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Study on the Braking Characteristics of Linear Induction Motors

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Introduction

The new production technologies require electrical drives to be able to operate under the mode of starting, operation, speed control and stabilization, accurate braking and positioning. When designing them, there are extensively applied not only the rotational electric motors, but also the linear induction motors (LIM). To this group there are attached the arc, drum and flat motors, motors with a disk rotor or segment stator as well as motors having two or more disk-type or hollow type rotors. The specific structural characteristic of such motors is the open magnetic circuit.

Due to the open magnetic circuit and because of the longitudinal edge effect, which appears in relation of the finite length of the active zone, these motors distinguish themselves as having the internal magnetic and electric asymmetry. That is why the well known mathematical models of electric motors and usual methods of investigation are not suitable for the extensive research on such asymmetric motors. Besides that when designing and implementing the automatic systems with LIM, there might arise the problems of braking of the moving parts. In practice, there are mostly implemented for the LIM the electric modes of braking such as dynamic, regenerative, single – phase, capacitor, over – synchronous, oposite connection, and braking by pulsating current

Nowadays all the theoretical issues of braking of (LIM) are usually analysed by applying the methods of the electromagnetic field theory [1, 2, 3]. One of the most progressive methods of the analysis is the spectral method of the magnetic fields. If to apply this method, one has to deal with the issues concerning the calculation of the spectral characteristics of the braking current, the primary and secondary magnetic fields, electromagnetic force and power, which haven't been sufficiently analysed recently.

The objective of the work is to review the electric modes of braking related to the LIM and derive the findings after applying the modelling of the magnetic field.

The schemes of braking

During the dynamic braking process in the windings of the inductor there flows the direct current, which generates the primary magnetic field. The D C source is possible to be connected to one, two or three windings as it is presented in Fig. 1.

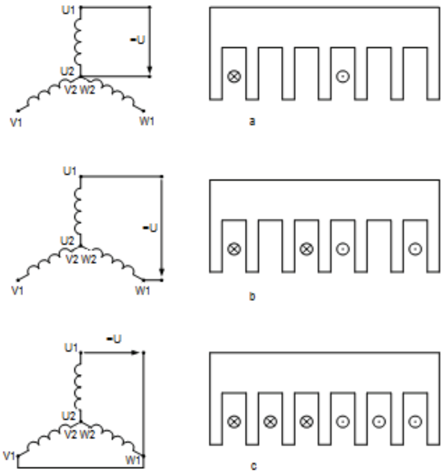


Fig. 1. Schemes of dynamic braking and directions of the currents in the inductor slots

In cases of single – phase braking, the windings are connected to the single – phase alternating current source that is why there is generated the primary magnetic field, pulsating in the space. The braking by means of the pulsating current is generated if the valve braking schemes are used (Fig. 2).

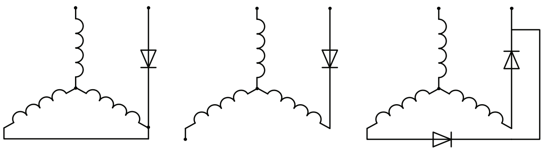


Fig. 2. Valve type braking schemes for the linear induction motor

The capacitor braking scheme for the LIM is presented in Fig. 3 [4]. When switching off the switch *QF*, there is initiated the discharging of the capacitors via the windings *u, v, w* of the inductor and the excitation process of the braking is generated.

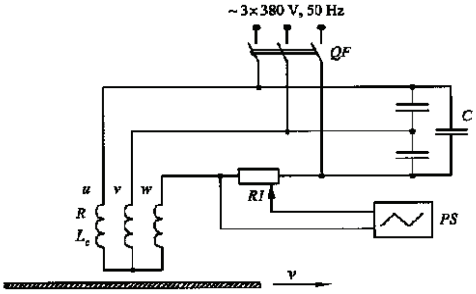


Fig. 3. Capacitor braking scheme for the linear induction motor

Elementary components of the braking modes and their characteristics

The theoretical model of double – sided LIM with the finite length L active zone is presented in Fig. 4.

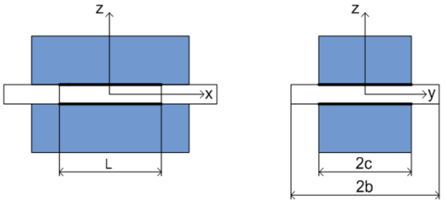


Fig. 4. LIM theoretical model: 2c – width of the active zone; 2b – width of the secondary element

During the moment of braking in the active zone L there is formed a sinusoidal wave of the braking current volumetric density, to which there are applied the Laplace and Fourier integral transformations. Thus there are derived the analytical expressions of the continuous spectrum of the volumic density of current. The work [5] presents that from the continuous spectrum with the exception of one component, there were derived the following expressions of the current density elementary components:

a) In the case of dynamic braking

$$\underline{j}_{de}=\frac{\underline{J}_{dm}}{\pi(\alpha_1+\alpha)}\sin\left[(\alpha_1+\alpha)\frac{L}{2}\right]e^{i\alpha x}d\alpha\,; \qquad (1)$$

where $\underline{J}_{dm}$ – is the complex amplitude of the current volumic density; α – is the variable frequency of the space; $\alpha_1=\pi/\tau$ – is space frequency of the volumic density; τ – is the pole pitch of the inductor; $i=\sqrt{-1}$.

b) In the case of single – phase braking

$$\underline{j}_{1e}=\underline{J}_{1m}\left\{\frac{\sin\left[(\alpha_1+\alpha)\frac{L}{2}\right]}{\alpha_1+\alpha}+\frac{\sin\left[(\alpha_1-\alpha)\frac{L}{2}\right]}{\alpha_1-\alpha}\right\}\times$$

$$\times\, e^{i(\omega t+\alpha x)}d\omega d\alpha\,; \qquad (2)$$

where $\underline{J}_{1m}$ – is the complex amplitude of the current volumic density; ω – is the variable angular frequency.

c) In the case of capacitor type of braking:

$$\underline{j}_{ke}=\frac{\underline{J}_{km}\omega_1\sin\left[(\alpha_1+\alpha)\frac{L}{2}\right]}{\pi(\alpha_1+\alpha)\left[(\delta+i\omega)^2+\omega_1^2\right]}e^{i(\omega t+\alpha x)}d\omega d\alpha\,; \qquad (3)$$

where ω_1 – is the angular frequency of the braking current; δ – is the coefficient of current attenuation.

The expressions of the elementary components of the primary magnetic field for each mode of braking are possible to be derived after having solved the following differential equation [3]:

$$\frac{\partial^2\underline{H}_{1e}}{\partial x^2}=-\frac{\partial\underline{j}_e}{\partial x}\,. \qquad (4)$$

(4) is solved together with the expressions (1) – (3) and the elementary components of the continuous spectrum of the primary magnetic field are derived: $\underline{H}_{1de}$; $\underline{H}_{1e}$ and $\underline{H}_{1ke}$.

In reality, in the expressions (2) and (3), the factor $e^{i(\omega t+\alpha x)}$ indicate that $\underline{j}_{1e}$, $\underline{j}_{ke}$, $\underline{H}_{1e}$ and $\underline{H}_{1ke}$ signify themselves by the characteristics of the travelling wave. In the process of energy conversion the direction of its motion depends on the frequency ω and α the signs. We have to determine the direction of the motion of the elementary components as well as their velocity v_e. If suppose, during the time moment *t*, the amplitude of the wave remains constant and when the signs of the frequencies coincide, it is possible to write the following:

$$\begin{cases}\omega t+\alpha x=const;\\-\omega t-\alpha x=const.\end{cases} \qquad (5)$$

These expressions are differentiated in accordance with the time *t* and then in both the cases we receive the following

$$\frac{dx}{dt}=-\frac{\omega}{\alpha}\,. \qquad (6)$$

Because $\alpha=\omega/v_e$, then instead it into (6) we derive

$$\frac{dx}{dt}=-v_e;\ (v_e<0)\,. \qquad (7)$$

These are the reverse components of the continuous spectrum, which at the moment of braking, have a tendency to move against the direction of the secondary element motion and tend to stop it.

In the cases when the signs of the frequencies are different:

$$\begin{cases}\omega t-\alpha x=const;\\-\omega t+\alpha x=const.\end{cases} \qquad (8)$$

Their derivatives are the following:

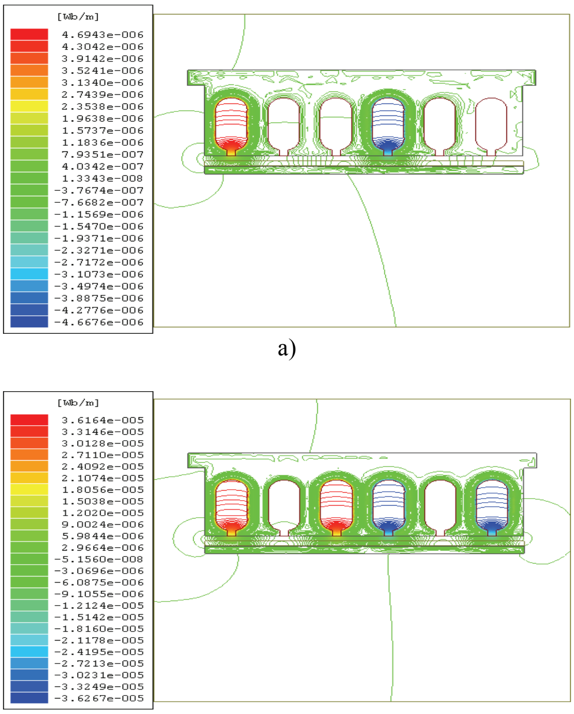
$$\frac{dx}{dt} = v_e;\ (v_e > 0)\,. \qquad (9)$$

These are considered to be the direct components of the current density and magnetic field, which generate the regenerative braking force or in some cases even the motor thrust force.

Modelling of the magnetic field

Thus, we continue to investigate the magnetic field of the LIM in accordance with the schemes of dynamic braking presented in Fig. 1. To simulate the magnetic field there was selected the software package *Maxwell.* During the process of simulation such parameters of the motor were changed: thickness and material of the secondary element, the braking current and the size of the air gap.

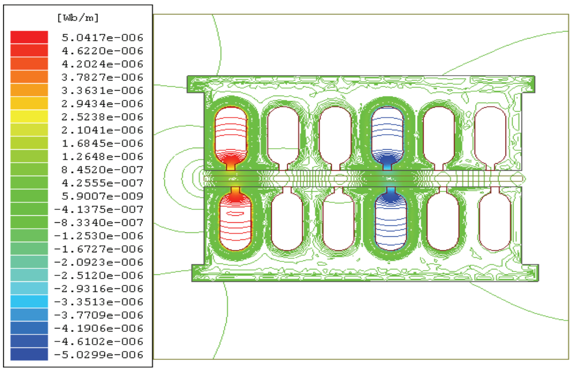
The views of the magnetic field dynamic braking for the single – sided inductor type are presented in Fig. 5, for the duoble – sided inductor – are presented in Fig. 6.



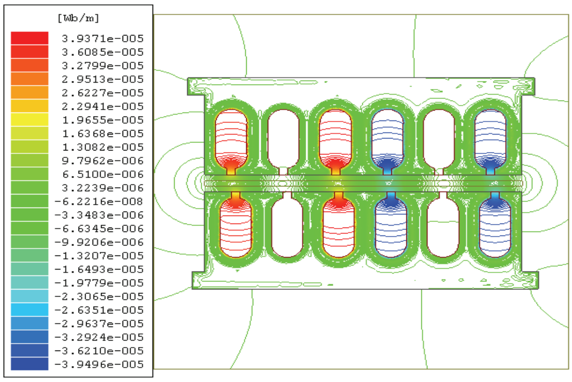
a)

b)

Fig. 5. Magnetic field lines at the dynamic braking: a) – one winding is connected; b) – two windings are connected



a)



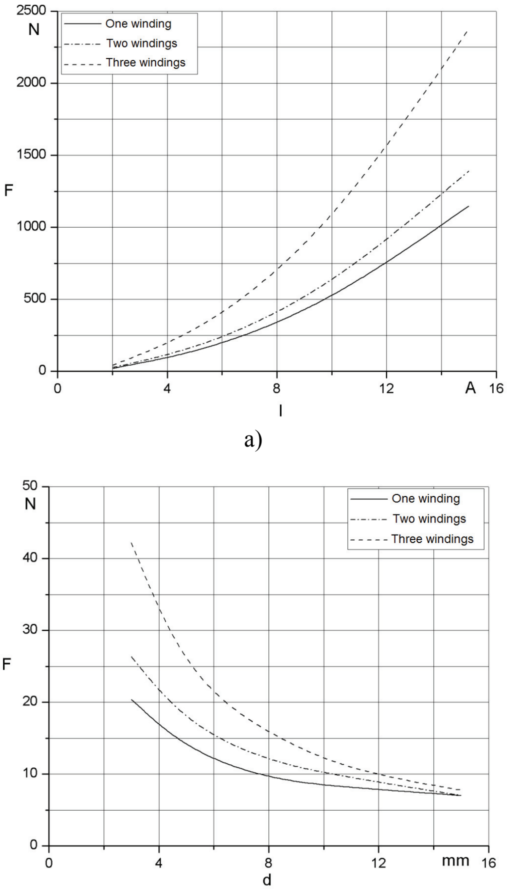
b)

Fig. 6. The magnetic field lines in duoble – sided motor: a) – one winding is connected; b) – two windings are connected

After the data of the simulation were obtained the force of the dynamic braking was calculated

$$F = -\mu_0 \underline{H} \times \underline{J}\,. \qquad (10)$$

The results of the calculations in the form of the curves are submitted in the diagrams in Fig. 7.



a)

b)

Fig. 7. Dependences of the dynamic braking force: a) – on the current of braking; b) – on the size of the air gap

The results of the calculations indicate that when a certain air gap is present, the maximum force of the dynamic braking is achieved, when to the D C sourse are connected all the three windings.

Conclusions

1. With the help of the spectral method, there were received the continuous spectrum of the amplitudes of the braking current volumic density and the primary magnetic field. Besides the main component of the magnetic field, the space frequency of which is $\alpha_1 = \pi/\tau$, during the process of braking, there participated the continuous spectrum of the elementary components, the space frequencies of which are equal to $\alpha = \pi/\tau_e$ and they occupy the infinite range from $-\infty$ to $+\infty$.

2. The greatest influence on the characteristics of braking has the components of the continuous spectrum, the space frequencies α of which are proximate to the main frequency α_1. The direction of the motion of the elementary components of the magnetic field during the energy conversion process depends on the signs of frequencies ω and α.

3. The views of the distribution of the magnetic field lines of the dynamic braking were received by the software package *Maxwell* in the motor with single – sided and duoble – sided inductor. The results of modelling indicate that the lines of the magnetic field in all cases tend to close not only in the air gap but and behind the boundaries of the active zone of the motor. That indicates that there exist the transversal and longitudinal edge effects which influence the characteristics of braking.

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B. Karaliunas. Study on the Braking Characteristics of Linear Induction Motors // Electronics and Electrical Engineering. – Kaunas: Technologija, 2012. – No. 2(118). – P. 49–52.

This paper presents the research results of the braking characteristics of linear induction motors. The spectrum analysis method of the magnetic fields is used. There were derived the expressions of the elementary components of the continuous spectrum amplitudes of the braking current volumic density and primary magnetic field as well as their characteristics were investigated. The assessment of the elementary components of higher frequency allows the increase of accuracy when calculating the characteristics of braking. For the simulation of the magnetic field of the dynamic braking there was applied the software package *Maxwell.* The received results indicates that there exist the transversal and longitudinal edge effects which influence the characteristics of braking. Ill. 7, bibl. 5 (in English; abstracts in English and Lithuanian).

B. Karaliūnas. Tiesiaeigių asinchroninių variklių stabdymo charakteristikų tyrimas // Elektronika ir elektrotechnika. – Kaunas: Technologija, 2012. – Nr. 2(118). – P. 49–52.

Straipsnyje pateikti tiesiaeigių asinchroninių variklių stabdymo charakteristikų tyrimo rezultatai. Tam tikslui taikomas spektrinis magnetinių laukų analizės metodas. Gautos stabdymo srovės tūrinio tankio ir pirminio magnetinio lauko amplitudžių ištisinio spektro elementariųjų dedamųjų išraiškos ir išnagrinėtos jų savybės. Aukštesniojo dažnio elementariųjų dedamųjų įvertinimas leidžia padidinti stabdymo charakteristikų skaičiavimo tikslumą. Dinaminio stabdymo magnetiniam laukui modeliuoti panaudotas programų paketas *Maxwell.* Gauti rezultatai rodo, kad egzistuoja skersinis ir išilginis kraštų efektai, kurie turi įtakos stabdymo charakteristikoms. Il. 7, bibl. 5 (anglų kalba; santraukos anglų ir lietuvių k.).