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DEVELOPMENT DYNAMIC MODEL OF LINEAR INDUCTION MOTOR CONSIDERING THE END EFFECTS

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Abstract: In this paper, a mathematical and simulation model taking into account the end effects and the core losses describes the dynamic behavior of linear induction motor. The need for such a model rises due to the complexity of linear induction motors electromagnetic field theory. The end affects by introducing speed dependent scale factor to the magnetizing inductance and series resistance in the d–axis equivalent circuit. Simulation results are presented to show the validity of the model during both no–load and sudden load change intervals. This model can also be used directly in simulation researches for linear induction motor vector control drive systems.
Keywords: Linear induction motor, model reference adaptive control (MRAC), MIT–rule, velocity independent of load

1. INTRODUCTION

The analysis of the linear induction motors (LIM's) seems to be very complicated when the LIM electromagnetic field theory is used, especially when the magnetizing inductance and resistance representing the core–losses are taken into account. This analytical model, with such a theory, will also suffer so much when it is required to represent the end effects [1]. Since the primary of the LIM continuously enters a new secondary region, the new secondary region and its influence on magnetic field change the LIM's performance in comparison with the conventional induction motor [2]. These effects must be taken into consideration during entry and exit from the secondary, in respect to the primary and represent them carefully to obtain the LIM's equivalent electrical circuit. It is very important to notice that the LIM's equivalent circuit is the same as conventional induction motor when there is no relative movement between the primary , which can be seen as infinite, and the secondary. Hence the end effects will be relatively small. The transient changes at the entry and exit ends as a function of the primary length are shown [3]. In this paper a dynamic model of LIM based on the d–q–model of equivalent electrical circuit is implemented and prepared for further study especially for the vector control drive systems for LIM's. During the modelling process it is assumed that the primary which is simply a rotary motor primary cut open and rolled flat.

2. MATHEMATICAL MODEL OF LIM

The dynamical mathematical model is proposed by the following equations [4]:

$$u_{ds} = R_s i_{ds} + R_r f(Q)(i_{ds} + i_{dr}) + \frac{d\lambda_{ds}}{dt} - \omega_e \lambda_{qs} \tag{1}$$

$$u_{qs} = R_s i_{qs} + \frac{d\lambda_{qs}}{dt} + \omega_e \tag{2}$$

$$0 = R_r i_{dr} + R_r f(Q)(i_{ds} + i_{dr}) - (\omega_e - \omega_r)\lambda_{qr} \tag{3}$$

$$0 = R_r i_{qr} + \frac{d\lambda_{qr}}{dt} + (\omega_e - \omega_r) \tag{4}$$

$$\lambda_{ds} = L_{ls} i_{ds} + L_m (1 - f(Q))(i_{ds} + i_{dr}) \tag{5}$$

$$\lambda_{qs} = L_{ls} i_{qs} + L_m (i_{qs} + i_{qr}) \tag{6}$$

$$\lambda_{dr} = L_{lr} i_{dr} + L_m (1 - f(Q))(i_{ds} + i_{dr}) \tag{7}$$

$$\lambda_{qr} = L_{lr} i_{qr} + L_m (i_{qs} + i_{qr}), \tag{8}$$

where: u_{ds}, u_{qs} – are d–q axes primary voltages in the synchronous reference frame; i_{ds}, i_{qs} – d–q axes primary currents in the synchronous reference frame; i_{dr}, i_{qr} – d–q axes secondary currents in the synchronous reference frame; $\lambda_{ds}, \lambda_{qs}$ – d–q axes primary flux; $\lambda_{rd},\lambda_{rq}$ – d–q axes secondary flux; R_s,R_r – resistance of the primary and secondary windings respectively, per phase; ω_e,ω_r – primary and secondary electrical frequency respectively; τ – pole pitch; L_m – mutual inductance; L_s,L_r – primary and secondary self–inductances respectively, per phase; L_{ls},L_{lr} – primary and secondary leakage inductances respectively, per phase.

In the above equations:

$$f(Q)=\frac{1-e^{-Q}}{Q}, \tag{9}$$

where

$$Q=\frac{DR_r}{(Lm+L_{lr})v} \tag{10}$$

Also the motor thrust force will be given as:

$$F_e=\frac{3}{2}\frac{\pi}{\tau}\frac{P}{2}(\lambda_{ds}i_{qs}-\lambda_{qs}i_{ds}), \tag{11}$$

where: τ – is the pole pitch; P – number of pole pairs; F – electromagnetic thrust force; D – primary length; Q – factor linked to the primary length; v – linear velocity.

The motion of the slider is governed by the Newton's law of motion, i.e., balance of various forces acting on it. As such, it has:

$$F_e-F_L=\frac{1}{M}\frac{dv}{dt}, \tag{12}$$

where: M – is the mass of the slider; F_L – internal load.

The Q factor is associated with the length of the primary, and to a certain degree, quantifies the end effects as a function of the primary, and to a certain degree, quantifies the end effects as a function of the velocity v as described by equation.

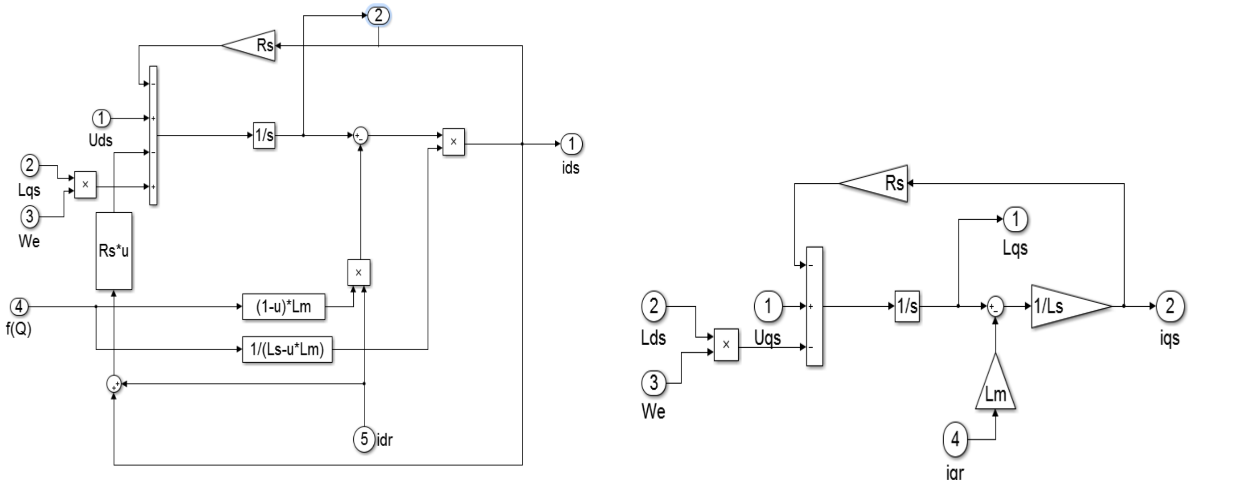
The LIM's primary and secondary d–q–currents are separable into two portions, of which the first is independent of the end effects, and the second dependent of the end effects. With this approach, the first portion behaves as a conventional induction motor current and the second portion as an attenuation function due to the LIM's end effects. The leakage fluxes are also separable into two parts, the first is independent of the end effects and will be denoted by the index–1, while the second describes the leakage flux dependent on the end effects, indicated by the index–2. The equations representing these fluxes and currents are given in [5].

3. SIMULATION OF LIM USING SIMULINK/MATLAB SOFTWARE PACKAGE

The parameters of the LIM used in the simulation are shown bellows:

Number of pole pairs: $P=2$; $R_s=5{,}348\ \Omega$; $R_r=11{,}603\ \Omega$; $D=2{,}1\,mm$; $L_m=0{,}09213\,H$; $L_s=0{,}1073\,H$; $L_r=0{,}094618\,H$; $\tau=1{,}05.10^{-4}\,m$; Primary width– $45.10^{-3}\,m$; Secondary thickness – $4{,}5.10^{-3}\,m$; Number of slots – 12; Air gap length– $4.10^{-3}\,m$; Mass of the slider – $M=30\,kg$

The Simulink dynamic model used in this simulation and its internal construction are show in Figs. (1–5).



a) b)

Figure 1. Simulink realization of equations (1–9). a),b)–for d axes

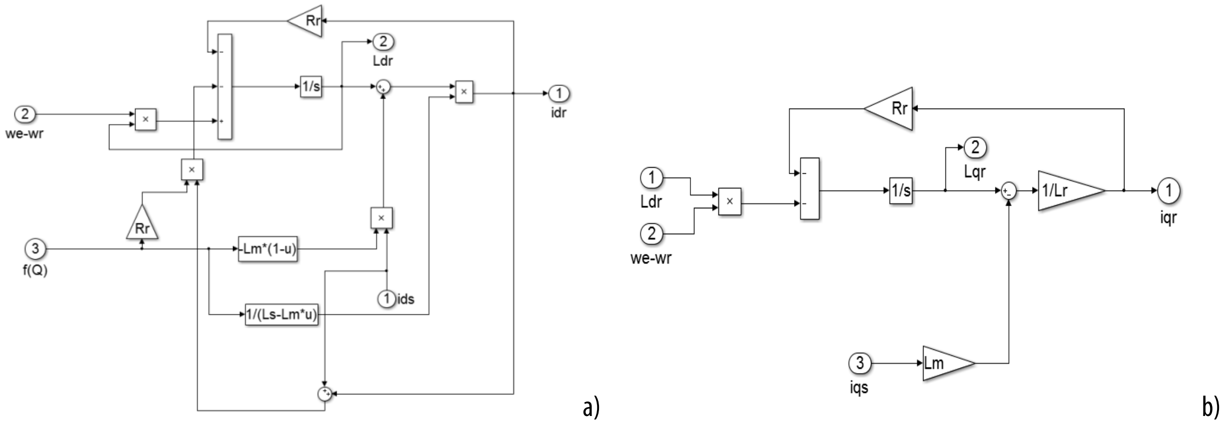


Figure 2. Simulink realization of equations (1–9). a), b)–for q axes

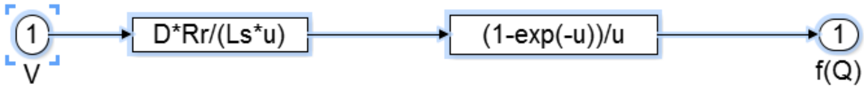


Figure 3. Simulink realization of equations (9–11)

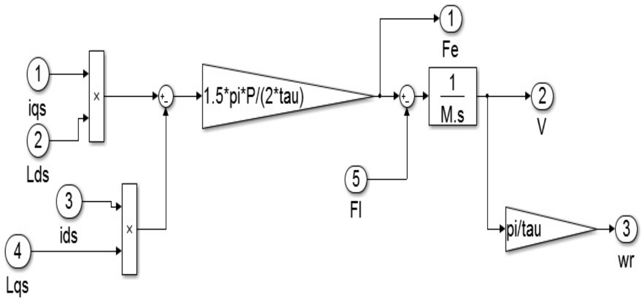


Figure 4. Simulink realization of mechanical equation

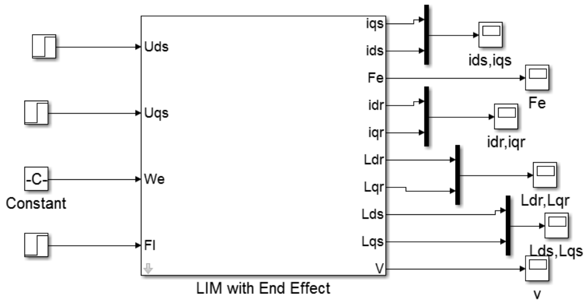


Figure 5. Simulink realization of LIM with end effect

The Figure (6) shows the LIM thrust force characteristics for no–load and several step change–loading conditions. The velocity response for such loading conditions is shown in Figure (7).

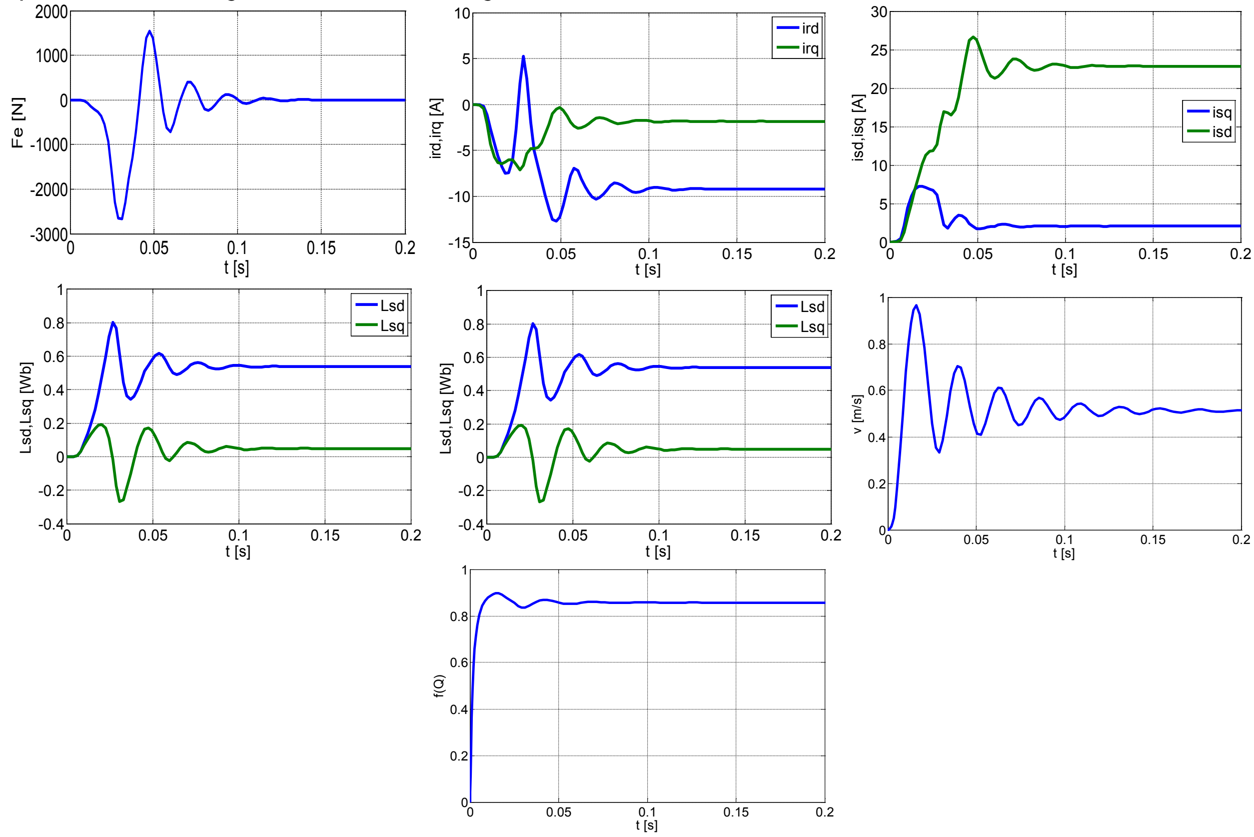


Figure 6. LIM with end effect and without load

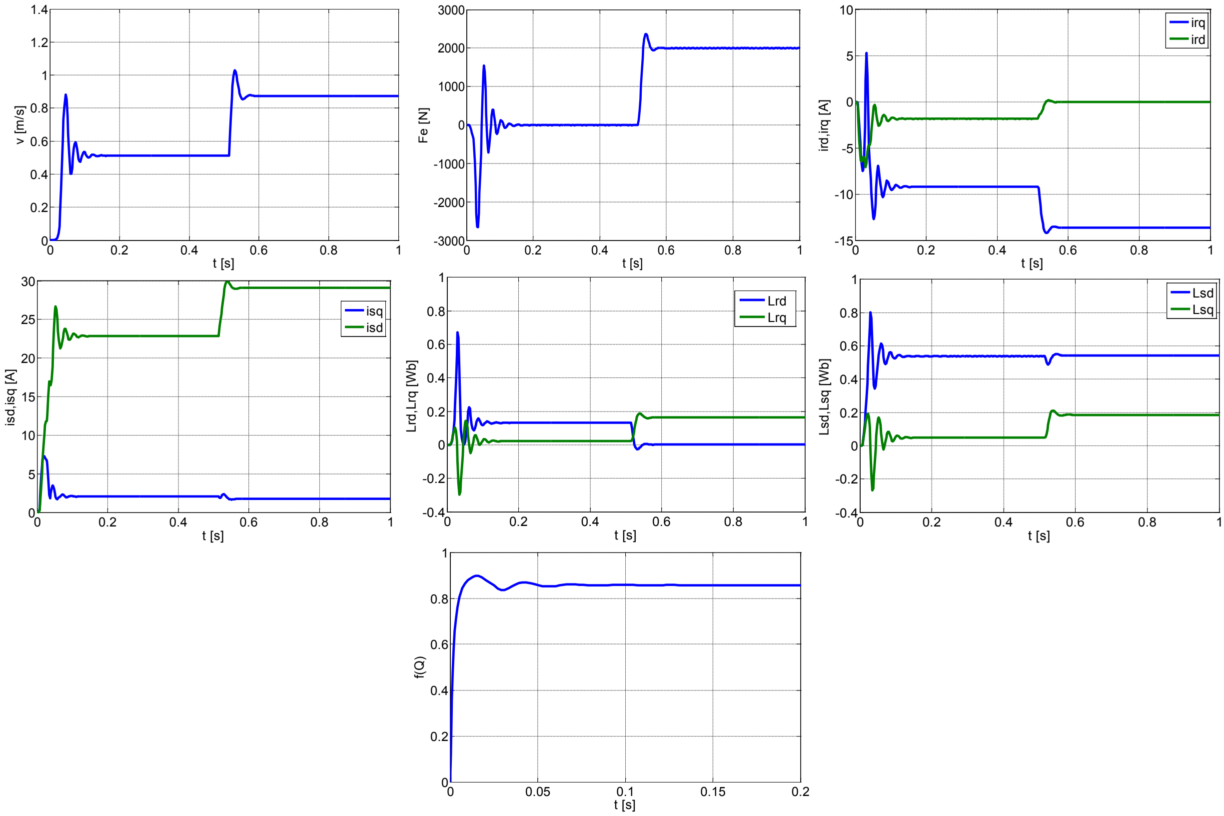


Figure 7. LIM with end effect and with load

4. CONCLUSIONS

In this work a LIM Simulink model modified into d–q frame is developed with the ability to represent its d–q currents and leakage fluxes (both for the primary and secondary) by two parts the first is independent of the end effects, and the second dependent of the end effects. Both flux and thrust coefficients were expressed with Q. The LIM model implemented is compatible to be used for vector control drives of LIM's. Such driven schemes requirements for space vector pulse width modulation controllers can be simplified with the d–q synchronized rotating reference frame voltage input ports of the implemented LIM model.

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