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Numerical Magnetic Field Computation in a Unilateral Linear Asynchronous Motor without Inverse Magnetic Circuit

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Introduction

Recent technical progress has considerably enlarged the use of LAM's.Their use in different mechanisms involving translation and sinusoidal motions simplifies the cinematic schemes, increases efficiency and dependability of the whole installation.
This has stimulated theoretical and experimental research in the LAM's area. The development of theories and computational methods in unilateral and bilateral LAM's a high standard [1, 3].
However, unilateral LAM's without inverse magnetic circuits have drawn less attention despite their widespread use; this is what motivated this work.

Assumptions of computational model of a LAM

Preliminary computations have shown that the moving body's length (laminated bars) is much greater than that of the inductor which allows neglecting the input /outputting effects of the moving body in the active zone (Fig. 1).

The motion speed being of 3 to 5 m/s, it is then possible to neglect the lateral longitudinal effect. The dimension of inductor's core is selected so as to exclude saturation and to avoid the transversal force on the sheets. Taking into account these considerations we have used the following assumptions in the computations:

1. The moving body is infinitely long
2. The inductor is infinitely long
3. The inductor's core has an unlimited magnetic permeability a zero electric conductivity
4. The core width is infinite
5. The conductor has neither teeth nor slots; in the computations an air gap is included
6. The magnetic permeability of the moving body is independent of the coordinates and the conductivity is constant.
7. The cross-section of the moving body is rectangular
8. The conductor winding is represented by an infinitely thin layer of current on the active surface of the core.
9. The winding does not contain higher harmonics so that the linear inductor equation will be:

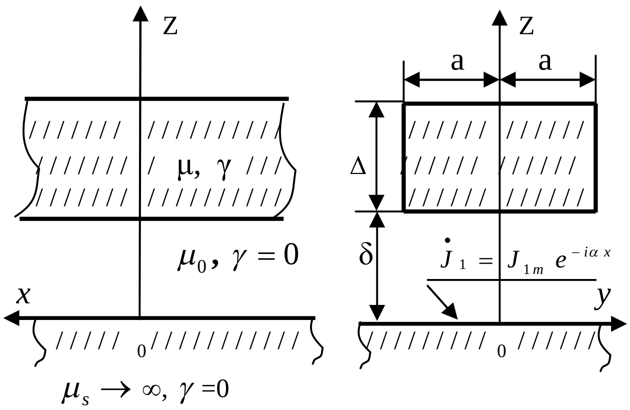

Fig. 1. LAM’s computation model

$$\dot{J} = J_{1m}\, e^{-i\alpha x}\,, \tag{1}$$

where x – a measurable coordinate in the direction of motion of the moving body; $\alpha = \pi / \tau$ – the pole step.

$$J_{1m} = \sqrt{2}\ A\ k_b\,, \tag{2}$$

where J_{1m} – the current density magnitude; A – the linear load; k_b – the winding factor.

Developments of computational model of a LAM

Given the above assumptions, the EM field varies periodically along the x coordinate which allows the representation of all quantities characterising the EM field in the corresponding form. For example, the complex magnitude EM field is given by:

$$\dot{H} = \dot{H}_m\, e^{-i\alpha x}\,, \tag{3}$$

where $\dot{H}_m$ – the magnitude of the field intensity is independent of the x coordinate.

Throughout in this article the index m in the notation of the field quantities refers to complex magnitude depending only on the y and z coordinates.

In the solution of the field equations, differentiation with respect to x corresponds, according to (3), to a multiplication by ($-i\alpha$). Hence integration with respect to x corresponds to a multiplication by ($-\frac{1}{i\alpha}$). This was, the three dimensional problem is reduced to a two dimensional problem. Using field symmetry, field computations will take place in a domain covering half the cross-section of the moving body; the model based on the above assumptions is represented in Fig. 2 [4, 5].

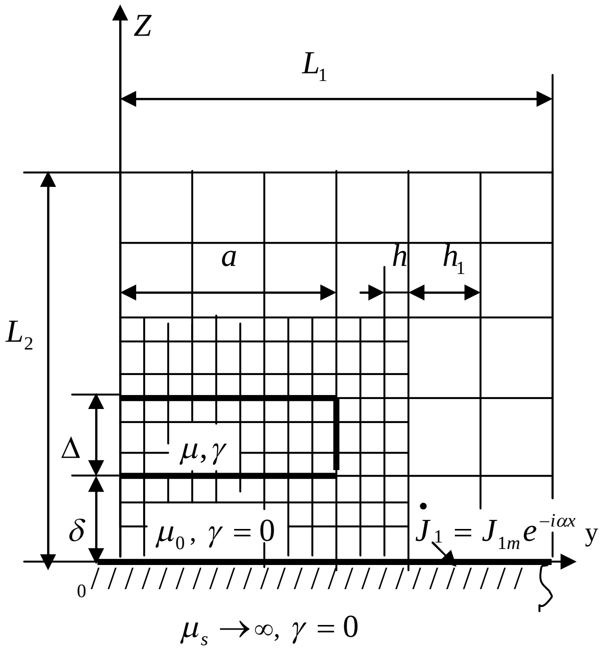

Fig. 2. computation’s grid

In Fig. 2 a – half the width of the moving body; Δ – thickness; δ – air gap.

The scalar magnetic potential method along with the vectorial current function density method [6–8] has been used in the field computations. According to this method, the magnetic field intensity will be:

$$\dot{H}_m = \dot{H}_{0m} - grad\ \dot{U}_m, \qquad (4)$$

where $\dot{H}_{0m}$ – the complex magnitude of the vectorial current function density; $\dot{U}_m$ – the complex amplitude of the scalar magnetic potential.

The above, along with Maxwell's first equation lead to:

$$rot\ \dot{H}_{0m} = \dot{J}_m\ . \qquad (5)$$

In general, the vector $\dot{H}_{0m}$ has components along the three coordinate axes. However, this number can be reduced to two due to the fact the magnitude of $\dot{H}_{0m}$ is unlimited except the case of formula (5). In our case, it is preferable to take $\dot{H}_{0mx} = 0$ leading to:

$$\begin{cases} \dot{J}_{mx} = \dfrac{\partial \dot{H}_{0mz}}{\partial y} - \dfrac{\partial \dot{H}_{0my}}{\partial z}\ , \\ \dot{J}_{my} = -\dfrac{\partial \dot{H}_{0mz}}{\partial x} = i\alpha\, \dot{H}_{0mz}\ , \\ \dot{J}_{0mz} = \dfrac{\partial \dot{H}_{0my}}{\partial x} = -\,i\alpha\, \dot{H}_{0my} \end{cases} \qquad (6)$$

and the components of the field intensity are

$$\begin{cases} \dot{H}_{mx} = -i\alpha\,\dot{U}_m\ , \\ \dot{H}_{my} = \dot{H}_{0my} - \dfrac{\partial \dot{U}_m}{\partial y}\ , \\ \dot{H}_{mz} = \dot{H}_{0mz} - \dfrac{\partial \dot{U}_m}{\partial z}\ . \end{cases} \qquad (7)$$

Using equations (2) to (7), Maxwell's equations lead to the following expression for $\dot{H}_{0m}$ and $\dot{U}_m$.

$$\frac{\partial^2 \dot{H}_{0my}}{\partial z} - \beta^2 \dot{H}_{0my} = k^2 \frac{\partial \dot{U}_m}{\partial y} + \frac{\partial}{\partial y}\left(\frac{\partial \dot{H}_{0mz}}{\partial z}\right), \qquad (8)$$

$$\frac{\partial^2 \dot{H}_{0mz}}{\partial z^2} - \beta^2 \dot{H}_{0mz} = k^2 \frac{\partial \dot{U}_m}{\partial z} + \frac{\partial}{\partial z}\left(\frac{\partial \dot{H}_{0my}}{\partial y}\right), \qquad (9)$$

where $k^2 = -\,i\omega\mu\gamma$; $\beta^2 = \alpha^2 - k^2$, $\omega = 2\pi f_1 s$ – angular frequency of current in the moving body; s – sliding, f_1 – the current frequency.

$$\frac{\partial^2 \dot{U}_m}{\partial y^2} + \frac{\partial^2 \dot{U}_m}{\partial z^2} - \alpha^2 \dot{U}_m = \frac{\partial \dot{H}_{0mz}}{\partial z} + \frac{\partial \dot{H}_{0my}}{\partial y}\ . \qquad (10)$$

These equations are solved in the moving body domain. In a non conductive environment where, we also have $\dot{J}_m = 0$ and $\dot{H}_{0m} = 0$. Hence the scalar potential satisfies Laplace equation:

$$\frac{\partial^2 \dot{U}_m}{\partial y^2} + \frac{\partial^2 \dot{U}_m}{\partial z^2} - \alpha^2 \dot{U}_m = 0 . \qquad (11)$$

Discussion

Equations (8) to (11) are solved in the following limit conditions: $y = a$, $\left.\dot{J}_{my}\right|_{y=a}$ = 0. Hence according to equation (6), we have:

$$\left.\dot{H}_{0mz}\right|_{y=a} = 0. \qquad (12)$$

Similarly, we have:

$$\left.\dot{J}_{mz}\right|_{\substack{z=\partial \\ z=\delta+\Delta}} = 0, \qquad (13)$$

$$\left.\dot{H}_{0my}\right|_{\substack{z=\delta \\ z=\delta+\Delta}} = 0, \qquad (14)$$

where the tangent components of $\dot{H}_{0m}$ at the moving body surface are zero. While the normal component may be computed using equations (8) and (9).

On the symmetry axes: $\left.\frac{\partial \dot{J}_{my}}{\partial y}\right|_{y=0}$ = 0, $\left.\dot{J}_{mz}\right|_{y=0}$ = 0 .

Furthermore $\left.\dot{H}_{my}\right|_{y=0}$ = 0. That is why, according to equations (6) and (7), we have:

$$\left.\dot{H}_{0my}\right|_{y=0} = 0 , \qquad (15)$$

$$\left.\frac{\partial \dot{H}_{0mz}}{\partial y}\right|_{y=0} = 0 , \qquad (16)$$

$$\left.\frac{\partial \dot{U}_m}{\partial y}\right|_{y=0} = 0 . \qquad (17)$$

The scalar potential equations on the moving body surface can be obtained using the continuity of the magnetic flux on the interface:

$$\oint BdS = 0 . \qquad (18)$$

Application of these conditions gives the scalar potential (Fig. 3).

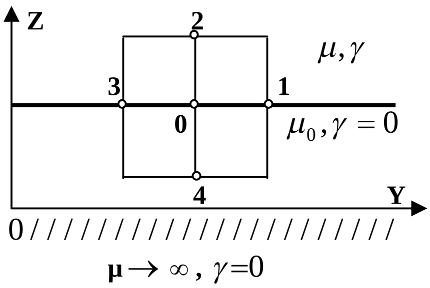

Fig. 3. Continuity conditions at the medium separation

$$\dot{U}_{m0} = \frac{(R+1)(\dot{U}_{m1}+\dot{U}_{m3}) + 2(R\dot{U}_{m2}+\dot{U}_{m4})}{(R+1)(4+\alpha^2 h^2)} - \frac{(\dot{H}_{0mn2}+\dot{H}_{0mn0})Rh}{(R+1)(4+\alpha^2 h^2)} , \qquad (19)$$

where $R = \mu / \mu_0$.

The index "n" in the expression of $\dot{H}_{0mn}$ indicates the normal component of the limit of the vectorial current intensity function.

The scalar potential at angular points of the moving body is determined by the same equations as for the case where, $\gamma = 0$.

On the inductor surface, we must have $\left.\dot{H}_x\right|_{z=0} = \dot{J}_1$, so that equations (2), (4) and (7) lead to:

$$\left.\dot{U}_m\right|_{z=0} = -\frac{i}{\alpha} J_{1m} , \qquad (20)$$

$$\left.\dot{U}_m\right|_{z=L_2} = -\frac{i}{\alpha} J_{1m}\, e^{-\alpha L_2} . \qquad (21)$$

It is necessary to set the external limits far enough from the moving body. In this case the scalar potential of the field must represent in itself, the field potential of the inductor in the absence of the moving body:

$$\left.\dot{U}_m\right|_{y=L_1} = -\frac{i}{\alpha} J_{1m} e^{-\alpha z} . \qquad (22)$$

To reduce computer memory storage requirements in the computation of the field, a special grid (Fig. 2) was developed and used [4]. In the region where the field varies a little, a grid with large cells h is used. The smaller cells used in the region of high variations of the field (air gap, moving body) are selected according to recommendations appeared in A. Medvediev's thesis [9].

$$h=0.24\sqrt{\frac{2}{\omega\mu\gamma}} , \qquad (23)$$

the ratio between cells in the different computation schemes has been chosen in the interval $\frac{h_1}{h} = (2 \div 4)$. Part of the lines in the finer grid do not extend over the limits.

Quadratic interpolation formulas have been used to compute the potential at critical modes of the finer grid. These values are used to compute the potential at modes of the larger grid [10].

Conclusion

1. A method for computing the EM field of a unilateral LAM without an inverse magnetic circuit has been developed for both magnetic and amagnetic bodies.
2. To compute numerically the field, the scalar potential method as well as the vectorial current intensity function was used. The latter simplifies the formulation and the solution of the problem. Satisfactory results were obtained from this mathematic model [11].

References

1. **Vesilovskii O. N., Konyaeva Y., Sarapoulo F. N.** Moteur linéaire asynchrone. – Moscou: Energoatomizdat, 1991. – 256 p.
2. **Miwa Zenichiro.** Perspective d'utilisation et de développement des moteurs linéaires // Shinko Elec. J. – 1982. – Vol. 27, No. 3. – P. 10–12.
3. **Igelia G. L., Rebov S. A., Chapovalenko A. G.** Moteur linéaire asynchrone. – Kiev : Technika, 1975. – 133 p.
4. **Boudiaf A.** Étude d'un moteur linéaire asynchrone unilatéral sans circuit magnétique inverse et à corps moteur amagnétique et magnétique / Thèse de PhD. – Leningrad. – 1985. – 126 p**.**
5. **Igor Tsukerman.** A new FD calculus: Simple grids for complex problems // The International compumag Society Newsletter. – ISSN 1026-0854. – July 2005. – Vol. 12, No. 2. – P. 3–7.
6. **Demirchian K. S., Chechurin W. L., Sarma M. S.** Scalar potential concept for calculating the study magnetic fields and eddy currents // IEEE trans. of magn. – 1976. – Vol 12, No. 6. – P. 1281–1283.
7. **Erdelyi E. A.** Nonlinear magnetic fields analysis of DC machines (part I theoretical fundamentals) // IEEE trans. Power. App. and Systems. – 1970. – Vol. 89, No. 7.
8. **Demirchian K. S., Rakitskii Y. V., Tsukerman I. A.** calcul des champs électromagnétiques tridimensionnels par la méthodes potentielle scalaire: technique et logiciel numériques, technologie de puissance // Académie de l'URSS des sciences. – 1988. – Vol 26, No. 4. – P. 146–152.
9. **Medvediev A. L.** Élaboration d'une méthode de calcul et étude des champs électromagnétiques des courants tourbillonnaires et des pertes dans les éléments de structure de la partie tronçonneuse des grosses machines électriques / Thèse PhD. – Leningrad. – 1982.
10. **Korn G., Korn T.** Ouvrage de mathématiques pour les ingénieurs et les scientifiques. Moscou : Nauka, 1984.
11. **Boudiaf A., Khantar H.** Caractéristiques mécaniques d'un moteur linéaire asynchrone // Bulletin de l'ENSET d'Oran. – Fév. 1996. – P. 31–36.

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A. Boudiaf. Numerical Magnetic Field Computation in a Unilateral Linear Asynchronous Motor without Inverse Magnetic Circuit // Electronics and Electrical Engineering. – Kaunas: Technologija, 2009. – No. 2(90). – P. 81–84.

This work is concerned with the development of a numerical method for computing the EM field acting in a unilateral linear asynchronous motor (L.A.M) without an inverse magnetic circuit, with and without a permanent magnet, the method does not take into account the longitudinal border effect. The scalar magnetic potential and the two dimensional vectorial current function are used to solve the field equations taking into account a volume distribution of current into driving body. To reduce space complexity during the numerical computation, a special grid with larger cells in the integration of weak field variations was used. Ill. 3, bibl. 11 (summaries in English, Russian and Lithuanian).

А. Боудиаф. Числовое вычисление магнитного поля в одностороннем линейном асинхронном двигателе без инверсной магнитной схемы // Электроника и электротехника. – Каунас: Технология, 2009. – № 2(90). – P. 81–84.

Анализируется развитие числового метода для вычисления электромагнитного поля, действующего в одностороннем линейном асинхронном двигателе без инверсной магнитной схемы. Представлены варианты когда в двигателе используется постоянный магнит и когда нет. Метод не включает продольный краевой эффект. Скалярный магнитный потенциал и двухмерные векторные функции текущих электрических токов используются для того, чтобы решить полевые уравнения, принимающие во внимание распределение объема тока. Ил. 3, библ. 11 (рефераты на английском, русском и литовском яз.).

A. Boudiaf. Skaitmeninis vienpusio tiesinio asinchroninio variklio be inversinio magnetinio grandyno magnetinio lauko skaičiavimas // Elektronika ir elektrotechnika. – Kaunas: Technologija, 2009. – Nr. 2(90). – P. 81–84.

Aptariama, kaip kuriamas skaitmeninis metodas, skirtas vienpusiame tiesiniame asinchroniniame variklyje be inversinio magnetinio grandyno sukuriamam elektromagnetiniam laukui apskaičiuoti. Analizuojami atvejai, kai variklyje naudojamas nuolatinis magnetas ir kai jis nenaudojamas. Metodas neįvertina išilginės ribos poveikio. Skaliarinis magnetinis potencialas ir dvimatės vektorinės srovės funkcija naudojami sprendžiant lauką išreiškiančias lygtis, įvertinant tūrinį srovės pasiskirstymą. Kad modelis būtų ne toks sudėtingas, tose zonose, kur laukas kinta nedaug, panaudotas didesnio žingsnio tinklelis. Il. 3, bibl. 11 (anglų kalba; santraukos anglų, rusų ir lietuvių k.).