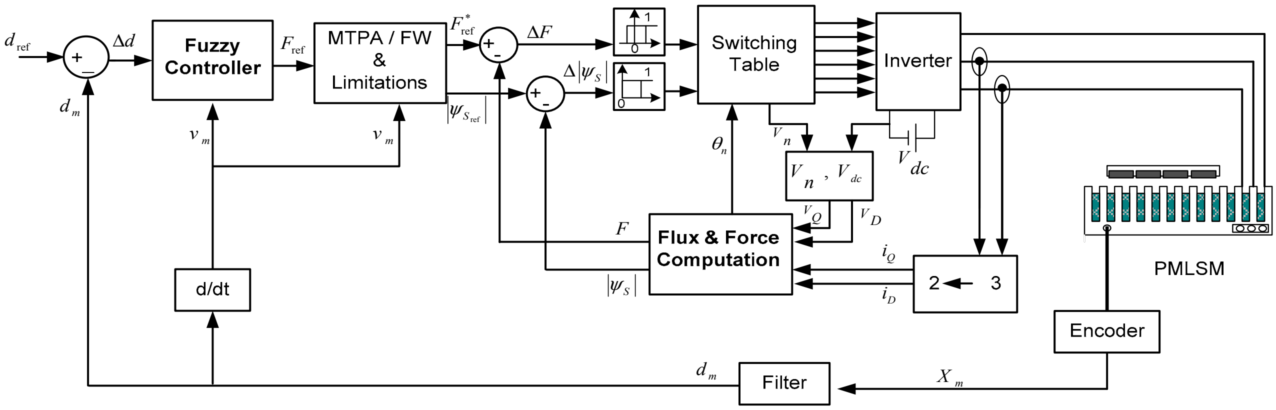


Fig. 4. Block diagram of the DTFC-based drive system with fuzzy position controller for PMLSM.

5. Simulation

To establish the effectiveness of the proposed drive system, two "MATLAB" package simulations are designed and simulation is done under following conditions:

$$d_{\text{ref}} = \begin{cases} 0\ m & t < 0s \\ 0.15\ m & 0s < t \end{cases} \qquad (6) \qquad\qquad External\ Force = \begin{cases} no\ load & t < 0.25s \\ 70N & 0.25s < t \end{cases} \qquad (7)$$

The simulation results are shown in Figs. 5-6. As shown in these figures, the DTFC-based drive system with fuzzy position controller has good responses for position command tracking with load disturbances.

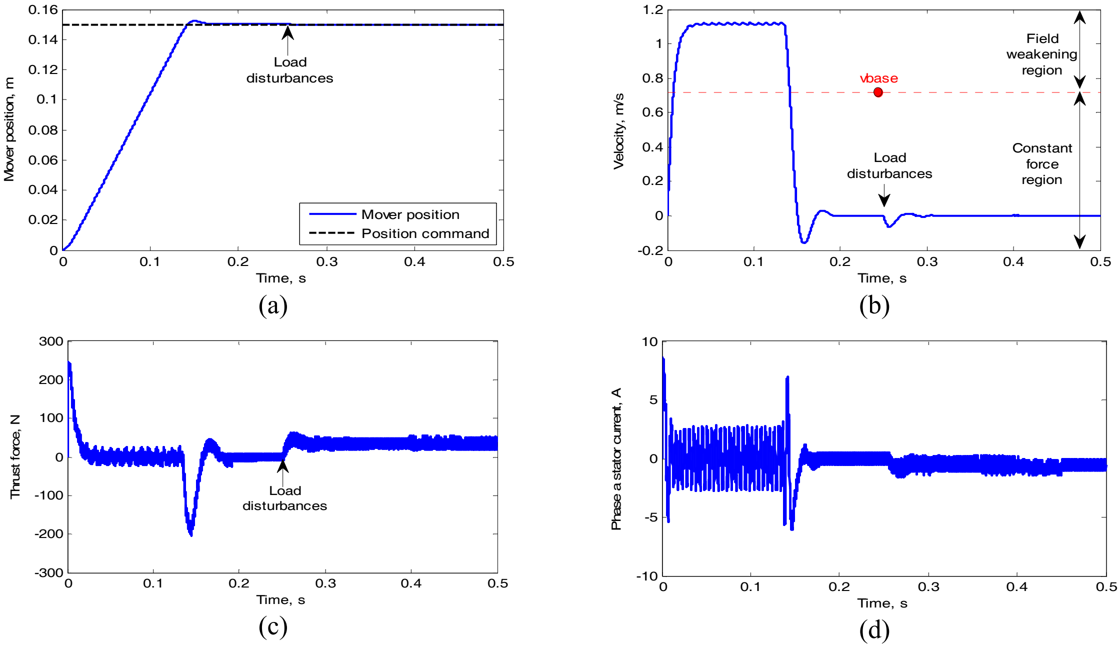
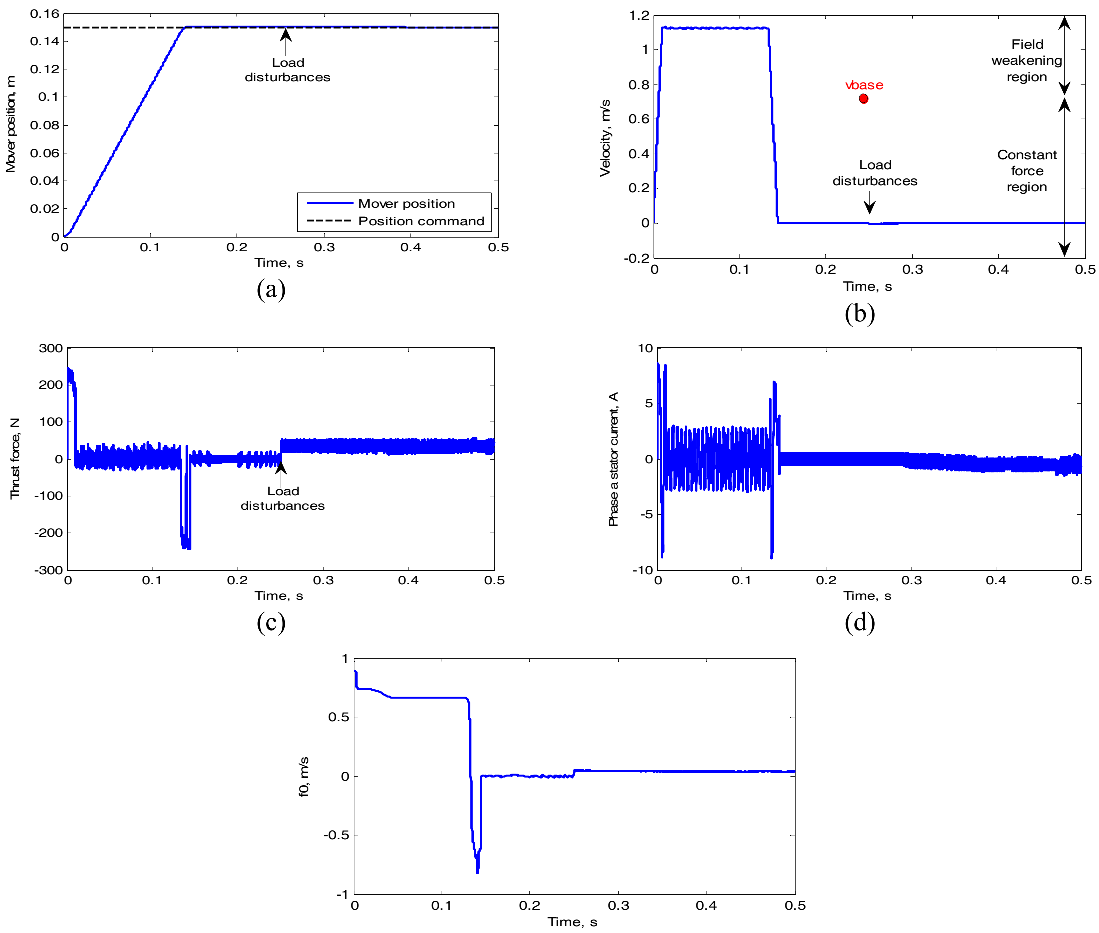


Fig. 5 Closed loop responses for PID-DTFC system: (a) position response, (b) velocity response, (c) force response, (d) the phase current of stator winding.



(e)

Fig. 6. Closed loop responses for Fuzzy-DTFC system: (a) position response, (b) velocity response, (c) force response, (d) the phase current of stator winding, (e) fuzzy controller output.

6. Conclusion

This paper present a DTFC-based drive system with fuzzy position controller which has good response with regard to load disturbances and cogging force. The dynamics of the proposed drive's responses fully satisfied the desired position and velocity of a mover in the position control mode under disturbances, such as step change in the velocity command above the base velocity and external force disturbances

7. References

[1] J. Zou and S. Zhu, "High performance motion control of sensorless interior permanent magnet linear synchronous motor", *Control, Automation, Robotics and Vision Conference, ICARCV 2004*, vol. 3., pp. 1780 – 1785, 6-9 Dec. 2004.

[2] S. A. Nasar and I. Boldea, "*Linear Electric Motors: Theory, Design, and Practical Applications*", Englewood Cliffs, NJ: Prentice-Hall, 1987.

[3] I. Boldea and S. Nasar, "*Linear Electric Actuators and Generators*", London: Cambridge University Press, 1997.

[4] K. Yoshida, Z. Dai, "Sensorless DTC propulsion Control of PMLSM vehicle", *Power Electronics and Motion Control Conference, Proceedings PIEMC*, pp. 191-196, 2000.

[5] C. Jiefan, "Analysis of direct thrust force control for permanent magnet linear synchronous motor", *Proceedings of the 5, World Congress on Intelligent Control, and Automation*, June 15-19, 2004.

[6] C. Jiefan, W. Hui, S. Qing, Z. Yi and Z. Lijun, "Research on Restraining Thrust Force Ripple for Permanent Magnet Linear Synchronous Motor", *5th International Power Electronics and Motion Control Conference, IPEMC 2006*, pp. 1-4, 2006.

[7] R.R. Yager and D.P. Filev, "Essential of fuzzy modeling and control", Wiley, New York , 1994.

[8] Y.S. Kung, N.K. Quang, L.T.V. Anh, "FPGA-based neural fuzzy controller design for PMLSM drive", *International Conference on Power Electronics and Drive Systems*, PEDS 2009, pp. 222-227, 2009.

[9] F.J. Lin, S.L. Chiu, "Adaptive fuzzy sliding-mode control for PM synchronous servo motor drives", *IEE Proceedings - Control Theory and Applications*, Vol. 145, Issue 1, pp. 63-72, 1998.

[10] S.T. Boroujeni, J. Milimonfared, M. Ashabani, "Design, Prototyping, and Analysis of a Novel Tubular Permanent-Magnet Linear Machine", *IEEE Transactions on Magnetics*, Vol. 45, Issue 12, pp. 5405-5413, 2009.

[11] H. Polinder, G. Slootweg, M. J. Hoeijmakers and J. C. Compter, "Modeling of a Linear PM Machine Including Magnetic Saturation and End Effects: Maximum Force-to-Current Ratio", *IEEE Transactions on Industry Applications*, Vol. 39, Issue 6, pp. 1681-1688, 2003.

Tab.1 Fuzzy inference rules

Δd \ v_m	NH	NL	N	Z	P	PL	PH
NH	PH	PH	PH	PH	PH	PH	PL
NL	PH	PH	PH	PL	PL	PL	PL
N	PH	PH	PH	PH	PH	PL	PL
Z	PH	PH	PL	Z	NL	NH	NH
P	NL	NL	NH	NH	NH	NH	NH
PL	NL	NL	NH	NH	NH	NH	NH
PH	NL	NH	NH	NH	NH	NH	NH