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Adaptive Sliding Mode Control of PMLSM Drive

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ABSTRACT

In this paper, we propose a study by software MATLAB/Simulink of the adaptive nonlinear controller of permanent magnet linear synchronous machine.The lumped uncertainties due for saturation magnetic and temperature and distribution load effects in performances of the system control. To resolve this problem the sliding mode controller is designed with estimator of load force by MRAS method the simulation results prove clearly the robustness of controlling law and estimator method.

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1. INTRODUCTION

The advantages of superior power density, high-performance motion control with fast speed, and better accuracy, are such that permanent magnet linear synchronous motors (PMLSMs) are being increasingly used as actuators in many automation control fields [1,2,4], including computer controlled machining tools, X-Y driving devices, robots, semi-conductor manufacturing equipment, transport propulsion and levitation, high-speed injection molding machines, dc solenoid, etc. However, due to load variety of the plant and the mechanical friction, the model uncertainty of PMSLM system has a great impact on the accuracy of control systems [3]. As a result, many control methodologies have been applied to the control of PMSLM system in order to eliminate the effects of uncertainty [20].

It is well known that the major advantage of sliding-mode control (SMC) system is its insensitivity to parameter variations and external-force disturbance once the system trajectory reaches and stays on the sliding surface [5,7,8]. The first step of SMC design is to select a sliding surface that models the desired closed-loop performance in state-variable space. The second step is to design a hitting-control law such that the system-state trajectories are forced toward the sliding surface. The system-state trajectory in the period of time before reaching the sliding surface is called the reaching phase. Once the system trajectory reaches the sliding surface, it slides along the sliding surface to the origin and is called the sliding mode. However, the robustness of the SMC is guaranteed usually by using the strategy of a large switching-control gain. This switching strategy often leads to the chattering phenomenon which is caused by switching function in hitting-control law [5,6,8]. To improve the chattering phenomena, a common method is to use the saturation function to replace the switching function [8].

2. PMLSM SYSTEM

The dynamics of PMLSM can be described as follows [10, 11]:

$$\frac{di_d}{dt} = -\frac{R_s}{L_d} i_d + \frac{L_q \pi}{L_d \tau} v i_q + \frac{1}{L_d} u_d \tag{1}$$

$$\frac{di_q}{dt} = -\frac{R_s}{L_q} i_q - \frac{L_d \pi}{L_q \tau} v i_d - \frac{\psi \pi}{L_q \tau} v + \frac{1}{L_q} u_q \tag{2}$$

$$\frac{dv}{dt} = \frac{3\pi}{2\tau M} i_q (\psi + (L_d - L_q) i_d) - \frac{F_L}{M} - \frac{B_m}{M} v \tag{3}$$

Where i_d, i_q and v are the state variables which represent direct-axis current, quadrature-axis current and linear speed, respectively, and u_d, u_q the direct-axis and quadrature-axis primary voltage components, respectively, M is the total mass of load, B_m the viscous damping coefficient, R_s the primary winding resistance, L_d, L_q the direct-axis and quadrature-axis primary inductors, respectively, ψ the permanent magnet flux, τ the polar pitch, and F_L is the load force [11].

3. CONTROLLER DESIGN FOR PMLSM BASED ON SLIDING MODE

The mathematical foundations of sliding mode can be found in several recent publications [12,13,14,15,21]. Sliding-mode design can be interpreted in several ways. One way of looking at it is to think of the design process as a two-step procedure. First, a region of the state space where the system behaves as desired is defined (sliding surface design). Then, a control action that takes the system into such surface and keeps it there is to be determined. Robustness is usually achieved based on a switched control law. The design of the control action can be attempted based on different strategies, a straightforward one being based on defining a Lyapunov-like condition that makes the sliding surface an attractive region for the state vector trajectories. For this discussion, consider first the time-varying surface S(t) in the state space R^n

$$S(\vec{x},t) = (\frac{d}{dt} + \lambda)^{n-1} \tilde{x} = 0 \tag{4}$$

Where $\tilde{x} = \vec{x} - \vec{r} = [x - r \; \dot{x} - \dot{r} \cdots (x^{n-1} - r^{(n-1)})]^T$ is the tracking error vector, λ is some positive constant, and n is the relative degree of the system [5, 26]. Any state trajectory x that lies on this surface tracks the reference r, since (4) defines a differential equation on the error vector that stably converges to zero. There are several possible strategies to design the control action that takes the system to the surface defined by (4). One such strategy is to define u in such a way that S becomes an attractive region for the state trajectories, for instance, by forcing the control action to satisfy a geometric condition on the distance to S as measured by S^2

$$\frac{1}{2}\frac{d}{dt}(S^2) \le \eta |s| \Leftrightarrow s\frac{ds}{dt} \le -\eta |s| \le 0 \tag{5}$$

Where η is a strictly positive constant this condition forces the squared "distance" to the surface to decrease along all state trajectories [5, 26], or, in other words, all the state trajectories are constrained to point toward S [26]. In sliding mode, the goal is to force the dynamics of the system to correspond with the sliding surface $S(x)$ by means of a control defined by the following equation:

$$u = u_{eq} + u_{disc} \tag{6}$$

We note that the control law is divided into two terms of different nature [9]. u_{eq} equivalent control. u_{disc} discontinuous control.

$$u_{disc} = -k \cdot sign(S) \tag{7}$$

In practice, the function sign(S) is never cancelled exactly, and the discontinuous nature of this term generates in steady operation the phenomenon of the commutations high frequency, or "Chattering", control characteristic by sliding mode. To reduce this phenomenon, which can have harmful effects on the system has controlled. To solve the problem of Chattering the function of sign is replaced by a function sat for calculates control. In this section the discontinuous component becomes:

$$u_{disc} = -k \cdot sat \text{ with} \begin{cases} sat(s) = \frac{s}{\mu} / si\ |s| \le \mu \\ sat(s) = sign(s) / si\ |s| \ge \mu \end{cases} \tag{8}$$

This switching function can be represents by the following Figure 1.

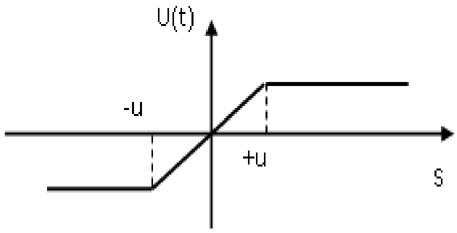

Figure 1. The switching function

4. DESING OF POSITION CONTROL OF PMLSM BASED ON SLIDING MODE

The design of the sliding mode control law consists of two Phases:
Defining an equilibrium surface (the sliding manifold) and a control action such that any state trajectory starting from the equilibrium surface evolves with a predefined behavior. Designing a discontinuous control law to force the state trajectory to reach the sliding surface in a finite time. Let us define the following sliding surface:

$$s(e\ ) = (\frac{d}{dt} + \lambda)^{r-1} e \tag{9}$$

Where e the error vector is λ is some positive constant, and r is the relative degree of the system

4.1. Control of position

In this subsection, we will develop the new sliding mode controller [8,16,17,18]. The control problem is to find a control law so that the state x can track the desired command x_{ref} accurately under the occurrence of the uncertainties. To achieve this control objective, define the tracking error as follows [8]:

$$e_x = x_{ref} - x \tag{10}$$

To determine the sliding surface, we take the form of general equation given by J.J.E.Slotine [5, 19]:

$$s(e_x) = (\frac{d}{dt} + \lambda)^{r-1} e_x \tag{11}$$

The relative degree of position with u_q equal r =3

$$s(e_x) = \frac{d}{d^2t}^2 e_x + \lambda^2 + 2\lambda \frac{d}{dt} e_x \tag{12}$$

$$\dot{s}(e_x) = \frac{d}{dt}\left[\frac{d}{d^2t}^2 e_x + \lambda^2 + 2\lambda \frac{d}{dt} e_x \right] \tag{13}$$

$$u_q^{eq} = \frac{1}{A + Bi_d}\left[\ddot{x}_{ref} + \frac{F_L}{M} + \frac{B_m}{M} v + \lambda(\dot{x}_{ref} - v) \right] \tag{14}$$

During the sliding mode the surface $s(e_x) = 0$ and $\dot{s}(e_x) = 0$. The law of control is defended by:

$$u_q = u_q^{eq} + u_q^{disc} \tag{15}$$

$$u_q = \frac{1}{A + Bi_d}\left[\ddot{x}_{ref} + \frac{F_L}{M} + \frac{B_m}{M} v + \lambda(\dot{x}_{ref} - v) \right] + k_x sat(e_x) \tag{16}$$

Or $A = \frac{3\pi}{2\tau M}\psi \quad B = \frac{3\pi}{2\tau M}(L_d - L_q)$

4.2. Control of direct current

The relative degree of direct current r=1.The error of direct current is defined by:

$$e_{i_d} = i_{dref} - i_d \tag{17}$$

The scalars function of the surface of sliding defined by the equation according to:

$$s(e_{i_d}) = (\frac{d}{dt} + \lambda)^{r-1} e_{i_d} \tag{18}$$

Relative degree of direct current r=1

$$s(e_{i_d}) = e_{i_d} \tag{19}$$

$$\dot{s}(e_{i_d}) = \dot{e}_{i_d} \tag{20}$$

$$u_d^{eq} = \frac{1}{L_d}(i_{dref} - \phi_2) \tag{21}$$

$$\phi_2 = -\frac{R_s}{L_d} i_d + \frac{L_q \pi}{L_d \tau} v i_q$$

The control voltage u_d is defined by:

$$u_d = u_d^{eq} + u_d^{disc} \tag{22}$$

$$u_q^{disc} = k_d sat(s(e_d)) \tag{23}$$

$$u_d = \frac{1}{L_d}(i_{dref} - \phi_2) + k_d sat(s(e_d)) \tag{24}$$

5. STRUCTURE OF THE PROPOSED MRAS TECHNIQUE

The adaptive system with model of reference (MRAS) is a technique, pertaining to the category of the indirect estimate speed by exploiting the stator tensions and currents. This approach was formulated the first time by Schauder 1989, the adaptive system with model of reference is composed of two models, the first, which does not introduce the size to be estimated, is called model of reference and the second is the adjusted model. The difference between the outputs of the two models controls an adaptive mechanism which generates the value an estimated. The latter is used in the adjustable model. The adaptive mechanism is very significant because, it must ensure the stability of the system, and that the estimated value converges towards the value of reference the structure general of the estimate by method MRAS is given by Figure.2.

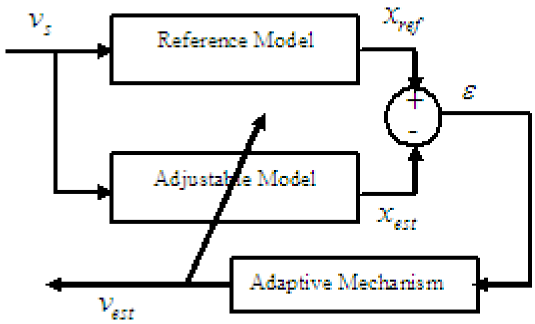

Figure 2. Structure of MRAS method

5.1. Structure of proposed MRAS-based load force estimation

The dynamic equations of the PMLSM in the rotating d--q reference he are given by:

$$\frac{dv}{dt}=\frac{3\pi}{2\tau M}i_q(\psi+(L_d-L_q)i_d)-\frac{\hat{F}_L}{M}-\frac{B_m}{M}v \tag{25}$$

As the load force F_L is included in these equations, we can choose the dynamic Equation model of the PMLSM as the adjustable model, and the motor itself as the reference model. These two models both have the output F_L . According to the difference between the outputs of the two models, through a certain adaptive mechanism, we can get the estimated value of the force load. A block diagram of the proposed MRAS based PMLSM force load estimator is shown in Figure 3.

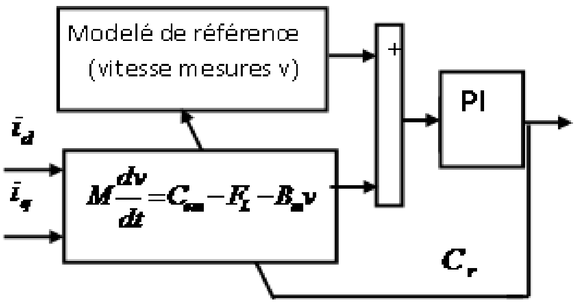

Figure 3. Block diagram of the load force estimated

Table 1. PMLSM Parameters

Primary Winding Resistance	1.32Ω
Direct-Axis Primary Inductance	11mH
Quadrature-Axis Primary Inductance	11mH
Permanent Magnet Flux	0.65Wb
Mass of the Primary Part	20kg
Polar Pitch	30mm
Viscous Damping Coefficient	2Ns/m

6. SIMULATION RESULTS

In order to validate the theoretical analysis and to establish the effectiveness of the proposed MRAS-based load force esteemed for sliding mode control of PMLSM drive have been verified by the following simulation tests. Starting with triangular wave input position with no-load and in 3s the load force applied is 100Nm and in 7s the load is eliminated, the simulation result shown in Figure 5, and starting with triangular wave position in load 100Nm the simulation result shown in Figure 6.

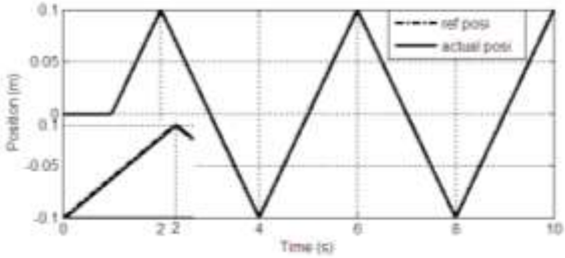

Figure 5a. Position

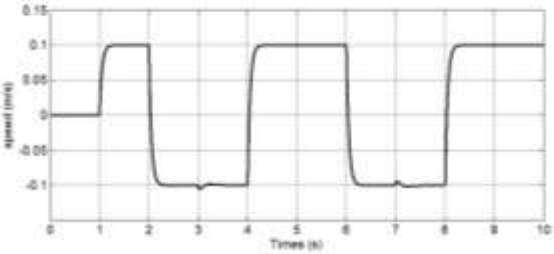

Figure 5b. Speed

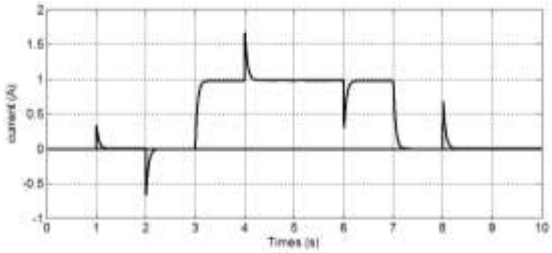

Figure 5c. d-q axis currents

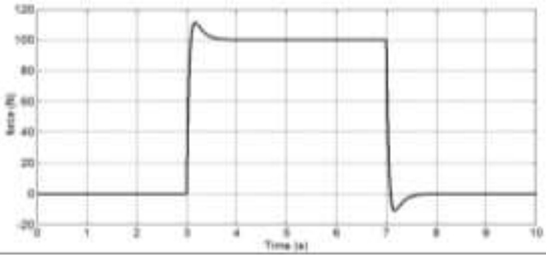

Figure 5d. Force load estimated

Figure 5. Performance of the adaptive sliding mode control with load force disturbance

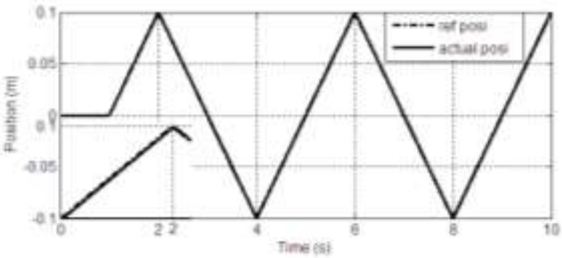

Figure 6a. Position

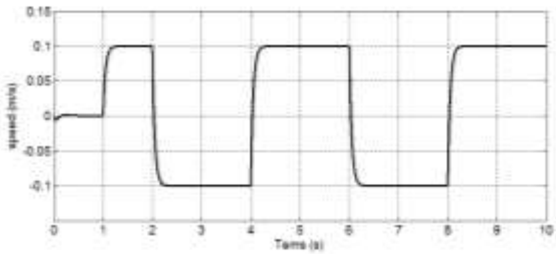

Figure 6b. Speed

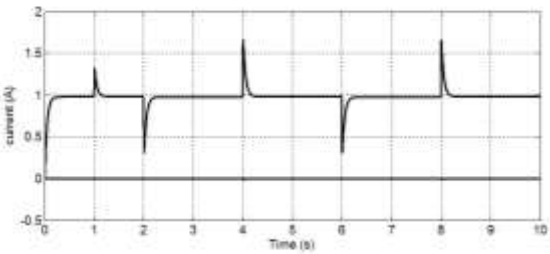

Figure 6c. d-q axis currents

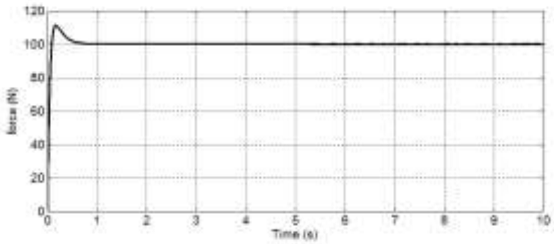

Figure 6d. Force load estimated

Figure 6. Performance of the adaptive sliding mode control

From the simulation results, we can conclude that position control of PMLSM mathematical model with an active disturbance rejection controller achieve good results. The position response closely follows the input command, and direct-axis current has been stable about 0 A indicating the control of permanent magnet synchronous motor using sliding mode control can achieve full decoupling and good estimation force for the proposed MRAS method.

7. CONCLUSION

The PMLSM can be used for variable speed and position precision and high performance electric motor drives. This performance depends on the types of controllers used. In this paper a nonlinear controller has been proposed for tracking position of a PMLSM which operates in extended region. The nonlinear controller is associated with MRAS estimator of load force for sliding mode control of PMLSM drive system. The simulation results of the drive system shown the performance of controllers was investigated at different operating conditions such as sudden change in command position load distribution. Computer simulation results obtained, confirm the effectiveness and validity of the proposed MRAS method. It was found from the results that the proposed MRAS method is robust and could be a potential candidate for high performance industrial drive application.

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