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A Novel Approach to Permanent Magnet Linear Synchronous Motor Parameter Estimation

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Abstract

Permanent magnet Linear synchronous machines (PMLSM) requires accurate knowledge of the parameters that describe their mathematical models. This parameter information enables the controller to optimize the drive performance and efficiency and to react to possible changes in the machine model. Most of the existing approaches to identification of machine parameters involve matching a given input-output behavior with empirical discrete-time approximations such as artificial neural networks, Fuzzy models, model based on wavelets etc. In this paper a nobel methodology is presented that is applicable for parameter identification of a iron-cored permanent magnet linear synchronous motor, by defining a set of Hartley modulating functions(HMF).. The advantages of these modulating functions are that the differential equations are reduced to a set of algebraic equations with real coefficients results, the formulations are free from boundary conditions, and the computations can be made using fast algorithms for standard discrete transformation. The effectiveness of the proposed parameter identification algorithm is validated using simulation.

Keywords: Permanent magnet Linear synchronous motor; Hartley modulating functions .

Introduction

High performance 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, better control characteristics like high speed, high acceleration and the most importantly, high motion precision and better efficiency. In the early days of linear motors, PMLSMs are used only in the high-tech industries like semiconductor and electronics. Due to its inherent benefits of direct drive now a day these motors are used in many applications like material handling, packing, medical & food processing etc.

In this paper a new methodology, a solution to the problem of on-line estimation is presented that is applicable to Permanent magnet Linear synchronous motor model equations, The HMF-method converts the nonlinear differential equation describing the nonlinear system into a Hartley spectrum equation using the frequency weighted least squares algorithm[2]. During conversion the method retains identical relationship between physical parameter coefficients in differential equations and Hartley spectrum equations. As a consequence, the presented method is able to estimate parameter even when sudden changes in operation take place.

A major advantage of this technique is that a simple relation exists between the spectra of signal and its derivative. A new family of modulating functions termed as Hartley modulating functions has been defined for this purpose. The advantage of this Hartley modulating function is that, they are real valued. Further, the resulting formulation for parameter estimation is free from boundary conditions and gives rise to a linear in parameters model

Dynamic Model of PMLSM

The mathematical analysis of Permanent Magnet Linear Synchronous Motor is a key factor in the development of motor control system. The mathematical model of PMLSM is basically as same as the PM rotary motor. The d-q voltage equations for PMLSM in mover reference frame are given by,

$$u_d = R_s i_d + \frac{d\psi_d}{dt} - \omega_r \psi_q \tag{1}$$

$$u_q = R_s i_q + \frac{d\psi_q}{dt} + \omega_r \psi_d \tag{2}$$

The flux equations are given as,

$$\psi_d = L_d i_d + \psi_{pm} \tag{3}$$

$$\psi_q = L_q i_q \tag{4}$$

Where u_d and u_q are the terminal voltage ψ_d and ψ_q are the armature winding flux linkages and i_d and i_q *are* the armature currents in the d and q-axis components . L_d and L_q are the d and q-axis components of the resultant armature inductance and ψ_{pm} is the flux linkage of the permanent magnet per phase.

The synchronous speed in a linear motor is

$$\omega_r = \frac{\pi v_r}{\tau} \tag{5}$$

where τ is the pole pitch. v_r is linear synchronous velocity

The electromagnetic thrust of a PMLSM with p pole pairs is

$$F_e = \frac{3}{2} p \frac{\pi}{\tau} \psi_{pm} i_q = K_f i_q \tag{6}$$

Where K_f is thrust constant in N/A & K_e is back emf constant in V/m/s.

The mechanical operating thrust equation can be represented as

$$F_e = M \frac{dv_r}{dt} + Bv_r + F_l \tag{7}$$

Where M is the mass of the mover, B is the friction coefficient, F_l is the load thrust

Hartley Modulating Functions (HMF)

Hartley modulating functions converts a differential equation into an exact algebraic equation form and nullifies both initial and final conditions. The Property of modulating functions, which enables this, is,

$$\phi_m{}^i(t) = 0 \tag{8}$$

For t = 0 and t = T, i= 0, 1…. n – 1 $\phi_m{}^i(t)$ is the ith time derivative of the mth member of family of Where modulating functions $\{\phi_m(t)\}$.When equation(8) is satisfied, and then $\phi_m(t)$ is called a family an nth order modulating functions.

Let us denote the mth member HMF spectral component of a signal, is defined within the interval (0,T) by, $\overline{H}(m\omega_0)$, that is

$$\overline{H}(m\omega_0) = \int_0^T x(t)\phi_m(t)dt \tag{9}$$

Then it can be easily verified by inspection that

$$\overline{H}(m\omega_0) = \sum_{j=0}^{n} (-1)^j \binom{n}{j} H\{(n+m-j)\omega_0\} \tag{10}$$

Where H (ω) is the continuous Hartley transform (CHT) of $x(t)$.

Hartley modulating function to the parameter estimation problem of non linear systems, is given below.

Spectra for Derivatives of Signal

If $x^{(t)}(t)$ denotes the ith derivative of the signal $x(t)$, then the HMF spectra of

$x^{(t)}(t)$ for 1≤ i ≤ n, is given by

$$\overline{H}^{(i)}(m\omega_0) = \sum_{j=0}^{n}(-1)^j \binom{n}{j} cas'\left((\frac{i\pi}{2})(n+m-j)^i \right)\omega_0^i \mathrm{H}\{(-1)^i(n+m-j)\omega_0\} \tag{11}$$

Where, cas' denotes the derivative of $cas(t)$ and is given by

$$cas'(t) = \cos(t) - \sin(t) \tag{12}$$

Model Simplification & Parameterization

The d-q voltage equations of PM Linear Synchronous Motor in rotor reference frame, substituting flux equations (3) & (4) in voltage equations (1) & (2), are

$$u_q = R_s i_q + L_q p i_q + \frac{\pi}{\tau} v_r L_d i_d + \frac{\pi}{\tau} v_r \psi_{pm} \tag{13}$$

$$u_d = R_s i_d + L_d p i_d - \frac{\pi}{\tau} v_r L_q i_q \tag{14}$$

The mechanical thrust balance equation using (6) and (7)

$$F_l = \frac{3}{2} p \frac{\pi}{\tau} \psi_{pm} i_{qs} - \beta V_r - M p V_r \tag{15}$$

Multiplying equations (13) and (14) with (9) and integrating them between the limits (0, T), we obtain

$$\overline{\mathrm{H}}_{u_q} = \underbrace{R_s}_{X_1} \overline{\mathrm{H}}_{i_q} + \underbrace{L_q}_{X_2} \overline{\mathrm{H}}_{i_q}^{(1)} + \underbrace{\frac{\pi}{\tau} L_d}_{X_3} \overline{\mathrm{H}}_{v_r i_d} + \underbrace{K_e}_{X_4} \overline{\mathrm{H}}_{v_r} \tag{16}$$

$$\overline{\mathrm{H}}_{u_d} = \underbrace{R_s}_{y_1} \overline{\mathrm{H}}_{i_d} + \underbrace{L_d}_{y_2} \overline{\mathrm{H}}_{i_{ds}}^{(1)} + \underbrace{(-L_q \frac{\pi}{\tau})}_{y_3} \overline{\mathrm{H}}_{V_r i_q} \tag{17}$$

$$\overline{\mathrm{H}}_{F_l} = \underbrace{K_f}_{z_1} \overline{\mathrm{H}}_{i_q} + \underbrace{(-\beta)}_{z_2} \overline{\mathrm{H}}_{v_r} + \underbrace{(-M)}_{z_3} \overline{\mathrm{H}}_{v_r}^{(1)} \tag{18}$$

The parameter vectors θ_{u_q}, θ_{u_d} and θ_{F_l} can be estimated by applying the least square estimation, using a cost function of the generic form

$$J(\theta) = \sum_{m=-M}^{M} [\overline{\mathrm{H}}(m\omega_0) - \phi^T(m\omega_0)\theta]^2 \tag{19}$$

Open Loop Simulation of PMLSM

The simulation is performed with a change in speed from 0.6 m/sec to 0.8 m/s at a constant load thrust of 20N

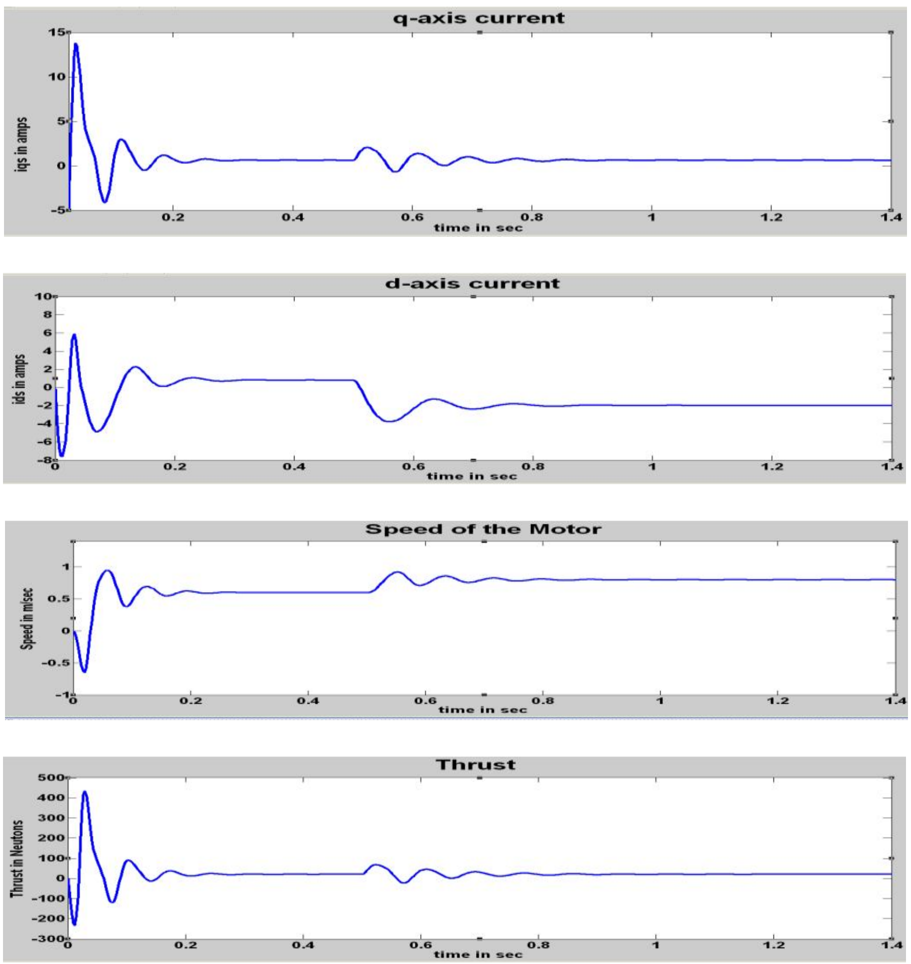

Figure 1: Simulation results of PMLSM parameters

Simulation Results

Simulation results are tabulated for different sample size. The parameters which have been used for simulation are taken as true values. It appears that the results are becoming more accurate with the increase in sampling time.

Table 1: Parameters of PMLSM with a change in speed from 0.8m/sec to 1.2 m/s at a load force of 20 N

Parameters	Units	Estimated value				Actual Value
		No. of samples				
		512	1024	2048	4096	
R	Ohm	2.097	2.099	2.098	2.098	2.100
L_d	H	0.1020	0.0510	0.0259	0.0129	0.0130
L_q	mH	0.1039	0.052	0.0261	.0131	0.0130
M	Kg	38.412	19.190	9.597	4.798	4.800
B	N/m/s	0.157	0.160	0.159	.1589	0.160
K_f	N/A	32.783	32.787	32.785	32.784	32.786
K_e	V/m/s	26.801	26.800	26.800	26.800	26.800

Specifications of PMLSM

Rated Thrust = 154N	Nominal power =3910W	Thrust constant=32.7N/A
Rated speed = 4.5m/s	Rated current = 4.67A	Back emf const.=27V/m/s
Resistance /phase=2.1 Ω	Inductance = 13.0 mH	Pole pitch =20mm

Conclusion

In this paper, a new approach based on Hartley modulating function is proposed for parameter identification of PMLSM with nonlinear model equations. HMF converts the non linear model equations into linear model equations by assuming all initial conditions are zero. Permanent Magnet Linear synchronous motors have been modeled in d-q axes representation .To observe the open loop behavior and physical parameters of the motor, the non linear model is simulated in MATLAB to sudden change in speed from 0.8m/s to 1.2m/s at a constant load thrust of Fl =20 N. Using the data obtained from open loop simulation, physical parameters such as stator resistance and inductances as well as mechanical parameters such as Mass of the mover, Force constant, Back emf constant and friction coefficient have been estimated with fair amount of accuracy. The use of a non linear model ensures that the technique can be used for determining the parameters of the system under all operating condition.

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