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Research of the Characteristics of the Linear Induction Motor

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Introduction

Nowadays it is known a lot of different types of linear induction motors (LIM) which are thoroughly analysed in resource [1]. Most of the scientific researches with linear induction motors were made when they worked in the regime of a motor. The main results of such research work are presented in [2 - 4] resources which could be named as the fundamental LIM theory. There are some attempts to join several aspects of the LIM theory into one and that will give the possibility to fulfil the comparative analyses of different types of LIM and to evaluate their peculiarities. One of the ways to succeed in the solution of this problem was the creation of the general LIM model [5, 6]. The main feature of the general LIM models that with its help it is possible to make not only the comparative analyses of the most types of LIM but also to find out the optimal type of LIM with the required characteristics. The use of such systematic methods make it possible to study The LIM more widely in the aspect of general LIM theory base.

The general LIM model is made of two flat inductors between which a secondary element (SE) is placed. SE is a ferromagnetic strip which is covered with no ferromagnetic layer from both sides that run the electric current through. There is air space between the inductors and the SE. The SE and its position between the inductors coil be symmetrical and asymmetrical. That is why the general LIM models are divided into symmetrical and asymmetrical ones.

The air span between inductors in the symmetric LIM is the same. The thickness of the no ferromagnetic layer of the SE is equal along all the length. Such kind of symmetric models are well studied by S.Yamamura and other scientists and the results of their works are presented in [2 - 4] resources.

The air gap length and the thickness of the no ferromagnetic layer of the SE in the asymmetric LIM model are different. This kind of asymmetric LIM model is well presented in [5] the scientific resource.

The difference between symmetric and asymmetric models is that the asymmetric model comparing with the symmetric one is more general and gives wider possibility for the research of different types of LIMs.

In both cases the LIMs are studied in static and the final results are presented as static characteristics. The LIM characteristics present the work of the motor in the steady regime.

The idea of this scientific article is to study the force of LIM operating along the x coordinate dependant on the SE features and the position of the inductors with the help of the general asymmetric model.

The technical features of the LIM used for the research are given in table 1.

Table 1. Technical data of LIM

No.	Title of the parameters	Marking	Value	Math units
1.	Voltage	U_1	220	V
2.	Network frequency	f_1	50	Hz
3.	Number of phases	m_1	3	-
4.	Number of coils	w_1	960	-
5.	Coefficient of windings	k_{ap}	1	-
6.	Width of inductor	2c	0,1	m
7.	Number of pair of poles	p	4	-
8.	Active resistance	r_1	2,82	Ω
9.	Inductive resistance	$x_{\sigma 1}$	5,96	Ω
10.	Length of pole	τ	0,06	m
11.	Reynolds's number	ε_2	1, 2, 3	-
12.	Reynolds's number	ε_3	1	-
13.	Magnetic permeability	μ_3	10000	-
14.	Air gap length	δ_1	0…50	mm
15.	SE thickness	Δ_1	0…50	mm
16.	SE thickness	Δ_3	0…50	mm

The calculated characteristics are made for three different no ferromagnetic SE at different Reynolds number ε_2.

All the calculations were made using the Mathcad 2001 Professional software.

The dependence of the LIM force on the features of the secondary element

The density of the equivalent layer of the current which flow in the real windings (creating the same main spatial harmonicas of magneto motive force) may be expressed by the formula [3]:

$$J_1 = \frac{3\sqrt{2} w_1 k_{ap}}{p\tau} I_1 ; \qquad (1)$$

where w_1 – is the number of windings; k_{ap} – is the coefficient of the winding; p – is the number of pole pairs; τ – length of pole; I_1 – is electric current.

The force of LIM is developed in the direction of x expressed by the formulas [6]:

$$F_x = \frac{m_1 L_{\delta 0} \alpha K_m U_1^2}{\left(r_1 - \omega_1 L_{\delta 0} K_m\right)^2 + \left(x_{\sigma 1} + \omega_1 L_{\delta 0} K_r\right)^2} ; \qquad (2)$$

$$L_{\delta 0} = \mu_0 \frac{m_1 w_1^2 k_{ap}^2 2c}{p} ; \qquad (3)$$

$$K = K_r + iK_m ; \qquad (4)$$

$$K^{NN} = \frac{a_1 sh\alpha\delta_1 + \beta b_1 ch\alpha\delta_1}{a_1 ch\alpha\delta_1 + \beta b_1 sh\alpha\delta_1} ; \qquad (5)$$

$$K^{NS} = \frac{a_2 sh\alpha\delta_1 + \beta b_2 ch\alpha\delta_1}{a_2 ch\alpha\delta_1 + \beta b_2 sh\alpha\delta_1} ; \qquad (6)$$

$$a_1 = ch\lambda_3\Delta_3 ch\lambda_2\Delta_1 + \Theta sh\lambda_3\Delta_3 sh\lambda_2\Delta_1 ; \qquad (7)$$

$$b_1 = ch\lambda_3\Delta_3 sh\lambda_2\Delta_1 + \Theta sh\lambda_3\Delta_3 ch\lambda_2\Delta_1 ; \qquad (8)$$

$$a_2 = sh\lambda_3\Delta_3 ch\lambda_2\Delta_1 + \Theta ch\lambda_3\Delta_3 sh\lambda_2\Delta_1 ; \qquad (9)$$

$$b_2 = sh\lambda_3\Delta_3 sh\lambda_2\Delta_1 + \Theta ch\lambda_3\Delta_3 ch\lambda_2\Delta_1 ; \qquad (10)$$

$$\alpha = \frac{\pi}{\tau}; \quad \beta = \frac{\alpha}{\lambda_2}; \quad \Theta = \frac{\lambda_2}{\lambda_3}\frac{\mu_3}{\mu_0}; \quad \omega_1 = 2\pi f_1 ; \qquad (11)$$

$$\lambda_2 = \alpha\sqrt{1 + i\varepsilon_2} ; \; \lambda_3 = \alpha\sqrt{1 + i\varepsilon_3} ; \qquad (12)$$

where m_1, f_1, ω_1 – U_1 is the number of phases of power supply voltage, frequency and angular frequency; w_1, k_{ap} – is the number of windings of phase coil and the coefficient of coil; $2c$ – is the width of inductors; $\mu_0 = 4\pi 10^{-7}\; H/m$ – is the magnetic permeability of void r_1, $x_{\sigma 1}$ – are the active and dispersion resistances of inductor winding; ε_2, ε_3 – are the Reynolds magnetic numbers of nonmagnetic and magnetic SE layers; $L_{\delta 0}$ – is the value having the value of inductance, K, K^{NN}, K^{NS} – are the complex coefficients, the inductance poles of which are homonymous (NN) and (NS) are opposite.

In the Fig. 1 it is shown the force dependence on δ_1 air gap length between inductors and the SE calculation results, when Δ_1 the thickness of no ferromagnetic layer is fixed and Δ_3 there is no magnetic layer.

Fig. 2 shows the graphics of the change of the force dependant on Δ_1 the thickness of the no ferromagnetic layer, if the δ_1 air gap is immutable and the Δ_3 layer is equal to nil.

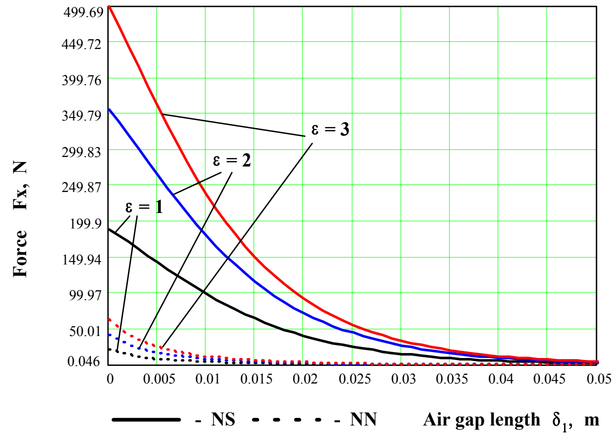

Fig. 1. The dependence of force against δ_1 air gap length: Δ_1 = 5mm, Δ_3 = 0

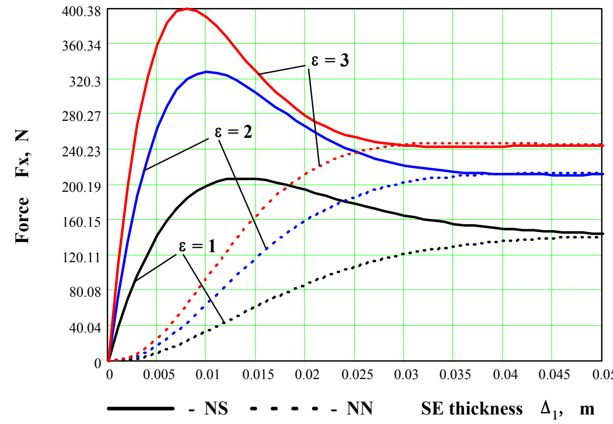

Fig. 2. The force dependence on Δ_1: δ_1 = 5 mm, Δ_3 = 0

The LIM mechanical characteristics

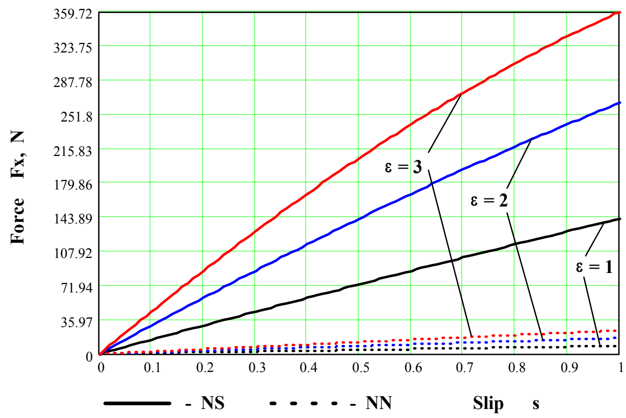

Fig. 3. The LIM force – slip characteristics: δ_1 = 5 mm, Δ_1 = 5 mm, Δ_3 = 0

In the picture Fig. 3 it is shown the calculation results of the mechanical characteristics, when the δ_1 air gap length and Δ_1 the thickness of no ferromagnetic layer is fixed and the Δ_3 layer is equal to nil.

The change of the LIM force removing the inductors

The force of the LIM could be changed by moving inductor poles relatively each other and this could be succeeded by the inductors remove. This kind of the force change is not enough studied.

The idealized model of the LIM force change, while the inductors are removed is presented in Fig. 4.

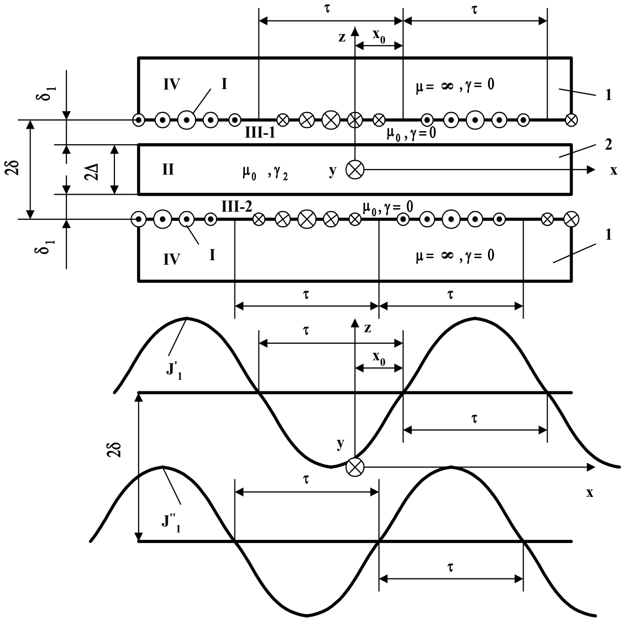

Fig. 4. The LIM force change, while the inductors are removed

Picture Fig. 5 shows that the change of force dependant on Δ_3 the thickness of the ferromagnetic layer appears even if there is a rather little layer. But the real great change appears if there is not any layer at all. That is why the change of the force by this way is possible if the SE has no ferromagnetic layer at all.

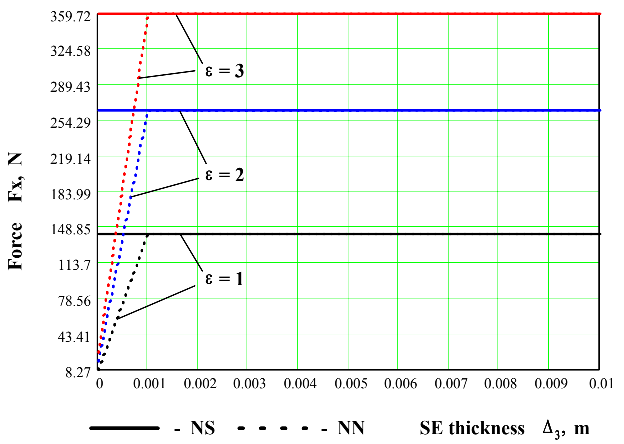

Fig. 5. The force dependence on the SE Δ_3: δ_1 = 5 mm, Δ_1 = 5 mm

To evaluate the force change when the poles are removed was implemented the force coefficient which shows the relation between the force and the location of NS and NN poles. This coefficient is calculated according to this expression:

$$K_F = \left| \frac{\left(a_2 sh\alpha\delta_1 + \beta b_2 ch\alpha\delta_1\right)\left(a_1 ch\alpha\delta_1 + \beta b_1 sh\alpha\delta_1\right)}{\left(a_2 ch\alpha\delta_1 + \beta b_2 sh\alpha\delta_1\right)\left(a_1 sh\alpha\delta_1 + \beta b_1 ch\alpha\delta_1\right)} \right|. \quad (13)$$

K_F the dependence of the force coefficient changing s sliding, when Δ_3 there is no ferromagnetic layer and δ_1 the air gap length between inductors and Δ_1 the thickness of the nonmagnetic layer is immutable is presented in Fig. 6.

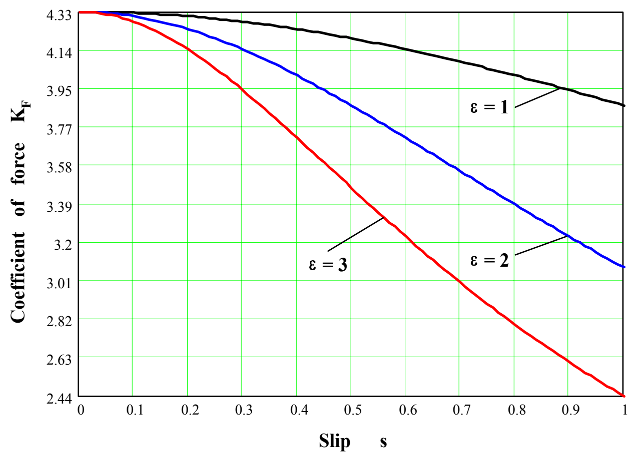

Fig. 6. The dependence of the force coefficient on the slip s: δ_1 = 5 mm, Δ_1 = 5 mm, Δ_3 = 0

Conclusions

1. While increasing the air gap between the inductors and the SE the force decreases irregularly and the intensity of the changes bigger and the Reynolds numerical evaluation is bigger too.
2. The thickness of the nonmagnetic layer of the SE has its optimal evaluation with the help of which it is possible to get the highest force of the LIM. The results of this research have practical importance and could be used in the LIM designing.
3. Increasing the thickness of the nonmagnetic layer, removing the inductors the change of the force decreases. This happens till some particular limit of the thickness of the layer and this limit decreases while increasing the Reynolds numerical evaluation.
4. Having opposite poles between the inductors (NN poles) the mechanical characteristics of the LIM are very gentle and deepened on the Reynolds numerical evaluation is very little.
5. The change of the force by the removing of the inductors is practically possible only if the SE dose not have any ferromagnetic layer.
6. This created idealized LIM model of the force change by the remove of the inductors could be used in the further research work denoting the natural change of the force in the intermediate position of the inductor poles between the limits of the NS and NN poles location.

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L. Radzevičius, E. Matkevičius. Research of the Characteristics of the Linear Induction Motor // Electronics and Electrical Engineering. – Kaunas: Technologija, 2007. – No. 6(78). – P. 9–12.

The scientific article gives the linear induction motor (LIM) characteristics research using systematic principal creating the asymmetric general mathematic LIM model. There was analysed the LIM force operating along the x coordinate dependence on the SE features and the position of the inductors at the limit state, when the poles of the inductors are opposite (NS poles) and the same ones (NN poles). It was denoted the force dependence on the air span between the inductors and the SE, the thickness of the nonmagnetic and magnetic layer of the SE. It was shown in the article that there is a particular evaluation of the thickness of the nonmagnetic layer that gives the possibility to get the higher LIM force. The change of the force by the removing of the poles of the inductors is possible only if the SE does not have any ferromagnetic layer. There was created the idealized model of the change of the LIM force by removing the inductors which could be used in the further research work denoting the natural change of the force in the intermediate position of the inductor poles between the limits of the NS and NN poles location. Ill. 6, bibl. 6 (in English, summaries in English, Russian and Lithuanian).

Л. Радзявичюс, Э. Маткявичюс. Исследование характеристик линейного асинхронного двигателя // Электроника и электротехника. – Каунас: Технология, 2007. – № 6(78). – C. 9–12.

Представлены исследования характеристик линейного асинхронного двигателя (ЛАД) на основе по системному принципу созданной несимметричной обобщенной математической модели ЛАД. Исследованы зависимости силы ЛАД, действующей в направлении x координаты, от параметров вторичного элемента (ВЭ) и взаимного положения индукторов в предельных случаях, когда полюса индукторов являются встречными (NS полюса) и одноименными (NN полюса). Установлены зависимости силы от ширины воздушного зазора между индуктором и вторичным элементом, толщиной немагнитного и магнитного слоев ВЭ. Показано, что существует некоторая толщина немагнитного слоя ВЭ, при которой можно получить максимальную силу ЛАД. Изменение силы путем перемещения полюсов индукторов возможно только при отсутсвии ферромагнитного слоя во ВЭ. Составлена идеализированная модель изменения силы ЛАД перемещением индукторов, которая может быть использована для дальнейших исследований при определении закономерностей изменения силы в промежуточных положениях индукторов между предельными NS и NN положениями. Ил. 6, библ. 6 (на английском языке; рефераты на английском, русском и литовском яз.).

L. Radzevičius, E. Matkevičius. Tiesiaeigio asinchroninio variklio charakteristikų tyrimas // Elektronika ir elektrotechnika. – Kaunas: Technologija, 2007. – Nr. 6(78). – P. 9–12.

Pateiktas tiesiaeigio asinchroninio variklio (TAV) charakteristikų tyrimas, naudojant sisteminiu principu sudarytą nesimetrinį apibendrintą TAV matematinį modelį. Ištirtos TAV jėgos, veikiančios išilgai x koordinatės, priklausomybės nuo antrinio elemento (AE) parametrų ir induktorių tarpusavio padėties ribiniais atvejais, kai induktorių poliai priešingi (NS poliai) bei vienvardžiai (NN poliai). Nustatytos jėgos priklausomybės nuo oro tarpo tarp induktoriaus ir antrinio elemento, nemagnetinio bei magnetinio AE sluoksnių storio. Parodyta, kad esant tam tikrai AE nemagnetinio sluoksnio storio vertei galima gauti didžiausią TAV jėgą. Jėgos keitimas, pastumiant induktorių polius, galimas tik tada, kai AE neturi feromagnetinio sluoksnio. Sudarytas įdealizuotas TAV jėgos keitimo, pastumiant induktorius, modelis, kuris gali būti panaudotas tolesniems tyrimams, nustatant jėgos kitimo dėsningumus tarpinėse induktorių polių padėtyse, tarp ribinių NS ir NN polių padėčių. Il. 6, bibl. 6 (anglų kalba; santraukos anglų, rusų ir lietuvių k.).