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Simulation of Linear Induction Motor Using Sliding Mode Controller Technique

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ABSTRACT:*In the present paper, the mover speed control of a linear induction motor (LIM) using a sliding mode control design is proposed. First, the indirect field-oriented control LIM is derived. The sliding mode control design is then investigated to achieve speed- and flux-tracking under load thrust force disturbance. The numerical simulation results of the proposed scheme present good performances in comparison to that of the classical sliding mode control.In the present paper, a sliding mode controller based onindirect field orientation is proposed for LIM speed controlwhile considering end effects. The proposed controller isapplied to achieve a speed- and flux-tracking objectiveunder parameter uncertainties and disturbance of loadthrust force.*

Keywords:_Linear induction motor, End effects, Compensation, Field-oriented control, Sliding mode_

I. INTRODUCTION

Currently, linear induction motors (LIMs) are widely used in many industrial applications, including transportation, conveyor systems, actuators, material handling, pumping of liquid metal, sliding-door closers, and others, with satisfactory performance . The most obvious advantage of a linear motor is that it has no gears and requires no mechanical rotary-to-linear converters. Linear electric motors can be classified into the following: DC motors, induction motors (IM), synchronous motors, stepping motors, and others. In the present paper, the mover speed control of a linear induction motor (LIM) using a sliding mode control design is proposed. First, the indirect field-oriented control LIM is derived. The sliding mode control design is then investigated to achieve speed- and flux-tracking under load thrust force disturbance. The numerical simulation results of the proposed scheme present good performances in comparison to that of the classical sliding mode control. An LIM has many advantages, such as high-starting thrust force, alleviation of gear between motor and the motion devices, reduction of mechanical losses and the size of motion devices, highspeedoperation,silence, and so on. The driving principles of an LIM are similar to those of a traditional rotary induction motor (RIM); however, its control characteristics are more complicated. The motor parameters are time-dependent because of changes in the operating conditions, such as the speed of the mover, temperature, and rail configuration. Moreover, significant parameter variations exists in the reaction rail resistivity, the dynamics of the air gap, slip frequency, phase unbalance, saturation of the magnetizing inductance, and end effects. Therefore, its mathematical model is difficult to derive completely.A significant amount of research has been conducted for the modeling of the dynamic performance of the LIM and all significant variations have been taken into consideration. However, uncertainties continue to exits, which are usually composed of unpredictable plant parameter variations, external load disturbance, unmodeled and nonlinear dynamics, in practical applications of the LIM.

II. LINEAR INDUCTION MOTORANDIT'SMATHEMATICALMODELLING

2.1 Linear Induction Motor:

The principle of operation of a LIM is the same as that of a rotary induction motor. A linear Induction motor is basically obtained by opening the rotating squirrel cage induction motor and laying it flat. This flat structure produces a linear force instead of producing rotary torque from **a cylindrical machine.** LIMs can be designed to produce thrust up to several thousands of Newtons. The winding design and supply frequency determine the speed of a LIM. The basic principle of LIM operation is similar to that of a conventional rotating squirrel-cage induction motor. Stator and rotor are the two main parts of the conventional three phase rotary induction motor. The stator consists of a balanced polyphasewinding which is uniformly placed in the stator slots along its periphery. The stator produces a sinusoidally distributed magnetic field in the air-gap rotating at the uniform speed 2ω/p, with ω representing the network pulsation (related to the frequency f by ω= 2pf) and p the number of poles. The relative motion between the rotor conductors and the magnetic field induces a voltage in the rotor. This induced voltage will cause a current to flow in the rotor and will generate a magnetic field. The interaction of these two magnetic fields will produce a torque that drags the rotor in the direction of the field. This principle would not be modified if the squirrel cage were replaced by a continuous sheet of conducting material.The primary (mover) of the adopted three-phase LIM is simply a “cut-open-and-rolled-flat” rotary-motor primary. The secondary generally consists of a sheet conductor using aluminium with an iron back for the return path of the magnetic flux. The primary and secondary form a single-sided LIM. Moreover, a simple linear encoder is adopted for the feedback of the mover position**.**In an LIM, as the primary moves, the secondary is continuously replaced by a new material that tends to resist a sudden increase in flux penetration and only allows a gradual build up of the flux density in the air gap. To obtain a suitable LIM equivalent circuit, quantifying the effects of the entry and exit of new material on the air gap flux distribution known as the end effect will be necessary. When the primary of an LIM does not move, there is no difference in the equivalent circuits of LIM and RIM, because the contribution of the end effects will be relatively small and can be neglected. However, if the primary coil of LIM moves, a new field penetrates into the reaction rail in the entry area, whereas the existing field disappears at the exit area, thereby creating the eddy current in the reaction rail.

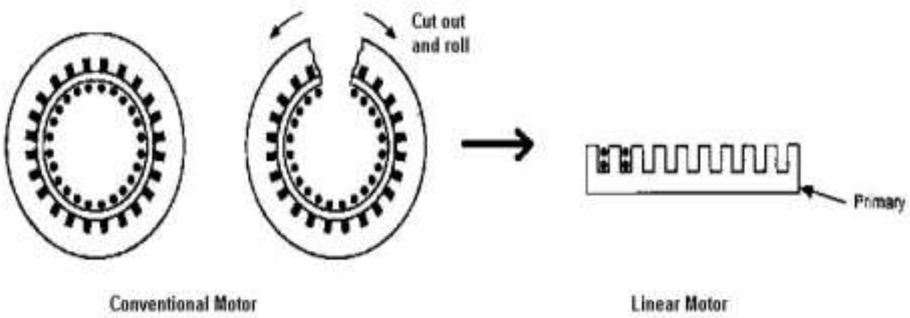

Fig.1: Imaginary process of unrolling a conventional motor to obtain a LIM

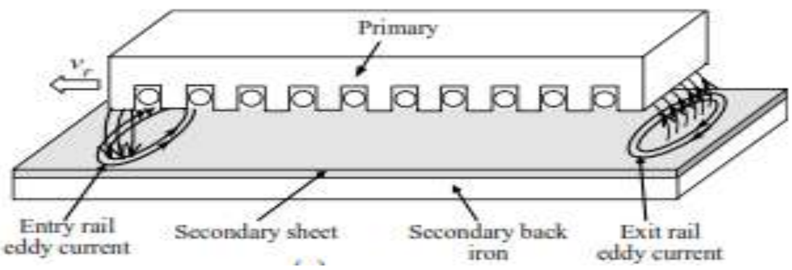

Fig 2: Conceptual construction of an Linear induction motor

The parameters of the motor model used in this paper are illustrated in Table 1

Table 1: Parameters of the motor

ϕ_{2s} [Wb]	0.9378	L_s [H]	0.1078
R_s [Ω]	0.34	f_e [Hz]	50
R_r [Ω]	0.195	M [kg]	5.47
L_r [H]	0.1078	D [Nm.s/rd]	26.36
L_m [H]	0.1042	P	2

2.2 Dynamic Modelling of Linear Induction Motor:

As the velocity increases, the primary’slength decreases, increasing the end effects, which reducesthe LIM's magnetization current. The magnetizinginductance can then be deduced, as shown below :

$$L'_m = L_m(Q) = L_m\{1 - f(Q)\} \quad (1)$$

Where Lm is the magnetising inductance at zero speed and

$$f(Q) = \frac{(1-e^{-Q})}{Q} \quad (2)$$

The secondary and primary inductances are expressed as:

$$L'_r = L_r(Q) = L_r - L_m f(Q) \quad (3)$$

$$L'_s = L_s(Q) = L_s - L_m f(Q) \quad (4)$$

Where

L_s – primary inductance, L_r- secondary inductance, L_m- magnetising inductance

2.3 Indirect Field Oriented Control of Linear Induction Motor:

As in DC machines, the main objective of the vector control of LIMs is to independently control the thrust force and the flux; this is accomplished using a *d*-*q* rotating reference frame synchronously with the primary flux space vector. In ideal FOC, the secondary flux linkage axis is forced to align with the d-axis.

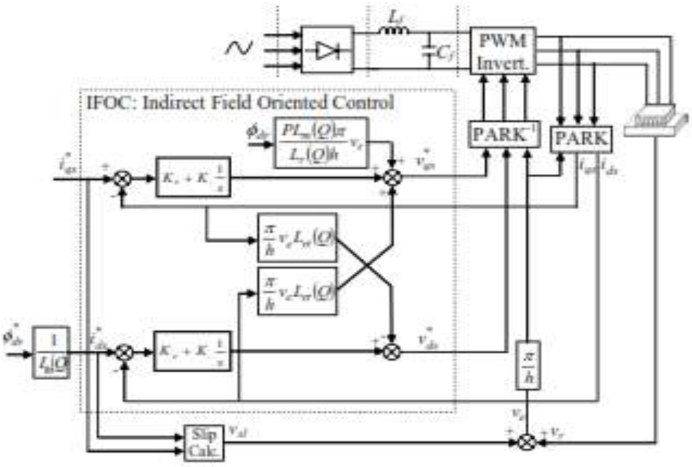

Fig. 3: Block diagram of IFOC for LIM

$$\phi_{qr} = \frac{d\phi_{qr}}{dt} = 0 \quad (5)$$

$$\phi_{dr} = \phi_r = \text{constant} \quad (6)$$

The field-oriented control (FOC) technique has been widely used in the industry for high-performance IM drives. The technique can provide the same performance as that of separately excited DC machines . The knowledge of synchronous angular velocity is often necessary in phase transformation to achieve the favourable decoupling control between motor torque and rotor flux for a separately excited DC machine. This technique can be performed using two basic methods: direct vector control and indirect vector control. Both direct field-oriented (DFO) and indirect field-oriented (IFO) solutions have been implemented in industrial drives demonstrating performances suitable for a wide spectrum of technological applications . However, the performance of these solutions is sensitive to the variation of motor parameters, especially the rotor time constant, which varies with the temperature and the saturation of the magnetizing inductance. Recently, much attention has been given to the possibility of identifying the changes in motor parameters of LIM while the drive is in normal operation.However, the performance of these solutions is sensitive to the variation of motor parameters, especially the rotor time constant, which varies with the temperature and the saturation of the magnetizing inductance. Recently, much attention has been given to the possibility of identifying the changes in motor parameters of LIM while the drive is in normal operation.

III. SLIDINGMODECONTROL

3.1 Concept of Sliding Mode Controller

In this control technique the concept of reaching law algorithm emphasizing on the benefits ofexponential reaching law are used to control the inner current loop and outer speed loop of the BLDC motor.Sliding mode control is a typical non linear control technique, that modifies the system performance bycontinuous switching of the controlled variable according to the current status of the known system state andthereby causes the trajectory to move on a predefined sliding surface.Fig.4 represents the phase trajectory of a sliding mode representing two modes of the system. In the firstpart, the trajectory starting from anywhere on the phase plane moves towards the sliding surface and reaches thesurface in finite time. This is known as reaching, hitting, or non-sliding phase and the system is sensitive toparameter variations and disturbance rejection in this part of the phase trajectory. The second part is the slidingphase in which the state trajectory moves to the origin along the sliding surface and the state never leave thesliding surface. During this period, the system is defined by the equation of the sliding surface and thus it isindependent of the system parameters and external disturbances. Sliding mode design involves two major tasks:a. The selection of a stable sliding surface in state space on which the state trajectory must ultimately lie in.b. Designing a suitable control law that makes this sliding surface attractive for the state trajectory to reach it infinite time.

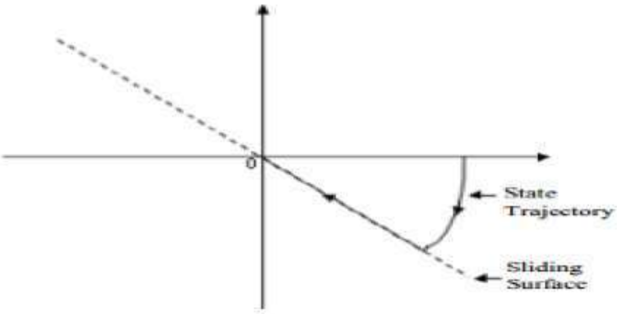

Fig.4: Phase Portrait of a sliding motion

Sliding surface can be either linear or nonlinear. For simplicity, only a linear sliding surface is used. Ifthe origin of the coordinate axes is taken as the stable equilibrium then the ultimate objective is to force the trajectory onto the sliding surface, “S” and then it should move towards the origin. The idea behind SMC is to define a surface along which the process can slide to its desired final value. The structure of the controller is intentionally altered as its state crosses the surface in accordance with a prescribed control law. Thus, the first step in SMC is to define the sliding surface s(t). s(t) is chosen to represent a desired global behavior for instance stability and tracking performance. The objective of control is to ensure that the controlled variable be equal to its reference value at all times means that error e(t) and its derivatives must be zero. Once the reference value is reached, it indicates that sliding surface s(t) reaches a constant value. To maintain s(t) at this constant value, means that error e(t) is zero at all times.

$$S^{\cdot} = \frac{ds(t)}{dt} = \frac{d(constant\ )}{dt} = 0 \quad (7)$$

Once the sliding surface has been selected, attention must be turned to design of the control law that drives the controlled variable to its reference value and satisfies above equation. The SMC control law, u, consists of two additive parts; a continuous part, ueq, and a discontinuous part, usw. That is ,

$u = u_{eq} + usw$ (8)

Without loss of generality, consider the design of a sliding mode controller for the following second order system:

$\ddot{x}+a_1.x + \dot{} a_2.x = b.u$, where $u(t)$ is the input to the system, and b>0 is assumed. A possible choice for the structure of a sliding mode controller is

$$u = u_{eq} + k.sgn(s)(9)$$

Where u_{eq} is called the equivalent control, which dictates the motion of the state trajectory along the sliding surface, k is a constant, representing the maximum controller output required to overcome parameter uncertainties and disturbances; and s is called the switching function because the control action switches its sign on the two sides of the switching surface s =0. A second-order system s is defined as

$$s = \dot{e} + \lambda.e \quad (10)$$

where$e$=$x_d - x$and $x_d$are the desired states;λisaconstant; and *sgn(s)* is the signum function

$$sign(s) = \begin{cases} 1 \text{ if } s > 0 \\ -1 \text{ if } s < 0 \end{cases} \quad (11)$$

To ensure that the system trajectories move toward and stay on the sliding surface s =0 independent of the initial condition, the following sliding mode condition must be fulfilled

$ss^{\cdot} \leq -n.s \rightarrow ss^{\cdot} \leq -n.sgn(s)\, s \rightarrow s^{\cdot}.sgn(s) \leq -n(12)$

where η is a positive constant that ensures a finite time convergence to s = 0.

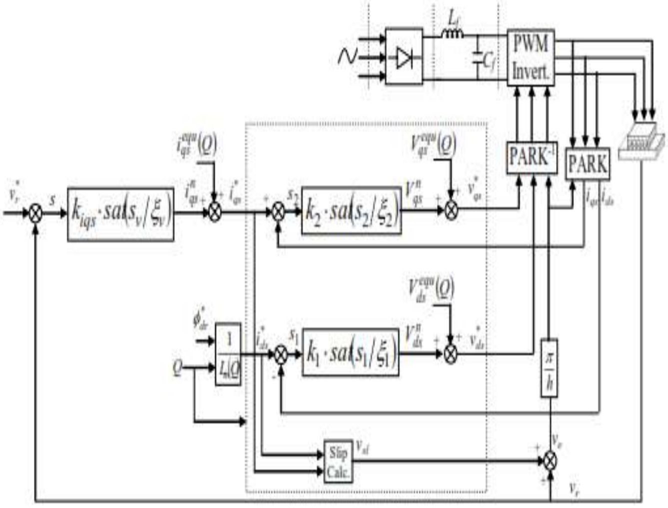

Fig.5: Block diagram of sliding mode speed and currents control of LIM

IV. SIMULATION AND RESULTS

Simulations were carried out in MATLAB/SIMULINK to demonstrate the effectiveness of the proposed controlscheme for speed control of the LIM. The block diagram ofthe proposed control system is shown in Fig. 5. Theproposed control system mainly consists of a linearinduction motor, a ramp comparison current-controlledpulse width modulated (PWM) inverter, a slip velocityestimator, an inverse park, IFOC bloc based on slidingmode current controller, and a speed feedback control loop that contains a sliding mode controller.

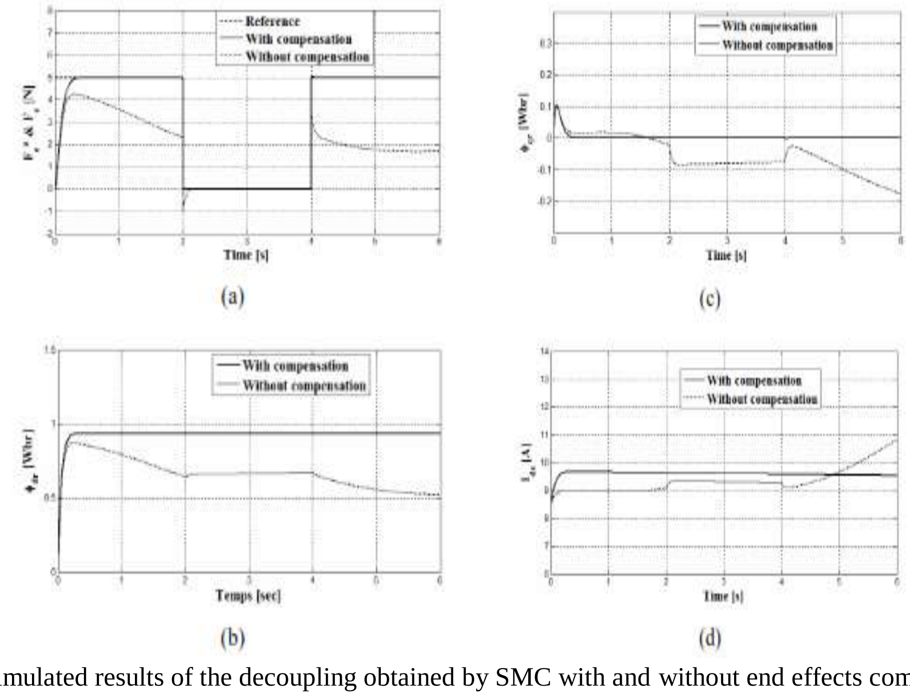

Fig.6 Simulated results of the decoupling obtained by SMC with and without end effects compensation

The simulated results of the SMC system with and without consideration on end effects for a rectangular shape thrust are shown in Fig. 7. The thrust is depicted in Fig. 6(a), and the directsecondary currenti_{ds} is depicted in Fig.6(d).Figs.6(b) and 6(c) show the direct and quadratic secondary fluxesϕ_{dr} and ϕ_{qr} respectively.With the conventional SMC, the flux level decreases as the speed increases. The thrust cannot track the rectangular shaped-thrust reference; thus, poor decoupled property is obtained. The fluxes cannot precisely track the desired fluxes because of the variation in the parameters (L_m, L_s, L_r).In contrast, with the proposed scheme, the fluxlevel is kept constant and no discrepancy is observedbetween the thrust command and the produced thrust. Thesame remarks are observed for the d-axis current. However,to keep the flux constant, i_{ds} needs to becompensated as motor speed increases or decreases.To further demonstrate the control performance of theproposed control scheme for speed control, the simulatedresults of the conventional and the proposed sliding mode control systems because of a step command are given in Figs. 7(a)-7(d).

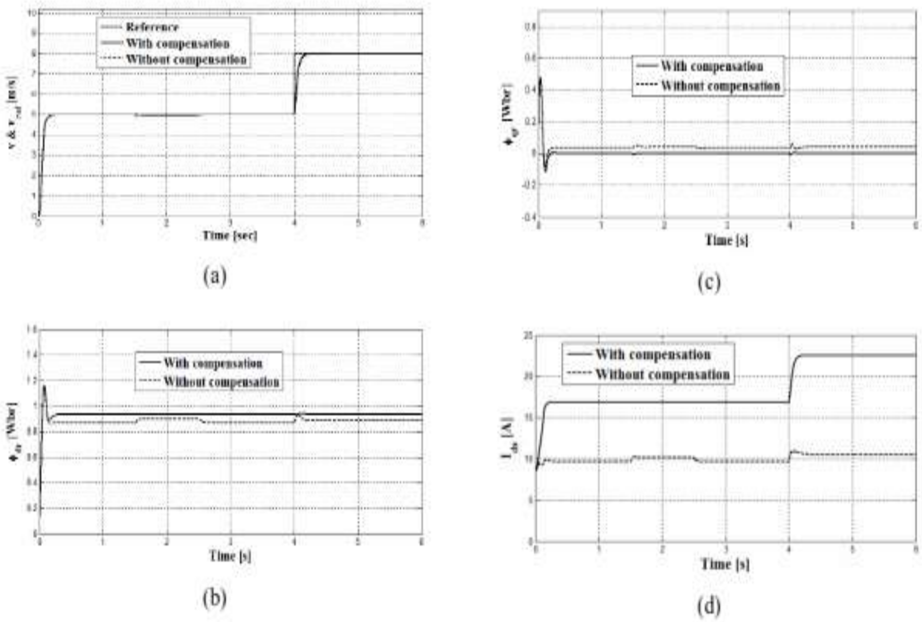

Fig.7 Simulated results of the speed control using SMC with and without end effects compensation

From the simulated results shown in Fig. 7, the proposed SMC scheme can achieve favorable trackingperformance even in relation to load force disturbance variation. In Figs. 7(a)-7(d), the speed response of theproposed SMC is observed to present better trackingcharacteristics and more robustness compared with that ofthe conventional sliding mode controller (without end effects compensation). In addition, the influence ofexternal disturbance on the speed response of the mover is much reduced; better decoupled properties are obtained, and the fluxes are able to track the desired fluxes precisely.

V. CONCLUSION

The present paper demonstrates the application of a nonlinear SMC system for the speed control of an LIM,considering end effects. First, an IFOC of LIM is designed,considering the end effects. Moreover, a SMC designtechnique is investigated to achieve a thrust-, flux-, andspeed-tracking objective under disturbance of load thrustforce. The control dynamics of the proposed hierarchicalstructure were investigated through numerical simulation.The proposed sliding mode controller with end effectscompensation presented satisfactory performances andprovided desirable decoupling between flux and thrust.However, the proposed scheme needs an adaptive controllaw or an estimation of the end effect and magnetizinginductance.

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