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Peculiarities of Linear Induction Machine, Operating at the Mode of Phase Regulator

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Introduction

One of the characteristics that hasn't been discussed so far regarding a linear induction machine (LIM) [1] is the characteristics of its operating mode to be similar to the mode of a linear phase regulator (LPR). The scientific publications haven't analyzed these issues yet.

In contract to rotating asynchronous machines they signify themselves by specific characteristics which particularly are distinguished when a LIM operates at the mode of a phase regulator.

The objective of the work is to introduce to the scientific society a LIM operating at the mode of a LPR, and exhibit the peculiarities as well as the results of the research carried out by the authors of the article.

The operation of rotational asynchronous machines at the mode of a phase regulator is known following the theory of classical electric machines. The results received on the theory of the fundamentals could be applied only to the infinitely long LIM having the size of an air gap typical for rotational machines. The operation of a LIM, possessing the finite length and width, and functioning at the linear phase regulator mode, differs from the rotational phase regulator regarding the magnetic system of a LIM which is nonsymmetrical and the air gap is significantly wider. The characteristics and magnetic fields of a LIM operating at the mode of a linear motor are analyzed on the list of publications [2]. In order the results of the research to be applied for wider variety of LIM structures, the characteristics of a LPR are required to be investigated on the basis of the summarized mathematical model.

Generalized mathematical model of LIM

The authors present the generalized model of a LIM with a double – sided inductor found on the list of publications indicated [3]. The operation of a LIM at the mode of a motor by changing the in – between position of the inductors is analyzed on the list of [2]. Fig. 1 presents the positioning of the magnetic poles of a linear motor by changing the in – between position of the inductors.

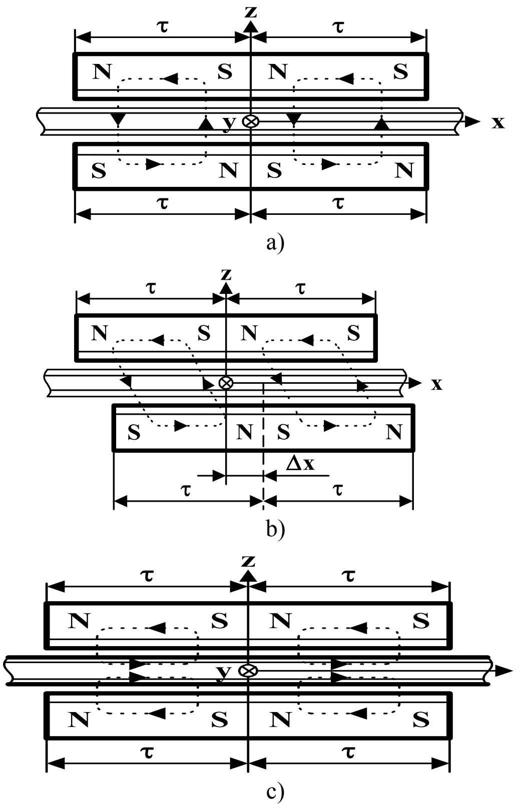

Fig. 1. Positioning of magnetic poles, by changing in – between the position of inductors: a – unlike poles (N – S); b – shifting of poles after changing the position of the inductors within the distance of Δx ; c – like poles (N – N)

The authors in this work investigated a LIM, at the operational mode of a phase regulator, and the characteristics were analyzed at the basis of that particular model. That made it possible for the authors to apply the mathematical expressions and to adapt them as they were obtained on the basis of the model obtained. In the indicated model presented on the list of publications [3] the thickness of the layered secondary element as well as both the air gaps between the inductors are not assessed. That means $\delta_1 = \delta_2 = \Delta_2 = \Delta_3 = 0$, or it is equal to a LIM version without the secondary element and without the air gap between the inductors.

If we connect the windings of the first double – sided inductor to the source of voltage (active inductor), and the second inductor with the windings (passive inductor) we shift in respect to the first within the boundaries of the double pole pitch 2τ, then we could get the operation of a LIM at the mode of a phase regulator. Such an operation of a LPR is illustrated by Fig. 2 presenting the scheme of a LIM.

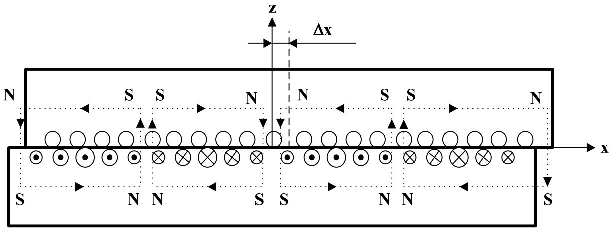

Fig. 2. LIM operating at the mode of a LPR without the secondary element and the distribution of the magnetic poles, when the inductors are shifted within the distance Δx

Fig. 2 indicates that both the inductive resistances of separate phases of the three phase inductor and at the same time the inductance of different phases are different.

In case of an ideal LPR, when the voltage drop and power losses are rejected, the diagram of the vectors of the voltages of a regulator with infinitely active zone and that of the electromotive forces are presented in Fig. 3.

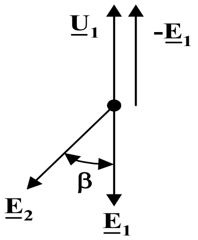

Fig. 3. Vectors diagram of an ideal LPR of voltages and electromotive forces

Fig. 3 indicates the following: $\underline{U}_1$ and $\underline{E}_1$ are both the vectors of the active inductor of phase voltage and electromotive force; $\underline{E}_2$ is the vector of the secondary electromotive force of the passive inductor; β is a phase angle between vectors $\underline{E}_1$ and $\underline{E}_2$.

If the finite length of LPR is assessed, then because of the change of the magnetic circuit, the size of the electromotive force $\underline{E}_2$ as well as its phase β is changed. In case to have one more assessment regarding the active and reactive losses of the active inductor ($r_1 \neq 0$; $x_{\sigma 1} \neq 0$), then the given diagram turns to be more complicated.

The results of the experimental research

To investigate the characteristics of the real LFR, the real variant of the regulator was analyzed experimentally, the parameters of which are the following:

- length of the inductor is $L = 200\ mm$;
- number of pairs of the inductor poles $p = 2$;
- pole pitch $\tau = 48\ mm$;
- number of windings in the phase W_1=190;
- inductor winding is three – phased, single – layered and concentrated.

To have the research, the windings of the active inductor (Fig. 2) were connected to the source of voltage, the passive inductor with windings was shifted in respect to the lactive by every 5 mm within the boundaries of the double pole pitch 2τ, i. e. from 0 to 96 mm. There were measured the phase supply voltages of the active inductor, phase currents and the active powers as well as the secondary electromotive forces induced in the phases of the passive inductor.

Following the data of the tests there were calculated the transformation coefficients for each phase of a LPR by means of the expressions:

$$k_{trA} = \frac{E_{2A}}{U_A}, \quad k_{trB} = \frac{E_{2B}}{U_B}, \quad k_{trC} = \frac{E_{2C}}{U_C}. \qquad (1)$$

where U_A, U_B and U_C – supply voltages of the active inductor phases *A, B* and *C*; E_{2A}, E_{2B} and E_{2C} – the induced secondary electromotive forces in the passive inductor phases *A, B* and *C*.

In Fig. 4 there are presented the dependencies of the transformation coefficients of a LPR on the relative shift value x/τ of the inductors.

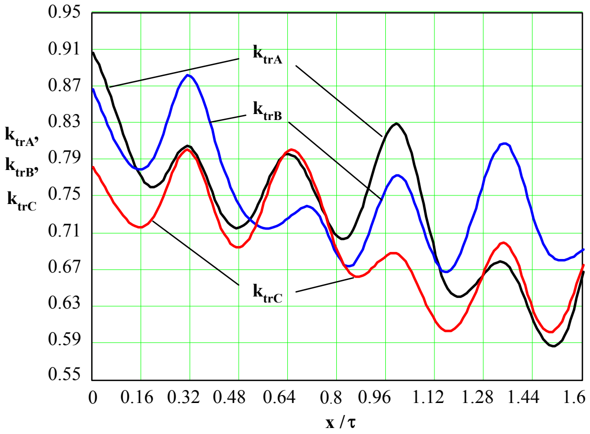

Fig. 4. Dependencies of the transformation coefficients on the relative shift x/τ of the inductors

Fig. 5 presents the variation of the active inductor currents in all the three phases when shifting the inductors in respect to each other. The dependencies of the active power of the phases of the active inductor on the relative shift value x/τ are submitted in Fig .6. The diagrams of the variations of the electromotive forces induced in the windings of the passive inductor are presented in Fig. 7.

Periodically changeable (wavy) character of the indicated curves there are describe the influence of the teeth of inductors, when shifting them in respect to each other.

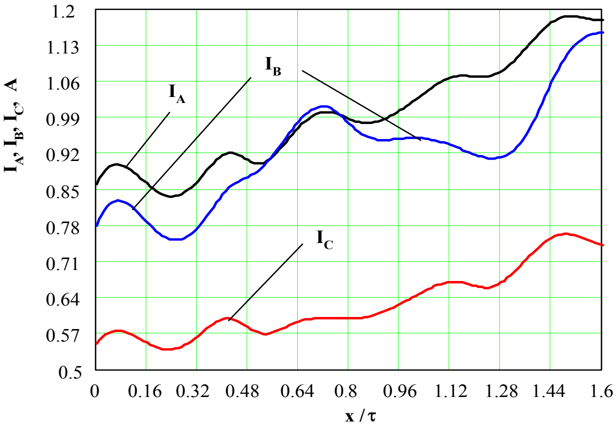

Fig. 5. Variation of the currents of the active inductor when shifting the inductors in respect to each other within the boundaries of a double pole pitch

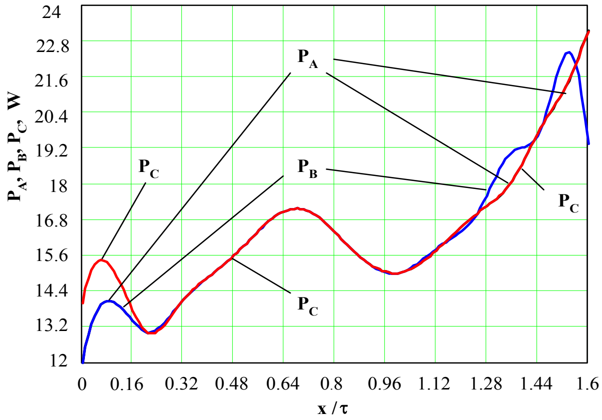

Fig. 6. Dependencies of the power of the active inductor on the relative shifting x/τ of the inductors

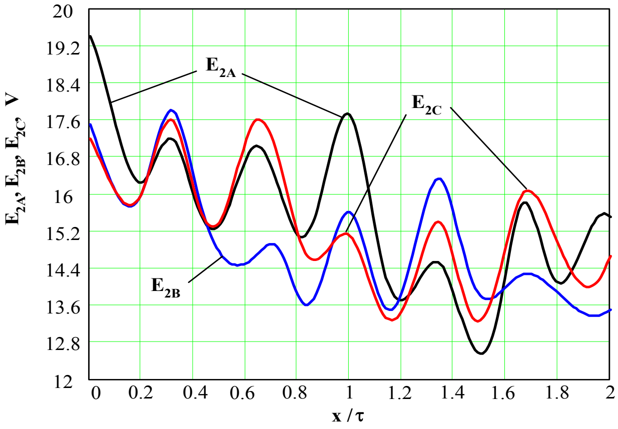

Fig. 7. Diagrams of variations of phase electromotive forces induced in the windings of the passive inductor

From the curves presented on the diagrams in Fig. 4 – Fig. 7 there are obtained the parameters of a LPR by the experimental method, when shifting the inductors in respect to each other within the distance of the double pole pitch. The obtained parameters vary and the variations determined are registered within the following boundaries:

- transformation coefficients from 0,91 to 0,59;
- currents in the phases from 0,54 A to 1,40 A;
- active powers of phases from 12 W to 23 W;
- induced electromotive forces from 19,4 V to 12,6 V.

There is pointed out the following, namely, in case of the ideal mathematical model of a LIM presented on the list of publications [3], having the inductors of the infinite length, the case of a LPR is derived, the operation of which is described by the diagram of vectors of voltages and electromotive forces presented in Fig.3. In case of a real LPR the diagram has to be adjusted taking into consideration the determined experimental data. The adequate LPR schemes are favorable to be applied in this case, but because of the limited space in this article the issues haven't been covered in a detailed way here.

Conclusions

The conclusions derived by means of the research are the following:

1. The characteristics of a LPR significantly differ from the characteristics of rotational phase regulators analyzed in the classical theory of electric machinery.
2. When a LIM having two flat inductors is operating under the mode of a phase regulator, the transformation coefficients of all the three phases are not constant and when shifting one inductor in respect to the other inductor, they are periodically getting lower, the induced electromotive forces are reduced as well.
3. The currents of phases and powers of a LIM operating at the mode of a phase regulator, when shifting the inductors are approaching to the values of one of inductors having an idle mode of operation.
4. The method of three transformation coefficients and the adequate schemes are suggested to be applied for the investigation of the operation and the characteristics of LPR.

References

1. **Yamamura S.** Theory of Linear Induction Motors (in Russian). Leningrad: Energoatomizdat, 1983. – P.180.
2. **Karaliūnas B., Matkevičius E., Radzevičius L.** 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.
3. **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.

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The article deals with the characteristics of the linear induction machines (LIM) with two flat inductors operating at the mode of a linear phase regulator (LPR). The mode is executed when shifting one inductor respect to the other within the boundaries of the double pole pitch. There are submitted the results of the experimental and theoretical research concerning LIMs as the linear phase regulator, when one inductor is connected to the source of the voltage and operates at the mode of the stator while the other operates at the mode of the stopping secondary element. There were determined the curves of the variations of the transformation coefficients between the windings of the both inductors, as well as the dependencies of the phase currents, powers and induced electromotive forces on the relative shifting of the inductors. The results received are presented for the first time. The recommendations are worked out for the further investigations on the linear phase regulator to be continued and to be applied with the method of three transformation coefficients and adequate schemes. Ill. 7, bibl. 3 (in English; summaries in English, Russian and Lithuanian).

Б. Каралюнас, Э. Маткявичюс, Л. Радзявичюс. Особенности линейной асинхронной машины, работающей в режиме фазорегулятора // Электроника и электротехника. – Каунас: Технология, 2009. – № 4(92). – С. 83–86.

В статье рассматриваются свойства линейной асинхронной машины (ЛАМ) с двумя плоскими индукторами, работающей в режиме линейного фазорегулятора. Такой режим получается при перемещении в пределах двойного полюсного деления одного индуктора относительно другого. Представлены результаты теоретического и экспериментального исследования ЛАМ как линейного фазорегулятора, когда один из индукторов подключен к источнику напряжения и работает в режиме плоского статора, а другой – в режиме заторможенного вторичного элемента. Получены кривые изменения коэффициентов трасформации между обмотками обоих индукторов, а также кривые изменения фазных токов, мощностей и индуцированных электродвижущих сил в зависимости от относительного перемещения индукторов. Результаты исследований такого рода представляются впервые. Для дальнейших исследований линейного фазорегулятора рекомендуется применять метод трех коэффициентов трансформации и эквивалентные схемы. Ил. 7, библ. 3 (на английском языке; рефераты на английском, русском и литовском яз.).

B. Karaliūnas, E. Matkevičius, L. Radzevičius. Tiesiaeigės asinchroninės mašinos, veikiančios fazės reguliatoriaus režimu, ypatumai // Elektronika ir elektrotechnika. – Kaunas: Technologija, 2009. – Nr. 4(92). – P. 83–86.

Straipsnyje nagrinėjamos tiesiaeigės asinchroninės mašinos (TAM) su dviem plokščiaisiais induktoriais savybės. Mašina veikia tiesinio fazės reguliatoriaus (TFR) režimu. Toks režimas sudaromas dvigubu poliaus žingsniu vieną induktorių perstumiant kito induktoriaus atžvilgiu. Pateikiami TAM, kaip tiesinio fazės reguliatoriaus, kai vienas induktorius prijungtas prie įtampos šaltinio ir veikia statoriaus, o kitas – sustabdyto antrinio elemento režimu, teorinio ir eksperimentinio tyrimo rezultatai. Gautos transformacijos tarp abiejų induktorių apvijų koeficientų kitimo kreivės, taip pat fazinių srovių ir galių bei indukuotų elektrovarų priklausomybės nuo santykinio induktorių perstūmimo. Tokie tyrimo rezultatai pateikiami pirmą kartą. Tolesniems tiesinio fazės reguliatoriaus tyrimams rekomenduojama taikyti trijų transformacijos koeficientų metodą ir ekvivalentines schemas. Il. 7, bibl. 3 (anglų kalba; santraukos anglų, rusų ir lietuvių k.).