ELECTRONICS AND ELECTRICAL ENGINEERING
ISSN 1392 – 1215 2008. No. 1(81)
ELEKTRONIKA IR ELEKTROTECHNIKA

T 190 ELECTRICAL ENGINEERING
ELEKTROS INŽINERIJA

Research on Electric and Magnetic Asymmetry of Linear and Arc Motors

B. Karaliūnas
Department of Automation, Vilnius Gediminas technical university,
Naugarduko str. 41, LT-03227 Vilnius, Lithuania, phone: +370 274 50 63, e-mail: bronius.karaliunas@el.vgtu.lt

Introduction

The main disadvantage of linear and arc induction motors greatly limiting their wider usage in modern technologies is the longitudinal and transverse edge effect [1]. Due to their influence on the three – phase motors there is formed inner electric and magnetic asymmetry. Although such type of motors are integrated into the symmetric network or are supplied power from the symmetric three – phase source, but in reality they are dissymmetrical electromechanical energy converters. The mentioned above asymmetry aggravates the calculation of the characteristics of such converters and complicates the implementation of microprocessors and computers to be applied for their control [2].

The techniques for calculation linear, arc and liquid metal magnet – hydrodynamic pumps [3, 4] were compiled and applied long ago. Their inner asymmetry is not taken into consideration but the assumption is made, that the mentioned converters have to be alternating – current supply from the symmetric three – phase current sourse. The influence of the edges effects on such technologies is evaluated by the brought in resistances of the resultant scheme as well as by the coefficients of correction. The data results of the experiments accumulated by some authors [5, 6, 7] state that by powering these motors from the symmetric source of the voltage, the obtained calculation might give diversity of 30% varying from the results received after having applied methods of calculation.

The objective of the research is to investigate the magnetic field structure of linear and arc motors to be as inner asymmetry in oder to be able to predict possible means and measures of its compensation.

Data of experimental motors

Some dipolar (p = 1,0) linear and arc motors have been experimentally researched under a special testing – bench with three non – ferrous secondary elements of variable width: the width of the first element is 64 mm, the second is 104 mm, the third is 104 mm, but with transversal gaps. Three – phase dipolar inductors differed by the number of windings and the cross – section of the wire, they have been alternating – current supply by symmetric voltage sources of 50 Hz and 400 Hz frequency.

The diagram for connecting the windings of a three – phase inductor when the number of slots per pole and phase is q = 1,0, is presented in Fig. 1.

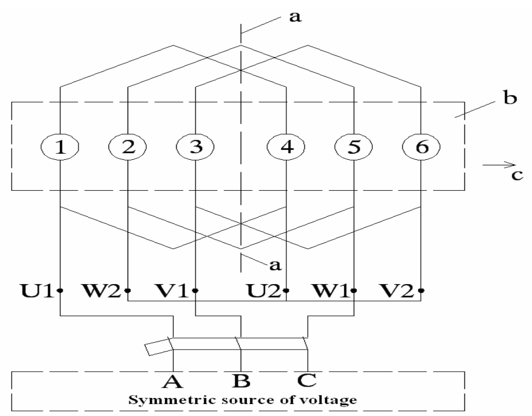


Fig.1. The scheme for connecting inductor windings: a – a is a transversal axis of the inductor; b – is an open magnetic core; c – is direction of movement of the secondary element

Fig. 1 presents the phenomenon when the axis of the medium winding W1 – W2 coincides with the transversal axis of the inductor a – a. That is why its conductors are located symmetrically in respect to the ends of the magnetic core b. The symmetry axis of the winding U1 – U2 in respect to the transversal axis a – a of the inductor is shifted against the direction c of movement of the secondary element within 60 electric degrees. The third winding V1 – V2 in respect to the transversal axis a – a is shifted towards the direction c of the secondary element by the same number of degrees.

Results of carried out tests

During the time of experimenting there were measured phase voltages U_u, U_w, U_v and currents I_u, I_w, I_v, active power P, starting power F and distribution of magnetic flux density B_δ within the air gap along the longitudinal axis L of the inductor. Then there were calculated complete power S, relative power F/P and F/S and currents of inverse sequence, using the technique of symmetric components. The results of tests and calculations are presented in Table 1, the curves of magnetic flux density are presented in Fig. 2.

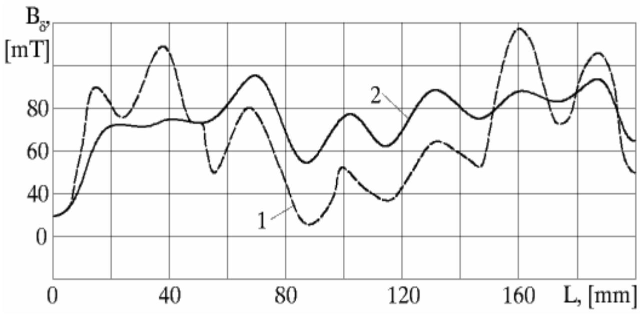


Fig. 2. Magnetic flux density distribution within the air gap of the motor when U = 200 V, 400 Hz and the secondary element I: 1 – without the means of compensation; 2 – with a shortly connected loop

The notes of Table 1 include the following markings: WMC – is a test without using the means of compensation; SC – is symmetrizing of electric circuit by applying capacitors; SCL – are tests with a shortly connected loop.

The data of the tests indicate that the currents of the inductor phases signify themselves by electric asymmetry creating currents of the inverse sequence, the value of which may comprise up to 10 – 30 % of the direct sequence currents. When carrying out test No.7 (see Table 1.), to each phase of the inductor there were connected capacitors of uneven capacity in series. This measure completely deletes the currents of the inverse sequence but it is unable to compensate the component of a fluctuacting magnetic field.

Magnetic field simulation

In order to have a more vivid view on the inner asymmetry of linear and arc motors it is necessary to carry out the magnetic field simulation within the whole magnetic circuit of the motor.

In a general case according to the law of energy exchange the electromagnetic force of the motor may be calculated in the following way:

$$F_{el} = -\frac{dW_m}{dx}; \quad (1)$$

where W_m – is magnetic field energy in the motor; *x* – is a longitudinal coordinate of the motor.

On the other side the electromagnetic force of the motor also depends on the angle θ of the inductor turn in respect to the axis perpendicular to its active zone:

$$F_{el} = k_w BA \cos\psi \cos\theta; \quad (2)$$

where k_w – is the coefficient of the inductor winding; *B* – is average value of the magnetic flux; *A* – is linear current load of the inductor; ψ – is the angle of differences of phases between the electromotive force of the secondary element and of the current vectors.

(1) and (2) expressions indicate that electromagnetic force depends not only on the magnetic field energy created in the motor but on the magnetic flux density distribution character in the air gap of the motor. That is why in order to provide the optimum sine distribution of the flux and reduce hazardous influence of the edges effects it is required to investigate the structure of the magnetic field of the motor.

In simulating magnetic field it is useful to make use of the generalized value – magnetic vector potential:

$$\mathbf{A} = \mathbf{i}A_x + \mathbf{j}A_y + \mathbf{k}A_z; \quad (3)$$

where **i, j, k** – are the orts of Descartes system of coordinates; A_x,, A_y, A_z – are on the axes *x, y, z* of vector potential projection.

The correspondence with two dimensional magnetic field flux density **B** is based on the following dependence:

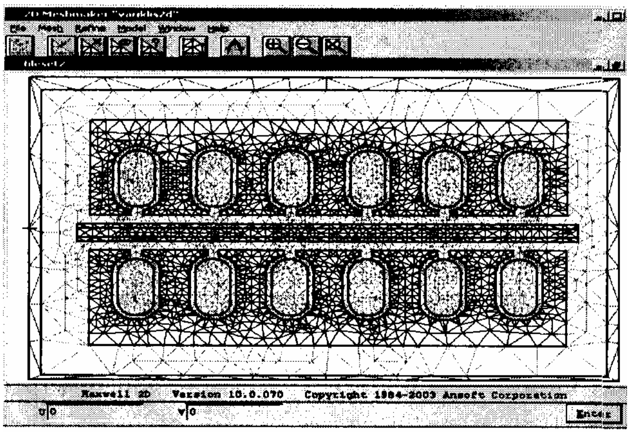
$$\mathbf{B} = \text{rot}\,\mathbf{A} = \mathbf{i}\frac{\partial A_z}{\partial y} - \mathbf{j}\frac{\partial A_z}{\partial x}; \quad (4)$$

Table 1. Data of the tests and calculations

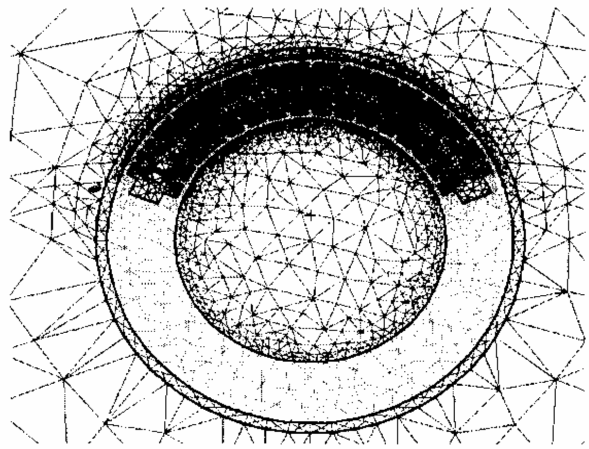
Test No.	Voltage, frequence	Secondary element	Currents, [A]			F/P, [N/kW]	F/S, [N/kVA]	Currents of inverse sequence, [%]	Notes
			I_u	I_w	I_v				
1	220 [V], 50 [Hz}	I	0,99	0,74	0,97	51,4	14,2	19,2	WMC
2		II	3,80	3,12	3,71	48,3	14.0	16,4	
3		III	3,22	2,61	3,05	54,5	18,4	15,2	
4	200 [V], 400 [Hz]	I	4,81	3,75	4,83	10,2	4,14	15,9	WMC
5		II	7,20	5,79	7,10	9,10	4,14	12,1	
6		III	6,05	4,96	5,82	12,7	7,38	11,7	
7	200 [V], 400 [Hz]	I	5,60	5,60	5,60	11,5	5,76	0	SC
8		I	4,70	3,90	4,70	10,1	4,34	11,1	SCL
9		II	7,10	6,22	7,24	9,45	4,.44	11,7	
10		III	6,10	5,02	5,55	13,2	7,62	11,7	

where A_z is normal component of the vector potential .

For the magnetic field simulation of motors there have been used the software package Maxwell SV 9.0 of the company ,,Ansoft". The software has been compiled by means of finite elements by attaching to certain geometric forms on the computer their names and peculiarities. Fig. 3 present the models of magnetic circuit finite elements of linear and arc motors.



a)



b)

Fig. 3. Finite elements models of linear a) and arc b) motor with two active zones

There was investigated the distribution of magnetic flux lines in both types of motors under different substances of inductor windings and the secondary element as well as by changing the frequency of inductor current and the size of the air gap. The results of simulation have been presented in Fig. 4 and Fig. 5.

The principal of the compensation of the component of edge effect and fluctuating magnetic field component in such type of motors is based on the compilation of the additional linkage at the ends of an open magnetic cores.

Conclusions

1. The experimental and simulation results indicate that inner asymmetry of three phase linear and arc motors

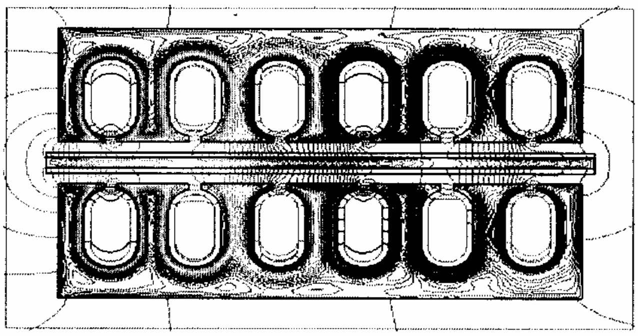


Fig. 4. Distribution of magnetic flux lines in the linear motor, when the secondary element is ferromagnetic and air gap is 2 mm

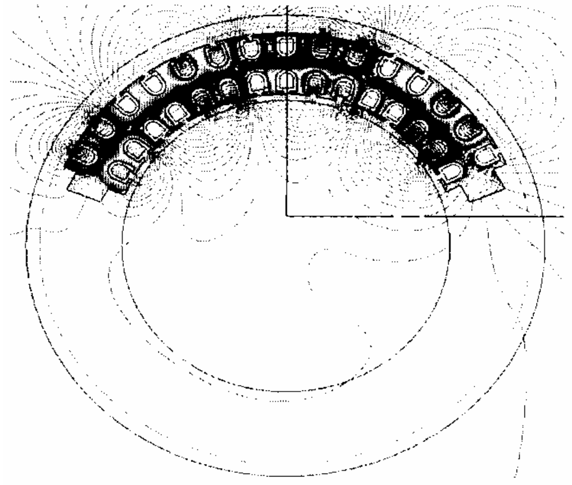


Fig. 5. Distribution of magnetic flux lines in the arc motor, when the substance of the secondary element is copper

powered from the sources of symmetric voltage mainly depend on the number of terminals, type of winding, frequency on the powered voltage and substance of the secondary element as well as on the design.
2. The amount of the electric asymmetry is evaluated by the coefficient of asymmetry, which is expressed by the ratio of reverse and linear sequence of the complex amplitudes of inductor phase currents.
3. When trying to reduce inner asymmetry of motors controlled by the valve converters in the canals of separate phases of converter there are required the controllers of current and voltage of variable parameters and structure.
4. When compiling optimum control systems of linear and arc motors, the application of all the measures of asymmetry compensation mentioned in this article has to be based on technology standards and economy level.

References

1. **Budig P. K.** The Application of Linear Motors // Proc. of 9-th Int. Conf. on Power Electronics and Motion Control. – Kosice, Slovak Republik. – 2000. – P. 1336 – 1341.
2. **Karaliunas B., Matkevicius E.** Calculation of the Parameters of Linear Electric Drive // Trans Tech

Publications, Mechatronic Systems and Materials, MSM 2005.– Switzerland, 2006. – Vol. 113. – P. 34 – 38.
3. **Boldea I.** Linear Electric Actuators and their Control: a Review // Proc. of the 10th Int. Conf. European Power and Drives Assoc. PEMC2002. – Dubrovnik, Croatia, 2002. – P. 12–19.
4. **Daruliene O., Karaliunas B.** Three Phase Equivalent Circuit of Linear Induction Motor // Electronics and Electrical Engineering. – Kaunas: Technologija, 2003. – No. 4(46). – P. 78–82.
5. **Davidson J. E., Gieras J. F.** New Shaded – pole Linear Induction Motor Computation of Characteristics using Classical and Finite Element Approach // Proc. of Int. Conf. on Electrical Machines. – 1996. – Vol. 2. – P. 283 – 288.
6. **Rinkeviciene R. Lisauskas S.** Model of Linear Induction Drive // Proc. of the V Workshop for Candidates for a Doctor's Degree OWD' 2003 Conference Archives PTETiS. – 2003. – Vol. 17. – P. 336–340.
7. **Torri S., Mori Y. and Efihara D.** Fundamental Investigations on Analysis of Linear Induction Motor using the Wavelet Transform Technique // Proc. of Int. Conf. on Electrical Machines. – Helsinki, Finland, 2000. – Vol. 1. – P. 99–102.

Submitted for publication 2007 10 22

B. Karaliūnas. Research on Electric and Magnetic Asymmetry of Linear and Arc Motors // Electronics and Electrical Engineering. – Kaunas: Technologija, 2008. – No. 1(81). – P. 61–64.

Issues concerning the experimental investigation on linear and arc motors as well as their usage in mechatronic system are discussed. The research proved that due to an open magnetic circuit in such type of motors there is formed inner electric and magnetic asymmetry, exhibiting itself by causing different currents in the phases of an inductor and providing unequal concentration of magnetic field in conformity with the longitudinal and transversal axes of the motor. The qualitative expression of such a type of asymmetry is regarded as longitudinal and transverse edge effects phenomenon limiting the application possibilities of such kind of motors.

Experimentally there have been carried out the research on three dipolar linear and arc motors with secondary elements of different width.The results of the experimental research were provided, when motors were alternating – current supply from symmetric voltage sources of 50 Hz and 400 Hz frequency. For magnetic field simulation of a linear and arc motor there has been used software package Maxwell SV 9.0 worked out by ,,Ansoft" company. There has also been investigated the distribution of magnetic flux lines in the motor under the condition of different substances used for the secondary element and by changing the frequency of the current of the inductor and the size of air gap. The results of the experimental research and modeling prove the structure of the magnetic field of motors to be a rather complicated one, for the analysis of which there are required new and sufficiently accurate mathematical models. The means and measures for edges effects and asymmetry compensation are being discused. Il. 5, bibl. 7 (in English; summaries in English, Russian and Lithuanian).

Б. Каралюнас. Исследование электрической и магнитной асимметрии линейных и дуговых двигателей // Электроника и электротехника. – Каунас: Технология, 2008. – № 1(81). – С. 61–64.

Рассматриваются вопросы экпериментального исследования линейных и дуговых двигателей, а также вопросы применения их в мехатронных системах. Показано, что из–за открытой магнитной цепи в такого рода двигателях образуется внутренняя электрическая и магнитная асимметрия, которая проявляется разными токами в фазах индуктора и неодинаковой концентрацией магнитного поля по продольной и поперечной оси двигателя. Качественным выражением такой асимметрии являются продольный и поперечный краевые эффекты, которые ограничивают применение этих двигателей в мехатронных системах.

Экспериментально были исследованы три двухполюсные линейные и дуговые двигатели с вторичными элементами разной ширины. Представлены результаты экспериментального исследования, когда двигатели были запитаны из симметричных источников напряжения частотой 50 Гц и 400 Гц. Для моделирования магнитного поля линейного и дугового двигателя был применен программный пакет Maxwell SV 9.0 фирмы „Ansoft". Исследовалось распределение магнитных силовых линий в двигателе при изменении частоты питающих токов индуктора, величины воздушного зазора и при разных материалах вторичного элемента. Результаты экспериментального исследования и моделирования свидетельствуют о сложной структуре магнитного поля, для анализа которой требуются новые и достаточно точные математические модели. Рассмотрены также способы и средства компенсации асимметрии и краевых эффектов. Ил. 5, библ. 7 (на английском языке; рефераты на английском, русском и литовском яз.).

B. Karaliūnas. Tiesiaeigių ir lankinių variklių elektrinės ir magnetinės asimetrijos tyrimas // Elektronika ir elektrotechnika. – Kaunas: Technologija, 2007. – Nr. 1(81). – P. 61–64.

Nagrinėjami tiesiaeigių ir lankinių variklių eksperimentinio tyrimo ir jų panaudojimo mechatroninėse sistemose klausimai. Parodyta, kad dėl atviros magnetinės grandinės tokio tipo varikliuose susiformuoja vidinė elektrinė ir magnetinė asimetrija, pasireiškianti skirtingomis srovėmis induktoriaus fazėse ir nevienoda magnetinio lauko koncentracija pagal variklio išilginę ir skersinę ašį. Tokios asimetrijos kokybinė išraiška yra išilginis ir skersinis kraštų efektai, ribojantys šių variklių taikymą mechatroninėse sistemose.

Eksperimentiškai buvo tiriami trys dvipoliai tiesiaeigiai ir lankiniai varikliai su skirtingo pločio antriniais elementais. Pateikti eksperimentinio tyrimo rezultatai, kai varikliai buvo maitinami iš 50 Hz ir 400 Hz dažnio simetrinių įtampos šaltinių. Tiesiaeigio ir lankinio variklio magnetiniam laukui modeliuoti buvo naudojamas ,,Ansoft" firmos programinis paketas „Maxwell SV 9.0". Buvo tiriamas magnetinio srauto linijų pasiskirstymas variklyje, esant skirtingai antrinio elemento medžiagai bei keičiant induktoriaus srovės dažnį ir oro tarpo dydį. Eksperimentinio tyrimo ir modeliavimo rezultatai byloja apie sudėtingą magnetinio lauko struktūrą, kurios analizei reikalingi nauji ir gana tikslūs matematiniai modeliai. Taip pat aptariamos kraštų efektų ir asimetrijos kompensavimo priemonės ir būdai. Il. 5, bibl. 7 (anglų kalba; santraukos anglų, rusų ir lietuvių k.).

DOI: 10.5755/j02.eie.11036