ELECTRONICS AND ELECTRICAL ENGINEERING
ISSN 1392 – 1215 2008. No. 5(85)
ELEKTRONIKA IR ELEKTROTECHNIKA

ELECTRICAL ENGINEERING
T 190
ELEKTROS INŽINERIJA

Magnetic Field in the Air Gap of Double–sided Linear Induction Machine

B. Karaliūnas, E. Matkevičius, L. Radzevičius
Department of Automation, Vilnius Gediminas Technical University,
Naugarduko st. 41, LT-03227 Vilnius, Lithuania, phone: +370 2745063, e-mail: bronius.karaliunas@el.vgtu.lt;
edvardas.matkevicius@el.vgtu.lt; lionginas.radzevicius@el.vgtu.lt

Introduction

While applying new technologies and mechatronic systems there are rather widely used rotating induction machines and electric machines with linear induction as well sliding motion. In mechatronic systems such type of machines mostly perform the function of executing elements, although after switching them into the mode of braking it is possible to stop the moving parts of the mechatronic system by electrical measures.

Briefly stated linear induction machines (LIM) and the electromagnetic processes executed in them are rather basically investigated. To be more precise there have been compiled a great number of various methods and their mathematical models. The analysis carried on the resources of literature demonstrates that all the models applied are divided into two main groups:

1. Models, based on the theory of electric and magnetic circuits.
2. Models, based on the theory of electromagnetic field.

Since the process of electromagnetic energy change is proceeding in the air gap of LIM, where the main energy of the electromagnetic field is concentrated, the research of the second group models is required more profound and extensive accordingly. Following the approach chosen the research of the electromagnetic field located between the inductors positioned in the air gaps and the secondary element of the machine is considered as one of the most relevant to be absorbed. The theory of LIM is expanded by means of such sort of research as well as the calculations of its characteristics are revised.

Therefore, there have appeared a great number of scientific publications recently, concerning the research field on the electromagnetic field of LIM. However, in the established works dealing with that particular research there has been insufficiently analysed the field structure of the LIM with the layered secondary element, there do not exist distribution evaluation methods and calculations for separate components.

The objective of this work is to derive analytic expressions and investigate the of the magnetic field in the air gap and separate layers of the secondary element of the double – sided LIM operating under the mode of the motor.

In the literary source [1] there is submitted the summarized model after the research carried on the LIM. The machine is comprised of two flat inductors between which there is placed a layered secondary element. When analysing a more general case such an element is compiled of the ferromagnetic band when both sides are covered with the non – magnetic layers conductive to electricity e. g. layers of copper. The thickness of these layers might be uneven that is why in the presented model they have been respectively marked as Δ_1 and Δ_2. The thickness of ferromagnetic band is marked as Δ_3. There are air gaps between the inductors and secondary element, the size of which may also be uneven. Accordingly they are marked as δ_1 and δ_2.

Based on the this model in article [2] there are presented the calculations on the force of pull of the linear induction motor (LIM) when the poles of the double – sided inductor are considered like poles N – N and when they are considered to be opposite or unlike poles N – S. The dependencies of forces on the thickness of separate layers of the secomdary element are also derived

The mathematical model of the impulse control of the LIM is analysed in article [3]. The expressions of the forces generated by the separate coils of the motor are received in accordance with which it is possible to formulate the total force of pull.

The calculations of the magnetic field and the main expressions

This article is meant for the more precise research of the magnetic field of the double –sided LIM and between its inductors in accordance with the mathematical model presented in article [1]. This model comprises the possibilities for investigating the magnetic field when the secondary element is a complicated one and on the basis of the obtained results it is possible continue the investigation of not complicated models. In order to simplify the task, there is accepted that the model is considered symmetrical i.e. the thickness of the copper layers Δ_1 and Δ_2 are equal, as well as air gaps δ_1 and δ_2. According to this model the magnetic field is analysed in the system of the right Descartes coordinates x, y, z connected with the inductor that is not movable.

Consequently there was analysed the change of the strength of the primary magnetic field generated by the double – sided inductor in the air gaps of the LIM, then in the separate layers of the secondary elements. There were received different expressions of the running wave of the magnetic field strength when in respect to each other there are located in opposition the inductors like (N – N) and unlike (N – S) poles [4].

When the poles of the double – sided inductor in respect to each other are like (N – N), the expressions of the components of the magnetic field H_x in the air gaps and in the various layers of the secondary element are (1)–(5). When the poles of the double – sided inductor in respect to each other are unlike (N – S), the expressions of the components of the magnetic field H_x in the air gaps and in the various layers of the secondary element are (6)–(10).

$$H_x^{II-1}(z) = -J_m \frac{ch\lambda_3\Delta_3 ch\lambda_2(z-\Delta_3) + \Theta sh\lambda_3\Delta_3 sh\lambda_2(z-\Delta_3)}{a_1 ch\alpha\delta_1 + \beta b_1 sh\alpha\delta_1} e^{i(\omega_1 t - \alpha x)}; \qquad (1)$$

$$H_x^{II-2}(z) = -J_m \frac{ch\lambda_3\Delta_3 ch\lambda_2(z+\Delta_3) - \Theta sh\lambda_3\Delta_3 sh\lambda_2(z-\Delta_3)}{a_1 ch\alpha\delta_1 + \beta b_1 sh\alpha\delta_1} e^{i(\omega_1 t - \alpha x)}; \qquad (2)$$

$$H_x^{II-3}(z) = J_m \frac{ch\lambda_3 z}{a_1 ch\alpha\delta_1 + \beta b_1 sh\alpha\delta_1} e^{i(\omega_1 t - \alpha x)}; \qquad (3)$$

$$H_x^{III-1}(z) = -J_m \frac{\beta b_1 sh\alpha(z-\Delta_3-\Delta_1) + a_1 ch\alpha(z-\Delta_3-\Delta_1)}{a_1 ch\alpha\delta_1 + \beta b sh\alpha\delta_1} e^{i(\omega_1 t - \alpha x)}; \qquad (4)$$

$$H_x^{III-2}(z) = -J_m \frac{a_1 ch\alpha(z+\Delta_3+\Delta_1) - \beta b_1 sh\alpha(z+\Delta_3+\Delta_1)}{a_1 ch\alpha\delta_1 + \beta b_1 sh\alpha\delta_1} e^{i(\omega_1 t - \alpha x)}; \qquad (5)$$

$$H_x^{II-1}(z) = J_m \frac{sh\lambda_3\Delta_3 ch\lambda_2(z-\Delta_3) + \Theta ch\lambda_3\Delta_3 sh\lambda_2(z-\Delta_3)}{a_2 ch\alpha\delta_1 + \beta b_2 sh\alpha\delta_1} e^{i(\omega_1 t - \alpha x)}; \qquad (6)$$

$$H_x^{II-2}(z) = -J_m \frac{sh\lambda_3\Delta_3 ch\lambda_2(z+\Delta_3) - \Theta ch\lambda_3\Delta_3 sh\lambda_2(z+\Delta_3)}{a_2 ch\alpha\delta_1 + \beta b_2 sh\alpha\delta_1} e^{i(\omega_1 t - \alpha x)}; \qquad (7)$$

$$H_x^{II-3}(z) = J_m \frac{sh\lambda_3 z}{a_2 ch\alpha\delta_1 + \beta b_2 sh\alpha\delta_1} e^{i(\omega_1 t - \alpha x)}; \qquad (8)$$

$$H_x^{III-1}(z) = -J_m \frac{a_2 ch\alpha(z-\Delta_3-\Delta_1) + \beta b_2 sh\alpha(z-\Delta_3-\Delta_1)}{a_2 ch\alpha\delta_1 + \beta b_2 sh\alpha\delta_1} e^{i(\omega_1 t - \alpha x)}; \qquad (9)$$

$$H_x^{III-2}(z) = -J_m \frac{a_2 ch\alpha(z+\Delta_3+\Delta_1) - \beta b_2 sh\alpha(z+\Delta_3+\Delta_1)}{a_2 ch\alpha\delta_1 + \beta b_2 sh\alpha\delta_1} e^{i(\omega_1 t - \alpha x)}; \qquad (10)$$

where $J_m = \frac{\sqrt{2} m_1 w_1 I_1 k_{ap}}{p\tau}$ – the amplitude of the surface density of the current of the inductor; $\alpha = \pi/\tau$; $\omega_1 = 2\pi f_1$; m_1 and w_1 – the numbers of the phases and conductors of the windings; I_1 and f_1 – the effective value of the inductor current and its frequency; k_{ap} – the coefficient of the winding; p – the number of the pair of the inductor poles; τ – the pole pitch of an inductor.

The markings and formula of the coefficients $a_1, a_2, b_1, b_2, \lambda_2, \lambda_3, \beta$ and Θ in the source [1].

Results of computations

The analytical calculation in accordance with the expressions (1) – (10) in respect to the component coordinate *z* of the magnetic field H_x was carried out by means of the software package Mathcad 2001 Professional. While calculating there was applied the following:

a) – the thichness of the copper layers of the secondary element are like and equal to $\Delta_1 = \Delta_2 = 4$ mm;

b) – air gaps between the inductors and the secondary element are like and equal to $\delta_1 = \delta_2 = 2$ mm.

When following the mentioned above conditions, the calculations were made in two stages:

a) – when the thickness of the ferromagnetic band is $\Delta_3 = 2$ mm ir $\Delta_3 = 0$ mm;

b) – when the poles of the inductor in respect to each other are like (N – N) and when they are unlike (N – S).

The results of the calculations are presented in the curves representing Fig.1 – Fig.4.

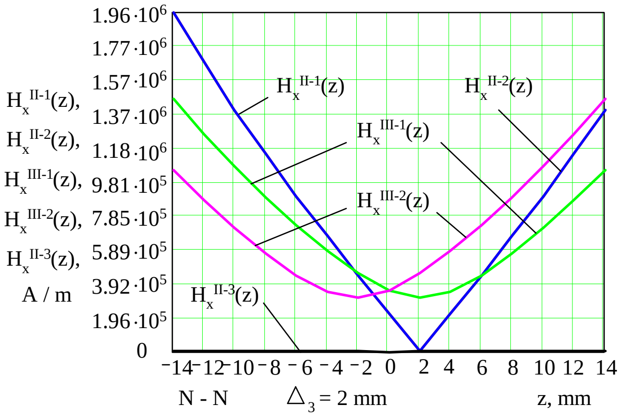

Fig. 1. Curves reflecting the change of $H_x = f(z)$ in separate layers when the poles of inductor are like (N – N) and are $\Delta_1 = \Delta_2 = 4$ mm; $\Delta_3 = 2$ mm; $\delta_1 = \delta_2 = 2$ mm

Conclusions

The conclusions are derived after summarizing the research made:

1. The calculation of the magnetic field component H_x is considered as a rather complicated one following the derived expressions of LIM having the layered secondary element and which is operating within the mode of the motor. There has to be applied the appropriate programs just for that purpose, one of them might be recommended as Mathcad 2001 Professional.
2. The derived findings of the research indicate that LIM with a layered secondary element and diverse positioning of the inductor poles as well as the structure of the magnetic field are rather complicated.

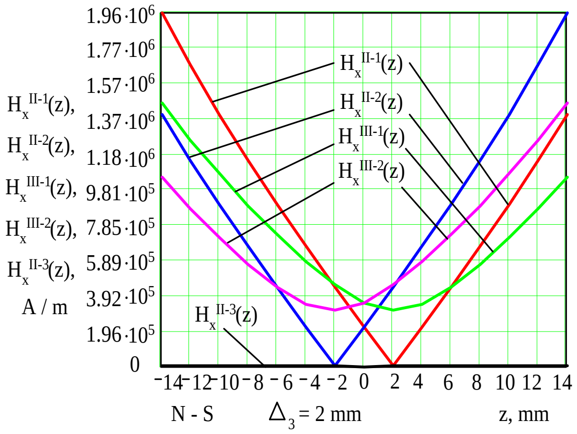

Fig. 2. Curves reflecting the change of $H_x = f(z)$ when the poles of double – sided inductor are unlike (N – S) and are $\Delta_1 = \Delta_2 = 4$ mm; $\Delta_3 = 2$ mm; $\delta_1 = \delta_2 = 2$ mm

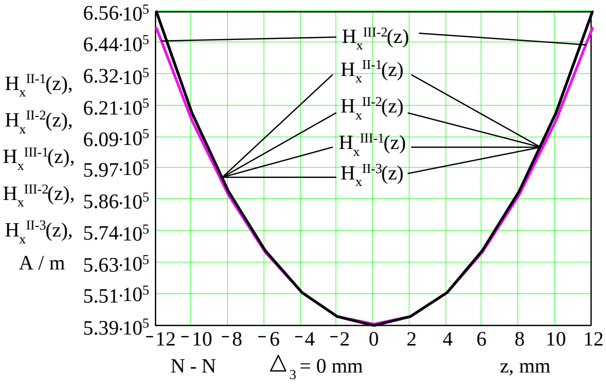

Fig. 3. Curves reflecting the change of $H_x = f(z)$ when the poles are like (N – N) and are $\Delta_1 = \Delta_2 = 4$ mm; $\Delta_3 = 0$ mm; $\delta_1 = \delta_2 = 2$ mm

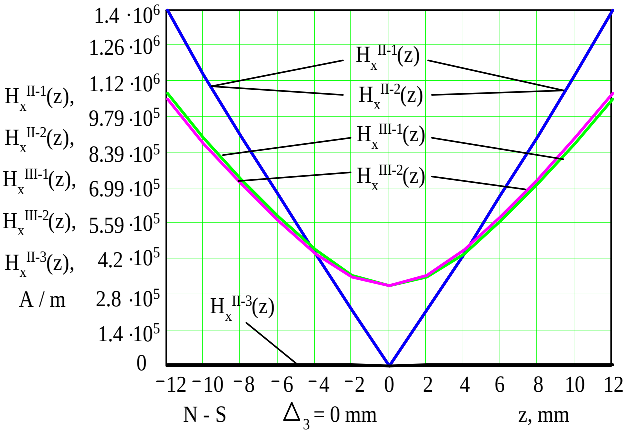

Fig. 4. Curves reflecting the change of $H_x = f(z)$ when the poles of double – sided inductor are unlike (N – S) and are $\Delta_1 = \Delta_2 = 4$ mm; $\Delta_3 = 0$ mm; $\delta_1 = \delta_2 = 2$ mm

3. From the results of calculations presented in the form of the curves in figures Fig. 1 – Fig. 4, there is derived the conclusion that the change of the magnetic fieldcomponent H_x following the coordinate z in air gaps and in separate layers of the secondary element is different.
4. The results of the research could be applied for more precise distribution of the inductor poles of the double – sided LIM for the investigation of the magnetic field research and for determining the optimal thickness of the layers of the secondary element.

References

1. **Radzevičius L., Matkevičius E.** The generalized model of the linear induction motor // Electronics and Electrical Engineering. – Kaunas: Technologija, 2006. – No. 7 (71). – P. 5–8.
2. **Radzevičius L., Matkevičius E.** Research of the characteristics of the linear induction motor // Electronics and Electrical Engineering. – Kaunas: Technologija, 2007. – No.6 (78). – P. 9–15.
3. **Matkevičius E., Radzevičius L.** Mathematical model of the linear motor // Electronics and Electrical Engineering. – Kaunas: Technologija, 2007. – No. 5(77). – P. 11–14.
4. **Radzevičius L.** Linear induction motor with a flaky secondary element. Summary of doctoral dissertation (in Russian). – Kharkov: Polytechnic Institute, 1981. – 32 p.

Submitted for publication 2008 02 11

B. Karaliūnas, E. Matkevičius, L. Radzevičius. Magnetic Field in the Air Gap of Double–sided Linear Induction Machine // Electronics and Electrical Engineering. – Kaunas: Technologija, 2008. – No. 5(85). – P. 13–16.

One of the peculiarities of the linear induction machines is that their air gap between the inductors is many times greater then the air gap in the rotating induction machines. That is why from the point of view of the magnetic field distribution in the air gap the linear induction machines differ from the rotating induction machines. The other characteristic of the linear induction machines if compared them with the rotating ones is the following. The secondary element of the linear machines differs from the rotor type torque machines in distribution of the magnetic masses. To investigate these characteristics it is necessary to extensively analyse on the basis of the corresponding linear machine model the magnetic field between the inductors of the linear machine. The mentioned above is considered to be the objective of this work.The article presents the research carried out concerning the magnetic field between the inductors of the linear machine possessing the layered secondary element with the distribution of different contrary poles. The obtained results could be applied in calculations of linear machines. Ill. 4, bibl. 4 (in English; summaries in English, Russian and Lithuanian).

Б. Каралюнас, Э. Маткявичюс, Л. Радзявичюс. Магнитное поле в воздушном зазоре двусторонней линейной асинхронной машины // Электроника и электротехника. – Каунас: Технология, 2008. – № 5(85). – С. 13–16.

Одной из особенностей линейных асинхронных машин является то, что воздушный зазор между индукторами в них во много раз больше чем воздушный зазор вращательных ассинхронных машин. Поэтому с точки зрения распределения магнитного поля в воздушном зазоре линейные ассинхронные машины отличаются от асинхронных машин вращательного движения. Другая особенность линейных машин по сравнению с вращательными машинами та, что вторичный элемент линейных машин по распределению магнитных масс отличается от вращательных машин роторного типа. Для того, чтобы исследовать эти особенности, необходимо во – первых на базе модели линейной машины подробно изучить магнитное поле между индукторами линейной машины. Это исследование и является целью настоящей работы. Представлены результаты исследования магнитного поля линейной машины с расслоенным вторичным элементом при различном распределении одноименных и разноименных полюсов индуктора. Полученные результаты могут быть использованы в расчетах линейных асинхронных машин. Ил. 4, библ. 4 (на английском языке; рефераты на английском, русском и литовском яз.).

B. Karaliūnas, E. Matkevičius, L. Radzevičius. Magnetinis laukas dvipusės tiesiaeigės asinchroninės mašinos oro tarpe // Elektronika ir elektrotechnika. – Kaunas: Technologija, 2008. – Nr. 5(85). – P. 13–16.

Vienas iš tiesiaeigių asinchroninių mašinų ypatumų yra tas, kad oro tarpas tarp jų induktorių yra daug kartų didesnis nei sukiųjų asinchroninių mašinų. Todėl magnetinio lauko pasiskirstymo oro tarpe požiūriu tiesiaeigės asinchroninės mašinos skiriasi nuo sukiųjų asinchroninių mašinų. Kitas tiesiaeigių asinchroninių mašinų, lyginant su sukiosiomis mašinomis, ypatumas tas, kad tiesiaeigių mašinų antrinis elementas pagal magnetinių masių išdėstymą skiriasi nuo rotorinių sukiųjų mašinų. Norint ištirti šiuos ypatumus, būtina, naudojantis atitinkamu tiesiaeigės mašinos modeliu, pirmiausia išsamiai ištirti magnetinį lauką tarp tiesiaeigės mašinos induktorių. Tai ir yra šio darbo tikslas. Pateikiami tiesiaeigės asinchroninės mašinos su sluoksniuotu antriniu elementu magnetinio lauko tarp induktorių su skirtingai išdėstytais priešiniais poliais tyrimų rezultatai. Gauti rezultatai gali būti panaudoti tiesiaeigių asinchroninių mašinų skaičiavimuose. Il. 4, bibl. 4 (anglų kalba; santraukos anglų, rusų ir lietuvių k.).