Dynamic Modes of Single Phase Braking of Linear Induction Motors

Roma Rinkevičienė, Saulius Lisauskas, Andrius Petrovas
Vilnius Gediminas Technical University
roma.rinkeviciene@el.vtu.lt

Abstract

The braking of linear induction drives usually requires selecting the braking mode, to obtain information about dynamic forces, speed and current of the motor. The article presents the dynamic models of single phase braking of linear induction drive at different connection of inductor windings. While the system is considered as non-balanced, the equations, describing operation of LIM in dynamic mode are written for direct, inverse and zero component of voltage and are used to develop model of single phase braking. The results of simulation give dynamic braking force, speed and current of the linear induction motor with different phase winding connection at single phase braking.

Keywords

Linear induction motor, single phase braking, dynamic modes, model

Introduction

Any technological equipment is characterized by proper operational parameters, which are set as requirements in elaborating mechatronic system with linear induction motors. As the linear induction motor (LIM) has worse efficiency, the advantage of mechatronic with LIM appears just in the case when LIM is designed for proper equipment singly and becomes a concurrent part of that. It is underlined in [1] that dynamic features of electric drive with LIM are always better than rotting that due to smaller inertia of moving parts. As the linear electric drive has less number of mechanical elements, its elasticity is smaller. Linear electric drive has no reducer present; therefore the linear drive has no clearance. Due to these features dynamic characteristics of the linear induction drive are better. Dynamic processes of the electric drive with linear induction motors include all types of possible transition processes, between them and braking those.

Braking mode of LIM compose a separate problem. Stationary mode of LIM braking is considered in [2] where the schemes of LIM winding connection at single phase braking are proposed.

Investigation of non-stationary braking mode considering the influence of the acceleration of motor with odd active zones is presented in [3]. The paper assumed constant acceleration during proper small time interval. In reality the acceleration changes over all braking time. Therefore [4, 5, 6] consider dynamic braking modes of linear induction motors at different connecting of windings. The braking with direct current is analyzed in [4, 5]. The problems of single phase braking are considered in [6].

This article discusses dynamic braking methods of the electric drive with LIM, using single phase alternating current, when braking voltage is connected to two and three phase windings of the motor.

Model of the linear induction motor braking mode

If the LIM is supplied by balanced three phase voltage and all the phase impedances of the LIM are assumed to be equal, then it’s mathematical and computer models, designed in moving with synchronous speed and stationary reference frame, are presented in [6]. These models give motor possibility to simulate motoring and reverse-current braking modes. If the LIM is operating in single phase braking mode, the possible ways to supply by single phase voltage the LIM windings is shown in Fig. 1. The circuits presented in the Fig. 1 indicate, that LIM during braking is supplied by unbalanced voltage, therefore the LIM windings connection manner must be considered during elaboration of LIM models during braking.

Fig. 1. The schemes of LIM winding connection at single phase braking mode

The model to investigate unbalanced dynamic modes of linear induction drive is designed on the base of symmetrical components, which employs the expanding of any unbalanced voltage to three symmetrical components. According to this, the model of single phase braking mode contains three models, developed for direct, reverse and zero components of supply voltage. The differential equations of LIM,
supplied by direct component, are inverse component, are derived from those for direct component, substituting expression $2 - s$ instead $s$ (where $s$ is slip).

Then the term $v_0 - v$ (where $v_0$ and $v$ is synchronous speed and speed of LIM) presenting in the equations [6] is rearranged in this way:

$$\frac{(v_0 - v) v_0}{v_0} = s \cdot v_0.$$  
(1)

Therefore the term $v_0 - v$ in the equations of LIM supplied by inverse component of voltage becomes:

$$(2 - s) v_0 = v + v_0.$$  
(2)

According to this, the differential equations of LIM in moving with synchronous speed reference frame, supplied by inverse component of voltage, are:

$$\frac{dp_2}{dt} = U_{1m} \cos \gamma \frac{\pi}{\tau} \psi_{s1} \psi_{s1} + \frac{\pi}{\tau} \psi_{s1} \psi_{s2} \frac{\pi}{\tau} \psi_{s1} \psi_{s1};$$

$$\frac{dp_{22}}{dt} = U_{1m} \sin \gamma \frac{\pi}{\tau} \psi_{s1} \psi_{s1} + \frac{\pi}{\tau} \psi_{s1} \psi_{s2} \frac{\pi}{\tau} \psi_{s1} \psi_{s1};$$

$$\frac{dp_{1}^2}{dt} = \frac{\pi}{\tau} \psi_{s1} \psi_{s1} \frac{\pi}{\tau} \psi_{s1} \psi_{s1} \frac{\pi}{\tau} \psi_{s1} \psi_{s1};$$

$$\frac{dp_{1}^2}{dt} = \frac{\psi_{s1} \psi_{s1}}{2 \tau \sigma_{\psi}}.$$  
(3)

The inductor current components are calculated in this way:

$$I_{s1} = \alpha_{s} \left( \psi_{s1} - \psi_{s2} K_{s} \right) \frac{U_{1m}}{r_{1}};$$

$$I_{s1} = \alpha_{s} \left( \psi_{s1} - \psi_{s2} K_{s} \right) \frac{U_{1m}}{r_{1}};$$

and phase current is found as:

$$I_{s} = I_{s1} \cos \alpha_{s} - I_{s1} \sin \alpha_{s}.$$  
(5)

The set of differential equations is solved together with the main equation of movement:

$$\frac{dv}{dt} = \frac{1}{m} (F - F_s);$$

and the equation to find the excursion of secondary:

$$\frac{dx}{dt} = v.$$  
(7)

There are used such notations in the equations (3 – 7): $\psi_{s1}, \psi_{s2}$ – inductor flux linkage components in the axis $x, y$; $\psi_{s2}, \psi_{s2}$ – secondary element flux linkage components on the axis $x, y$; $U_{1m}$ – amplitude value of reverse component of applied voltage; $\gamma$ – voltage phase angle at switching instant; $\tau$ – pole pith; $v_0$ – synchronous speed of LIM; $v$ – speed of LIM; $F_s$ – load; all other coefficients are calculated using known resistances and reactances of LIM [7]. The force developed by motor $F$ in the equation (6) is the algebraic sum of direct component $F_d$ and reverse component $F_r$.

The main result of the model made for LIM supplied by direct component of voltage, is the force, developed by the motor and speed. Model, made according to (3 – 7) equations, gives the opposite direction force. The forces, developed by two models are summarized and the total force acts the secondary element. The secondary element moves with speed $v$. The zero component doesn’t develop force. Developed entire computer model to simulate single phase breaking is shown in Fig. 2.

The model to calculate inductor currents is made on the base of Eqs. (4, 5). It is shown in Fig 3. Similar equations were used to develop the model of secondary element currents. The model is presented in Fig. 4. Developed model gives possibility to simulate not only starting and steady-state modes but also to investigate various unbalanced modes (brakes with direct current, single phase braking), to compare obtained characteristics and to investigate influence of LIM parameters or load to dynamic characteristics.

**Simulation results**

Simulation results of single phase braking when only one LIM windings is supplied by voltage are presented and discussed in [6]. If the voltage is connected according to the circuits shown in Fig. 1 b and 1 c, the LIM doesn’t stops and its speed decreases in accordance with the load. The graph of LIM, which windings are connected according to Fig 1b, speed at different load is shown in Fig 5. If the motor operates at no-load, the speed of LIM reduces until 4 m/s and at sufficiently high load the motor stoppage occurs.

In the Fig. 6 the graphs of speed of LIM, which windings are connected according Fig. 1c at different load are presented. In this case the speed of no-load motor reduces from 6 m/s to 5.5 m/s and at sufficiently high load the secondary element of LIM stops. These modes of LIM windings connection can be used if the technological equipment requires to reduce the speed, but not to stop it.

Fig. 7 and Fig. 8 presents the dynamic force graphs, when the windings of LIM are connected according to Fig. 1a and Fig. 1c schemes. In the Fig. 9 and Fig. 10 the secondary element current dependence upon time, when the LIM windings are connected according to Fig. 1a and Fig. 1c is given. These figures indicate that the current is induced in the secondary element also after stoppage. Therefore the braking voltage must be switched off when motor stops.
Fig. 2. The model of LIM single phase braking

Fig. 3. Model to calculate components of currents $I_{x1}, I_{y1}, I_{x2}, I_{y2}$
Fig. 4. Model to calculate phase currents of inductor and secondary element

Fig. 5. Graphs of speed at LIM windings connected according to Fig. 1a
Fig. 6. Graphs of speed at windings connected according to Fig. 1 c scheme

Fig. 7. Graphs of dynamic force if LIM windings are connected according to Fig. 1 a

Fig. 8. The dynamic force developed by LIM at connection of windings according to Fig. 1 c

Fig. 9. Current of the secondary element when windings are connected according to Fig. 1 a

Fig. 10. Current of the secondary element when windings are connected according to Fig. 1 c

Conclusions

1. Developed model gives possibility to investigate braking mode of LIM by single phase current if braking voltage is attached to LIM windings, connected in different ways and evaluate influence of LIM parameters and load to dynamic of braking.

2. If the motor windings are connected according to Fig. 1a, LIM, operating at no load, does not stop, but its ideal no-load speed diminishes up to 4 m/s. If the windings are connected according Fig. 1c, it also does not stop, but its speed reduces to 5.5 m/s, when synchronous speed of LIM is 6 m/s. Operating with quit great load, LIM stops.

3. Braking time depends on the way of winding connection and load. The single phase braking gives the greatest stoppage time 2 s. Therefore, if
the shorter stoppage time is required, the dynamic braking mode should be used.

4. At the single phase braking the voltage should be switched off after LIM stoppage, because braking voltage produces alternating current in the LIM inductor and induces current at move less secondary element.

References


