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The Experimental Research of the Linear Motor

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Introduction

When designing electric drives using linear electromagnetic motors (LEM), it is necessary to have mathematical model of the motor which allows calculating static and dynamic operating modes of the drive.

Experimental research of the linear electromagnetic motor is a complicated task requiring use of special experimental equipment [1]. In order to calculate static characteristics for the linear electromagnetic motor with heterogeneous armature it is necessary to determine conductivity and its derivative with respect to the position, and then to calculate dependence of the electromagnetic force on the position [2].

Table 1. Parameters of the motor's physical model

Item	Parameter name	Symbol	Value	Unit
1.	Pole height	a_c	15	mm
2.	Pole width	b_c	14.5	mm
3.	Tooth height	a_z	15	mm
4.	Tooth width	b_z	15	mm
5.	Tooth thickness	2Δ	16	mm
6.	Tooth pitch	b_t	15	mm
7.	Air gap	δ	1.1	mm
8.	Number of induction coils	S_R	3	vnt.
9.	Number of coils	w	2200	-
10.	Wire diameter	d	0.04	mm
11.	Coil resistance	R	32.7	Ω

Physical model of the motor was experimentally analyzed in order to elaborate an idealized dynamic mathematical model of the defined linear electromagnetic motor [3]. Dependence of the interlinked magnetic flux $\Psi(x)$ and inductance $L(x)$ on the position of the secondary element, at different supply voltages, was experimentally analyzed, a well as dependence of the interlinked magnetic flux on the current i, with fixed position of the secondary element (SE) ($x = const$), and dependence of the traction force $F(x)$ on the position of the secondary element, at different supply voltages. In order to carry out experimental researches a physical model of the linear electromagnetic motor was used with the parameters specified in Table 1, which were used to obtain approximation of the inductance change curve and to develop the mathematical model [4].

The goal of this article is to define experimentally dependence of the linear electromagnetic motor parameters on the secondary element position.

Dependence of the interlinked magnetic flux on the position, at different supply voltages

Static state of the electromagnetic motor is obtained by switching on the excitation current and mechanically securing the secondary element with respect to the stator poles. A coil of 0.15 mm diameter copper wire with ten windings is wound on one magnetic circuit pole of the stator to measure interlinked magnetic flux by milliwebermeter. Experimental family of static characteristics reflecting dependence of the interlinked magnetic flux Ψ on the position x of the secondary element, at different supply voltages (currents), is shown in Fig. 1.

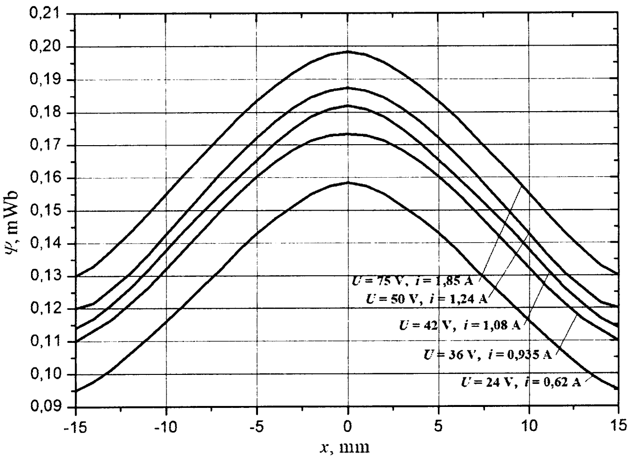

Fig. 1. Dependence of the interlinked magnetic flux on the position of the secondary element

It can be seen from the curves of Fig. 1 that the function $\Psi(x)$ has periodic character at different voltages.

Dependence of the interlinked magnetic flux on the current

Dependence of the interlinked magnetic flux on the current, with fixed position of the secondary element and 24 V supply voltage was experimentally explored. The same coil and milliwebermeter was used for the measurements. Obtained results are shown in Fig. 2.

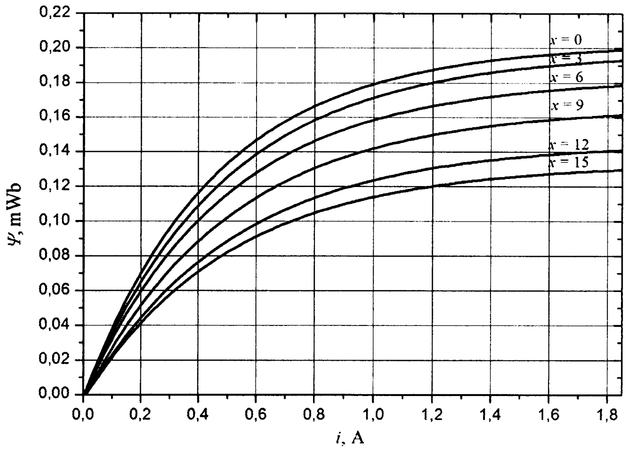

Fig. 2. Dependence of the interlinked magnetic flux on the current

It can be seen from the curves of Fig. 2 that almost linear dependence of the interlinked magnetic flux on the current is recorded in the range of operating currents (up to 0.4 A). It is possible to assume on the basis of the experimental data obtained that in the range of operating currents the inductance of the excitation coil depends only on the position of the secondary element and only slightly depends on the current, therefore the following dependence is valid:

$$\Psi = L(x) \cdot i. \quad (1)$$

Dependence of the inductance on the position, at different supply voltages

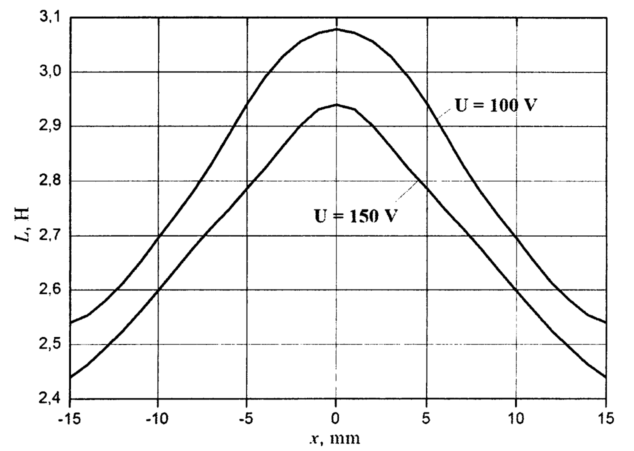

Fig. 3. Dependence of the inductance on the position, at 100 V and 150 V supply voltages

Expression of useful motor traction force along the coordinate *x* can be obtained using the electromechanical energy conversion theory [5–8]. According to this theory, it is necessary to know the function of changing of the motor inductance with respect to the coordinate *x*. After experimental tests with a physical model of the linear motor, the main parameters of which are specified in Table 1, the change of the motor excitation coil inductance shown in Fig. 3 was determined.

Experimental curve can be approximated by this formula with the accuracy sufficient for engineering calculations:

$$L(x) = L_0 + L_m \cdot \cos\frac{2\pi}{\tau} x\,, \ -b \le x \le b\ ; \quad (2)$$

$$L_0 = \frac{L_1 + L_2}{2}\,; \quad (3)$$

$$L_m = \frac{L_1 - L_2}{2}\,; \quad (4)$$

here L_0, L_m – amplitude of fixed and variable component of the excitation coil inductance; L_1, L_2 – values of the excitation coil inductances when the coil pole is located in the middle of the tooth and the middle of the tooth pitch; $\tau = 2 \cdot b$ – pole pitch of the toothed secondary element; b – the width between the similar tooth and spans of the secondary element.

Graph of the inductance change is shown in Fig. 4.

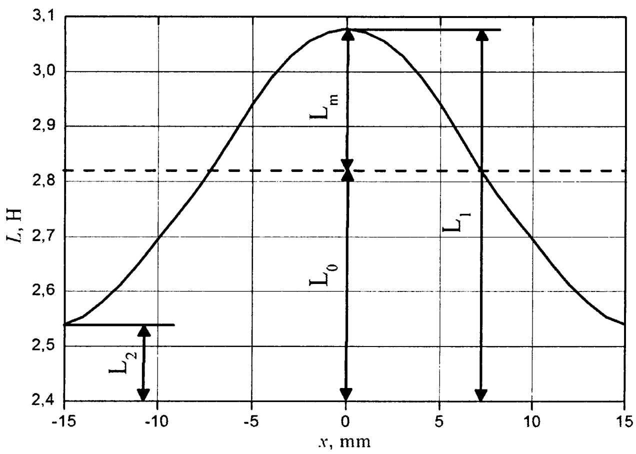

Fig. 4. Graph of the inductance change, at 100 V DC supply voltage

Dependence of the traction force on the position

Dependence of the motor traction on fixed position of the secondary element can also be regarded as static characteristics [9–11]. The force generated by one excitation coil is measured in this case, securing the position of the secondary element each 1 mm. The results obtained are shown in Fig. 5.

It can be seen from Fig. 5 that the motor traction force is decreasing markedly approaching to the pole edge since magnetic link between the pole of the electric magnet and the secondary element is lost. If supply voltage of the linear electromagnetic motor is changed, the motor traction force is also changing; therefore it is possible to develop a desired law of the summary motor traction force change meeting specific requirements of the technological process, choosing certain values of the supply voltages of separate motor windings due to this reason.

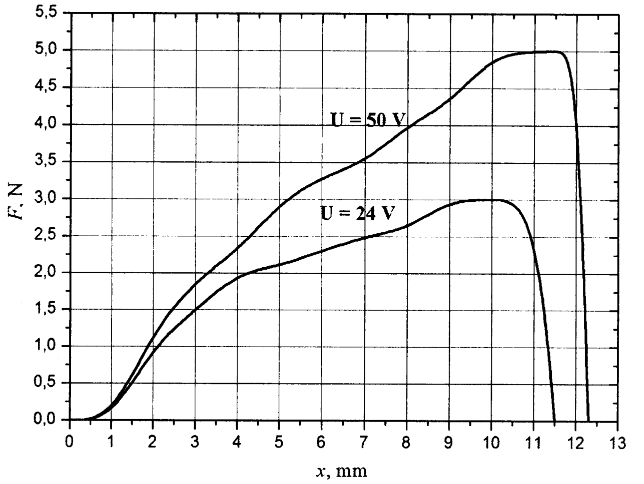

Fig. 5. Dependence of the traction force on the position of the secondary element, at 24 and 50 V supply voltages

Conclusions

1. Linear electromagnetic motor was experimentally examined and dependence relations of the interlinked magnetic flux, inductance and traction force on the position of the secondary element, at different supply voltages of the motor, were obtained.
2. The law of changes of the linear motor inductance was examined and the mathematical expression of the approximation of this law was obtained.
3. Approximate linear relationship between the interlinked magnetic flux and the current is maintained in the range of operating currents (up to 0.4 A), and due to this we can regard inductance as being independent from the current.
4. It is possible to develop a desired law of the summary motor traction force change meeting specific requirements of the technological process, choosing certain values of the supply voltages of separate motor windings.
5. It can be seen from the relationship between interlinked magnetic flux and the graph of the secondary element position that the density of magnetic flux decreases at the ends of the magnetic circuit poles. This means that with approaching of the secondary element to the middle of the magnetic circuit poles, decreasing portion of interlinked magnetic flux is locked in the air.

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The results of experimental researches of the linear electromagnetic motor in the form of graphs are presented. Dependence of the interlinked magnetic flux and inductance on the position of the secondary element, at different supply voltages of the motor, was obtained. Also, dependence of the interlinked magnetic flux on the current, with fixed position of the secondary element, and dependence of the traction force on the position of the secondary element, at different supply voltages, were obtained. On the basis of experimental diagrams the laws of changes of the relationships were established. The relationship between the change of the motor excitation coil inductance and the shift along the coordinate *x*, which can be approximated by analytical expression with the accuracy sufficient for engineering calculations, was established. The formula of the inductance change was obtained, with the presumption that magnetic system of the motor is not saturated and no magnetic link exists between the coils. After a number of experiments the conclusions were made defining dependences of the electromagnetic parameters of the linear electromagnetic motor on the position of the secondary element. When designing electric drives using linear electromagnetic motors (LEM), it is necessary to have mathematical model of the motor which allows calculating static and dynamic operating modes of the drive. Mathematical model takes into account static load of the motor and load components, which are dependent on the shift along the coordinate *x* and speed, and therefore can be used to examine the drives with the linear motors. Il. 5, bibl. 11 (in English; the summaries in English, Russian and Lithuanian).

М. Молис, Э. Маткявичюс, Л. Радзявичюс. Экспериментальное исследование линейного двигателя // Электроника и электротехника. – Каунас: Технология, 2008. – № 7(87). – С. 57–60.

Представлены экспериментальные результаты исследования линейного электромагнитного двигателя в графическом виде. Экспериментально исследованы зависимости магнитного потока, индуктивности от положения вторичного элемента, при различных напряжениях питания, а также зависимость магнитного потока от силы тока, при фиксированном положении вторичного элемента и зависимость силы тяги от положения вторичного элемента, при различных напряжениях питания. Следуя из экспериментальных графиков, установлены законы изменения зависимостей. Установлен закон изменения индуктивности катушки возбуждения двигателя в зависимости от перемещения вдоль координаты x, который с приемлемой для инженерной практики точностью, аппроксимируется аналитическим выражением. Формула изменения индуктивности получена при допущении, что магнитная система ненасыщена и между отдельными катушками двигателя нет магнитной связи. Выполнив ряд экспериментов, получены выводы, характеризующие зависимость электромагнитных параметров линейного электромагнитного двигателя от положения вторичного элемента. Проектируя электроприводы, в которых используются линейные электромагнитные двигатели необходимо иметь математическую модель, которая предоставляет возможность подсчёта статических и динамических режимов работы привода. Математическая модель учитывает статическую нагрузку, а также составляющие нагрузки двигателя, зависящие от перемещения вдоль координаты x и скорости, поэтому модель может быть использована для исследования приводов с линейными двигателями. Ил. 5, библ. 11 (на английском языке; рефераты на английском, русском и литовском яз.).

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Grafikų pavidalu pateikiami tiesiaeigio elektromagnetinio variklio eksperimentinių tyrimų rezultatai. Eksperimentiškai ištirta magnetinio srauto ir induktyvumo priklausomybė nuo antrinio elemento padėties, esant skirtingoms maitinimo įtampoms, taip pat magnetinio srauto priklausomybė nuo srovės, esant fiksuotai antrinio elemento padėčiai, bei traukos jėgos priklausomybė nuo antrinio elemento padėties, esant skirtingoms maitinimo įtampoms. Pagal eksperimentinius grafikus nustatyti priklausomybių kitimo dėsniai. Nustatytas variklio žadinimo ritės induktyvumo kitimo priklausomai nuo poslinkio išilgai x koordinatės dėsnis, kuris inžinerinei praktikai pakankamu tikslumu aproksimuojamas analitine išraiška. Induktyvumo kitimo formulė gauta darant prielaidą, kad variklio magnetinė sistema neįsotinta ir tarp ričių nėra magnetinio ryšio. Atlikus keletą eksperimentų, gautos išvados, apibūdinančios tiesiaeigio elektromagnetinio variklio elektromagnetinių parametrų priklausomybes nuo antrinio elemento padėties. Projektuojant elektros pavaras, kuriose naudojami tiesiaeigiai elektromagnetiniai varikliai, būtina turėti variklio matematinį modelį, kuris leistų apskaičiuoti statinius ir dinaminius pavaros darbo režimus. Matematinis modelis įvertina variklio statinę apkrovą bei apkrovos dedamąsias, priklausančias nuo poslinkio išilgai x koordinatės ir greičio, todėl gali būti naudojamas pavaroms su tiesiaeigiais varikliais tirti. Il.5, bibl. 11 (anglų kalba; santraukos anglų, rusų ir lietuvių k.).