IJE TRANSACTIONS A: Basics Vol. 36 No. 04, (April 2023) 630-639

International Journal of Engineering

Journal Homepage: www.ije.ir

A New Speed Control Approach of Linear Induction Motor Based on Robust RST Controller and Model Reference Adaptive System Estimator

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PAPER INFO

Paper history:
Received 05 July 2022
Received in revised form 23 December 2022
Accepted 24 December 2022

Keywords:
End-effect
Field-oriented
Control
Model Reference Adaptive System
RST
Polynomial

ABSTRACT

In this paper, a new model of linear induction motor including the impact of the end-effect on the motor performances is proposed. Moreover, a new strategy of control approach based on the Field-Oriented Control (FOC) technique is suggested and investigated. The proposed approach can provide a robust control strategy and overcome the limitations imposed by FOC technique, which suffers with some drawbacks in linear induction motor (LIM) such as sensitivity to parameter variations and imperfect dynamic tracking performance. In this context, the developed technique combines the benefits provided by the both approaches polynomial (RST) regulator and Model Reference Adaptive System (MRAS) observer, in order to achieve a robust controller by minimizing the external disturbances effects and reducing the influence of parameter variations. Moreover, it is revealed that the proposed conrol approach enables an improved rotor speed response with a reduced number of overshoot values as function of mass variations, where the reccorded maximum overshoot value is 8%. Besides, the devopped controller demonstrates a reducded rise and settling time values under wide applied external force conditions. This confirms that the proposed MRAS-RST technique offers a good dynamic response against the parameter variations. The accuracy and control performance of the proposed technique is checked and validated using Matlab/Simulink environment software tool. Simulation results show the effectiveness of the proposed estimator with improved better robustness for RST controller for different reference tracking and disturbance rejection parameters. These significant results make the proposed approach a promising technique dedicated to the design of high-performance controller, which is highly suitable for industrial and electrical applications.

***doi**: 10.5829/ije.2023.36.04a.03*

1. INTRODUCTION

Linear induction motor (LIM), developed Linear induction motor (LIM), developed to achieving linear propulsion, has many advantages such as simple structure, alleviation of gear between motor and the motion devices, reduction of mechanical losses and the size of motion devices, high-speed operation, silence and high-starting thrust force [1-4]. Geometrically, the linear induction motor was inspired from the conventional rotational induction motor structure (RIM). Figure 1 shows a structure of the LIM to be investigated in this work. Besides, when the three phase supply is given to coil assembly (stator winding) a magnetic field is created, this latter induces currents in the conducting layer on the surface of the secondary linear, which produces a second traveling magnetic field. The interaction of these two magnetic fields produces a thrust force, which tends to move the primary along the surface of the secondary linear at synchronous speed [5]. Basically, the most fundamental difference between LIM and rotary induction motor (RIM) is that LIM has dynamic end-effect phenomenon [6]. On the other hand, many researchers have concentrated on reducing the causes due to end effect and control of LIM's for the performance improvement [7]. To reach this goal, field-oriented

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Please cite this article as: L. Khettache, R. Abdessemed, A New Speed Control Approach of Linear Induction Motor Based on Robust RST Controller and Model Reference Adaptive System Estimator, ***International Journal of Engineering, Transactions A: Basics***, Vol. 36, No. 04, (2023), 630-639

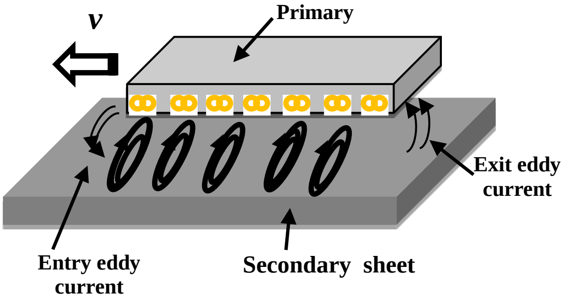


Figure 1. Structure of the LIM

control (FOC) of alternating current (AC) machines is becoming an important research topic of electrical engineering. The associated theory is based on making the AC motor identical to the separately excited DC motor. As well as, this technique (FOC) is performed by two basic methods namely direct and indirect vector control. For the direct FOC, the synchronous speed is computed based on the flux angle, which is available from flux estimator or flux sensors (Hall effects) [8]. In essence, the direct field oriented control can be adopted to decouple the dynamics of the thrust force and the secondary flux amplitude of the LIM. Despite this, a major drawback of this technique based on a proportional-integral (PI) regulator is its dependency on motor parameter variations and as imperfect dynamic tracking performance [9]. In this context, to solve the problem of parametric variations, a RST regulator was proposed .

In the RST design formalism, the most useful method to synthesize this controller is based on the well-known closed-loop poles placement [10]. Hence, the canonical RST structure considered in this contribution consists of three polynomials. In fact, the polynomials R and S allow creation of a feedback control in order to be robust to uncertainties, while the polynomial T is introduced to achieve the desired tracking performance [11]. Moreover, the RST controller is a robust and effective control strategy, that is widely used in industrial applications [12-15]. In addition, the performance studies of sensorless LIM drives concerning the variation effect of these parameters were subject of several previous works such as, the model reference adaptive system (MRAS) [16]. Numerous MRAS estimators based on various quantities have been proposed in the literature so far. These include MRAS based on: reactive power [17-21], rotor flux [22-24], active power [25], PY quantity [26], X quantity [27], q-axis rotor flux [28], d-axis stator voltage [29]. The basic concept of MRAS comprises two mathematical models which are simultaneously evaluated by Holakooie et al. [30]. These models are named respectively “reference model”, which is independent from uncertain model parameters, and “adjustable model” which is instead dependent on such parameters. Moreover, an adaptation mechanism estimates the desired variable by driving the difference between the reference and adaptive model to zero. Motivated by the above discussed literature review, our main purpose here is to design a robust control based on a combination between a polynomial RST regulator for control speed and MRAS observer for rotor speed estimation in order to achieve high stability and reduced sensitivity to the linear induction machine parameters.

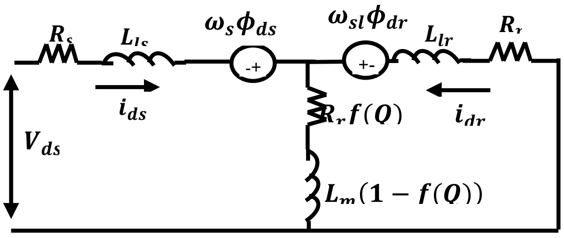
This paper is organized as follows. Section 2 describes the linear induction motor (LIM) dynamic model in the coordinate d-q while a theoretical background of field oriented motor control principle is explained in sections 3. The section 4 presents the structure and stability of the proposed MRAS observer, and its implementation for motor speed estimation. Section 5 deals with RST regulator for speed control. The performance and robustness of the proposed controller scheme are evaluated under MATLAB /SIMULINK environment; and the Simulation results are depicted to confirm the analysis and the efficiency of the proposed technique in section 6. Finally, section 7 summarizes the findings and concludes the paper.

2. MODEL OF LINEAR INDUCTION MOTOR

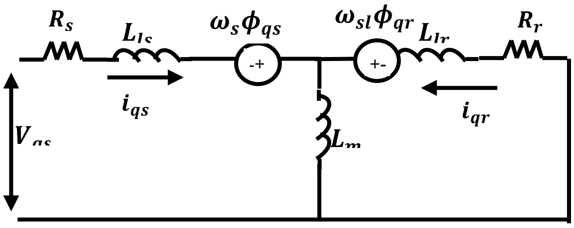
In recent decades, a number of papers on the LIM performance analysis, involving steady and dynamic states, have been published [31]. Gieras et al. [32] and Faiz et al. [33] developed an equivalent circuit by superposing the synchronous wave and the pulsating wave caused by the end-effect. In this section, the dynamic model of the LIM is described based on the d-q model of the equivalent electrical circuit considering end-effects [34].

As illustrated in Figures 2(a) and 2(b), the equivalent circuit of LIM can be separated in two parts, where the first one is independent from the end-effects (identical to the q-axis equivalent circuit of the induction motor) and the second one is dependent on this effect (d- axis in which the parameters vary with the end-effects).

By applying Kirchhoff’s-voltage-law (KLV) to above circuits, the below voltage equations of LIM in synchronously rotating frame are expressed as follows:



(a) d- axis equivalent circuit



(b) q- axis equivalent circuit

Figure 2. LIM equivalent electrical circuit taking into account end-effects [5, 31]

$$\begin{cases} V_{ds} = R_s i_{ds} + R_r f(Q)(i_{ds}+i_{dr}) + \dfrac{d\phi_{ds}}{dt} - \omega_s\phi_{qs} \\ V_{qs} = R_s i_{qs} + \dfrac{d\phi_{qs}}{dt} + \omega_s\phi_{ds} \\ 0 = R_r i_{dr} + R_r f(Q)(i_{ds}+i_{dr}) + \dfrac{d\phi_{dr}}{dt} - \omega_{sl}\phi_{qr} \\ 0 = R_r i_{qr} + \dfrac{d\phi_{qr}}{dt} + \omega_{sl}\phi_{dr} \end{cases} \tag{1}$$

The primary angular frequency can be determined by adding the secondary angular speed with the slip frequency. This will give as follows:

$$\omega_s = \omega_{sl} + \omega_r \tag{2}$$

The transformation of linear speed of the LIM to an angular speed is given below:

$$\omega_r = \frac{\pi}{\tau_p} v \tag{3}$$

with τ_p: is the pole pitch

The linkage fluxes are given by the following equations:

$$\begin{cases} \phi_{ds} = L_{ls} i_{ds} + L_m(1-f(Q))(i_{ds}+i_{dr}) \\ \phi_{qs} = L_{ls} i_{qs} + L_m(i_{ds}+i_{dr}) \\ \phi_{dr} = L_{lr} i_{dr} + L_m(1-f(Q))(i_{ds}+i_{dr}) \\ \phi_{qr} = L_{lr} i_{qr} + L_m(i_{ds}+i_{dr}) \end{cases} \tag{4}$$

where Q is an important parameter, it is used to express the end-effects phenomenon:

$$Q = \frac{D.R_r}{(L_m + L_{lr})v} \tag{5}$$

where D denotes the primary length, v the speed of a LIM, and L_{lr} and R_r the secondary inductance and resistance, respectively.

The three-phase magnetizing inductance varying with Q is defined as follows:

$$\hat{L}_m = L_m\left[1 - f(Q)\right] \tag{6}$$

where:

$$f(Q) = \frac{1-e^{-Q}}{Q} \tag{7}$$

Considering the eddy current losses, there is a resistance appearing in the transversal branch, the resistance $\hat{R}_r$ is:

$$\hat{R}_r = R_r f(Q) \tag{8}$$

The dynamic equation of LIM is expressed as follows:

$$F_e = Mv + B\dot{v} + F_L \tag{9}$$

where electromagnetic thrust F_e is defined as follows:

$$F_e = \frac{3\pi}{2\tau_p}\frac{p}{2}\left(\phi_{ds} i_{qs} - \phi_{qs} i_{ds}\right) \tag{10}$$

and

$$\begin{aligned} F_e &= \frac{3\pi}{2\tau_p}\frac{p}{2}\frac{L_m(1-f(Q))}{L_r - L_m f(Q)}\left(\phi_{dr} i_{qs} - \phi_{qr} i_{ds}\right) \\ &= Mv + B\dot{v} + F_L \end{aligned} \tag{11}$$

2. FIELD ORIENTED VECTOR CONTROL

The main of the field oriented control is to maintaining constant the d-axis secondary flux and making null the q-axis secondary flux [5, 35]. Figure 3 depicts the dynamic model of FOC applied to LIM considering end-effect in the synchronously rotating reference frame [36].

Under the rotor flux orientation conditions, the rotor flux is aligned on the d-axis of the d-q rotor flux oriented frame and the rotor flux equations can be written as follows:

$$\begin{cases} \phi_{qr} = 0 \\ \phi_{dr} = \phi_r = constant \end{cases} \tag{12}$$

Substituting Equations (12) in the rotor linkage fluxes Equations (4), the rotor currents are derived as in Equations (13) and (14).

$$i_{dr} = \frac{\phi_r - \hat{L}_m.i_{ds}}{L_r} \tag{13}$$

with $L_r = L_{lr} + L_m\left[1 - f(Q)\right]$

$$i_{qr} = \frac{-L_m.i_{qs}}{L_{lr} + L_m} \tag{14}$$

where: L_r is the secondary inductance, L_{lr} the secondary leakage inductance, and L_m the magnetizing inductance.

Using Equations (12) to (14) in stator voltage of Equation (1), the differential equations of decoupling current and voltage compensation can be expressed as follows:

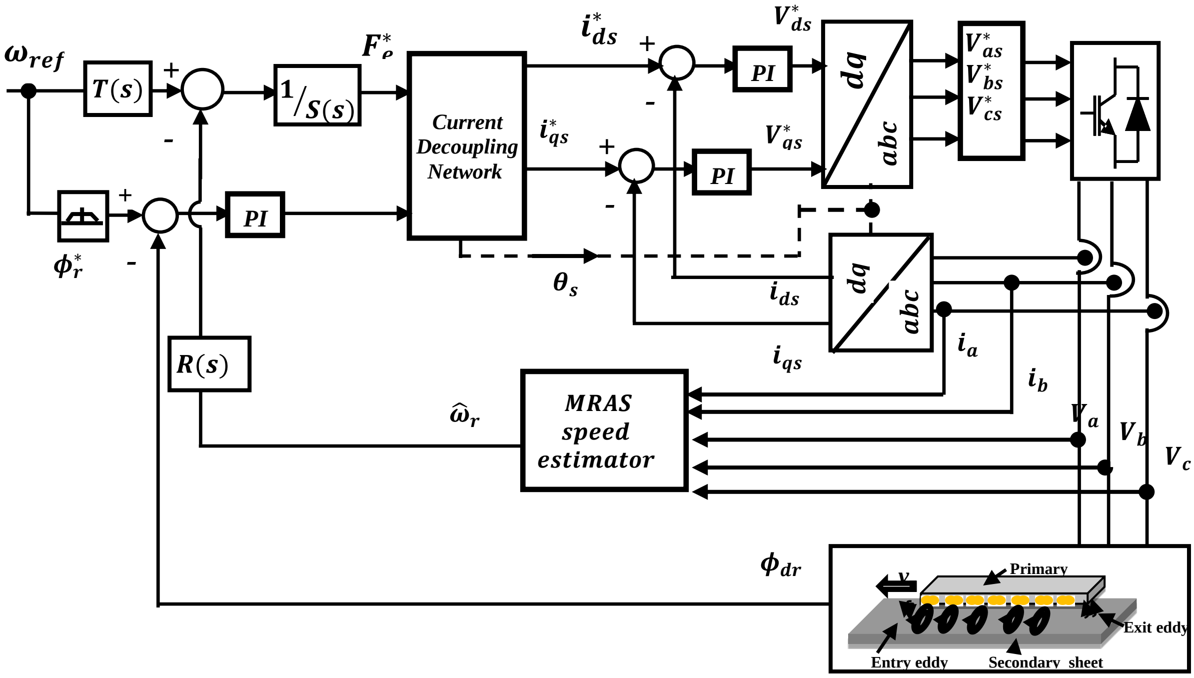


Figure 3. Block diagram of the field oriented control for LIM

$$\begin{cases} V_{ds} = \left(R_s + \hat{R}_r - \dfrac{\hat{R}_r.\hat{L}_m}{L_r} \right) i_{ds} + \dfrac{\hat{R}_r}{L_r}\phi_r + \sigma L_s \dfrac{di_{ds}}{dt} - \omega_s \sigma' i_{ds} \\ V_{qs} = R_s i_{qs} + \sigma' \dfrac{di_{qs}}{dt} + \omega_s \sigma L_s i_{ds} + \omega_s \dfrac{\hat{L}_m}{L_r}\phi_r \end{cases} \tag{15}$$

As shown in Equation (15), the stator voltage components are coupled by the d- and q- back electromotive force given by:

$$\begin{cases} E_d = -\dfrac{\hat{R}_r}{L_r}\phi_r + \omega_s \sigma' i_{ds} \\ E_q = -\omega_s \sigma L_s i_{ds} - \omega_s \dfrac{\hat{L}_m}{L_r}\phi_r \end{cases} \tag{16}$$

Finally, the feed forward decoupling method [37] is applied in order to have linear terms as provided below:

$$\begin{cases} V'_{ds} = \left(R_s + \hat{R}_r - \dfrac{\hat{R}_r.\hat{L}_m}{L_r} \right) i_{ds} + \sigma L_s \dfrac{di_{ds}}{dt} \\ V'_{qs} = R_s i_{qs} + \sigma' \dfrac{di_{qs}}{dt} \end{cases} \tag{17}$$

$$L_s = L_{ls} + \hat{L}_m \tag{18}$$

$$\begin{cases} \sigma = 1 - \dfrac{\hat{L}_m^2}{L_s L_m} \\ \sigma' = \left(L_{ls} + L_m\right) - \dfrac{L_m^2}{\left(L_{lr+}L_m\right)} \end{cases} \tag{19}$$

where: σ, σ' the leakage coefficients associated to cases with and without end-effect, respectively.

Thus, the thrust force is represented in the rotor flux oriented reference frame as follows:

$$F_e^* = K_f . i_{qs}^* \tag{20}$$

$$K_f = \frac{3\pi}{2\tau_p} \frac{p}{2} \frac{L_m\left(1 - f(Q)\right)}{L_r - L_m f(Q)} \phi_{dr}^* \tag{21}$$

$$i_{qs}^* = \frac{4\tau_p}{3\pi p} \frac{L_r - L_m f(Q)}{L_m\left(1 - f(Q)\right)} \frac{F_e^*}{\phi_{dr}^*} \tag{22}$$

3. STRUCTURE OF MRAS TECHNIQUE

The model reference adaptive system (MRAS) is one of the most popular adaptive observers used in sensorless drive control applications. In this paper, The MRAS model employs two independent equations for the time derivative of rotor fluxes as shown in Figure 4, where it is obtained from equations of the LIM model in the stationary reference frame α-β. In fact, the system that does not include the estimated rotor speed is called a reference Model (MR), while the other one is called the adaptive Model (MA) [38, 39]. A proportional-integral (PI) control adjusts the error between the reference and adjustable model with the aim of developing a suitable adaptation mechanism, which generates the estimated rotor speed [40].

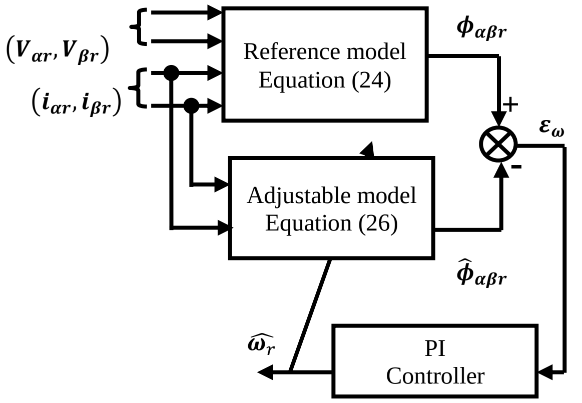


Figure 4. Speed estimation of the linear induction motor using MRAS

3. 1. Reference Model

The reference model (MR) is expressed by using stator voltage Equation (1) in stationary reference frame ω_s=0):

$$\begin{cases} V_{\alpha s} = R_s i_{\alpha s} + R_r f(Q)(i_{\alpha s} + i_{\alpha r}) + \dfrac{d\phi_{\alpha s}}{dt} \\ V_{\beta s} = R_s i_{\beta s} + \dfrac{d\phi_{\beta s}}{dt} \end{cases} \tag{23}$$

Substituting Equation (13) into (23), and with some mathematical manipulations, the reference model is derived as follows:

$$\begin{cases} \dfrac{d\phi_{\alpha s}}{dt} = \dfrac{L_r}{\hat{L}_m}\left[V_{\alpha s} - \left(\hat{R}_s - \dfrac{\hat{L}_m}{L_r}\right)i_{\alpha s} - \sigma\dfrac{di_{\alpha s}}{dt} - \dfrac{\hat{R}_r}{L_r}\phi_{\alpha r}\right] \\ \dfrac{d\phi_{\beta s}}{dt} = \dfrac{L_{lr} + L_m}{L_m}\left[V_{\beta s} - R_s i_{\beta s} - \sigma'\dfrac{di_{\beta s}}{dt}\right] \end{cases} \tag{24}$$

$$\hat{R}_s = R_s + R_r f(Q) \tag{25}$$

3. 2. Adaptive Model

Similarly, the adjustable model (MA), is determined by substituting (13) into rotor voltage Equation (1), the expression of (MA) in stationary reference frame (ω_{sl}=−ω_r) becomes [41]:

$$\begin{cases} \dfrac{d\hat{\phi}_{\alpha r}}{dt} = -\left(\hat{R}_r - \dfrac{\hat{R}_r^{'}\hat{L}_m}{L_r}\right)i_{\alpha s} - \dfrac{\hat{R}_r^{'}}{L_r}\hat{\phi}_{\alpha r} - \hat{\omega}_r\hat{\phi}_{\beta r} \\ \dfrac{d\hat{\phi}_{\beta s}}{dt} = \dfrac{R_r}{L_{lr} + L_m}\left[L_m i_{\beta s} - \hat{\phi}_{\beta r}\right] + \hat{\omega}_r\hat{\phi}_{\alpha r} \end{cases} \tag{26}$$

where:

$$\hat{R}_r^{'} = R_r + R_r f(Q) \tag{27}$$

3. 3. Adaptation Mechanism Model

The adaptation algorithm is based on the error between the estimated and the measured rotor fluxes based on the Lyapunov function. This error is defined by equation (28), and driven to zero by means of a *proportional–integral* PI regulator, where its output generates the estimated rotor speed ($\hat{\omega}_r$) in Equation (29) [42].

$$\varepsilon_\omega = \phi_{\beta r}\hat{\phi}_{\alpha r} - \phi_{\alpha r}\hat{\phi}_{\beta r} \tag{28}$$

$$\hat{\omega}_r = \left(K_p + \frac{K_i}{p}\right)\varepsilon_\omega \tag{29}$$

The implementation of the MRAS observer is shown in Figure 4.

4. RST CONTROLLER

In this section, the canonical RST regulator elucidated in Figure 5 is proposed in order to achieve the effectiveness and robustness rotor speed control of the LIM.

The polynomials R(s), S(s) and T(s) are obtained by a pole-placement strategy and solutions of the Diophantine equation [13, 40]:

$$A(s)S(s) + B(s)R(s) = P_D(s)P_F(s) = P(s) \tag{30}$$

where: $P(s)$ the desired closed loop poles; it is decomposed into two parts, one representing the desired dominant poles $P_D(s)$ and the other corresponding to the auxiliary poles $P_F(s)$ that are necessary to adjust the sensitivity function as described below. The polynomials *R(s), S(s)* and *T(s)* are given by:

$$\begin{cases} R(s) = r_1 s + r_0 \\ S(s) = s_2 s^2 + s_1 s \end{cases} \tag{31}$$

where: $deg(R) = deg(A) = 1$ and $deg(S) = deg(A) + 1$

The closed-loop transfer function is given by:

$$H_{BF}(s) = \frac{T(s)B(s)}{A(s)S(s) + B(s)R(s)} \tag{32}$$

The calculation of the polynomials *R* and *S* is carried out starting from the choice of polynomial *P*:

$$P(s) = p_0 + p_1 s + p_2 s^2 + p_3 s^3 \tag{33}$$

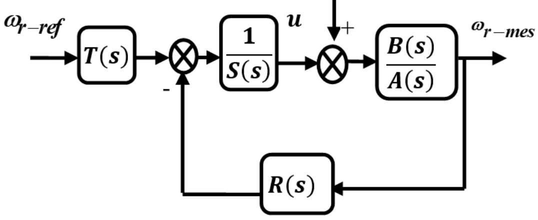


Figure 5. RST closed loop configuration [39]

Within the strategy of robust pole placement, the polynomial *P(s)* is written as follows:

$$P(s)=P_D(s)P_F(s)=\left(s+\frac{1}{T_c}\right)\left(s+\frac{1}{T_f}\right)^2 \tag{34}$$

such that:
P_D: Command polynomial;
P_F: Filter polynomial;
T_c : Control horizon;
T_f: Filtering horizon;
To determine the coefficients of T, we assume that T=R(0).
In the proposed model, we have:
The denominator *A* and the numerator *B* of the transfer function rotor speed is defined by:

$$\begin{cases} A = Js + f \\ B = 1 \end{cases} \tag{35}$$

By identification between Equations (30), (31) and (34), it is possible to obtain a system of four equations with four unknown terms [43]. Thus, we can determine the polynomial coefficients *R(s)* and *S(s)* by using Sylvester matrix as follows:

$$\begin{bmatrix} p_0 \\ p_1 \\ p_2 \\ p_3 \end{bmatrix} = \begin{bmatrix} J & 0 & 0 & 0 \\ f & J & 0 & 0 \\ 0 & f & 1 & 0 \\ 0 & 0 & 0 & 1 \end{bmatrix} \begin{bmatrix} s_2 \\ s_1 \\ r_1 \\ r_0 \end{bmatrix} \tag{36}$$

5. SIMULATION RESULTS

The main goal of this paper is the investigation of the speed control of LIM with the consideration of the end-effects. For this purpose, the parameters and data of the LIM used in this research and Gains of RST regulator, PI controllers used to estimate the speed are summarized in Tables 1 and 2, respectively.

TABLE 1. Linear Induction Motor Parameters

Parameters	**Values**
Primary resistance-$\boldsymbol{R_s}$	1.25Ω
Secondary resistance-$\boldsymbol{R_r}$	2.7Ω
Primary leakage inductance-$\boldsymbol{L_{ls}}$	40.1mH
Secondary leakage inductance-$\boldsymbol{L_{lr}}$	33.1mH
Magnetizing inductance-$\boldsymbol{L_m}$	32.6mH
Pole pitch- $\boldsymbol{\tau_p}$	0.0641m
Primary length- $\boldsymbol{D}$	0.286 m
Mass of the LIM-*M*	8 kg
Number of pole pairs -*p*	4

TABLE 2. Regulator values

RST	**MRAS**
$\boldsymbol{r_0}$ =6056.25	Kp=0.128
$\boldsymbol{r_1}$ = 215.75	Ki=130
$\boldsymbol{s_1}$ =31.875	/
$\boldsymbol{s_2}$ =0.125	/
$\boldsymbol{T(0)} = \boldsymbol{t}$=6056.25	/

In Figure 6, it can be observed the external force of F_L=50 *N* disturbance at t= 2.5s then the motor reference speed is changed from 150 (rad/s) to 250 (rad/s) at t=5 s. Hence, the results display clearly satisfactory performance for the proposed (RST-MRAS) control schema in tracking and a pursuit between measured (blue line) and estimated speed (green line) of the reference speed (red line).

Furthermore, in order to check the robustness of the proposed controllers, the obtained results during modified mass operating condition (*M* (kg) is doubled from its nominal value) are discussed in figures below.

Figure 7 displays the estimated speed under mass variation (*2×M*); very small change has observed in the response shape (the doubled mass does not have any influence on the MRAS observer).

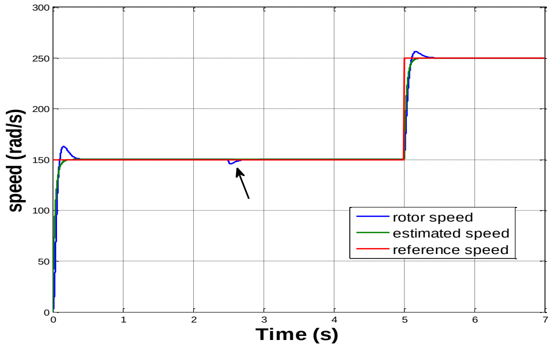


Figure 6. Rotor speed response without mass variation

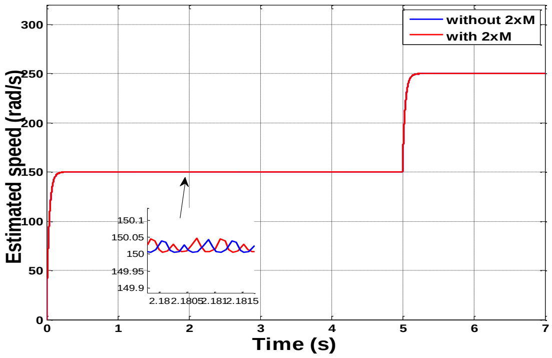


Figure 7. Estimated speed response with mass variation (2×M)

As one can see, the measured speed follows the reference with negligible error as observed in Figure 8. The speed was reached satisfactory without oscillating when a load force is applied.

From field orientation theory, which based on the decoupling between force and rotor flux linkage, the rotor force can be independently controlled by adjusting stator q component current iqs (see Equation (20)). This can be depicted in Figure 9(b), where the iqs value (iqs= 0.74A) is determined accordingly to reference force. Figure 9(a) shows that the current component ids is in direct relation with the rotor flux linkage, which is maintained constant during control simulation (ids= 18.84A). Note that the last one change with speed reference variation (ids = 26.43 A) at t=5 s.

The direct and quadrature rotor flux are shown in Figure 10(a) and Figure 10(b) respectively. It can be seen that ϕ_{dr} converges to reference value ϕ_{dr} = 0.4 Wb , while ϕ_{qr} is maintained at zero (ϕ_{qr} = 0 Wb). When the speed reference changes, a remarkable peaks are observed at t= 5 sec. The results indicate good decoupling properties of the vector controller (i.e the Equation (12) is justified).

From Figure 11, the electromagnetic forces increase to reach the peak values 400N and 600N (start-up phenomena) and falls down to be close to zero value because the LIM is operating in no-load. Under load conditions, a high peak force values are observed (300 N and 400 N) at t = 5 s.

In order to test the robustness of the proposed controller; a comparative dynamic performance (overshoot, rise time, settling time) is shown in Table 3.

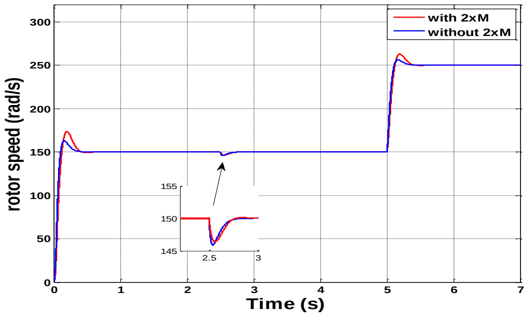
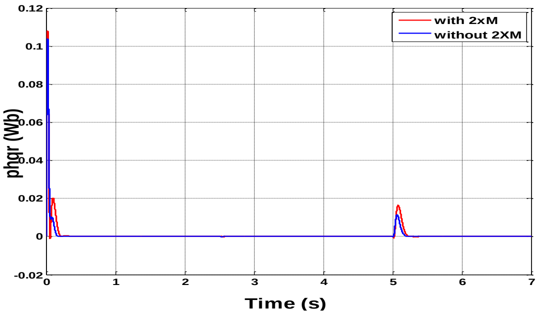
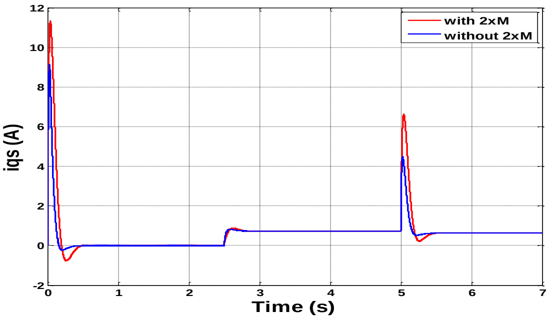


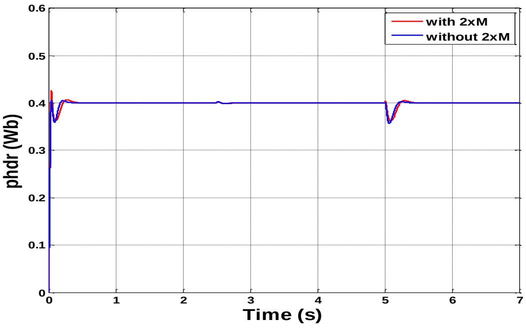
Figure 8. Speed response where blue line is without mass variation and red line is with 2×M



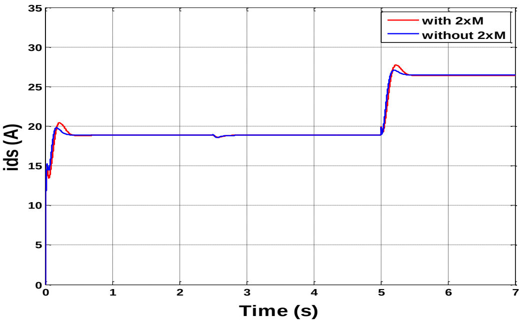
(a) d-axis current



(b) q-axis current
Figure 9. Primary current



(a) d-axis flux with reference 0.4Wb



(b) q-axis flux with reference 0 Wb
Figure 10. Primary flux

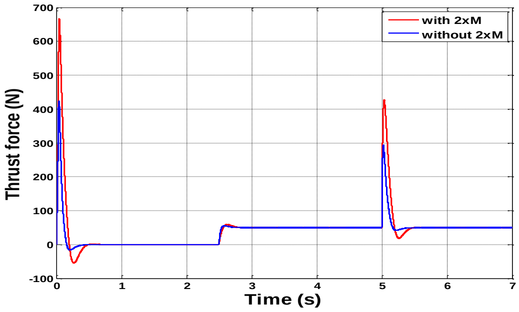


Figure 11. Thrust force

TABLE 3. Rotor speed performance under Mass variation

	M	100% M
Rotor speed response (rad/s)	(**Ov %**)= 7.86%	(**Ov %**)=15.53%
	Rise time **tr** =0.105	Rise time **tr**=0.12
	Peak **time tp**=0.161	Peak **time tp**=0.1964
	Settling time **ts** =0.5	Settling time **ts** =0.58

It is important to note that the variation of parameters at the same time deteriorates the performance of the controller (i.e. PI, PID) in terms of response time, oscillation and tracking. Through Table 3, we can say that the response time is significantly reduced with a small overshoot and the oscillation was eliminated. Considering these significant benefits, the proposed controller based on the combination between RST and MRAS estimator is believed to offer new potential directions for high-performance control than recently study [6, 30, 44].

5. CONCLUSION

In this paper, a new model based on field oriented control (FOC) technique is proposed to control a linear induction motor (LIM) by taking into account the end-effects; the FOC is implemented to separately control the produced force and magnetizing flux components. An effective control strategy is proposed using a combined RST regulator and MRAS observer approach to enhance the control procedure by minimizing the effect of parameters variation and reducing the impact of perturbations (external forces) on the control approach. Finally, the effectiveness of the proposed technique is confirmed through MATLAB/SIMULINK simulations, where good tracking to the reference values is recorded under external perturbations and superiority of robustness to internal parameters changes. These significant results make the proposed approach a promising control strategy dedicated to the design of high-performance and reliable controllers, which are highly suitable for industrial and engineering applications. It is worthy to note that this work can be extended by including new advaced techniques based on Artificial Intellegence and deep machine learning to improve the controller performances and stability behavior. Howeever, new complex models and simulations should be devlopped.

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Persian Abstract

چکیده

در این مقاله، مدل جدیدی از موتور القایی خطی شامل تاثیر اثر پایانی بر عملکرد موتور پیشنهاد شده است. علاوه بر این، یک استراتژی جدید از رویکرد کنترل مبتنی بر تکنیک کنترل میدان گرا (FOC) پیشنهاد و بررسی شده است. رویکرد پیشنهادی می‌تواند یک استراتژی کنترل قوی ارائه کند و بر محدودیت‌های تحمیل‌شده توسط تکنیک FOC غلبه کند، که با برخی اشکالات در موتور القایی خطی (LIM) مانند حساسیت به تغییرات پارامتر و عملکرد ردیابی دینامیکی ناقص رنج می‌برد. در این زمینه، تکنیک توسعه‌یافته مزایای ارائه شده توسط هر دو رویکرد تنظیم‌کننده چند جمله‌ای (RST) و مشاهده‌گر سیستم مرجع تطبیقی مدل (MRAS) را ترکیب می‌کند تا با به حداقل رساندن اثرات اغتشاشات خارجی و کاهش تأثیر تغییرات پارامتر، به یک کنترل‌کننده قوی دست یابد. . علاوه بر این، نشان داده شده است که رویکرد کنترلی پیشنهادی یک پاسخ سرعت روتور بهبود یافته را با کاهش تعداد مقادیر بیش از حد به عنوان تابعی از تغییرات جرم، که در آن حداکثر مقدار بیش از حد ثبت شده ۸٪ است، قادر می‌سازد. علاوه بر این، کنترل‌کننده توسعه‌یافته، مقادیر زمان افزایش و ته‌نشینی کاهش‌یافته را تحت شرایط نیروی خارجی اعمال شده گسترده نشان می‌دهد. این تایید می کند که روش پیشنهادی MRAS-RST پاسخ دینامیکی خوبی در برابر تغییرات پارامتر ارائه می دهد. دقت و عملکرد کنترل تکنیک پیشنهادی با استفاده از ابزار نرم افزار محیطی Matlab/Simulink بررسی و تایید می شود. نتایج شبیه‌سازی اثربخشی برآوردگر پیشنهادی را با استحکام بهتر برای کنترل‌کننده RST برای پارامترهای مختلف ردیابی مرجع و رد اختلال نشان می‌دهد. این نتایج قابل توجه، رویکرد پیشنهادی را به یک تکنیک امیدوارکننده اختصاص داده شده برای طراحی کنترل‌کننده با کارایی بالا، که برای کاربردهای صنعتی و الکتریکی بسیار مناسب است، تبدیل می‌کند.