ANNALS of Faculty Engineering Hunedoara
– International Journal of Engineering

Tome XII [2014] – Fascicule 3 [August]
ISSN: 1584-2673 [CD-Rom, online]

a free-access multidisciplinary publication
of the Faculty of Engineering Hunedoara

[1.] Bojidar MARKOV, [2.] Diana TSANKOVA

MIT RULE BASED MODEL REFERENCE ADAPTIVE CONTROL OF LINEAR INDUCTION MOTOR

[1-2.] University of Food Technologies - Plovdiv, BULGARIA

Abstract: It is known, the load influences on the velocity of a linear induction motor (LIM). In order to be overcome this influence, a model reference adaptive system (MRAS) using MIT rule is proposed for a secondary element flux vector control of the velocity of LIM. The obtained "independence" of the velocity from the load is confirmed by simulations in MATLAB environment.
Keywords: Linear induction motor, model reference adaptive control (MRAC), MIT-rule, velocity independent of load

1. INTRODUCTION

Linear induction motors (LIMs) have gained increasing attention in recent years [11,8]. High performance control of these motors especially by the vector control method has also been presented in many works. Vector control of LIMs has mostly carried out in secondary flux oriented scheme [11,6,2,10]. It is mainly due to the fact that in this orientation the decoupling of motor thrust and flux can easily be achieved [11,6]. However, a major drawback of this scheme is its dependency on motor parameter variations. Motor parameter estimation methods have been proposed to overcome the problem [13,5]. But these methods cause difficulties like system complexity and require high processor capabilities which in turn add to the system cost. An alternative solution is a secondary element flux oriented vector control (RFVC) system that features parameter robustness and desirable dynamic performance. Despite these merits, RFVC has rarely applied to LIMs due to a lack of total decoupling of motor force and flux. Also the end effect has not been considered in RFVC yet [12, 9].

A number of articles dealing with a MRAS-based sensorless control in induction motors are known [12], but in the field of linear motors, these investigations are rare, and looking at private cases.

The purpose of the paper is to propose an approach for a secondary element flux vector control of the velocity of LIM, which uses MIT rule based model reference adaptive system, and intends to overcome the problem with the influence of the load on the linear velocity. The proposed method is simple, needs a low computation power and has a high speed adaptation. Its validation has been carried out by means of MATLAB simulations.

2. THE MODEL

A LIM mathematical model is proposed by the following equations [7,3,4]:

$$\vec{u}_s = R_s.\vec{i}_s + \frac{d\vec{\lambda}_s}{dt} + j.\omega_b\vec{\lambda}_s \quad (1)$$

$$0 = R_r\vec{i}_r + \frac{d\vec{\lambda}_r}{dt} + j.(\omega_b - \omega).\vec{\lambda}_r \quad (2)$$

$$\vec{\lambda}_s = L_s\vec{i}_s + L_m\vec{i}_r \qquad \vec{\lambda}_r = L_m\vec{i}_s + L_r\vec{i}_r \quad (3)-(4)$$

$$F_X = -\frac{3}{2}\frac{\pi}{\tau}\text{Im}(\vec{\lambda}_s.\vec{i}_s^*) \quad (5)$$

$$\omega_b = \frac{\pi}{\tau}v_s \quad v_s = \frac{2.\tau.f}{Pp} \quad v = \frac{dx}{dt} \quad \omega = \frac{\pi}{\tau}v \quad (6)\text{-}(9)$$

$$M\frac{dv}{dt} = F_X - D.v - F_{Load}, \quad (10)$$

where $\vec{u}_s$ is the vector of three phase primary element power supply; $\vec{i}_s, \vec{i}_r$ are vectors of primary and secondary element currents; $\vec{\lambda}_s, \vec{\lambda}_r$ - vectors of primary and secondary element flux linkage; L_s, L_r - the induction of the primary and secondary element; L_m - the induction in the air gap; ω_b - the angular velocity of the magnetic field of primary element; ω - the angular velocity of the secondary element; τ - the pole pitch; f - the frequency of the power supply; v - the linear speed of the secondary element; v_s - the linear synchronous speed of the primary element; Pp - the number of pole pair; F_X - the linear force of LIM; M - the mass of LIM; D - the viscous and coulomb friction coefficients in the LIM; F_{Load} - the load; x - the linear displacement of the secondary element.

If the vector quantities of the linear induction motor are expressed in the complex frame (α, β) rotating at arbitrary speed, i.e.:

$$\vec{u}_s = u_{s\alpha} + j.u_{s\beta}, \quad \vec{i}_s = i_{s\alpha} + j.i_{s\beta}, \quad \vec{i}_r = i_{r\alpha} + j.i_{r\beta}, \quad \vec{\lambda}_s = \lambda_{s\alpha} + j.\lambda_{s\beta}, \quad \vec{\lambda}_r = \lambda_{r\alpha} + j.\lambda_{r\beta},$$

and the real and imaginary parts of the above system of equations are separated, we obtain the following system of differential equations describing the dynamic processes in the LIM:

$$\frac{d\lambda_{s\alpha}}{dt} = u_{s\alpha} - \frac{1}{\sigma T_1}\lambda_{s\alpha} + \omega_b\lambda_{s\beta} + \frac{k_2}{\sigma T_1}.\lambda_{r\alpha} \quad \frac{d\lambda_{s\beta}}{dt} = u_{s\beta} - \frac{1}{\sigma T_1}\lambda_{s\alpha} - \omega_b\lambda_{s\alpha} + \frac{k_2}{\sigma T_1}.\lambda_{r\beta} \quad (11)\text{-}(12)$$

$$\frac{d\lambda_{r\alpha}}{dt} = \frac{k_1}{\sigma T_2}.\lambda_{s\alpha} - \frac{1}{\sigma T_2}\lambda_{r\alpha} + \omega_p\lambda_{r\beta} \quad \frac{d\lambda_{r\beta}}{dt} = \frac{k_1}{\sigma T_2}.\lambda_{s\beta} - \frac{1}{\sigma T_2}\lambda_{r\beta} - \omega_p\lambda_{r\beta} \quad (13)\text{-}(14)$$

$$i_{s\alpha} = \frac{1}{\sigma L_s}(\lambda_{s\alpha} - k_2\lambda_{r\alpha}) \quad i_{s\beta} = \frac{1}{\sigma L_s}(\lambda_{s\beta} - k_2\lambda_{r\beta}) \quad i_{r\alpha} = \frac{1}{\sigma L_r}(\lambda_{r\alpha} - k_1\lambda_{s\alpha}) \quad i_{r\beta} = \frac{1}{\sigma L_r}(\lambda_{r\beta} - k_1\lambda_{s\beta}) \quad (15)\text{-}(18)$$

$$F_x = \frac{3}{2}P_P\frac{\pi}{\tau}\frac{k_1}{\sigma L_s}(\lambda_{r\alpha}\lambda_{s\beta} - \lambda_{s\alpha}\lambda_{r\beta}) \quad (19)$$

$$\omega_p = \omega_b - P_P\omega \quad (20)$$

where: $k_1 = \frac{L_m}{L_s}$; $k_2 = \frac{L_m}{L_r}$; $\sigma = 1 - k_1.k_2$; $T_1 = \frac{L_s}{R_s}$; $T_2 = \frac{L_r}{R_r}$; $\omega_p = k_2.R_r.\frac{i_{s\beta}}{\lambda_2}$.

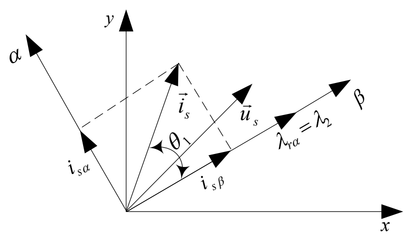


Figure 1. Vector diagram $\lambda_r = const$

In an ideally decoupled induction motor, the secondary element flux linkage axis is forced to be aligned with the α-axis, and the field orientation conditions can be applied. It follows that:

$\lambda_{r\beta} = 0$, i.e., $\vec{\lambda}_r = \lambda_{r\alpha} = \lambda_2$ (Figure 1).

Using (4), the desired vector of secondary current is:

$$\vec{i}_r = \frac{1}{L_r}(\vec{\lambda}_2 - L_m\vec{i}_s) \quad (21)$$

The vector of primary element current of equation (21) is substituted in (3), i.e.

$$\vec{\lambda}_s = \sigma L_s\vec{i}_s + k_2\lambda_2 \quad (22)$$

The equations (21) and (22) are substituted in (1) and (2):

$$\vec{u}_s = R_s[(\sigma T_1 s + 1) + j.\omega_b.\sigma.T_1]\vec{i}_s + k_2(s + j.\omega_b)\vec{\lambda}_2 \quad (23)$$

$$0 = -L_r.k_2.\vec{i}_s + [(T_2 s + 1) + j.\omega_p T_2].\vec{\lambda}_2 \quad (24)$$

The following reduced system of differential equations is obtained:

$$\begin{cases} i_{s\alpha} = \dfrac{1/R_s}{\sigma T_1.s}[u_{s\alpha} - R_s i_{s\alpha} + \omega_b \sigma T_1 R_s i_{s\beta} - k_2.s.\lambda_2] \\ i_{s\beta} = \dfrac{1/R_s}{\sigma.T_1.s}[u_{s\beta} - R_s.i_{s\alpha} - \omega_b.\sigma.T_1.R_s.i_{s\alpha} - k_2.s\lambda_2] \\ \lambda_2 = \dfrac{1}{T_2.s}(L_m.i_{s\alpha} - \lambda_2) \\ v = \dfrac{1}{M}.\dfrac{F_x - F_{load}}{Ds+1} \\ F_x = \dfrac{3}{2}.P_p.k_2.\dfrac{\pi}{\tau}.\lambda_2.i_{s\beta} \end{cases} \tag{25}$$

where s is the complex parameter of the Laplace transform.

3. MRAC OF THE LINEAR INDUCTION MOTOR

Model reference adaptive control (MRAC). A reference model describes system performance (Figure 2). The adaptive controller is designed to force the system/plant to behave like the reference model. The output of the model is compared to the actual output, and the difference is used to adjust feedback controller parameters. MRAC has two loops: an inner loop (controller loop) that is an ordinary control loop consisting of the plant and controller, and an outer (adaptation loop) that adjusts the parameters of the controller in such a way as to decrease the error between the model output and plant output to zero.

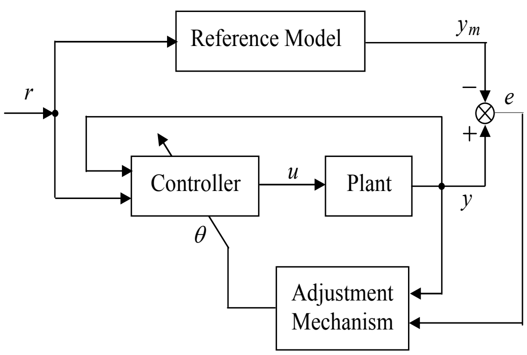


Figure 2. Model Reference Adaptive Control System

The MIT rule. The rule is developed in Massachusetts Institute of Technology (MIT) and is used in the MRAC approach. In this rule [1] the loss function is defined as

$$J(\theta) = \frac{1}{2}e^2(\theta), \tag{26}$$

where, $e = y - y_m$ is the output error - the difference of the output of the reference model and the actual model (system, plant), and θ is the adjustable parameter. The parameter θ is adjusted in such a way so that the loss function is minimized.

To make $J(\theta)$ small, it is reasonable to change the parameter θ in the direction of the negative gradient of J, that is [1]

$$\frac{d\theta}{dt} = -\gamma\frac{\partial J}{\partial\theta} = -\gamma e\frac{\partial e}{\partial\theta}, \tag{27}$$

where, $\partial e/\partial\theta$ is the "sensitivity derivative", and γ is a positive quantity which indicates the adaptation gain of the controller.

The proposed MRAC for the linear induction motor. For the sake of simplicity the model of the linear induction motor (25), is unified by the following substitutions:

$$k_f = \frac{3\pi L_m}{2\tau L_r};\ c_0 = -\frac{1}{\sigma L_s}\left(R_s + k_2\frac{L_m}{T_2}\right);\ c_1 = \frac{k_2}{\sigma T_2 L_s};\ c_2 = -P_P\frac{\pi}{\tau};\ c_3 = -\frac{k_2}{R_s};\ c_4 = \frac{1}{\sigma L_s};\ c_5 = -\frac{1}{\sigma T_1};$$

$$c_6 = -k_2 R_s;\ c_7 = -P_P\frac{\pi}{\tau};\ c_8 = -\frac{k_2^2}{\sigma T_1};\ c_9 = -\frac{k_2\pi}{\tau\sigma L_s};\ c_{10} = \frac{1}{\sigma L_s};\ c_{11} = \frac{L_m}{T_2};\ c_{12} = -\frac{1}{T_2};\ c_{13} = \frac{k_f}{M};\ c_{14} = -\frac{D}{M};$$

$$c_{15} = -\frac{1}{M};\ F_{load\,\mathrm{m}} = F_{load};\ \mathbf{r} = [r_1\ \ r_2]^T = [u_{s\alpha}\ \ u_{s\beta}]^{\mathrm{T}};\ \mathbf{x}_{\mathrm{m}} = [x_{1\mathrm{m}}\ \ x_{2\mathrm{m}}\ \ x_{3\mathrm{m}}\ \ x_{4\mathrm{m}}]^{\mathrm{T}} = [i_{s\alpha}\ i_{s\beta}\ \lambda_2\ v]^T.$$

The following type of equations is derived after the substitutions:

$$\begin{cases} \dot{x}_{1\mathrm{m}} = c_0 x_{1\mathrm{m}} + c_1 x_{3\mathrm{m}} + c_2 x_{2\mathrm{m}} x_{4\mathrm{m}} + c_3 x_{3\mathrm{m}} x_{2\mathrm{m}}^2 + c_4 r_1 \\ \dot{x}_{2\mathrm{m}} = c_5 x_{2\mathrm{m}} + c_6 x_{2\mathrm{m}}^2 x_{3\mathrm{m}} + c_7 x_{2\mathrm{m}} x_{4\mathrm{m}} + c_8 x_{2\mathrm{m}} x_{3\mathrm{m}}^2 + c_9 x_{3\mathrm{m}} x_{4\mathrm{m}} + c_{10} r_2 \\ \dot{x}_{3\mathrm{m}} = c_{11} x_{1\mathrm{m}} + c_{12} x_{3\mathrm{m}} \\ \dot{x}_{4\mathrm{m}} = c_{13} x_{2\mathrm{m}} x_{3\mathrm{m}} + c_{14} x_{4\mathrm{m}} + c_{15} F_{load\,\mathrm{m}} \end{cases} \tag{28}$$

ISSN: 1584-2673 [CD-Rom, online]

The reference model (28) describes the desired system performance. The actual model of the linear induction motor can be obtained by formal replacement of the reference output vector $\mathbf{x}_{\mathrm{m}} = [x_{1\mathrm{m}} \;\; x_{2\mathrm{m}} \;\; x_{3\mathrm{m}} \;\; x_{4\mathrm{m}}]^{\mathrm{T}}$ with the output $\mathbf{x} = [x_1 \;\; x_2 \;\; x_3 \;\; x_4]^{\mathrm{T}}$, and the reference load $F_{load\,\mathrm{m}}$ with the actual one - F_{load}.

Furthermore, in order to guarantee the independence of the linear velocity x_4 from the influence of the motor's load F_{load} the inputs r_1 and r_2 are manipulated by the proposed adaptive controller as it follows (Figure 3):

$$u_1 = \theta_1 r_1, \qquad u_2 = \theta_2 r_2, \tag{29}$$

where θ_1, θ_2 are the adjustable parameters, tuned by MIT rule, and u_1, u_2 - the modified actual inputs of the linear induction motor. The resultant mathematical description is:

$$\left|\begin{array}{l} \dot{x}_1 = c_0 x_1 + c_1 x_3 + c_2 x_2 x_4 + c_3 x_3 x_2^2 + c_4 \theta_1 r_1 \\ \dot{x}_2 = c_5 x_2 + c_6 x_2^2 x_3 + c_7 x_2 x_4 + c_8 x_2 x_3^2 + c_9 x_3 x_4 + c_{10} \theta_2 r_2 \\ \dot{x}_3 = c_{11} x_1 + c_{12} x_3 \\ \dot{x}_4 = c_{13} x_2 x_3 + c_{14} x_4 + c_{15} F_{load} \end{array}\right. \tag{30}$$

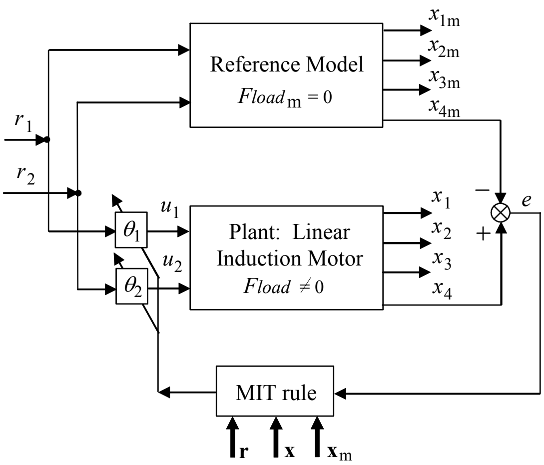


Figure 3. MRAS for linear induction motor (where $\mathbf{r} = [r_1 \;\; r_2]^{\mathrm{T}}$, $\mathbf{x} = [x_1 \;\; x_2 \;\; x_3 \;\; x_4]^{\mathrm{T}}$, $\mathbf{x}_{\mathrm{m}} = [x_{1\mathrm{m}} \;\; x_{2\mathrm{m}} \;\; x_{3\mathrm{m}} \;\; x_{4\mathrm{m}}]^{\mathrm{T}}$)

The MIT rule (27) in this case is:

$$\frac{d\theta_i}{dt} = -\gamma_i (x_4 - x_{4\mathrm{m}}) \frac{\partial x_4}{\partial \theta_i}, \; i = 1,2. \tag{31}$$

Therefore, to determine controller's parameters θ_1 and θ_2, the derivatives $\partial x_4 / \partial \theta_1$ and $\partial x_4 / \partial \theta_2$ have to be calculated. For this purpose the two sides of the system (30) must be differentiated by the adjustable parameters θ_1 and θ_2. After the differentiation by θ_1 the following replacements are adopted: $\frac{\partial x_1}{\partial \theta_1} = p_1$, $\frac{\partial x_2}{\partial \theta_1} = p_2$, $\frac{\partial x_3}{\partial \theta_1} = p_3$, $\frac{\partial x_4}{\partial \theta_1} = p_4$, $\frac{\partial}{\partial \theta_1}(\dot{x}_1) = \frac{\partial}{\partial \theta_1}\left(\frac{dx_1}{dt}\right) = \frac{d}{dt}\left(\frac{\partial x_1}{\partial \theta_1}\right) = \dot{p}_1$, $\frac{\partial}{\partial \theta_1}(\dot{x}_2) = \dot{p}_2$, $\frac{\partial}{\partial \theta_1}(\dot{x}_3) = \dot{p}_3$, and $\frac{\partial}{\partial \theta_1}(\dot{x}_4) = \dot{p}_4$. The resultant system of differential equations for determining $\partial x_4 / \partial \theta_1$ (i.e. p_4) is:

$$\left|\begin{array}{l} \dot{p}_1 = c_0 p_1 + c_1 p_3 + c_2 (p_2 x_4 + x_2 p_4) + c_3 (p_3 x_2^2 + 2 x_2 x_3 p_2) + c_4 r_1 \\ \dot{p}_2 = c_5 p_2 + c_6 (2 x_2 x_3 p_2 + x_2^2 p_3) + c_7 (p_2 x_4 + x_2 p_4) + \\ \qquad + c_8 (p_2 x_3^2 + 2 x_2 x_3 p_3) + c_9 (p_3 x_4 + x_3 p_4) \\ \dot{p}_3 = c_{11} p_1 + c_{12} p_3 \\ \dot{p}_4 = c_{13} (p_2 x_3 + x_2 p_3) + c_{14} p_4 \end{array}\right. \tag{32}$$

After the differentiation of (30) by θ_2 the following analogical replacements are adopted: $\frac{\partial x_1}{\partial \theta_2} = q_1$, $\frac{\partial x_2}{\partial \theta_2} = q_2$, $\frac{\partial x_3}{\partial \theta_2} = q_3$, $\frac{\partial x_4}{\partial \theta_2} = q_4$, $\frac{\partial}{\partial \theta_2}(\dot{x}_1) = \dot{q}_1$, $\frac{\partial}{\partial \theta_2}(\dot{x}_2) = \dot{q}_2$, $\frac{\partial}{\partial \theta_2}(\dot{x}_3) = \dot{q}_3$, $\frac{\partial}{\partial \theta_2}(\dot{x}_4) = \dot{q}_4$. The system of differential equations for determining $\partial x_4 / \partial \theta_2$ (i.e. q_4) is:

$$\left|\begin{array}{l} \dot{q}_1 = c_0 q_1 + c_1 q_3 + c_2 (q_2 x_4 + x_2 q_4) + c_3 (q_3 x_2^2 + 2 x_2 x_3 q_2) \\ \dot{q}_2 = c_5 q_2 + c_6 (2 x_2 x_3 q_2 + x_2^2 q_3) + c_7 (q_2 x_4 + x_2 q_4) + \\ \qquad + c_8 (q_2 x_3^2 + 2 x_2 x_3 q_3) + c_9 (q_3 x_4 + x_3 q_4) + c_{10} r_2 \\ \dot{q}_3 = c_{11} q_1 + c_{12} q_3 \\ \dot{q}_4 = c_{13} (q_2 x_3 + x_2 q_3) + c_{14} q_4 \end{array}\right. \tag{33}$$

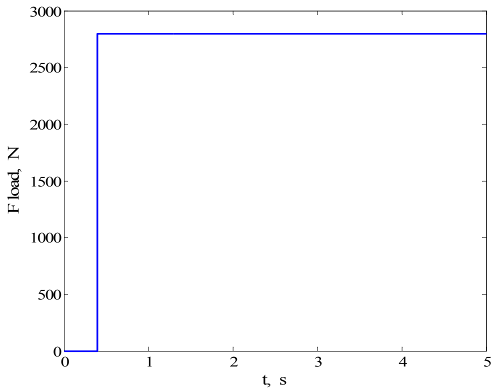
In the light of the above laying the adaptive rule (31) can be written as

$$\left|\begin{array}{l}\dot{\theta}_1 = -\gamma_1 (x_4 - x_{4\mathrm{m}}) p_4 \\ \dot{\theta}_2 = -\gamma_2 (x_4 - x_{4\mathrm{m}}) q_4\end{array}\right. \tag{34}$$

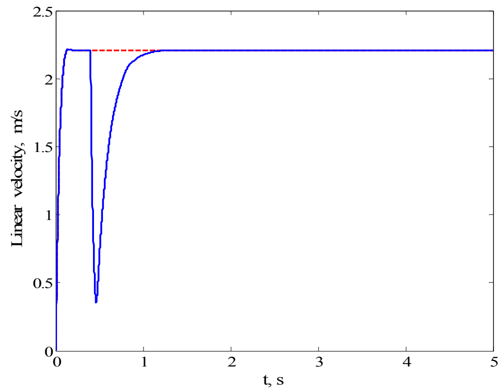
The algorithm of MRAC includes systems (32), (33) and (34), whose solutions use the output vectors from the model (28) and the plant (30) - $\mathbf{x}_{\mathrm{m}} = [x_{1\mathrm{m}} \;\; x_{2\mathrm{m}} \;\; x_{3\mathrm{m}} \;\; x_{4\mathrm{m}}]^{\mathrm{T}}$ and $\mathbf{x} = [x_1 \;\; x_2 \;\; x_3 \;\; x_4]^{\mathrm{T}}$, respectively.

4. RESULTS AND DISCUSSIONS

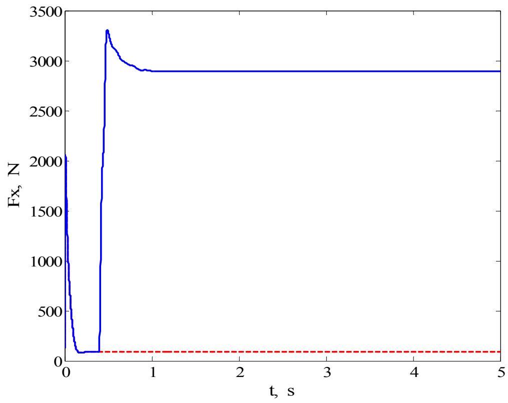
To illustrate the performance of the proposed model reference adaptive controller, the linear induction motor equipped with it was simulated in MATLAB environment and tested on several examples. In accordance with the linear induction motor's model adopted in Section 2 the following parameters of the motor were chosen: $R_s = 5.3685\,\Omega$, $R_r = 5.5315\,\Omega$, $L_m = 0.024$ H, $L_r = 0.0285$ H, $L_s = 0.0285$ H, $\tau = 0.027$ m, $p = 4$, $D = 40$, $M = 40.78$ kg, $F_{load} = 2800$ N, $u_{s\alpha} = u_{s\beta} = 220$ V. The reference load was set to $F_{load\,\mathrm{m}} = 0$ N. The simulated motor's sampling time was $T_0 = 0.001$ s. The LIM under consideration possesses the following catalogue values of the velocity: $v_{\max} = 3$ m/s and $v_{\mathrm{nom}} = 3$ m/s.



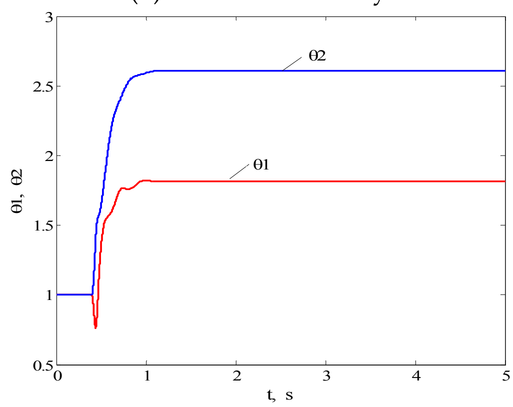
(a) The load variation



(b) The linear velocity



(c) The electromagnetic linear force



(d) The adjustable parameters of linear speed

Figure 4. MRAC - simulation results

In order to demonstrate the adaptation capability of the control scheme to execute desired velocities in the face of load variations, an example when the load of the linear induction motor was change from $F_{load} = 0$ N to $F_{load} = 2800$ N was executed. The inputs were $r_1 = r_2 = 220$ V. The adaptation gains were chosen $\gamma_1 = \gamma_2 = 5$.

The performance of the considered MRAS under these conditions is depicted in Figure 4. The step variation of the load is shown in Figure 4(a). In Figure 4(b) the actual linear velocity is marked with a solid line while the reference velocity - with a dashed line. The electromagnetic linear force is shown in Figure 4(c), and the time evolution of the two adjustable parameters of the MRAC is presented in Figure 4(d). The linear velocity of the motor before and after the change of load is almost the same (except in the transient period of time about 0.7 s). This is due to the adaptive capabilities of the MRAC using MIT rule with on-line tuning of parameters. The transient period could be reduced by increasing the adaptation gain γ. But bigger values of γ can cause oscillations and could make the system unstable.

5. CONCLUSIONS

The paper proposes MRAC for linear induction motor, whose linear velocity is maintained equal to reference velocity independently of the load. MRAC uses MIT rule, whose adaptation gain γ is chosen heuristically. Simulations in MATLAB environment confirm the good performance of the proposed adaptive control for the considered motor.

The main drawback of the MIT rule is that the stability of the closed-loop system is not guaranteed. The stability depends on the adaptive gain γ that has to be small value.

Future work will improve the performance of the system (from the stability point of view) by using the normalized MIT rule. Furthermore, the theory of Lyapunov stability will be taken into account, as a modern approach to adaptive control design.

REFERENCES

[1.] Astrom K.J., B. Wittenmark, Adaptive Control, 2nd ed., Addison-Wesley Publishing Company, USA, 1995.

[2.] Atencia J., M. Martinez-Iturralde, A new approach to vector control for linear induction motor considering end effects, Electric Machines and Drives Conference, Vol.3, pp.1651-1655, 2003.

[3.] Atencia, J., M. Martinez, R. Garcia and J. Florez, Modeling of linear induction motors as linear drives, IEEE Proc. on Power Tech, Vol. 4, pp.5-7, 2001.

[4.] Boldea, I., S.A. Nasar, Linear Electric Actuators and Generators, Cambridge University Press, 1997.

[5.] Da Silva, E.F.—dos SANTOS, E. B., Dynamic Model for Linear Induction Motors, IEEE International Conference on In-dustrial Technology, Vol. 1, pp. 478-482, 2003.

[6.] Kang, G. and K. Nam, Field-Oriented Control Scheme or Linear Induction Motor with the End Effect, IEEE Proc. Electr. Power Appl., Vol. 152, No. 6, November 2005.

[7.] Nasar S.A., I. Boldea, Linear Electric Motors, Prentice-Hall, Inc., Englewood Cliffs, New Jersey, 1987.

[8.] Nasar S. A., I. Boldea, Linear Motion Electromagnetic System, John Wiley & Sons Inc., 1995.

[9.] Ong, Ch.-M., Dynamic Simulations of Electric Machinery: Using MATLAB/SIMULINK, Prentice Hall PTR, 2007.

[10.] Rathore, A.K., S.N. Mahendra, Simulation of Secondary Flux Oriented Control of Linear Induction Motor Considering Attraction Force &Transverse Edge Effect, CIEP, pp.158-163, 2004.

[11.] Silva, E.F., E.B.Santos, C.M.Machado and A.A.Oliveira, Vector control for linear induction motor, IEEE ICIT Maribor, Slovenia 2003, http//:www.ieeexplore.ieee.org/ie15/9059.pdf.

[12.] Trzyradloski, A.M., Control of induction motors, Academic press, 2001.

[13.] Xu, Ei., Equivalent Circuits for Single-Sided Linear Induction Motors, IEEE Transactions on Industry Applications 46 No. 6 (Nov/Dec 2010), 2410–2423.

ANNALS of Faculty Engineering Hunedoara – International Journal of Engineering